Proceedings of the 12th IPI-Congress

Optimizing Yields – The Role of Fertilizers

International Potash Institute 1982

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Publisher: International Potash Institute
P.O. Box 121
CH-3048 Worblaufen-Bern/Switzerland
Phone 031 58 53 73 Telex 33430 ipibe ch

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Opening Session

The Aims of the International Potash Institute

Dr. *N. Celio*; former President of the Confederation of Switzerland. Chairman of the International Potash Institute, Bern/Switzerland

It is my pleasure to welcome you to the twelfth Congress of the International Potash Institute and to the ancient royal city of Goslar. This I do in the name of our Board of Administrators who have bidden me to wish you fruitful participation in this high level scientific meeting and a useful exchange of views in pleasant surroundings here in the foothills of the Harz.

The proceedings which begin today break new ground for our Institute: this is the first IPI Congress to be held in the home country of one of our two founder members, Kali und Salz AG. That we have had to wait as long as 30 years from our foundation in *1952* until we were able to hold such a meeting in the Federal Republic signalizes two important special features of our Institute upon which our founders – the Federal German and the French potash producers – insisted from our earliest beginnings.

1. The activity of the IPI is truly international and knows no geographical or political boundaries; this is because it is our conviction that scientific work can prosper only on the basis of full understanding between the peoples of different nations and different cultures.

2. The second is in truth a compliment to the potash producers of the Federal German Republic, France, Israel, Spain, England, Canada and Italy who have not failed in their active support throughout our history. The International Potash Institute is dedicated to scientific truth and has always sought to remain true to this principle. As a man who is familiar with the inside working of politics and business for more years than I care to remember, I can assure you that this principle and, more important, true devotion to maintaining such standards, is not, unhappily, universally recognised. I say 'unhappily' advisedly because scientific research and the transfer of its results into practice has become a *conditio sine qua non* for innovation in the industrialised world – including its agriculture – and also for the urgently needed improvement of living conditions in the developing world.

Though I know that many of you are quite familiar with the aims and work of the International Potash Institute, I can see some new faces in my audience who are taking part in one of our scientific meetings for the first time, so perhaps I may be permitted to give you a brief outline.

The IPI has set itself the task of collecting and evaluating the results of research and experimentation throughout the world on potassium, as one of the three major plant nutrients, and of disseminating the results of our work to agricultural and research workers throughout the world who are active in this and related fields.

For this purpose we use the following tools:

- First there are periodical and non-periodical publications which go to practically every relevant research and experimental establishment in the world. As examples here I would specially mention the *Potash Review* which appears monthly in four languages (English, French, German, Spanish), its content is on a high scientific level, and also *Mengel and Kirkby's* 'Principles of Plant Nutrition', already in its third edition which is a real 'best-seller'.

- Our scientific meetings, colloquia and congresses, are arranged in working cycles, detailed aspects of an overall theme being dealt with in the colloquia, while the congress brings together the results of individual colloquia, evaluating them and discussing how these findings can contribute to agricultural practice. For example the present working cycle with the title 'Optimizing yields – the Role of Fertilizers' will be completed in this Goslar Congress.

- We have access to a computerised information bank in which all the literature relating to potassium in plant nutrition is digested. This forms a basis for our own work and for all specialists who approach us for information.

- Every three or four years we hold a competition for young research workers aged less than 40 years. The last such competition in 1980 attracted 80 entries from 53 young research workers in 30 countries. The entries were judged by the Scientific Board and the winner recognised by the award of a cash prize.

- Another important element of our activity is the employment of qualified agronomists, particularly overseas. At the present time, such delegates are stationed in the Mediterranean area and in South Africa, while others in cooperation with the Potash and Phosphate Institute of Atlanta/USA, are working in Japan, Korea, Singapore and Brazil. IPI agronomists make occasional visits to other countries such as India, the People's Republic of China, Latin America, West Africa, etc. where good cooperation with local research institutes has been established.

- In pursuing our aims it has been necessary to build close contact with other international organisations. Here I would like to mention the *Potash and Phosphate Institute* in Atlanta, USA, the *Centre d'Etude de l'Azote* in Zürich, the *International Fertilizer Association* in Paris, *IMPHOS*, also in Paris, in fact any institutes whose aims are similar to our own.
  FAO occupies a special place in our cooperation in the international field and here we are actively concerned in the work of the several of the Working Groups of the FAO Fertilizer Programme. There are a number of publications commenting on the efficiency of this programme.

Our present fields of interest are: soil science, plant physiology and the manuring of farm crops with particular reference to potassium. The theme potassium cannot be dealt with properly in isolation so we are much concerned with soil problems, interaction with the other plant nutrients, nutrient cycles, etc.; in fact our work is interdisciplinary. Thus, it is significant that for the Goslar Congress we have for the first

time invited the participation of agricultural economists in order to have a complete discussion of the problems of optimising yields.
After this short survey of the many-sided activities of our Institute I would like to conclude on the hopeful note that this congress will be hard-working and fruitful so that every participant will return home satisfied. The choice of Goslar as the venue should assist us in this aim. Surely the pleasant and restful atmosphere of this beautiful little city will stimulate our creativity and provide a congenial atmosphere for evening discussions outside the conference chamber.
It is a fine tradition in meetings of the International Potash Institute that we should bring together north and south, east and west – people from different continents and with different outlooks to give them the opportunity to inform themselves and to discuss the possibilities for improving the quality of life. It is my confident hope that the same will be the case in Goslar.
I wish to thank particularly Professor *Schroeder* for undertaking the duties of Chairman of this Congress, and, with my good wishes, I shall now hand him the microphone so that he may introduce the scientific programme.
I declare the 12th Congress of the International Potash Institute open!

Introduction – The Congress Theme

D. Schroeder, Plant Nutrition and Soil Science Institute, Christian-Albrechts-University, Kiel/ Federal Republic of Germany; Member of the Scientific Board of the International Potash Institute*

As Chairman of this Congress my first and very pleasant duty is to extend to you a hearty welcome to Goslar and to the Federal German Republic; in this I am joined by all my German colleagues. This is the first congress of this sort to be held in West Germany and we are most grateful to the *International Potash Institute* and to its *Scientific Board* that this year the choice has fallen on our country. In passing, I should mention that the Institute held a colloquium at Landshut in Bavaria in 1972 which dealt with the problems of potassium in soils, so that in this year, almost thirty years from the foundation of the *International Potash Institute*, we celebrate a kind of jubilee of our own – the tenth anniversary of the Institute's first scientific meeting in our country.

Congress and Colloquia

It falls to me to introduce the theme of this congress. For the past twenty years it has been our practice to organise a three year cycle of colloquia in which regional or otherwise specialised topics have been discussed in a close group of specialists, and in the fourth year to hold a larger scale congress in which the conclusions of the colloquia are reported and summarised. There was a break in this plan when the 11th congress was held in Bern 4 years ago as this marked the silver jubilee of the *Scientific Board*, and it was then felt that it would be appropriate to consider the progress in potassium research made in the past 25 years and to take a look forward at the likely research requirements for the next 25 years.

This 12th Congress also departs from the general run and has a special character of its own. The programme follows a new plan. Up to now it has been usual to introduce each session with a main lecture which was followed by a number of short communications. This time, in order to allow more time for full discussion, there will be only a few, 3 or 4, invited papers in each session and the discussion of the topic will be completed during that session instead of arranging the final discussion at the end of the congress when the proceedings of the individual sessions were reported on by coordinators.

* *Prof. Dr. D. Schroeder*, Institut für Pflanzenernährung und Bodenkunde, Christian-Albrechts-Universität, Olshausenstrasse 40–60, D-2300 Kiel/Federal Republic of Germany

The programme attempts to cover several aims.

1. The first two sessions will, as usual, look back to the preceding colloquia. The 14th Colloquium in Seville in 1979 was concerned with *Soil in Mediterranean Type Climates and their Yield Potential.* At Wageningen in 1980, the theme was *Physiological Aspects of Crop Productivity* and the 16th Colloquium in Warsaw last year carried the title *Agricultural Yield Potentials in Continental Climates.* Thus we have discussed the potential of the various European agricultural systems developed on the soils of the Mediterranean, maritime and continental climates.
   The first session of this congress will deal with the optimisation of crop yield and the second with the optimisation of animal production.
2. Thus far we follow the traditional plan; now comes the change. The third session will consider new trends in crop utilisation and fertilizer practice. Much topical discussion centres on the possibility of using crops as a renewable source of energy and on giving greater prominence to the non-food crops. In the light of the current worlds food situation and the likely future worsening of this situation, our theme is in fact a rather 'hot' topic which should lead to an interesting and full discussion.
3. The fourth session breaks completely new ground, dealing as it does with agricultural and economic policies. These aspects have been touched upon in past meetings, but only marginally. Our feeling is that economic forces are exerting an ever stronger influence and that the development of policies to deal with the world food problem is of such over-riding importance that a scientific meeting such as this is compelled to consider these problems.
4. Following this line of thought we are introducing another new idea for the fourth. session, which will take the form of a panel discussion. This will deal with the ever more pressing problem faced by agriculture – that of providing sufficient food for our growing world population. True enough, this problem is under constant discussion by many organisations but we believe that we, with the aid of the distinguished authorities brought together in our panel, can make our own contribution.

The proceedings of this congress are described by the general title: '*Optimising Yields – the Role of Fertilizers*'. Though this title was agreed at the last congress in Bern, that is before the beginning of the last cycle, it is really surprising looking back that the word 'optimisation' is not mentioned in the title of any of the colloquia and occurs only once in the titles of the 36 papers presented. Instead, the words used have been 'yield potential' or 'maximisation of yield'. It may seem necessary therefore to concern ourselves with the meanings of these words and to define the concepts more exactly.

Potential yield, maximisation and optimisation of yields

Potential yield: Here it is useful to distinguish between a theoretical strictly scientific yield potential and a more practical and realistic potential. The first is biologically and genetically defined and expresses the full potential of the photosynthetic process as might be achieved, for instance, in a phytotron. In the field, depending on the constellation of yield determining factors at a particular site it is possible to realise only

part of the full potential. This is the practical potential which is the concern of us agriculturalists.
For an example of such a potential yield we could take at the present time a yield of 15 t/ha in Schleswig-Holstein. Leading farmers already achieve 80% of this potential with yields of 12 t/ha, while the average yield for the whole of the Federal Republic of Germany is still around 5 t/ha.

Yield maximisation and yield optimisation: For the precise definition of these terms we have to go back to the Latin. Maximisation comes from *maximus* the superlative of the Latin adjective *magnus* meaning great or high (with several subsidiary meanings). Thus yield maximisation implies striving for the highest possible yield in purely *quantitative* terms. The definition is expressed mathematically as the point on a curve whose ordinate is greater than those of neighbouring points. The concepts of quality and profitability have no part in such a definition.
Optimisation comes from the Latin *optimus*, the superlative of *bonus* meaning good (again with subsidiary meanings). Optimisation thus means providing the best conditions in order to achieve the *best* yield. This definition includes by implication a qualitative aspect, recognising the importance of the condition and quality of the produce. Naturally, 'best' in this context connotes the highest possible yield of plant or animal produce of real value to mankind. That the highest yield is not necessarily the best yield is well known. This holds in both scientific and economic terms.
Optimum yield must therefore not just be high it must also be of the highest quality from every point of view (food value, palatibility, suitability). In recent years, the significance of quality has been more widely recognised, not only the quality of crop and animal produce but also the quality of life including the environment. In striving for optimum yield these aspects must also receive attention so that all the measures taken to optimise yield also serve to conserve or even to improve our environment.
Optimisation in the economic sense is the achievement of the optimum yield which gives the highest profit. Optimum yield in this sense is not usually the maximum yield which can only be reached by incurring extra expense which brings no profit.
On the above grounds we have chosen to use the word *optimisation* because it embraces so much more than maximisation and is a greater challenge to the farmer.

The laws of yield

As we are holding in Germany this congress on optimizing yield and fertilizer use, it is appropriate to call to mind the names of some of the German scientists who have worked on the connection between yield and nutrient supply.
Justus von Liebig must stand in the first place with his *Law of the Minimum*, which is at the same time a law of the maximum, propounded in 1855, that the nutrient which is in minimum supply limits the attainable yield. *Liebig* went on from here to state that as the supply of the limiting factor is increased, yield increases linearly until another limiting factor intervenes. We know today that the Law of the Minimum is not universally applicable; nevertheless, in our own day, as in *Liebig*'s, we know that when we are concerned with the lower portion of the yield curve it is at the least very nearly true.

In 1897 *W. Wollny* formulated the so-called *Law of the Optimum*, according to which increasing the level of a factor first increased yield up to an optimum but that further increase resulted in a decline in yield.
Then from 1909 *E.A. Mitscherlich* and his colleagues developed the *Law of Growth Factors* which stated that it was not only the minimum factor which influenced yield but that all growth factors did so. According to this law, the increase in yield produced by unit increase in a factor is proportional to the amount by which the yield falls short of the maximum yield obtained when conditions are ideal.
Mitscherlich's Law states that the yield curve takes an asymptotic shape and does not therefore allow for the decrease in yield which arises when the optimum is exceeded as propounded by *Wollny*.
When it was realised that excessive supply of a factor, for instance too much nitrogen fertilizer, could cause yield to fall, a 'second approximation' was introduced in 1928 in which adverse factors were included and it was realised that the yield curve was not asymptotic but took an overturning shape.
Mitscherlich had originally assumed that the growth factors were independent of each other and that they were constant in their action. But several workers then showed that this concept did not meet the case and that there were in fact complex interactions between the various factors. This resulted in the 'third approximation of the law of yield in actuality' of *E. von Boguslawski* and *B. Schneider* (1960).
Even though relatively simple laws cannot account exactly for all that happens in practice, they have greatly aided us in improving our understanding of the connexion between yield and the factors which affect it, and particularly so in the field of fertilizer research.
The significance of fertilizers for attaining optimum yield will be described in the coming days and our papers and discussions will show how complex and many-sided are the effects of the various factors determining yield and their interactions. It will also be shown how successful science and agricultural practice have been in raising yields over the past few decades, enabling agriculture to participate fully in the increasing prosperity. Even more than in the past, in the light of prevailing economic conditions and future trends, it is overwhelmingly important that agriculture should do its utmost to achieve optimum yield.
To conclude my introductory talk it is incumbent upon me to thank all who are taking part in this Congress for their interest in our theme. Special thanks are due to the lecturers and to those who will lead the discussions; their cooperation ensures success and is most gratefully acknowledged. I trust that we shall all benefit from our proceedings and will enjoy a pleasant stay here in Goslar.

12th Congress of the International Potash Institute
June 1982 at Goslar/Fed. Rep. of Germany

1st Session

The Basis for Optimum Yields

Co-ordinator *Prof. Dr. A. van Diest*, Dept. of Soil Science and Plant Nutrition, Agricultural University Wageningen/The Netherlands; member of the Scientific Board of the International Potash Institute

Soil and Climate as a Basis of Plant Production in Europe

B. Meyer, Institute of Soil Science, University of Göttingen/Fed. Rep. of Germany*

Summary

The soil geography of Europe is briefly reviewed, grouping the soils into three main areas: the north, northwest and northeast directly affected by glaciation; the periglacial area in which were deposited sediments originating from the glaciers with further deposition of loess; the Mediterranean area. In contrast to other areas like Africa or S. America, European soils, with few exceptions, are of recent origin. The predominating factor is the nature, physical and chemical, of the sediments on which the soils were formed. Man, through his methods of soil cultivation and exploitation has greatly influenced soil quality and in modern 'transformation agriculture' some soils regarded as unproductive under conditions of earlier 'concentration agriculture' have been transformed into highly productive soils. The influence of cultivation methods and of soil organic matter is briefly discussed.

As a student I was somewhat concerned as to whether the results of experience and experiment on loess soils in the neighbourhood of Göttingen could be more widely applied to the many soil types and agricultural conditions of central Europe. Thus I have always been interested in agricultural geography and much of my more recent activity has been devoted to a consideration of soils on a geographical basis rather than concentrating on pedological details and the distribution of the different soil types.

In reviewing the soils of central Europe, I must say something about the concepts used in present-day soil geography. I could begin by dividing Europe into geomorphological zones, in itself a departure from the old idea of soil geography. If we assume that our soils are the result of the operation of six factors – parent rock, vegetation, relief, climate, soil water regime and the activity of man – we start by arranging these factors in order of importance and we regard one factor as being of dominant importance and the rest as subsidiary. This kind of concept was the basis of the old zonal soil classification, which had the defect right from the beginning that there were very many exceptions to the rule.

Alternatively, soils can be arranged according to geomorphic zones or regions based on the description of clearly recognizable landscapes. More detailed classification within the main groups can be based on variation in a single factor as applied for instance to the series comprising a catena. Using such a system, Europe can be described as a series of landscapes of different origin. There are the alpine regions, the younger mountain chains of the Pyrenees and, across the Alps, the Carpathians and the Caucasus and their Mediterranean outliers – the Appenines, the Dynarske and the Balkan mountains. Then there are the plateaux and hill landscapes of west and central Europe, mainly derived from mesozoic formations, with high lying tablelands, saddles and basins in which tectonic influence is only slight. There are the lower-lying areas either

* Prof. Dr. *B. Meyer*, Institut für Bodenkunde, Universität Göttingen, V. Siebold-Strasse 4, D-3400 Göttingen/Fed. Rep. of Germany

side of the mountains with their accumulated sediments. A very large geomorphological region was covered by ice in the Pleistocene where glacial and fluvoglacial sediments were laid down, as over north central Europe and most of the northeast. Finally, there are areas of tectonic subsidence like the basins of Hungary and Rumania and the areas of recent sediments originating from the activity of man, like the great river valleys and coastal areas, particulary on the southern part of the North Sea coast, with their marshy sediments.

It takes a long time to cover such a descriptive scheme – in the Göttingen course sixty hours of lectures which are basic to the consideration of the soils not only of Europe but also of the rest of the world. For the purpose of this lecture I must use a different approach, placing the soil associations of Europe in larger units in a somewhat summary fashion.

We can start with Scandinavia, Great Britain, the Netherlands, the greater part of north and central Germany, Poland, the Baltic coast, Finland and most of White Russia. This area was directly or indirectly affected by glaciation during the Pleistocene. We may distinguish the areas which were directly affected by the ice-cover and the fluvoglacial areas in which the rivers flowing from the melted ice deposited their sediments far from the glaciers. The properties of these soils depend upon the physical and chemical properties of the parent materials. The ground moraines deposited under the ice represent in their mineral composition a cross section of the earth's crust and contain many types of rock of palaeozoic and volcanic origin. It is important that we should take account of the composition of these sediments before we come to consider the effects of climate.

The minerals produced by the weathering and transport of ground moraine material vary in their granularity. Thus resistant materials like quartz and some of the feldspars are abundant in the coarser fractions, while the more strongly weathered materials like most of the feldspars, the heavy minerals and, especially, micas predominate in the finer fractions. Transport of these weathering products in water from the ice has resulted in coarse and fine sediments being laid down adjacent to each other.

The second large area, which includes western Europe north of the Pyrenees, France, central Europe north of the Alps to the Caucasus and the Urals, we designate periglacial. This is the area which bounded the ice-cap and in which climate varied greatly in accordance with the advance and retreat of the glaciers. We can see the results of the alternation of wet cold and dry cold climates in the profiles of the sediments and soils of central and western Europe; wet cold as the ice advanced from north to south, dry cold when the glaciers were static or when they retreated. These climatic changes were decisive in ordering the deposition of the sediments which were the parent materials for soil formation in the Holocene. During wet cold periods, the vegetation and soil-surface conditions of Europe were like those which now obtain in the arctic and subarctic tundras. Over the frozen subsoil, the so-called permafrost, the surface layer thawed and re-froze each year. Under such conditions, the surface layer moves over the frozen layer even when the gradient is as little as 2% a process known as solifluction. This downward movement on the slopes introduced materials of glacial origin into the streams and then the great rivers with the result that glacial materials became widely spread, forming the gravel plains and terraces of the central European lowlands.

As well as the sediments of glacial origin which were laid down in the periglacial area there were also deposits of wind-borne sediments (loess) which, like the glacial sedi-

ments, also represent a cross-section of the earth's crust. The origin of the finer loess, which was transported over very long distances is still unclear. There are indications that some may have originated from the foothills of the Carpathians under periglacial conditions, but there are also mineralogical indications of a north African origin.
An understanding of the soils of western and central Europe demands knowledge of their stratigraphical history; a knowledge of the sediments is more important for the assessment of soil quality than is a knowledge of pedology.

The third important region of Europe is the Mediterranean, and our knowledge of climatic conditions here in the Pleistocene is still incomplete. We do know that in dry cold periods there was great modification of loess deposits as intense rainfall transported the material. We know less about what happened in periods corresponding to the wet cold periods of the periglacial area and we can say only that there was intensive soil formation on the widespread calcareous sediments and rocks, giving rise to the so-called red-brown earths which are also found in north Africa.
The above is but a very crude outline of the pleistocene prehistory of Europe but sufficient to show how our soils are dominated by the sediments on which they were formed. It is a characteristic of Europe that there are scarcely any old soils, in stark contrast to, for instance, Africa or South America where old soils from the Tertiary survive. The effects of the ice age were to expose fresh rock material so that, for all practical purposes, soil formation in the Holocene began from scratch. There are few soils of Tertiary origin in Europe.
When we come to consider the effects of pedogenetic differentiation in the Holocene on the quality of our soils we run into the difficulty of defining standards which would adequately describe soil quality. Professor *Schroeder* who spoke before me, defined optimum yield and maximum yield but he did not use the words 'soil fertility' and it may be questionable whether soil fertility can actually be defined or measured. It is variously described by different authors; I have tried to make an analysis based on the history of soil utilization in central Europe.
Arable farming began in central Europe some five and a half thousand years B.C. and was concentrated on the loess, especially on the chernozem. It was an exhaustive system of farming resulting, largely because of the difficulty of controlling weeds, in the abandonment of worked-out soils and the opening up of new areas. Such soil exploitation, running down the natural reserves of soil fertility continued in Europe, as it did in other parts of the world, into the present century. Various ways of soil exploitation were evolved and particularly interesting are the methods used in north central Europe and to some extent in England, southern Scandinavia and parts of France, where, via livestock, nutrients and organic matter were transferred from large areas of grassland and concentrated on areas near the homestead. This was the only method by which light sandy soils, subject to nutrient leaching, could be made to yield. Such a system might be termed 'concentration' farming.
Soil fertility depends essentially on two things: the store of nutrients in the natural soil and the rate at which they can be delivered to the plant, but it can be modified by man's intervention in improving them. This kind of view of soil fertility was the basis for the soil evaluation system *(Reichsbodenschätzung)* introduced in Germany at the beginning of the 1930's and still in use today. It attempted to evaluate soils on the basis of their effective fertility. The system has stood the test of time.
The productivity of soils can be evaluated in terms of natural fertility, and there are still

areas in Europe, where reliance is placed on this. Alternatively it can be evaluated in terms of potential productivity in which the soil is regarded as a medium for transforming inputs, including plant nutrients, into yield. The latter is more appropriate to the developed areas. In such areas, the 'concentration' farming alluded to above has been replaced by 'transformation' farming.

The result of applying new technology, in particular perhaps of the use of fertilizers, has been to change soils which, according to the Reichsbodenschätzung, would be regarded as unsuitable for arable farming into highly productive soils. Such is the case particularly with the light sandy soils. Capital investment, intensification of management and generous fertilizer usage have changed some of the soils which in the thirties and forties were regarded as fit only for afforestation into deep fertile soils enriched in organic matter and nitrogen. Their inherent natural fertility is still low and, if fertilizers were witheld, they would soon lapse into their former infertile state.

The influence of climate on soil productivity can be well illustrated by considering the loess soils which are so widely distributed over Europe. The productivity of these soils, which include chernozems, para brown earths and pseudogleys, depends very much on their physical properies, *i.e.* upon their ability to hold and supply water.

The fact that in Schleswig-Holstein yields of more than ten tonnes wheat can be grown on moraine and marsh soils is largely accounted for by the fact that these soils can hold sufficient water to support such high yields. The availability of water to the crop depends on rainfall and its distribution and on the water holding capacity of the soil. Here in Goslar we are at the boundary between the maritime climate ofWestern Europe and the continental climate of Eastern Europe. Total annual rainfall is 650 mm of which 400 mm falls in the 6 summer months. Evapotranspiration accounts for 520 mm (450 in summer and 70 mm in winter). To the summer requirement must be added 60 mm percolation into the subsoil so that the total summer deficit is 110 mm which must be made good from soil reserves. This must be replenished by the winter rainfall and, in fact, sufficient rain falls every winter to ensure that this happens.

The change in climate from the Atlantic coast to the mouth of the Don is illustrated in Figures 1–5. At Brussels (Figure 1) annual rainfall is 850 mm well distributed through the year, and more than sufficient for full crop growth. In this area (Göttingen – Goslar) (Figure 2) there is less rain (650 mm) with a peak in summer, characteristic of the continental climate of Central Europe (Figure 3). In the Halle – Bernburg area, only 80 km further east, we are in the true contjnental climate; rainfall is only 469 mm and there is a pronounced summer peak. There is insufficient winter precipitation to replenish soil moisture reserves and the available water is insufficient to support the yields to which we are accustomed in our own area. The further east we go the more adverse are the conditions: Kiev (Figure 4) with 528 mm and finally Rostov on Don (Figure 5) where the summer growing season is definitely restricted by drought. The potential productivity of the loess soils is absolutely dependent on climate. The Mediterranean region is characterized by high winter rainfall and summer drought and the water holding capacity of the soil is decisive.

Soil organic matter has an important influence on soil productivity. The light soils which were podsolized in the Middle Ages and which, until recently were regarded as unfit for arable farming, can be highly productive under modern conditions, largely on account of their accumulated capital of organic matter. Some years ago, when our soils were not so deeply cultivated, organic matter contents were higher in the maritime

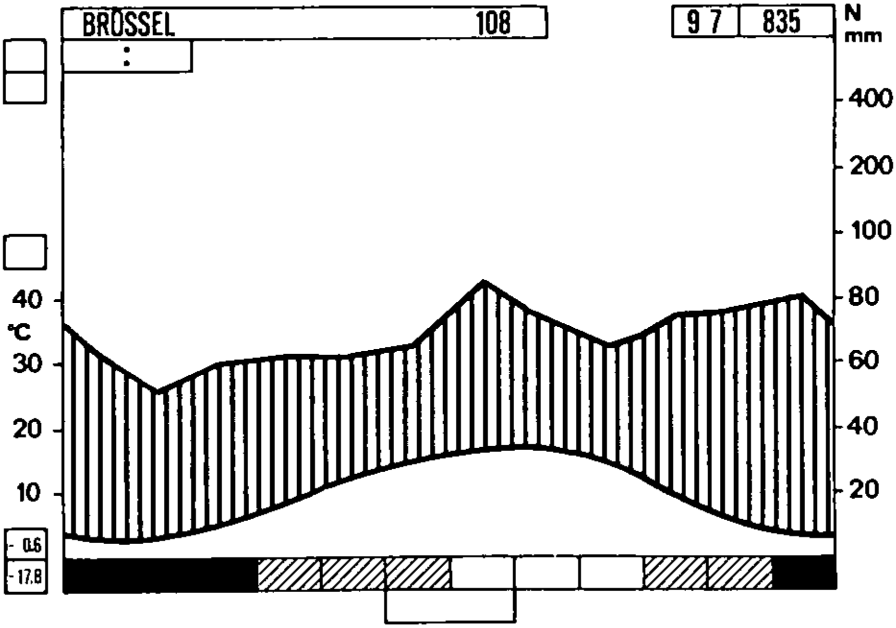

Fig. 1. Annual rainfall in the Brussels area (Belgium)

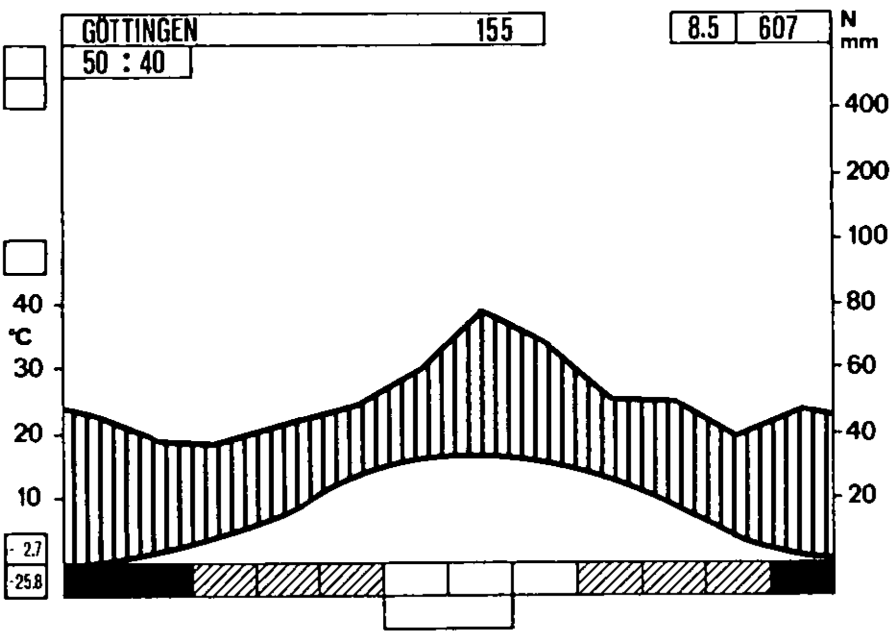

Fig. 2. Annual rainfall in the Göttingen-Goslar area (Fed. Rep. of Germany)

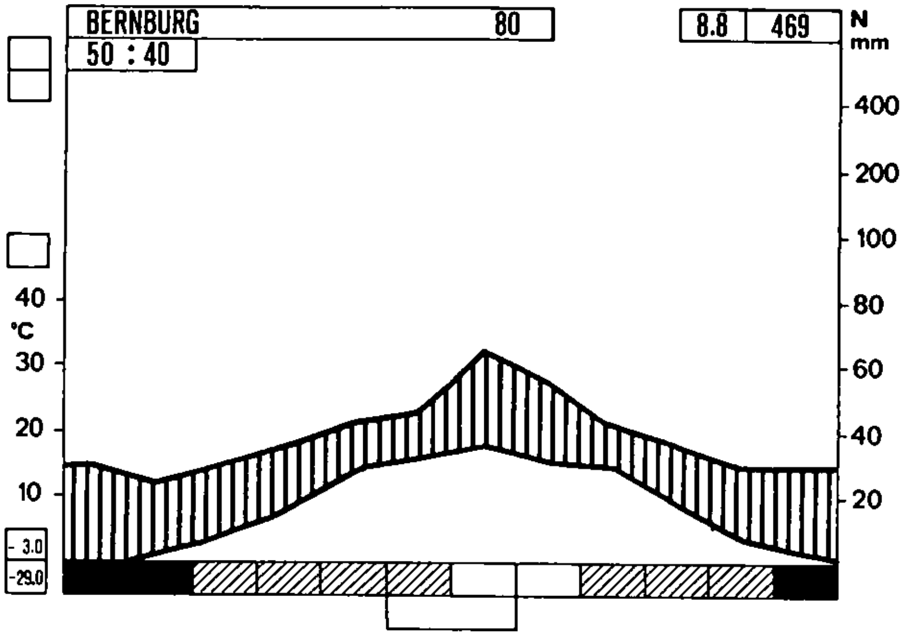

Fig. 3. Annual rainfall in the Halle-Bernburg area (German Democratic Republic)

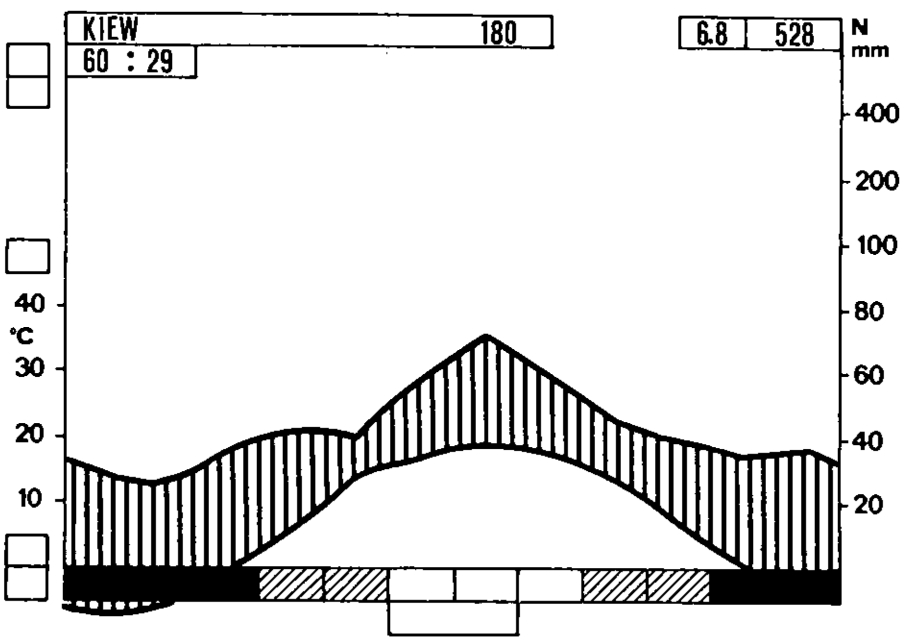

Fig. 4. Annual rainfall in the Kiev area (USSR)

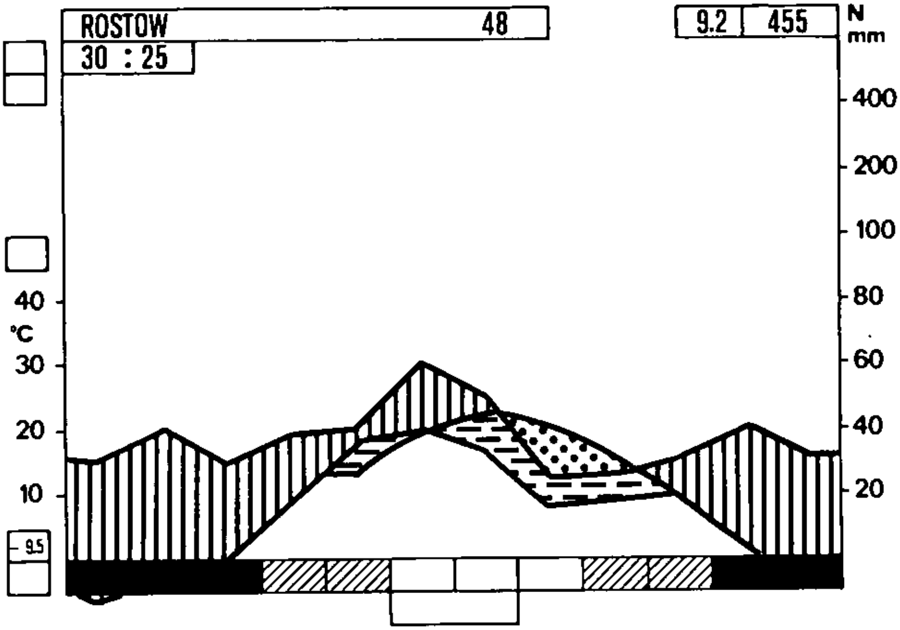

Fig. 5. Annual rainfall in the Rostov area (USSR)

climate of Western Europe than in the central regions and they fell off as we moved further east. Organic matter contents were very low in the Mediterranean region. Nowadays, as crop yields are increasing so are organic matter contents of the soil, through the incorporation of a greater mass of plant roots and other crop residues, and this trend is altering the overall picture.

Ever since the Middle Ages, farmers have felt the urge to cultivate deeper and deeper; even Albrecht Thaer wrote that soil fertility increased as the depth and intensity of cultivation increased. In the middle of the last century farmers growing root crops seized on the steam plough which could plough to a depth of 50 or 55 cm. The modern tractor plough cannot penetrate to such a depth and we are faced with a problem. While all cultivations loosen the soil, creating more secondary pores, they also destroy soil structure, compacting the aggregates. When the deeply cultivated layer is left undisturbed, compaction is the inevitable result. It is for this reason that we are concerned about the modern tendency to deeper cultivation which began about ten years ago. Modern ploughs can work to a depth of 40 cm, and 35 cm is by no means uncommon. Deep cultivation can result in loss of organic matter as when the surface is inverted organic matter may be placed in anaerobic conditions at depths of 35 or 40 cm. It may be that the high yields mentioned by Prof. *Schroeder* are obtained with deep cultivation, but this is deep cultivation carried out with skill and with a proper eye to weather and soil conditions. The conditions appropriate for deep ploughing may not be found all over Europe.

We can experience wet winters and wet early springs in central Europe as was the case in 1976 and these can induce anaerobic conditions in the plough-layer, particularly severe following a difficult beet harvest when the tops may be ploughed in to depth. There is a great danger of enhanced fungal growth, particularly of slime fungi which can result in very rapid breakdown of organic matter. We have heard of cases where arable soils have declined from an organic matter content of 2.2% down to 0.8 or 0.5% even though receiving generous dressings of farmyard manure. A further problem is the deep incorporation of organic matter which can adversely affect the soil N supply in the following growing season. Anaerobiosis leads to denitrification.

A summary of results of minimum cultivation experiments by Prof. *Bäumer* and myself in Göttingen shows that the yields obtained are at least as high as those with conventional cultivation, though it may be necessary slightly to increase nitrogen applications. Minimum cultivation preserves the natural soil structure and gives better natural drainage. It seems possible that the use of minimum cultivation techniques would be able to bring back into cultivation some of the heavy soils which have been regarded as too heavy and difficult to work and on which only a restricted range of crops can be grown. In this sense minimum cultivation not only offers cost-saving but opens up other possibilities.

On the other hand, deep tillage can be helpful in soil amelioration as in the Mediterranean region where ploughing to 50 or 60 cm of completely dry soil at the beginning of summer turns up huge clods which collapse and form a fine tilth with the first rain.

This has been a very brief survey of the soils of Europe and of how their productivity is affected by climate. It has emphasized the importance of the composition and properties of the sediments on which many of our soils have been formed and has touched on the measures used by man to improve or modify their productivity. It is hoped that it will serve as a basis for further discussion.

Physiological and Environmental Determinants of Potential Crop Productivity

J. H. J. Spiertz, Centre for Agrobiological Research Wageningen/The Netherlands*

Summary

Total production of dry matter in temperate regions is strongly associated with the amount of intercepted radiation and to a lesser extent determined by the efficiency of photosynthesis. Radiation interception depends on earliness of crop development and the duration of maintaining a closed canopy. Crop response to environmental constraints determines rate and duration of canopy production and growth of the storage organs. Interrelations between assimilating organs (source) and storage sites (sink) play an important role in the carbon and nitrogen economies of the crop.

Crop productivity has been increased by a combination of improved varieties and technological innovations. The genetic improvement of varieties concerns mainly a more favourable dry matter distribution towards organs to be harvested (seeds, tubers, etc.) and to a lesser extent an increase of total biomass production. Although further improvement of harvest-indices is still possible, there is a need for increasing biomass production.

Introduction

The potential production rate of a crop is usually defined as the growth rate of a closed green canopy with ample water and nutrient supply, grown in a disease-, pest- and weed-free environment *(cf. de Wit et al. [1979])*, and is therefore determined by the crop response to the prevailing weather conditions. Even under optimum growing conditions differences exist between species. In C_4-plants (maize, sorghum, sugar cane, tropical grasses) the potential production rate varies from about 350 kg dry matter ha^{-1} d^{-1} in warm and sunny climates to about 200 kg ha^{-1} d^{-1} in cooler temperate, climates; for C_3-plants (rice, wheat, potatoes, sugar beet, grasses) this rate is about 200 kg dry matter ha^{-1} d^{-1} *(Loomis* and *Gerakis [1975], Cooper [1975])*.

Research on crop growth and development must be focussed on genetic and environmental factors which limit crop production and provide the breeder and farmer with information that can be used for increasing the yields and quality of their crops. In this way world food demands may be met by exploiting the production potential of land already in use and making a more restricted and efficient use of fossil fuel, fertilizers and chemicals for crop protection *(de Wit [1979])*.

* Dr. Ir. *J.H.J. Spiertz*, Deputy Director, CABO, P.O. Box 14, NL-6700 AA Wageningen/ The Netherlands

In this paper the following topics are discussed:

- crop establishment and development
- light interception, leaf and canopy photosynthesis
- biomass yield, growth efficiency and duration
- partitioning of assimilates; carbon and nitrogen economy.

Crop establishment and-development

The rate at which leaves expand early in the season determines the amount of radiation that can be intercepted. This is particularly important in temperate climates where the spring is cold, and some crops do not cover the ground until almost half of the year's irradiance has been received *(Legg [1981])*.

The driving forces for germination and juvenile growth are soil temperature and moisture. Critical temperatures for germination and emergence differ strongly between species. In cereals and grasses these processes proceed already at temperatures as low as 5°C, whereas for an acceptable rate of emergence, maize and sugar beet require much higher soil temperatures (above 12°C). Emergence of seeds under field conditions is possible at slightly lower average soil temperatures than the critical temperature (Figure 1). This phenomenon exists due to the diurnal variation of temperature in the seed-bed; as a consequence soil temperature exceeds the critical temperature for some hours during daytime. Farmers expoit this phenomenon for advancing crop establishment in spring by careful preparation of the seedbed. The top-layer requires a soil structure which accumulates heat rapidly, but the sub-layers need sufficient compaction for an adequate water supply to the seeds.

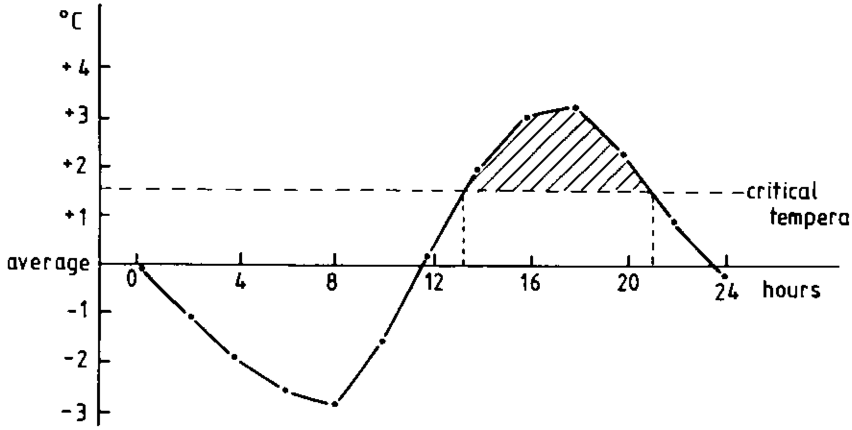

Fig. 1. Diurnal variation in soil temperature; a schematic presentation of the duration, over which temperatures exceed a critical level for growth.

Several plant growth processes show a linear and not an exponential response to temperature. This response is important to the concept of degree-days, where growth and development are assumed to be proportional to temperature and are related to a summation with time of temperatures above an effective minimum for growth. To apply this approach it is necessary to know which part of the plant is sensing the environment. There are indications that the response of plants to temperature is located in the growing parts of the organs. *Kleinendorst* and *Brouwer [1970]* found that growth functions of young maize plants were associated with temperatures of the growing point. In cereals soil temperature exerts the main influence before stem elongation and air temperature during the later growth stages, as was shown by *Gallagher [1979]* for growth of the wheat plant. During the vegetative growth period leaf growth was linearly related to the sum of degree-days based on soil temperatures; after ear initiation and stem elongation leaf growth was initially linearly related to the heat sum of air temperatures, but later on the vapour pressure deficit of the air became the most limiting factor. A near-linear response of growth to increasing temperatures would explain why similar effects are brought about by fluctuating and steady temperatures, which have the same mean *(Friend* and *Helson [1976])*. The linear relationship is seriously disturbed if temperatures exceed the optimum for growth for a significant part of the growing period *(Bierhuizen [1973])*.
The promoting effect of nitrogen on tillering and leaf growth of cereals and grasses under temperate conditions is well established. Especially for crops like grasses, where the leaves are the main harvestable fraction, nitrogen shortens the duration of a growing cycle from cutting to a defined dry matter yield *(Prins et al. [1980])*. The total annual yield of grass may vary from 6 to 20 tons of dry matter per ha with nitrogen dressings ranging from 0 to 400 kg N per ha. This huge increase in herbage production is the combined result of:

- an enhanced rate of leaf initiation and leaf expansion, leading to more light interception and as a consequence to a higher rate of photosynthesis per unit ground area;
- a delay of leaf senescence, which is associated with prolonged photosynthetic activity per unit leaf area;
- a shift towards higher shoot/root ratios.

The vegetative phase of cereals extends from shoot emergence to ear initiation, but growth of some vegetative organs (*e.g.* roots) continues until anthesis and even afterwards. In the early vegetative phase, leaf and root growth predominate; root growth may exceed shoot growth at low temperatures, but as temperatures rise the growth of shoots increases more than that of roots. Usually growth of the root system continues until heading, after which root growth may cease and roots may even degenerate during the grain-filling period. With an adequate water and nutrient supply, however, root growth and nutrient uptake continue well into the grain-filling period.
Throughout the early life of the wheat plant, the leaf blades are the main photosynthetic organs. The rate of leaf formation as well as the size of the mature lamina depend on temperature, light intensity, daylength and nutritional status under which the plant is grown *(Friend and Helson [1976])*. Leaves formed prior to ear initiation originate close to the crown, but elongation of stem internodes separates the leaves in the

vertical plane, leading to a more effective light distribution within the canopy. Towards the end of the life cycle, photosynthesis by the stems, leaf sheaths and ears tends to become increasingly important as the leaves senesce.
The double-ridge stage is usually considered as a key stage in the development of cereals, by marking the end of vegetative development and the beginning of ear development. The rate of ear development is affected by light intensity, daylength and temperature. The number of fertile spikelets formed increases with higher light intensities; at high planting densities and in densely tillered stands, therefore, the number of fertile spikelets may be reduced by mutual shading. After the terminal spikelet has been formed, environmental conditions no longer influence spikelet number, but they may affect the number of florets differentiated within each spikelet.
In cereals moderate temperatures during the ear development phase enhance grain number *(Warrington et al. [1977])* and during the grain-filling phase a decreased rate of grain growth is associated with a corresponding increase in duration *(Spiertz [1977], Sofield et al. [1977])*. Over a certain range of temperature, changes in rate are balanced by changes in duration with only minor differences in final yield. *Vos [1981]* showed that the effect of higher temperatures on grain yield of wheat is balanced by a rise in visible radiation of 130–180 J m^{-2} min^{-1} per degree-centigrade. So, under field conditions where radiation and temperature are confounded to a large extent, similar yields may be expected under warm and sunny as well as under cool and dull weather conditions.

Light interception, leaf and canopy photosynthesis

The photosynthetic system forms the basis of almost all plant productivity. In a crop with a green canopy, several variables influence the net influx of CO_2. These variables include:

- leaf area index and leaf area duration
- gross assimilation rate of single leaves and of the canopy
- photosynthetic adjustment to changes in environmental conditions
- rate of maintenance and growth respiration.

Before and after the canopy achieves full light interception, variation in leaf area is a much stronger determinant of crop growth rate than is variation in photosynthesis rate per unit leaf area *(Gifford [1981])*. Therefore, the highest correlations between leaf area index and crop yield are found when leaf development and growth are restricted or leaf senescence is accelerated by drought, nitrogen shortage or disease *(Legg et al. [1979])*. It is well-known that stress factors accelerate leaf senescence in cereals and shorten the duration of the grain-filling period *(Spiertz* and *Ellen [1978])*. By comparison, indeterminate crops such as potatoes and sugar beet are able to continue the formation of new leaves, and as a consequence to extend the period of light interception and crop photosynthesis *(Sibma [1977])*.
The pattern of light interception by forage crops is illustrated for grass and lucerne

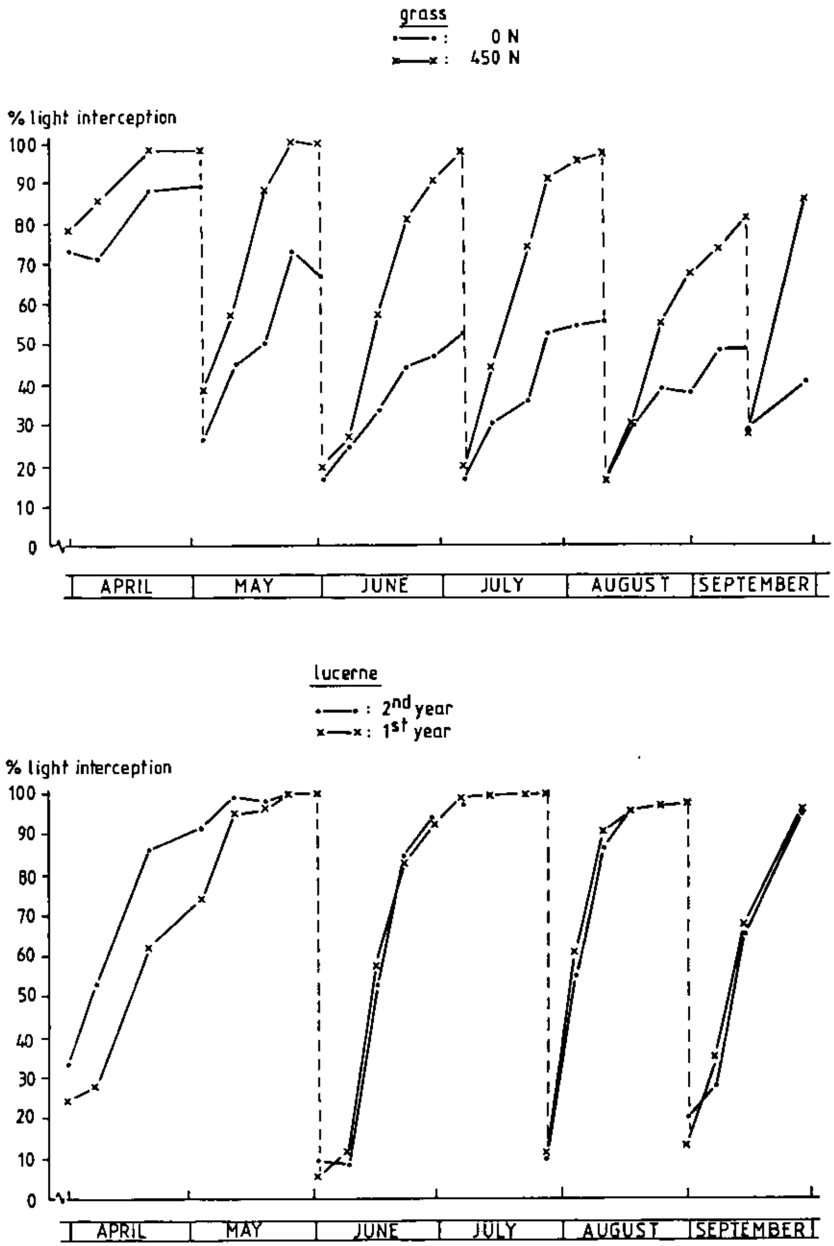

Fig. 2. Pattern of light interception throughout the growing season for grass (a) and lucerne (b). Location: Flevopolder; growing seasons: 1980 and 1981.

(Figures 2A and B). The duration of full light interception by the canopy is determined by cutting frequency. Accumulated radiation by these crops greatly depends on the rate of leaf development (regrowth) after cutting.

Monteith [1977] concluded that the amount of light intercepted is a major discriminant of yield rather than amount of incident light. The potential yield of a crop is therefore correlated with the longevity of the canopy, the so-called leaf area duration *(Watson [1952])*.

The obvious way to increase total biomass production under optimal supplies of water and nutrients is to extend the growth period of one crop or by growing more than one crop within the growing season. However, in many regions the length of the growing season is restricted by frost, drought, heat damage or problems with pests and diseases. Under those conditions, the opportunities for increasing crop yields depend very much on the improvement of crop photosynthesis and on the distribution and storage of photosynthetic assimilates.

Crop photosynthesis represents the total net CO_2-exchange by photosynthetically active organs. An important determinant of the CO_2-exchange rate is stomatal conductance, which largely depends on the mechanism to maintain the CO_2-concentration inside the stomata at a fixed level. This regulation level is about 210 vpm in C_3 and 120 vpm in C_4-plants *(de Wit [1978])*. The consequence of this difference in regulating mechanism is that at the same rate of CO_2-exchange, stomatal opening and hence the transpiration rate in C_4 plants (*e.g.* maize) is about half of that in C_3 plants (*e.g.* wheat). CO_2-exchange rate and transpiration rate are the main determinants of the transpiration coefficient, which may be as low as 100 and 200 kg water per kg dry matter for C_4 and C_3-plants, respectively, if stomatal opening is fully controlled by the internal regulation of the CO_2-concentration. The characteristic response curves for the dependence of crop assimilation and transpiration on the absorbed photosynthetically active irradiance are shown in Figure 3. Photosynthesis-light response curves of individual leaves of C_3 plants show light saturation at about 1 J cm^{-2} min^{-1}, whilst those of crops hardly attain a maximum for net assimilation. The potential CO_2-exchange rate per unit ground area can only be achieved when all individual leaves at the various heights in the canopy attain their maximum rates. Values for maximum leaf photosynthesis of C_3 and C_4 plants vary from 15–50 kg CO_2 ha^{-1} h^{-1} and from 30–90 kg CO_2 h^{-1}, respectively *(Alberda et al. [1977], de Wit et al. [1979])*.

Generally, the various leaves differ in age and illumination. Therefore the calculation of crop assimilation from photosynthesis-light curves of individual leaves is rather complicated. For this reason computer models have been developed, which also include leaf angle distribution, reflection and transmission coefficient of the leaves and position of the sun *(de Wit [1978])*. Integration of the CO_2-assimilation rates of all leaves during a diurnal cycle yields the daily CO_2-exchange rate of the crop. Daily total gross CO_2-assimilation for a closed crop canopy (LAI = 5) with a random leaf angle distribution is shown in Figure 4 for clear and overcast days as derived from *Goudriaan* and *Van Laar [1978]*.

Growth and maintenance respiration were thoroughly studied by *Penning de Vries [1975]*, who found that the conversion from photosynthesis substrate to plant constituents was related to the chemical composition. Higher temperatures increase the rate of the conversion process, but its efficiency remains unaltered. Efficiencies of conversion for various end-products are shown in Table 1, showing that lipids are

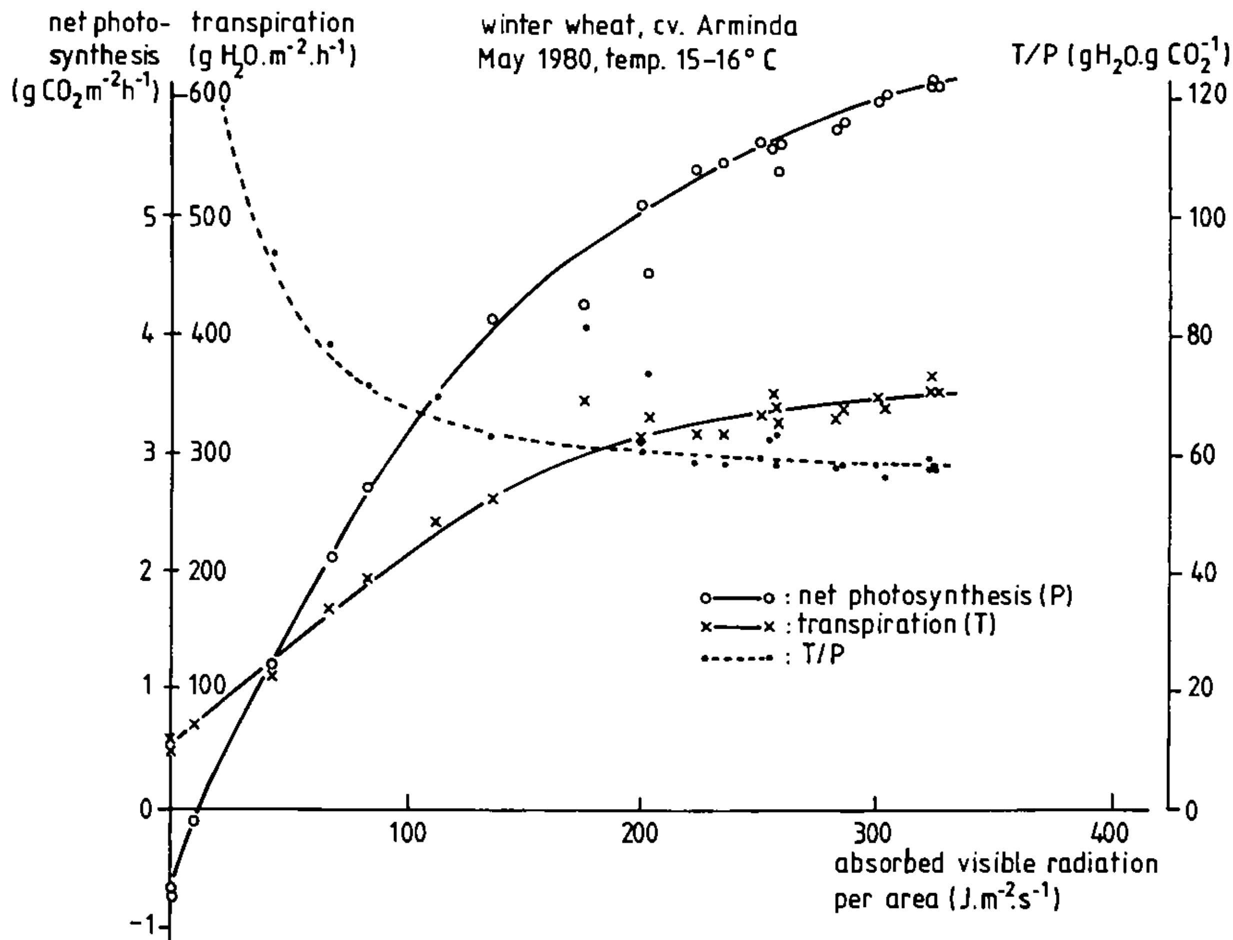

Fig. 3. Response of net photosynthesis and transpiration to absorbed photosynthetically active radiation (PAR).

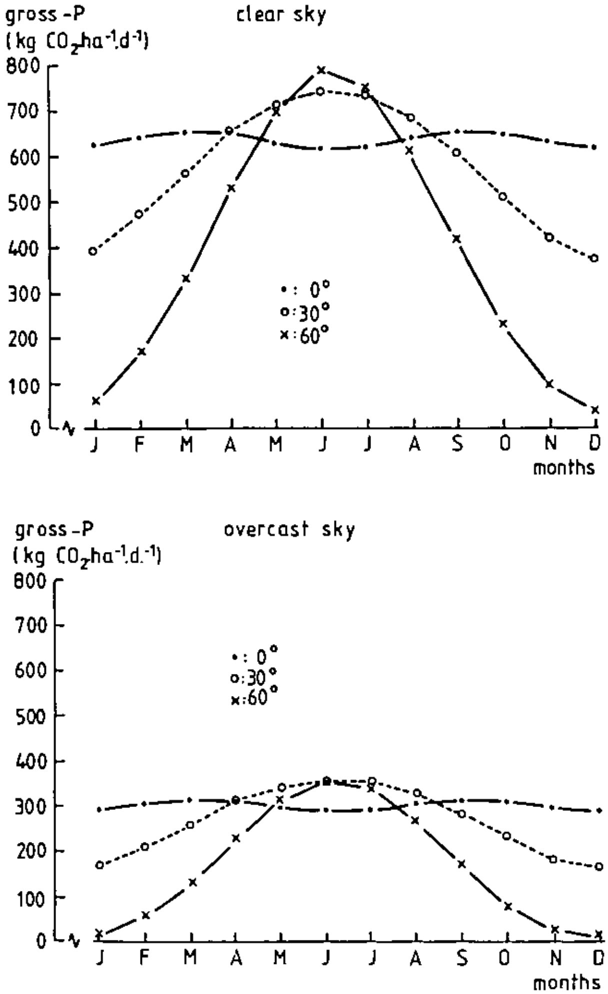

Fig. 4. Course of gross photosynthesis for clear and overcast sky at three different geographical latitudes.

'expensive' and carbohydrates relatively 'cheap' to manufacture, in terms of efficiency of conversion. Maintenance respiration can be defined as all dark respiration processes which are not related to growth of new organs; these respiration processes generate the energy required for transport through membranes, turn-over of enzymes, etc. The rate of maintenance respiration was estimated by *Penning de Vries [1975]* at 15 g CH_2O kg^{-1} (dry weight) d^{-1} at a protein content of 200 g kg^{-1} (dry weight).

Table 1. Efficiency of conversion of photosynthate (glucose-units) into plant constituents

Compounds	Production calue (g material/g glucose)
Carbohydrates	0.826
Nitrogenous compounds from NO^{-}_3	0.040
from NH_3	0.616
Organic acids	0.104
Lignin	0.465
Lipids	0.330

(from: *Penning de Vries [1975]*)

Considerable variation in respiration exists among species, varieties and environmental conditions. *Wilson [1975]* found differences in dark respiration in fully expanded leaves of perennial ryegrass *(Lolium perenne)*. The low-respiration genotypes have about a 10% growth rate advantage in both simulated swards and field plots *(Robson [1980])*. In recently published experiments *(Robson [1982])* a total biomass increase of 23 percent was associated with a 22–24 percent lower rate of dark respiration per unit dry weight. Half the extra dry weight could be attributed to more economic use of carbon; the rest could be related to a greater tiller number and more light interception. Reduction of maintenance respiration would be particularly worthwhile at the later growth stages and under warm and poor light conditions. Under these circumstances maintenance respiration may consume half of the daily gross photosynthesis.

Biomass yield, growth efficiency and duration

The net daily increase in dry matter can be calculated with the following equation *(de Wit et al. [1979])*.

$$Pn = 0.07 \times (Pg - 0.015 \times W) \qquad (1)$$

where Pn = daily net gain in dry weight

Pg = daily gross photosynthesis

W = standing dry matter

0.7 = conversion efficiency

0.015 = average maintenance respiration

Such equations can be used for the calculation of potential growth rate under optimal conditions. However, more sophisticated calculation methods are required which also take into account the limitations by environmental factors (temperature, water shortage, lack of nutrients) for predicting actual growth rates *(Penning de Vries [1980])*.
The dependence of potential productivity and efficiency of solar energy utilization on leaf photosynthetic capacity has recently been evaluated by *Murata [1981]*. He found a

close relationship between maximum crop growth rate and maximum leaf photosynthesis. Under the conditions where maximum growth rates for the various crops were attained, such environmental factors as light intensity, temperature and supply of water and nutrients may be considered to have been nearly at their optimum levels. However, crops are mostly grown under circumstances where at least during a part of the growth cycle the conditions are suboptimal. Therefore, as *Monteith [1977]* has pointed out, the growth rate is mostly not restricted by photosynthetic ability, but by environmental constraints. A typical example is the growth rate of the C_4 crop maize; under the climatic conditions of N.W. Europe its growth rate is virtually identical to that of C_3-crops, in contrast to more continental climates, where temperature and radiation are often more favourable for C_4-crops.

Annual crops, like wheat, potatoes and sugar beet, show an extended period with a closed canopy and after initiation of reproductive growth allocate the major part of the assimilates in storage organs. The growth rates of storage organs vary under optimal conditions between 200 and 350 kg dry weight ha^{-1} day^{-1} mainly depending on temperature. Data on dry matter accumulation of the main agricultural crops in the Netherlands are presented in Figure 5A and by *Sibma [1977]*. It shows that the growth rate of the aerial parts of the crop over extended time intervals amounts to 200 kg ha^{-1} day^{-1}. The levelling off in growth rate starts when senescence of leaves proceeds to the upper layers of the crop canopy. Vegetative crops, like potatoes and sugar beet, can maintain a photosynthetically active canopy by replacement of older leaves by new ones.

It is well established that perennial crops, like grasses and forage legumes (lucerne and white clover), which allocate a relatively large proportion of the assimilates to the roots, show a growth rate of the above-ground parts varying from 100 to 200 kg ha^{-1} day^{-1} (Figure 5B). Another typical feature of these crops is, that the growth rate progressively decreases during the growing season *(Alberda [1971])* and as a consequence does not reflect the seasonal radiation pattern. This gradual decrease in growth rate might have been brought about by:

- remobilization of reserves from roots and stubbles, which contribute to above-ground growth early in the growing season,
- allocation of more assimilates to the underground parts of the crop during the later stages of the growing season,
- unfavourable ratio between radiation and temperature later in the growing season due to the fact that air and soil temperature lag behind the seasonal pattern in radiation. As a consequence, maintenance respiration will be higher during the later stages,
- high temperatures, lack of nitrogen and drought during the summer, which may restrict the regrowth of shoots after cutting. A delay in regrowth leads to an extended period with incomplete light interception.

Proper management, by optimizing cutting frequency, nitrogen fertilization and water supply, will shorten the intervals between growth phases with a closed canopy and maximum growth rate. As a result the mean growth rate is enhanced.

Potential crop productivity can also be analyzed in terms of efficiency of solar energy

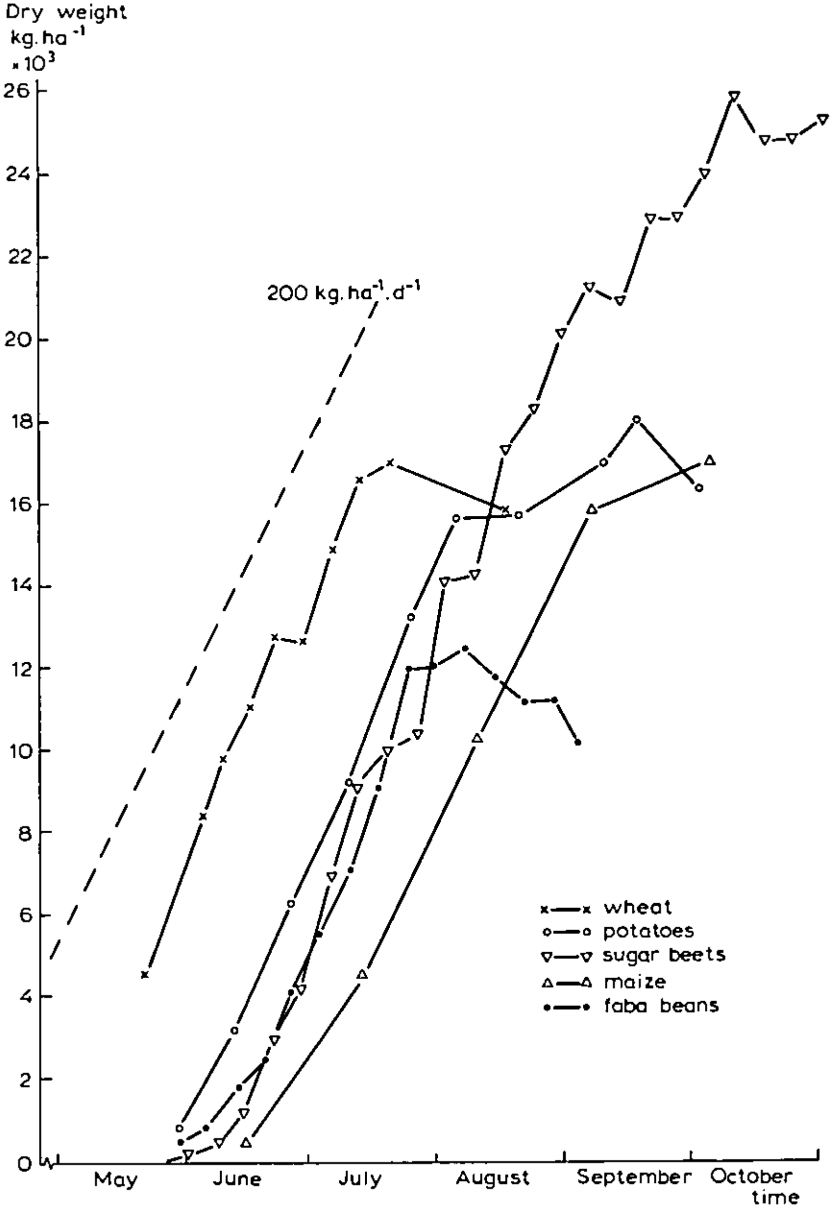

Fig. 5A. Course of dry weight accumulation in arable crops.

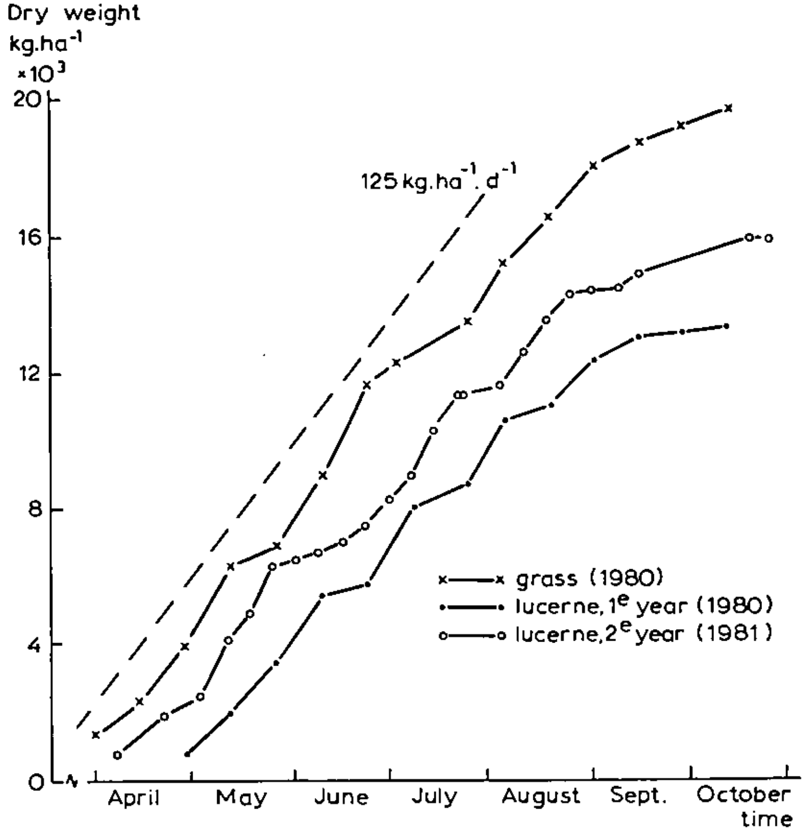

Fig. 5B. Course of dry weight in forage crops.

utilization and accumulated amount of absorbed photosynthetically active radiation, respectively. Crop yield may therefore be calculated as:

$$\underset{(\text{g m}^{-2})}{\text{Biomass yield}} = \underset{(\text{M. Joule m}^{-2})}{\text{Accumulated intercepted radiation}} \times \underset{(\text{g M. Joule}^{-1})}{\text{Efficiency of solar energy conversion}} \quad (2)$$

This approach of calculating biomass yield has some severe shortcomings, such as not taking into account the decline in efficiency of solar energy conversion with the ageing of the crop. However, its main advantages are the simplicity of the procedure to calculate potential biomass yield and the conversion of 'duration' into a physical determinant of yield. It has been shown that the rate at which crops accumulate dry matter is proportional to the amount of visible radiation absorbed by the canopy *(Monteith [1977], Gallagher and Biscoe [1978])*. Seasonal light interception was estimated on 0.33, 0.37 and 0.49 as a fraction of annual radiation for maximum yields of wheat, potatoes and sugar beet, respectively. Hence, the amount of accumulated intercepted radiation ranged from 1200 to1600 MJ m^{-2} for these crops.

Gallagher and Biscoe [1978] expressed efficiency of solar energy conversion as the ratio between net photosynthesis and intercepted radiation and found a value of about 3 g MJ^{-1} for a closed crop canopy under favourable conditions, whereas *Murata [1981]* reported maximum efficiency values of 3.95 and 2.89 g MJ^{-1} for C_4 and C_3 crops, respectively. *Milford et al. [1980]* found a linear relationship between accumulated dry weight of sugar beets and accumulated intercepted radiation. The efficiency of conversion of intercepted radiation to total dry matter was estimated from the slopes of the regression lines for 1978 and 1979. In both years the regressions were linear till crops had intercepted about 1000 Mega Joule m^{-2}; the efficiencies of conversion being 1.98 and 1.77 g MJ^{-1} in 1978 and 1979, respectively. A key to increasing dry matter production by sugar beet crops is therefore to maximize the amount of intercepted radiation. Early growth of sugar beet leaves is largely governed by temperature; although nitrogen and water supply can also affect leaf area development to a large extent. In our own experiments with winter wheat in two contrasting growing seasons, 1976 (hot and sunny) and 1978 (cool and cloudy), the conversion rate amounted to about 2 g M $Joule^{-1}$. The higher radiation level in 1976 was counteracted by a shortening of leaf longevity, the crop senescing already after mid-July. In contrast, in 1978 radiation levels were lower, but the growth period was extended by 3 weeks.

In seed crops, like cereals and pulses, the longevity of the leaves is determined by direct morphogenetic effects of environmental factors and by indirect effects through the requirements of the seeds for nitrogen *(Sinclair* and *de Wit [1975], Spiertz [1980])*. Generally, warmth accelerates the rate of grain growth and shortens the duration of growth, whilst adequate water and nitrogen supply delay leaf senescence, but do not affect rate and duration of grain growth directly *(Legg et al. [1979], Spiertz* and *Ellen [1978])*. Although the potential duration of grain growth is determined by temperature, the effective duration will depend on supply of assimilates to the grain. Nitrogen relocation and protein accumulation show a stronger response to temperature than carbohydrate accumulation *(Spiertz [1977], Vos [1981])*. Nevertheless the effect of temperature on protein yield of the grains is smaller than on dry matter yield due to a negative feedback from higher temperatures on protein depletion of the leaves and photosynthesis and leaf senescence.

The duration of the period of potential grain growth of cereals (D) may be derived from the following parameters: rate of assimilation during the grain-filling period, available reserves temporarily stored in the stems, leaves or roots (Rc), and rate of grain growth (Rg).

It follows, that:

$$D = \frac{Rc}{Rg - Ra}$$

Two examples:

a) duration based on supply and use of carbohydrates:

$$D = \frac{1500 \text{ kg } CH_2O \text{ ha}^{-1}}{200 \text{ kg } CH_2O \text{ ha}^{-1} \text{ d}^{-1} - 150 \text{ } CH_2O \text{ ha}^{-1} \text{ d}^{-1}} = 30 \text{ days}$$

b) duration based on supply and use of nitrogen

$$D = \frac{90 \text{ kg N ha}^{-1}}{4 \text{ kg N ha}^{-1} \text{ d}^{-1} - 1 \text{ kg N ha}^{-1}/\text{d}^{-1}} = 30 \text{ days}$$

It follows that for a grain yield level of 6000 kg ha^{-1} an average post-floral net photosynthesis of 150 kg CH_2O ha^{-1} d^{-1} is required, besides 1500 kg CH_2O ha^{-1} mobile reserves. For attaining higher yield levels, an extended duration of grain growth or higher rates of all involved post-floral processes are required.
With increasing yield levels, nitrogen supply becomes a critical factor. Nitrogen uptake, especially during the post-floral period, may be limited by: reduced activity of the root system or decreased availability of inorganic nitrogen in the soil. In all cases where the requirements of the seed cannot be met by supplies from the root, the required nitrogen is remobilized from the vegetative parts of the plants, especially the leaves. As a result senescence and a decline in photosynthesis might be accelerated leading to a reduction in the supply of photosynthates to the seeds.

Measures aimed at lengthening the growth period of cereals may be focussed on the following topics:

- a prolonged root activity,
- a larger pool of carbohydrate and nitrogen reserves built up before the start of grain growth, to overcome adverse conditions during the post-floral period,

The above-mentioned strategies are of less importance for vegetative crops. Most vegetative crops with an indeterminate apex are able to continue leaf formation throughout the growth period. However, longevity of existing leaves and new leaf formation might be severely restricted by environmental constraints (heat, water and nutrient shortage, lack of carbohydrates). Most are very susceptible to constraints in water availability. So better adaptation to short cycles of drought might enhance the yield stability of crops. The various mechanisms of crop response to drought are discussed in detail by *Fischer* and *Turner [1978]*.

Partitioning of assimilates; carbon and nitrogen economy

For most crops dry matter distribution between shoot, root and reproductive organ is a key-factor for growth and yield performance. It is a dynamic pattern largely determined by the sequence and rate of developmental processes (floral, root or tuber initiation) and the consecutive growth rate of the organs present during a developmental phase. In seed crops there is an extensive overlap in development and growth between different parts of the plant (roots, leaves, stem, floral structures and seeds). Due to the considerable overlap in the development and growth of vegetative and reproductive organs, the latter are not only dependent upon but also competitive with the vegetative organs for assimilate supply. An ample assimilate supply favours floral initiation and development, seed set and seed filling in grain crops, but also the growth of storage organs in vegetative crops. Generally, cool and sunny weather conditions promote assimilate supply to the reproductive organs. The main reason is that moderate temperatures slow down the development rate of most organs, but hardly affect rate of photosynthesis *(Wardlaw [1979])*.

The major difference among crops in partitioning of assimilates lies in the type of organ where the major part of their assimilates is accumulated. In the early stages of domestication some yield increase might have resulted from selection for a high proportion of harvestable product. However, in the absence of supportive inputs – like herbicides, fertilizers, and water – progress was slow, because, to maintain competitive ability, the plants had to invest assimilates in tall stems and a large root system. When weeds, pest, diseases and other biotic competitors are controlled, the assimilates initially needed for competitive and recovery purposes can be used for storage in harvested organs. In a similar manner, adequate supplies of fertilizers and water could allow selection for a reduced root system.

The proportion of total "above-ground" biomass that is allocated in the organs to be harvested (like seeds, tuber, etc.), is called the harvest-index. This index is mostly expressed on a dry matter basis, but it has also been applied for nitrogen and phosphate. Typical values of the harvest-index based on dry weight, H.I.-DM, are 0.45, 0.65 and 0.85 for wheat, sugar beet and potatoes, respectively.

There is a basic necessity for differential partitioning of carbon and nitrogen between organs. *Sinclair* and *de Wit [1975]* showed that the photosynthate and nitrogen requirements for seed production by various crops vary widely. The dry matter of whole plants contains a relatively constant proportion by weight of carbon (about 400 g kg^{-1}) and an amount of nitrogen ranging from 10 to 70 g kg^{-1} depending on species, age and nutrient supply. Nitrogen contents tend to be higher in shoot than in roots and higher in leaves than in stems *(Vos [1981])*. Values in excess of 45 g N kg^{-1} may indicate the presence of NO^{-}_{3} in leaves (see: *Kemp* in this volume); however, mature seeds of legumes may contain up to 70 g N kg^{-1} as protein.

Throughout the growth period the plant is continuously involved in a series of transfers of previously accumulated carbon and nitrogen between its constituent parts and tissues. During vegetative development this mobilization occurs mainly from old to young leaves and from old to young parts of stem and root but, once reproduction has commenced, mobilization takes place from all of these vegetative parts to seeds or to other harvestable parts such as tubers (potato) and bulbs (onions, tulip).

As a general rule nitrogen is remobilized much more effectively from senescent plant tissue than are carbohydrates. Part of the carbon is fixed in cell walls. The carbon bound into sugars, higher oligosaccarides and starch is potentially mobilizable, but these carbohydrates constitute only a relatively small part of the total carbon. In general the balance of assimilates during reproductive growth can be presented as follows:

STORAGE = *ASSIMILATION* + *REMOBILIZATION*

in wheat:

– for *carbon*	80–90%	10–20%
– for *nitrogen*	20–50%	50–80%

Thus the carbon requirement for grain filling is met largely by photosynthesis after anthesis, whereas the nitrogen requirement for grain growth can be met to a large extent with nitrogen taken up before anthesis *(Spiertz* and *Ellen [1978])*.

The overall partitioning of dry matter is influenced by many environmental factors, including light, temperature, soil moisture and nutrition. These factors affect sink activity as well as the number and size of sinks. Sink activity controls assimilate partitioning because rapidly growing sinks generate a steeper concentration gradient in the phloem resulting in a greater flux of assimilates. This pattern is shown by the distribution of assimilates within the ear of wheat. *(Solansky [1979])*.

The storage capacity of cereals is a function of grain size and especially of number of grains. Under temperate growing conditions at least 18 000 grains m^{-2} are required for maximum grain yields of wheat. There is a close association between number of grains per m^{-2} and above-ground dry matter yield at anthesis. The ratio between grain number and dry weight of vegetative parts amounts to about 20 grains per g dry weight under favourable conditions. It was found that environmental limitations (shade, drought, lack of nitrogen) during the pre-floral period strongly reduce the number of grains.

The nitrogen harvest-index (H.I.-N) of wheat usually varies between 0.70 and 0.80 *(Spiertz [1980])*. The contribution of genetic improvement in dry matter distribution to increased grain yields of winter wheat has been significant. *Austin et al. [1980]* found a rise in dry matter harvest-index from 0.36 to 0.51 over the past fifty years. Comparison of old and new varieties when grown under the same conditions, shows that at the same time there has been only a small increase in total biomass production. The same conclusion may be derived from data of *De Vos* and *Sinke [1981]* showing a rise in harvest-index from 0.37 to 0.49 and only minor differences in total biomass, nitrogen yield and nitrogen harvest-index (Table 2). Further improvements in yield potential of wheat cultivars might be expected by raising the harvest-index to a value of 0.55–0.60 *(Spiertz [1980], Austin et al. [1980])*.

Table 2. Yield characteristics of five winter wheat cultivars

Variety (year of introduction)	Total biomass minus roots ($t\,ha^{-1}$)	Grain yield (15% moisture) ($kg\ m^{-2} \times 10^{-2}$)	Harvest-index (DM) ($g\ g^{-1}$)	Nitrogen yield ($g\ m^{-2}$)	Harvest-index (N) ($g\ g^{-1}$)
Staring (1941)	18.1	79.0	0.37	21.2	0.73
Felix (1958)	17.4	87.8	0.43	19.5	0.78
Manella (1964)	16.2	89.4	0.47	19.7	0.79
Arminda (1977)	16.8	96.9	0.49	20.7	0.82
Hobbit (1975)	17.7	101.8	0.49	21.3	0.79

(based on data of *De Vos* and *Sinke [1981]*)

A somewhat different pattern applies to legume crops such as *Vicia faba*. *Dantuma* and *Klein Hulze [1979]* found an average growth rate of the seeds of 206kg DM ha^{-1} day^{-1}, whereas concurrently the weight loss of leaves, stems and shells amounted to 118 kg DM ha^{-1} day^{-1}. Thus more than half of the assimilates required for seed growth, may have been derived from the vegetative parts. The nitrogen yield of the seeds ranged from 280 to 340 kg ha^{-1} of which the contribution by vegetative parts amounted to 120 to 150 kg N ha^{-1}. Thus a significant part of the nitrogen assimilation occured during the seed-filling period at a rate of about 5 kg N ha^{-1} day^{-1}. The final distribution of dry weight and nitrogen varies from 0.50 to 0.65 and from 0.83 to 0.89, respectively, depending on varietal characteristics (Table 3).

Table 3. Seed yield (in kg DM ha^{-1}) and distribution (in %) of dry matter and nitrogen at the final harvest for *Vicia faba* grown as a field crop in 1977

Cultivar:	Wierboon C.B.		Maxime		Minica	
Seed yield (kg ha^{-1})	6840		5902		7176	
Dry matter and nitrogen	*DM*	*N*	*DM*	*N*	*DM*	*N*
– seeds	51	83	50	86	65	89
– shells	12	5	13	5	14	4
– stem	36	11	37	9	23	6
– leaves	1	1	–	–	1	1

(based on data of *Dantuma* and *Klein Hulze [1979]*)

The consequences of a further reduction in stem and leaf weights for adaptation and yield stability are poorly understood. It has been shown with beans, *Vicia faba*, that there are no biological constraints to achieving harvest-indices of 0.65 and 0.90 for dry weight and nitrogen, respectively *(Dantuma* and *Klein Hulze [1979])*. These genetic improvements of grain yield can only be realized when the level of agronomy allows their greater potential to be expressed.

Concluding remarks

Crop yields respond to weather and soil coditions in dynamic and complex ways. This paper has focussed attention on several development and growth processes affected by temperature and radiation. These features of crop environment are constantly changing in a diurnal and annual pattern. There is one factor, however, which has been continuously increasing worldwide since monitoring began, and that is the carbon dioxide concentration in the atmosphere. It has increased from 315 parts per million by volume in 1958 to almost 338 in 1980, and a further enrichment may be expected if trends of the past few decades are to continue. Besides direct effects of atmospheric CO_2 on crop growth there could be indirect effects acting via climatic change. Quantitative prediction of field crop yields are mainly based on radiation levels, temperature and water constraints and do not take into account the effects of a rise in atmospheric CO_2 on physiological phenomena such as stomatal conductance and as a consequence photosynthesis and transpiration. So there is a need to have studies on the growth and yield of crops with CO_2 enrichment under various constraints of radiation, water and nutrient supply.

Actual yields often lag behind the genetic potential as expressed in record yields. The major constraints are imposed by unpredictable weather (water shortage, heat damage), incidence of pests, diseases and weeds and soil factors (fertility, rooting depth). High yields are obtained when farmers match good management with high yielding, stable varieties well adapted to a given environment. Crop yield limitations are difficult to evaluate because variations in weather, soil conditions and genetic traits are interactive. In recent years, crop system approach has been used as a means of integrating the behaviour of crop plants in response to weather, water and nutrient supply.
The systems approach attempts to quantify existing knowledge of crop production, its major components and processes, and feedback mechanisms. This approach does not eliminate the need for experimentation, but provides a basis for more objective field and laboratory research that can fill gaps in present knowledge.

References

1. *Alberda, Th., Louwerse, W., van Laar, H.H., Kremer, D., de Wit, C.T., de Vos, N.M. Bodlaender, K.B.A.* and *Toxopeus, H.:* Crop photosynthesis: methods and compilation of data obtained with a mobile field equipment. Agric. Res. Reports no. 865, 46 pp., PUDOC, Wageningen (1977)
2. *Alberda, Th.:* Potential production of grassland. In: Potential crop production, a case study. Eds.: *P.F. Wareing* and *J.P. Cooper*, 159–171, Heinemann Educational Books Lim., London, 1971
3. *Austin R.B., Bingham, J., Blackwell, R.D., Evans, L.T., Ford, M.A., Morgan ,C.L.* and *Taylor, M.:* A comparison of the yields of old and new varieties of winter wheat at two levels of soil fertility. J. agric. Sci. *94*, 675–689 (1980)
4. *Bierhuizen, J.F.:* The effect of temperature on plant growth, development and yield. *In:* Plant response to climatic factors. Proceedings Uppsala Symposium, 89–98, UNESCO, 1973
5. *Biscoe, P.M.* and *Gallagher, J.N.:* Weather, dry matter production and yield. *In:* Environmental effects on crop physiology (Eds. *J.J. Landsberg* and *C.V. Cutting)* pp. 75–100 London, Academic Press, 1977
6. *Cooper, J.P.:* Control of photosynthetic production in terrestrial systems. *In:* Photosynthesis and productivity in different environments. Ed.: *J.P. Cooper*, pp. 593–621, Cambridge University Press, London, 1975
7. *Dantuma, G.* and *Klein Hulze, J.A.:* Production and distribution in dry matter and uptake, distribution and redistribution of nitrogen in *Vicia faba* major and minor. *In:* Some current research on *Vicia faba* in Western Europe. Eds.: *D.A. Bond, C.T. Scarascia-Mugnozza* and *M.H. Poulson*. Commission of the European Communities, 369–406, 1979
8. *Evans, L.T.:* The natural history of crop yield. American Scientist *68*, 4, 388–397 (1980)
9. *Fischer, R.A.* and *Turner, N.C.:* Plant productivity in the arid and semi-arid zones. Ann. Rev. Plant Physiol. *29*, 277–317 (1978)
10. *Friend, D.J.C.* and *Helson, V.A.:* Thermoperiodic effects on the growth and photosynthesis of wheat and other crop plants. Botanical Gazette *137*, 75–84 (1976)
11. *Gallagher, J.N.:* Field studies of cereal leaf growth. I. Initiation and expression in relation to temperature and ontogeny. J. Exp. Bot. *30*, 117, 625–636 (1979)
12. *Gallagher, J.N.* and *Biscoe, P.V.:* Radiation absorption, growth and yield of cereals. J. Agr. Sc., Cambr. *91*, 47–60 (1978)
13. *Gifford, Roger M.* and *Evans, L.T.:* Photosynthesis, carbon partitioning and yield. Ann. Rev. Plant Physiol. *32*, 485–509 (1981)
14. *Goudriaan, J.* and *Van Laar, H.H.:* Calculation of daily totals of the gross CO_2-assimilation of leaf canopies. Neth. J. agric. Sci. *26*, 373–382 (1978)
15. *Kleinendorst, A.* and *Brouwer, R.:* The effect of temperature of the root medium and of the growing point of the shoot on growth, water content and sugar content of maize leaves. Neth. J. agric. Sci. *18*, 140–148 (1970)

16. *Legg, B.J., Day, W., Lawlor, D.W.* and *Parkinson, K.J.:* The effects of drought on barley growth: models and measurements showing the relative importance of leaf area and photosynthetic rate. J. agr. Sci. Cambr. *92*, 703–716 (1979)
17. *Legg, B.J.:* Aerial environment and crop growth. *In:* Mathematics and Plant Physiology. Eds.: *D.A. Rose* and *D.A. Charles-Edwards*, pp. 129–149. Academic Press Inc., London, 1981
18. *Loomis, R.S.* and *Gerakis, P.A.:* Productivity of agricultural ecosystems. *In:* Photosynthesis and productivity in different environments. Ed.: *J.P. Cooper*, pp. 145–172, Cambridge University Press, London, 1975
19. *Milford, G.F.J., Biscoe, P.V., Jaggard, K.W., Scott, R.K.* and *Draycott, A.P.:* Physiological potential yields of sugar beet. *In:* Opportunities for increasing crop yields. Eds: *Hurd R.G. Biscoe, P.V.* and *Dennis, C.*, 71–83 Pitman Publ. Lim., London, 1980
20. *Monteith, J.L.:* Climate and the efficiency of crop production in Britain. Phil. Trans. Royal Soc., London *B 281*, 277–297 (1977)
21. *Murata, Y.:* Dependence of potential productivity and efficiency of solar energy utilization on leaf photosynthetic capacity in crop species. Japan J. Crop. Sci. *50*, 2, 223–232 (1981)
22. *Pate, J.S.* and *Layzell, D.B.:* Carbon and nitrogen partitioning in the whole plant: a thesis based on empirical modelling. *In:* Nitrogen and carbon metabolism; Ed.: *J.D. Bewley*, 94–134, Martinus Nijhof/Dr. W. Junk Publishers, The Hague, 1981
23. *Penning de Vries, F.W.T.:* Use of assimilates in higher plants. *In:* Photosynthesis and productivity in different environments. Ed.: *J.P. Cooper*, 459–480, Cambridge University Press, 1975
24. *Penning de Vries, F.W.T.:* Simulation models of growth of crops, particularly under nutrient stress. *In:* Physiological aspects of crop productivity. Proc. 15th Coll. Int. Potash Inst., 213–226, Wageningen, (1980)
25. *Prins, W.H., van Burg, P.F.J.* and *Wieling, H.:* The seasonal response of grassland to nitrogen at different intensities of nitrogen fertilization. *In:* 'The role of nitrogen in intensive grassland production', Proc. int. Symp. Eur. Grassland Fed., 35–49, PUDOC, Wageningen, 1980
26. *Robson, M.J.:* A physiologist's approach to raising the potential yield of the grass crop through breeding. *In:* Opportunities for increasing crop yields. Eds.: *R.G. Hurd, P.V. Biscoe* and *C. Dennis*, 33–49, Pitman Publ. Lim., London, 1980
27. *Robson, M.J.:* The growth and carbon economy of selection lines of *Lolium perenne* cv. S23 with differing rates of dark respiration. 1. Grown as simulated swards during a regrowth period. Ann. Bot. *49*, 321–239 (1982)
28. *Sibma, L.:* Maximisation of arable crop yields in the Netherlands. Neth. J. agric. Sci. *25*, 278–287 (1977)
29. *Sinclair, T.R.* and *de Wit, C.T.:* Photosynthate and nitrogen requirements for seed production by various crops. Science, *189*, 565–567 (1975)
30. *Sofield, I., Evans, L.T., Cook, M.G.* and *Wardlaw, I.F.:* Factors influencing the rate and duration of grain filling. Aust. J. Plant Phys. *4*, 785–797 (1977)
30.a *Solansky, S.:* Distribution of assimilates within the ear of wheat. *In:* Crop physiology and cereal breeding. Eds.: *J.H.J. Spiertz* and *Th. Kramer*. Proc. EUCARPIA-workshop, 50–54, PUDOC, Wageningen, 1979
31. *Spiertz, J.H.J.:* The influence of temperature and light intensity on grain growth in relation to the carbohydrate and nitrogen economy of the wheat plant. Neth. J. agric. Sci. *25*, 182–197 (1977)
31. *Spiertz, J.H.J.* and *Ellen, J.:* Effects of nitrogen on crop development and grain growth of winter wheat in relation to assimilation and utilization of assimilates and nutrients. Neth. J. agric. Sci. *26*, 210–231 (1978)
33. *Spiertz, J.H.J:* Grain production of wheat in relation to nitrogen, weather and diseases. *In:* Opportunities for increasing crop yield. Eds.: *R.G. Hurd, P.V. Biscoe* and *C. Dennis*, 97–114, Pitman Publ. Lim. London, 1980
34. *Vos, J.:* Effects of temperature and nitrogen supply on post-floral growth of wheat: measurements and simulations. Agric. Res. Rep. No. 811, 164 pp. (1981)
35. *De Vos, N.M.* and *Sinke, J.:* Progress in yield of winter wheat during the period 1940–1980. (Original in Dutch). Bedrijfsontwikkeling *12*, 6, 615–618 (1981)
36. *Wardlaw, I.F.:* The physiological effects of temperature on plant growth. Proc. Agronomy Soc. of N.Z., *9*, 39–48 (1979)

37. *Warrington, I.J., Dunstone, R.L.* and *Green, L.M.:* Temperature effects at three develop ment stages on the yield of the wheat ear. Aust. J. agric. Res. *28*, 11–27 (1977)
38. *Watson, D.J.:* The physiological basis of variation in yield. Adv. in Agronomy *4*, 101–145 (1952)
39. *Wilson, D.:* Variation in leaf respiration in relation to growth and photosynthesis of Lolium. Annals of Applied Biology *80*, 323–338 (1975)
40. *De Wit, C.T.:* Simulation of assimilation, respiration and transpiration of crops. Simulation Monograph 137 pp., Pudoc, Wageningen, 1978
41. *De Wit, C.T., Van Laar, H.H.* and *Van Keulen, H.:* Physiological potential of crop production. *In:* Plant breeding perspectives. Eds.: *J. Sneep* and *A.J.T. Hendriksen*, 47–82, PUDOC, Wageningen, 1979
42. *De Wit, C.T.:* The efficient use of labour, land and energy in agriculture. Agricultural Systems *4*, 279–287 (1979)

The Influence of Farming Systems on the Optimization of Yield

E. R. Keller, Department of Crop Science, Swiss Federal Institute of Technology, Zürich/Switzerland*

Summary

The object of crop production is defined as 'the provision of healthy food and fodder while at the same time preserving the yielding capacity of the soil in the light of ecological, economic and social considerations so that soil cultivation is preserved over the long term'. Optimisation of yield embraces not only quantity but also crop quality; further, optimisation must be considered always from the economic point of view and often also as regards its ecological impact. The concept of farming system implies an all-embracing (or integrated) production system which will maintain the soil's capacity to yield. It also includes the concept of plant protection which conserves the environment. It should take account also of crop quality as well as quantity.

Among the elements of a crop production system, rotation offers a number of possibilities for yield optimisation, for example the proportion of grain crops, the exploitation of residual effects and inter-crop compatibility. The effects of organic and inorganic manures or their combination on yield optimisation are described and it is concluded that the application of straw can, in many cases, replace farmyard manure if the latter is lacking. Minimum cultivation methods which suit the plant at least as well as conventional methods offer advantages of economy. On the question of quality, examples are drawn from potatoes, sugar beet and wheat. Finally the question is posed as to whether yield optimisation throughout the whole of a system is practically possible. In recent years, a number of so-called 'blueprint' systems for individual crops have been described in various regions. This kind of work needs to be expanded to include investigation of complete production systems. Many such experiments are now in progress and it will emerge from this work whether or not the blueprints devised for individual crops will be compatible with the farming system as a whole.

In the conclusion the question is raised as to how we can deal with the mass of data which will flow from these investigations so that the conclusions can be passed on to the practical farmer. It is likely that modelling techniques will be useful and it must be born in mind that the results must eventually be presented to the farmer in a readily assimilable form.

1. Definition of the terms 'crop production' and 'yield optimisation'

1.1 The aim of crop production

Whether crop production is achieved by traditional or conventional methods or by so-called ecological or alternative methods the aim is always 'the provision of healthy food and fodder and the preservation of the yielding capacity of the soil while taking into account ecological, economic and social considerations for which the cultivation of the soil in the long term must provide.' *(Keller [1980])*.

* Prof. Dr. *E. R. Keller*, Institut für Pflanzenbau, Eidg. Technische Hochschule, ETH-Zentrum, CH-8029 Zürich/Switzerland

A number of papers have been presented in recent years at symposia and colloquia of the *International Potash Institute* covering the fields of the physiology of yield formation or dealing with so-called 'blueprints'. The objectives of the work described have been to achieve maximum yield of the various crops. As *Cooke [1981]* has said the aim of this kind of work must be to identify the constraints which are making it impossible for crops to yield their theoretical maximum. Blueprint investigations are a good basis for multidisciplinary research. Such investigations must, among other things, try to answer the question how to incorporate the findings for individual crops into a whole crop production system, *i.e.* whether they are mutually supportive or mutually exclusive, in other words whether they are really suitable for practical use.

1.2 The concept of 'optimum yield'

Our definition of crop production implies a striving for optimum yield. However, the concept of optimum yield needs to be examined from various points of view.

- yield optimisation should not be concerned only with obtaining the maximum crop yield per unit area of land manipulation of yield-controlling factors but it should take account of economic and ecological aspects, of the quality of the produce and the energy output/input ratio.
- the economic optimum yield is that at which marginal cost is still covered by marginal financial yield and this as a rule will not coincide with the physiological potential yield for the site.

The achievement of optimum economic yield is not alone sufficient. The methods used to achieve it must harmonise as nearly as is possible the wishes of the grower of the crop and the need to preserve the environment. We do not need only to obtain high yield per unit area, we also need to preserve the soil by minimising the effects of erosion and preserving soil fertility for the long term.
The agriculturalist cannot afford to ignore any factor which may affect the long-term fertility of the soil. What have been the contributions of plant-breeding and cultural improvements (fertilizer, weed-control, plant protection, seedbed preparation, seed quality, cultivation, etc.) to the closing of the gap between potential and actual crop yield? We need to know the answer in order to point the way to yield optimisation. Table 1 *(Keller et al. [1981])* lists some examples. Over the past 30 years, the yield of maize, thanks largely to the plant-breeder, has more than doubled; there has been an enormous increase in potato yield though in this case the plant-breeder's contribution has been only small, while sugar yield has increased rather modestly by almost 50%. Examining the trends over time, it is seen that the rate of yield increase has decreased in recent years as compared with the first half of the period. Husbandry improvement has made a large contribution in all crops. For wheat, the main factors have been fertilizers and weed-control, in the case of maize as well as these two factors sowing technique (plant density) has made a large contribution. Similar factors have been responsible for raising sugar beet yield but for potatoes, the most important, besides fertilization, have been improvement of seed quality, pre-sprouting and disease control.

Table 1. Increase in yield of various crops in Switzerland from 1950–1952 to 1976–1979

Crop	Average yield, q/ha 1949–1951	1976–1979	Rel. increase, %	Proportion of increase due to:	
				Plant breeding (%)	Cultural technique (%)
Winter wheat	26	44	69	40–50	60–55
Grain maize	31	69	122	52–57	48–43
Sugar beet sugar/ha	57	84	47	33–45	55–65
Potatoes[1]	206	392	89	17–23	ca. 80

[1] Average 1950–1952

Table 2. Decrease in labour requirement by various crops 1950/52–ca. 1980 (FAT, Tänikon/Switzerland)

Crop	Labour requirement ca. 1950		ca. 1980		Remarks
	Man pow. h/ha	relative	Man pow. h/ha	relative	
Winter wheat	970	100	35	21	1950 single furrow plough, binder 1980 two furrow plough, combine in contrast
Grain maize	180	100	25	14	1950 hand picking, single furrow plough 1980 two furrow plough, combine in contrast
Sugar beet appr.	1000	100	140	14	1950 multigerm seed, lifted by plough 1980 monogerm seed, precision sowing, large complete harvester
Potatoes	630	100	180	29	1950 combined equipment, scrub-clearing 1980 automatic planter, herbicide, large complete potato harvester

Table 2 shows how the labour requirements of the same crops has reduced in Switzerland since 1950: by an astonishing 80–85% for grain maize and sugar beet and by as much as 70% for potatoes.

I have quoted these examples to illustrate the following:

- while we are still a long way from achieving maximum yield overall, here and there we are already knocking at the door. According to *Vetter et al. [1981]* the economical optimal rates of fertilizer now applied in the Federal Republic of Germany are in many cases very near to the maximum at which measurable yield increases can be obtained, but there are farms – as in other countries – where, on economic grounds the rates should be reduced, so that the marginal cost is fully covered by yield increase.

- the farmer must constantly have in mind the possibility of reducing production costs favoring *e.g.* yield optimisation by reduced labour requirement (Table 2); the same importance attaches to the avoidance of losses between harvesting and marketing of the crop.

Bäumer's *[1971]* scheme for the choice of farming system (Figure 1) takes full account of the economic factors.

There can be no doubt that at the present time the aim for optimum yield is very delicately balanced between technical progress, ecology and economy. I must, however, emphasise that such yield optimisation must ensure that the farmer can achieve an adequate income and, thus, is motivated to use his soil with due care and to maintain or improve its fertility.

2. Crop production in the context of a comprehensive (integrated) cultural or production system

A plant production system has to meet several demands which can only be satisfied in the framework of an integrated system and over a period of time. Some of these are:

- the concept of the maintenance of the soil's capacity to yield
- the concept of environmentally suitable plant protection
- the concept of the optimisation of both yield and quality of crop yield.

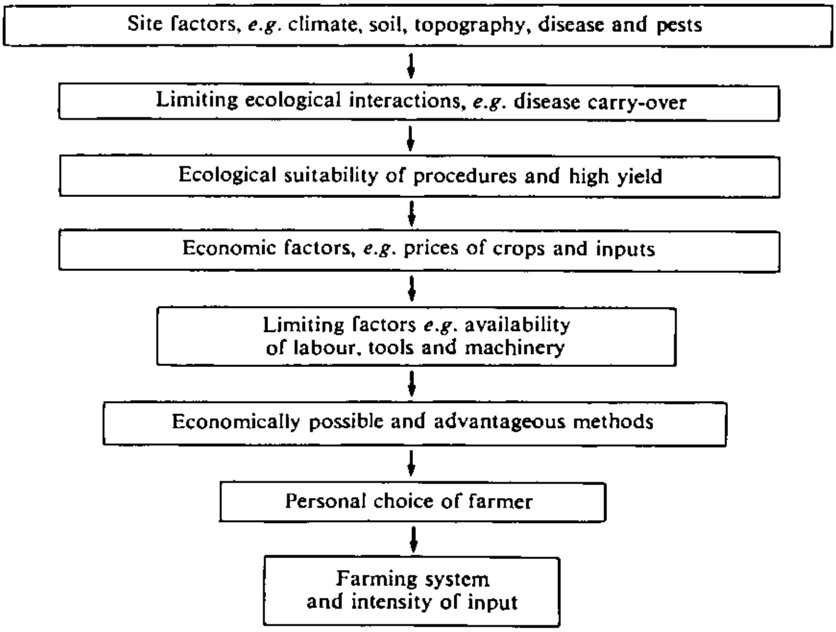

Fig. 1. Criteria in choice of a farming system *(Bäumer [1971])*.

The definition of the production system is thus far-reaching. Rotation plays an important role in all three of the above objectives. In addition, and this is the theme of the following, in all three concepts, many other factors are relevant.

The need to maintain soil fertility lies at the root of all comprehensive or integrated systems. The term status of soil fertility (= soil productivity) after *von Boguslawski [1965]* is equivalent to the yielding capacity of a soil (Figure 2). The aim must be to

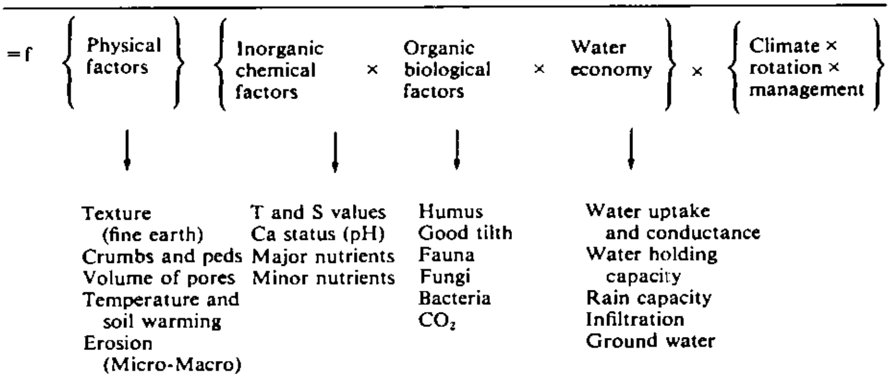

Fig. 2. Status of soil fertility (= productivity of soil) *(Von Boguslawski [1965]).*

bring the interacting factors to the optimum and to maintain this condition; today, great importance is ascribed to the biological factors (for example the activity of soil organisms). *Cooke [1981b]* stresses that research to develop the so-called blueprints should take into account and understand the components of soil fertility so that the growing crop can be offered always sufficient nutrients and water. The implications of such an approach for the optimisation of yield and quality resp. with plant protection adapted to the environment are obvious.

Integrated and thus *environmentally* proper plant protection can be defined *(V. Delucchi* in *Keller et al. [1981])* as 'a strategy through which all economically, ecologically and toxicologically defensible methods are used to ensure that the level of pest and disease organisms is kept below the economically damaging level and in which priority is given to the use of natural methods'. As well as the control of pests and disease we include in this strategy weed control. Today's yields of crops (including vegetables and fruit), can only be maintained or improved if agricultural chemicals are used. The problem is not to decide whether such chemicals should be used but to ensure that they are used correctly. *Hanus [1979]* rightly refers to the difficulties attached to the realisation of integrated plant protection in practice. So long as it remains impossible to forecast the severity of a possible attack it remains difficult for the farmer to take the risk of abandoning his usual practice, *e.g.* by foregoing prophylactic measures. *Heyland [1981]* also points to similar difficulties in the case of weed control. The wheat breeder, for instance, tries to achieve higher grain yield with varieties with shorter straw and less leafy than the old varieties, but this has reduced the crop's ability to compete with weeds. This aspect is illustrated in Table 3 *(Ammon et al. [1982]).*

Table 3. Crop cover and weed cover in wheat varieties at two rates of N and CCC treatment *(Ammon et al. [1982])*

Variety	Probus	Zenith	Probus	Zenith
CCC rate (l/ha)	0.0	0.0	2.5	1.25
Crop cover, %				
N rate 1 (80-N min)	91.26	89.43	91.38	84.40
2 (120-N min)	99.33	93.29	98.67	88.00
Haulm length, cm				
N rate 1 (80-N min)	137.7	113.3	119.6	97.5
2 (120-N min)	143.2	120.3	127.8	106.1

3. The effect of production systems on the optimisation of yield and quality

In the following discussion we confine ourselves to the effects of rotation, organic manures and fertilizers, and soil cultivation. We know a good deal about the effects of cultural techniques and fertilizer treatment on the individual crops. We are not here concerned with these as they are only indirectly connected with the principles of a system.

In order to make a final judgement of a system it would be necessary to consider economic aspects and, in many cases, also ecological aspects.

3.1 Influence of some factors of production technique on quantitative yield optimisation

It is well known that fertilizer dressings which prove profitable will be higher the more favourable we can make growing conditions as a whole and we point out that the elements of such a system which we mention in the following show many interactions as far as they affect yield optimisation.

3.1.1 Rotation

A suitable rotation need not necessarily be rigid. While the rotation should allow some flexibility, necessary changes should not be made on impulse but should be carefully considered *(Keller [1979])*.

The crop succession has to be so chosen that each succeeding crop is given the opportunity to express its full potential over a long period. The question may also arise as to whether a rotation is needed at all. Fundamentally it is, but we must bear in mind that according to climatic conditions and soil properties it is often difficult to evolve the optimum rotation.

An important consideration is the possible incompatibility between individual crops. Much has been written on this point *(e.g. Kämpf [1980])* and I confine myself to a summary of the more important aspects of the problem illustrated in Table 4.

It can be concluded from this that the proportion of the rotation taken up by cereals is of great importance and many research workers have gone into this question. *Debruck [1976]* came to the conclusion that in the climate of the Federal Republic of

Table 4. Rotational characteristics of crops

Winter wheat	little self-tolerant, susceptible to root disease, preceding crop must be harvested early and leave the ground clean
Spring wheat	self-tolerance somewhat less than winter wheat
Winter barley	not self-tolerant, susceptible to root disease, though more tolerant than wheat, sown early
Spring barley	see spring wheat
Rye	most self-tolerant cereal, only slightly subject to root disease, needs to be sown early in autumn
Oats	non-self tolerant *(Heterodera avenae)*; scarcely affected by root disease
Maize	self-tolerance not uncontested; susceptible to stem rot and boil smut
Potatoes	moderately self-tolerant; interval of 3–4 years advised and obligatory for seed crops *(Globadera rostochiensis)*
Sugar beet	self-intolerant – nematodes *(G. schachtii, Ditylenchus dipsaci)*. Cropping interval 3–5 years
Rape	moderately self-tolerant, interval advised 3 years. Host for beet nematodes
Field beans	useful as a relatively self-tolerant legume and compatible with other legumes except peas and lucerne
Vining peas	self-intolerant susceptibility to foot rots and wilts makes cropping interval of 7–9 years necessary
Red clover	self-intolerance less marked in grass mixtures, incompatible with other legumes
White clover	relatively self-tolerant
Lucerne	similar to red clover, soil requires resting
Catch crops	intolerant crops (legumes, rape and similar) increase intolerance of corresponding main crops

Germany 75 or even 80% cereals was acceptable provided that the cereals were not all of one type, *e.g.* wheat. A so-called 'health interval' must be allowed as was also advised by *Kämpf [1976]*. *Höflich et al. [1981]* recommend that in the case of *Pseudocercosporella herpotrichoides* this should be 2 years. *Debruck [1976]* names as unfavourable factors resulting from a high proportion of cereals which are connected with changes in soil fertility, the dangers of weed infestation and pest and disease attack. When the proportion of cereals is over 80% yields especially of winter wheat may decline by as much as 25% (take-all and eyespot). Yield reductions for winter barley and spring wheat may be 15% for rye and spring barley up to 10% and for oats 5%. In a review *Diercks et al. [1980]* say that winter wheat is more susceptible than spring barley. In order to limit the accumulation of pathogen damage especially by *Heterodera avenae*, *Pseudocercosporella herpotrichoides* and *Gaeumannomyces graminis*. *Steinbrenner et al. [1978]* would limit in the G.D.R. cereals to 75% at the most. *Schönrock et al. [1980]* recommend a level of 60% in order to keep the eelworm population within acceptable limits so long as oats are included once in the rotation. *Vez [1975]* conducted long-term experiments on this aspect and his conclusions (Table 5) are that, on good cereal soils, 75% is acceptable. Our own experiments *(Maillard [1981])* show that the grain yield of spring wheat in a cereal rotation (60% cereals, 20% maize, 20% field beans) and in a maize dominated rotation (60% maize, 20% wheat, 20% field beans) can be higher than in a normal rotation (40% leys, 40% cereals and 20% potatoes) provided that weed control in the two first named rotations is improved.

The preceding crop has important effects on yield. I do not speak about monoculture of, for instance, wheat or maize, since such systems are only suitable for special

Table 5. Value of different wheat-entries *(Vez [1975])*

Proportion of cereals in rotation (%)	Rotation resp. wheat-entry	Relative yield of wheat 1968	1972
100	Continuous wheat since 1964	100	100
	wheat–wheat–rye–oats	137	110
75	wheat–wheat–wheat–rape	145	118
	wheat–wheat–rye–rape	156	116
50	wheat–wheat–ryegrass–rape	156	118
	wheat–wheat–potatoes–rape	157	121
	wheat–potatoes–wheat–rape	148	123
	wheat–rape–wheat–rape	150	118
	wheat–maize–wheat–maize	131	118
Least sign. diff. at 5%		9.8	11.3

circumstances. *Balla et al. [1977]* found in experiments in Hungary that wheat can yield just as well when grown in monoculture as when it follows maize for the reason that maize ripens too late to allow proper preparation for wheat. There are other cases in which the date of maturity of the preceding crop is important. Referring to Table 4 again emphasises the importance of forage and break crops, since the suitability of row crops and rape as preparatory crops for wheat is well known. *Vez [1972]* mentions the particular value of fodder legumes and grass-clover mixtures in this connection. From his results (Table 6) he advises the inclusion of two or even three year breaks under grass-clover in long rotations. *Simon et al. [1981]* advise the inclusion of lucerne in rotations including row-crops and expect an increase in grain yield of up to 10% by including a main forage crop in the rotation if cereals or row crops are the first subsequent crops. *Liste et al. [1974]* make the point that the effect of crop succession is greater in moist than in dry regions. Nevertheless, the soil type must also be considered, light soils being less suitable for lucerne and grass-clover mixtures. *Nystrom [1975]*, like *Vez* (Table 6, Grangeneuve), concludes that the favourable

Table 6. Effect of type of ley and its duration as entry for wheat *(Vez [1972])*

Preceding crops			Length of ley	Rel. yield of winter wheat site		
1967	1968	1969	years	Grange-neuve 1970	Changins 1970 1st year	1970 2nd year
oats	maize	potatoes	0	100	100	100
oats	maize	clover	1	101.2	102.0	95.8
oats	maize	ryegrass	1	89.7	93.7	100.2
oats	red clover	ryegrass	2	98.3	116.3	104.9
oats	red clover/ryegrass	ryegrass	2	98.3	112.5	104.3
oats	ryegrass	ryegrass	2	93.2	96.5	104.2
lucerne	ryegrass	ryegrass	3	100	128.2	112.9
red clover/grass-mixture	ryegrass	ryegrass	3	97.0	115.4	104.0
grass-mixture	ryegrass	ryegrass	3	94.8	110.5	108.6
L.S.D. (5%)				5.5	14.5	9.3

effect of fodder crops as preceding crop is not evident in all experiments and is not always shown in the first year after the break; nevertheless, the overall result is positive. This is why the Swiss arable farmer maintains the clover break in his rotation so long as this is not excluded by a change in farming system (stockless farming).
The inclusion of clover in the rotation is the best guarantee for many farmers to maintain soil fertility because of the favourable effects on soil structure, particularly crumb stability. *Liste et al. [1974]* found yield increases of 5–8% in grain and row crops as a result of soil-improving break-crops. *Heyland et al. [1980]* found that the yield of spring wheat depended on the time under a break-crop. Yield increases result from the phytosanitary effect of the break crop so long as that crop does not make too great demands on soil nitrogen; this is the reason for the particularly favourable effect of legumes. *Diercks et al. [1980]* obtained more favourable effects from break-crops as green manure in moist as compared with dry sites. It has also been found that the grain legumes (faba beans and peas) are good preparatory crops.

3.1.2 Organic manures and fertilizers

When the rotation forms part of a mixed farming system the accumulated animal manure forms the basis of crop nutrition as under European conditions. It is well-known that animal manures have favourable long-term effects resulting from nutrient supply, improvement of aggregate stability and preventing the run down of soil organic matter. *Rixhon [1979]* applied 40 t/ha farmyard manure every 4 years to his rotation and thereby was able to maintain the organic matter content of the soil at 1.7% over 16 years (4 periods of a 4 year rotation). Table 7 shows how the decline in organic matter content was limited by applying straw and even more so by the combination of straw, green manuring and the ploughing in of sugar beet tops. In similar experiments, however, *Vez [1979]* found that soil organic matter declined over 16 years from an initial level of 3.5% to 2.6% no matter what the treatment (40 t/ha farmyard manure compared with applying straw and sugar beet tops or no application of organic matter). The apparent contradiction between these two results arises from the large difference in organic matter content of the soil. The combination of farmyard manure with fertilizers which results in complex interactions *(Debruck et al. [1979])* has in recent years contributed to crop yield increase. Even though *Kofoed [1976]* obtained as good or even better yields over the long term with NPK on loam and sandy soils as with a combination of fertilizers and farmyard manure, he is still of the opinion that the combination of fertilizers and manure is preferable. *Gervy [1981]* says that

Table 7. Comparison of different systems (4 year rotation) *(Rixhon [1979])*

	Annual decrease in organic matter content[1] %	Development of aggregate stability
No organic matter applied	0.88	Decrease
Straw applied thrice in rotation	0.38	No change
Straw applied 3 ×, 1 × sugar beet tops, and 1 × green manure per rotation *(Rixhon [1979])*	0.14	Improvement

[1] Org. matter content in control = 1.7% = 100%

mineral fertilizers are responsible in different European countries for 60–70% of cereal yield, the appropriate figure for mixed farms is 40–50%. There is no doubt that, provided attention is paid to time of application, in relation to the crop, the combination makes an important contribution to yield optimisation. In intensive cereal growing it is now most important to make up for the lack of farmyard manure by applying straw. *Debruck [1980]* came to the conclusion from his own extensive experiments and the work of others that the lack of farmyard manure in intensive cereal rotations with 80% cereals could be made good by applying straw with the appropriate compensatory N dressings and green manuring. *Bachtaler [1979]* obtained somewhat lower grain yields by annual application of straw and green manure as compared with periodical application of farmyard manure combined with fertilizers. *Ansorge et al. [1980]* are more reluctant in regard to the value of straw. In interpreting all these results it must be born in mind that the manurial treatments and experimental sites are not always strictly comparable. Nevertheless, it can be concluded, as *Kämpf [1980]* among others says, that in cereal dominated rotations green manuring and the ploughing in of straw can make an important contribution to yield optimisation on good sites and this is because the application of organic material improves biological activity in the soil. *Eiland [1981]* has definitely demonstrated this for farmyard manure. The investigations of *Maillard [1981]* (Table 8) demonstrate that CO_2 evolution by the soil is raised by organic manure applied over 5 years as compared with fertilizer treatment, though this is not necessarily translated into positive effects on yield. It is also established that in comparison with a normal rotation including 2 years ley, a high proportion of maize is more damaging than a high proportion of other cereals.

Table 8. Effect of rotation and manuring on CO_2 evolution by soil; relative values *(Maillard [1981])*

	Cereal dominated rotation		Maize dominated rotation	Normal rotation	
Manuring	Expt. I	Expt. II	Expt. II	Expt. I	Expt. II
Mineral fertilizers	92.3	87.0	84.4	97.3	96.6
Mineral fertilizers + organic manures	99.4	97.3	87.8	100	100
L.S.D. 5%: Expt. I 6,3%; Expt. II 5.1%					
Rotation, see Figure 4					

3.1.3 The effect of soil cultivation on yield optimisation

In recent years there have been many changes in soil cultivation for arable crops. The new methods aim to economise in time and energy, to improve soil structure and to produce better seedbeds. They substitute so-called minimum cultivation partly or wholly for conventional ploughing. I can only deal here with a few of the many results that have been obtained in so far as they relate to yield optimisation. *Kahnt [1976]* holds that continuous grain cropping without ploughing is not possible under central European conditions but that the method is suitable for mixed rotations of grain crops and fodder crops where biological action loosens the soil. In fact it is necessary to suit the cultivation method to the needs of the crop. The development of new, more efficient tools, and their proper combination have made it more possible to carry out cultivation at the appropriate time, in relation, for instance to soil moisture content, than was the case formerly. Thus, cultivation, especially taking account of the economies offered by the newer methods can make a large contribution to yield optimisation. *Frankinet et al. [1979]* found that in a mixed four course rotation yields from direct sown crops were 20%, 15% and 12% below those given by ploughing to about 30 cm in the cases of sugar beet, silage maize and spring barley respectively, while oats and winter wheat were indifferent to cultivation method and field beans yielded 5% more when direct sown. Table 9 summarises results obtained in Switzerland by *Vez [1980]* and these show that the various crops react differently to minimum cultivation without ploughing.

Table 9. Effect of minimum cultivation[1] on crop yield (1966–1976) *(Vez [1980])*

Crop	No. of experiments	No. of cases with yields of unploughed plots:		
		at least 5% lower	same	at least 5% higher
Winter wheat	46	9	20	17
Winter barley	8	3	4	1
Spring cereal	7	3	4	0
Rape	15	6	3	6
Maize after autumn preparation	16	4	8	4
Maize after spring preparation	(10)	(2)	(4)	(4)
Potatoes	3	3	0	0
Sugar beet	3	3	0	0
Total	98	31	39	28

[1] Light surface cultivation or direct drilling according to experiment

Pidgeon [1980/81] is in favour of minimum cultivation for both spring and autumn sown cereals in Scotland as it avoids the damage done by cultivating when the soil is wet. Such a procedure could be combined with broadcasting the seed. Minimum cultivation is used widely in the south of Britain. *Herzog et al. [1980]* advise minimum cultivation for a cereal rotation. They quote results from other workers which show that direct drilling every year can favour the invasion of weed. Yield reductions, which in any case were not observed on all sites, were accompanied by a reduction in biological activity making necessary supplementary N dressings. The authors envisage possibilities for minimum cultivation in cereal – row-crop rotations where, in agreement with *Vez [1980]* account is taken of the particular requirements of the crops. *Bäumer [1981]* says that the plant's root system is most adaptable to the soil structure developed under various systems provided weathering does not cause slaking or compaction. This shows that the reaction to minimum cultivation is dependent on site and prevailing seasonal weather conditions.

Minimum cultivation should only be used when soil structure is good. When this is so the technique is also suited for heavy soils as it avoids the formation of heavy furrow slices which happens when ploughing under wet conditions. In true arable rotations the land should be ploughed at convenient intervals, *e.g.* for sugar beet or potatoes, to control perennial weeds and to spread nutrients and organic matter through the rooting depth *(Ellis et al. [1980/81], Vez [1980])*. It is important for the farmer to make correct judgements in arranging his cultivations.

One problem which affects choice of rotation and choice of cultivation technique alike and which must be given more attention in future is erosion control, particularly under sugar beet or maize. Where these crops are grown to any large extent, the cultivation technique should be such as to minimise erosion between autumn and the time when crop cover is established and there may be possibilities for using catch crops through which sugar beet or maize can be sown. Such a technique could offer possibilities for optimising yields.

3.2 Influence of some factors of crop production techniques on yield optimisation through improvement of crop quality

The production of high quality food and fodder requires optimisation of crop composition and the avoidance of the accumulation of undesirable constituents. As an example we may recall the connection between N manuring and sugar content of sugar beet. As Figure 3 shows, increasing the rate of N increases root yield over a wide range, but beyond a certain point the sugar content decreases, so that, in this example, maximum yield of sugar is obtained at approximately 150 kg/ha N. But there is a further effect in that increasing N also increases the content of so-called noxious nitrogen and of soluble ashes, both lowering cristallization so that the maximum yield of refined sugar is obtained at only about 130 kg/ha N.

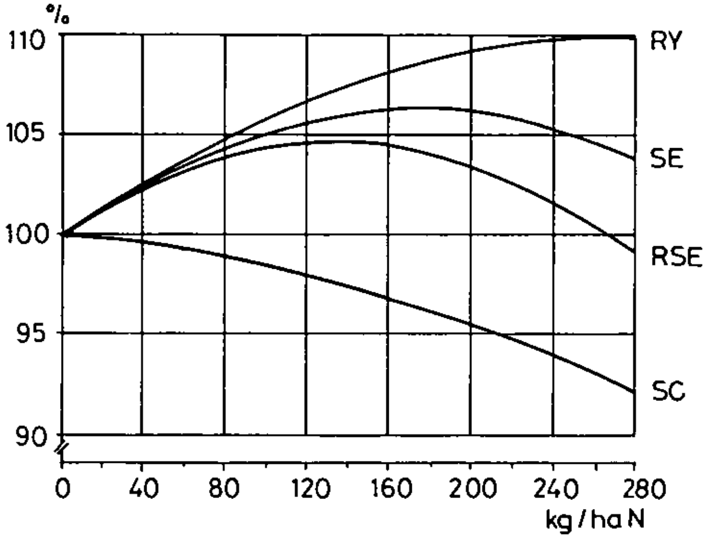

Fig.3. Effect of increasing mineral N on yield and quality of beet (relative); 100 = without N fertilizer *(Winner [1981])*.
RY = root yield　　SE = theoretical sugar yield
RSE = refined sugar yield　　SC = sugar content

For potatoes we may quote the example of *Keller et al. [1982]* summarised in Table 10, which shows the effect of some cultural techniques on some quality factors. By the correct choice of cultural technique the farmer can increase dry matter content (industrial potatoes), can reduce the susceptibility of the crop to damage at lifting (table, processing and seed potatoes) and can greatly reduce internal blackening (table and processing). These, and other, measures must be taken if the potatoes are to meet the requirements of the market and are paid according to quality; poor quality potatoes are only fit for stockfeed.

Table 10. Effect of cultural measures on aspects of quality in potatoes

Quality criteria	Effect	
	positive	negative
1. Dry matter content of early and 2nd early	– Sprouting, early planting – Mineral soils – Generous P and K manuring	– Excessive N dressing – Spring application of potassium chloride
2. Tolerance at lifting against mechanical damage	– P favours maturity – Sprouting favours maturity – Generous K reduces internal blackening	– Excessive N dressing delays ripening – Careless lifting and sorting
3. Internal blackening	– K increases K and citric acid contents – Warm storage of tubers – Maturity	– Very high dry matter

3.3 Can yields from a farming system be optimised?

Blueprints for the maximisation of yields of grain crops, sugar beet, oilseeds, maize, potatoes, lucerne, field vegetables and soyabeans were described at the 1981 Colloquium of the International Potash Institute *(Cooke [1981])*. The papers referred to the area stretching from the Balkans up to Poland. It would take too long to enlarge on other blueprints – even if we confined ourselves to Europe – and to discuss the results obtained, in order to try to come to some conclusion as to what kind of technique should be used to obtain as much as possible the theoretical yield potential. All such experiments, which are concerned particularly with cultural systems, and others concerned with crop physiology, can yield valuable information appropriate to breeding measures of so called ideotypes with the aim of achieving optimum yield as defined in para. 1.2 above; such investigations are essential. Yield optimisation in the context of farming system requires the integration of the various factors as illustrated in Figure 1. Blueprints developed for various regions or environments will differ and the farming systems which emerge must be re-assessed under local conditions.

The layout of such field experiments is complicated and laborious. It is necessary to ensure that components of the system are mutually compatible; it is necessary to take into account effects on soil productivity and the effects of disease and weed control.

There is a further difficulty: there are involved interactions between cultural methods and genotype which greatly affect yield optimisation, and we may speculate on what the future may bring in the field of plant breeding.
Investigations into farming systems are in progress or have even been completed at several places. Without any pretension to completeness we may mention work at the University of Giessen/Rauisch-Holzhausen *(Debruck [1980])*, at Gembloux *(Frankinet et al. [1979])*, at Nyon-Changins *(Vez [1975])*, at Askov *(Kofoed, [1976])* and at Freising *(Diercks et al. [1980])*. At the latter a new complex experiment has been started for several years *(Pommer [1982])* which comprises two rotations, 4 fertilizer treatments, 4 plant-rotation treatments and 4 crop varieties. Our own experiment was conceived a long time since, and begun in 1973 *(Maillard [1981])* and is designed to clarify the effect of biological, chemical and physical factors in the soil, in dependance on weed control and fertilizer treatment, on the yielding capacity of the soil (Figure 4). Based on the results of the first cycle (1973–78) we expect interesting information on yield optimisation after the second cycle (1978–83).
This short survey shows something of the work in progress at several places with complete systems or parts thereof. There can be no doubt that such work must be expanded and perhaps modified; the information for such type of work could be derived from blueprints.

Factors	Experiment I		Experiment II		
Herbicide type	Urea derivatives		Triazines derivatives		
Herbicide rate	Light Normal Double		Light Normal Double		
Manurial treatment	Organic + Mineral Organic		Organic + Mineral Organic		
Rotations	Normal	Cereal dominant	Normal	Cereal dominant	Maize dominant
Year (2nd rotation)					
1978	Spring wheat	Spring wheat	Spring wheat	Spring wheat	Spring wheat
1979	Potatoes	Spring wheat	Potatoes	Spring wheat	Beans
1980	Spring barley with sowing ley	Spring barley	Spring barley	Spring barley	Maize
1981	Ley	Maize	Ley	Maize	Maize
1982	Ley	Beans	Ley	Beans	Maize
1983	Wheat	Wheat	Wheat	Wheat	Wheat

Fig. 4. Outline of field experiment on maintenance of soil fertility, Tänikon (Dept. of Crop Science, ETH, Zürich (*Srzednicki et al. [1978]*).
Beginning of the first period of rotation 1973; 6 replications

4. Conclusion

It is legitimate to pose the question as to how the enormous quantity of data emerging from these investigations can be digested, summarised and passed on to the farmer for practical use. The use of computer modelling is now enjoying great popularity and opens up new possibilities for interpretation *(e.g. Penning de Vries [1980], Loomis et al. [1979], Malet [1980], Hansen [1980]). Heyland [1979]* would like, with the help of computer programmes, to be able to advise the farmer on the decisions he must make in growing a crop of wheat. *Ewing et al. [1982]* think that it would be possible to develop a model with the aid of which potato growing could be introduced to new areas, *e.g.* the warm humid tropics. Is it possible that models could be developed eventually for whole farming systems? Whether or not this proves to be possible in the future, we must always remember that the farmer should remain a farmer and has to make the final decision as to whether he adopts this or that practice in order to optimise his farming system. He needs help to find his way through the multitude of factors which will affect the results he obtains, otherwise he runs the risk of being crushed between the demands of ecology and economics *(Heyland [1981])*.

5. References

Aeppli, A.: Einfluss von Sorte, Erntetermin und Standort auf die Blauempfindlichkeit der Kartoffel sowie Beziehungen zwischen Blaufleckigkeit und Knollenrespiration. Thesis ETH-Zürich No. 6330 (1979)

Ammon, H. U. and *Kunz, P.:* Einfluss der Konkurrenzkraft kurzhalmiger Getreidesorten auf die Entwicklung einiger Unkräuter. Mittlg. Schweiz. Landw. *30*, 1/2, 12–17 (1982)

Ansorge, H. and *Jauert, R.:* Untersuchungen über den Einfluss einer langjährigen differenzierten organischen Düngung auf die Wirkung der mineralischen Stickstoffdüngung. Arch. Acker- u. Pflanzenbau u. Bodenkunde, Berlin *24*, 11, 727–736 (1980)

Bachthaler, G.: Standortabhängige Auswirkungen getreidestarker Fruchtfolgen im 18jährigen Versuchsverlauf. Bayer. Landw. J.buch *7*, 857–886 (1979)

Balla, A. and *Sarkadi, J.:* Field experiments comparing maize and wheat yields in continuous cropping and crop rotation. Növenytermeles *26*, 1, 69–79 (1977)

Bäumer, K.: Allgemeiner Pflanzenbau. UTB *18*, Verlag Ulmer, Stuttgart, 1971

Bäumer, K.: Tillage effects on root growth and crop yield. Proc. 16th Coll. Int. Potash Inst. (1981)

Boguslawski, E. von: Zur Entwicklung des Begriffes Bodenfruchtbarkeit. Zeitschr. Pfl.ernähr., Düngung u. Bodenkunde *108*, 97–115 (1965)

Cooke, G. W.: Value of 'Blueprints' in Research and Advisory Work. Proc. 16th Coll. Int. Potash Inst. (1981)

Debruck, J.: Untersuchungen über getreidereiche Fruchtfolgen unter besonderer Berücksichtigung der mineralischen und organischen Düngung. Habil.schrift Universität Giessen, 1976

Debruck, J. and *Boguslawski, E. von:* Die Wirkung der Kombination von organischer und mineralischer Düngung auf Grund von langjährigen Versuchen. Landw. Forsch., Sonderh. *36*, 405–419, Kongressband Giessen (1979)

Debruck, J.: Modelle der Bewirtschaftung am Beispiel einer getreidereichen Fruchtfolge. Landw. Forsch. *33*, 236–256 (1980)

Diercks, R., Bachthaler, G. and *Pommer, G.:* Langjährige Auswirkungen unterschiedlicher Fruchtfolge- und Anbausysteme auf Ertrag und Schaderregerbefall von Winterweizen und Sommergerste. Z. Acker- und Pfl.bau *149*, 454–471 (1980)

Diest, A. van: Soils and crops in the Netherlands – Potentialities and constraints. Proc. 15th Coll. Int. Potash Inst. (1980)

Eiland, F.: Organic manure in relation to microbiological activity in soil. Proc. 16th Coll. Int. Potash Inst. (1981)

Ellis, F.B. and *Howse, K.R.:* Effect of cultivation on the distribution of nutrients in the soil and the uptake of nitrogen and phosphorus by spring barley and winter wheat on three soil types. Soil & Tillage Research *1*, 35–46 (1980/81)

Ewing, E.E. and *Keller, E.R.:* Limiting factors to the Extension of the Potato into Non-Traditional Climates. Proc. 10th Ann. Congress Internat. Potato Center, Lima (1982)

Frankinet, M., Rixhon, L., Crohain, A. and *Grevy, L.:* Labour, demi-labour ou semis direct en continu: conséquences phytotechniques. Bull. Rech. Agron. Gembloux *14*, 1, 35–96 (1979)

Gervy, R.: Der Beitrag der Mineraldüngung zur Nahrungserzeugung in wirtschaftlich hochentwickelten Ländern. Im Blickfeld *32*, 56, 5–9 (1981)

Hansen, G.K.: A model for temperate European vegetative crops. Proc. 15th Coll. Int. Potash Inst. (1980)

Hanus, H.: Entwicklungstendenzen im Ackerbau. Schriftenreihe des Agrarwissenschaftl. Fachbereiches der Universität Kiel, Heft 60, 35–52 (1979)

Herzog, R., Kunze, A., Stielicke, A., Blau, O. and *Fischer, K.:* Auswirkungen unterschiedlicher Intensität der Bodenbearbeitung auf die Erträge und einige Bodeneigenschaften. Arch. Acker- u. Pflanzenbau u. Bodenkunde, Berlin, *24*, 2, 115–124 (1980)

Heyland, K.U.: Die Pflanzenentwicklung als Grundlage produktionstechnischer Ablaufmodelle. Vortrag Ges. f. Pflanzenbauwissenschaften 4.10.1979, Bonn.

Heyland, K.U. and *Braun, H.:* Einfluss von Futter-Zwischenfruchtanbau auf den Ertrag von Sommerweizen. Das wirtsch. eig. Futter *26*, 1, 15–31 (1980)

Heyland, K.U.: Die Unkrautbekämpfung – ein Teil des Produktionssystems. Zeitschr. f. Pfl.krankh. u. Pfl.schutz, Sonderheft *IX*, 33–41 (1981)

Heyland, K.U.: Tendenzen der produktions-technischen Entwicklungen im Getreidebau Deutschlands. Die Grüne *109*, 16, 11–17 (1981)

Höflich, G. and *Roth, R.:* Auftreten von Getreidefusskrankheiten in Praxisschlägen in Abhängigkeit von der Fruchtfolgegestaltung. Nachr.bl. f. d. Pfl.schutz in der DDR *35*, 4, 79–81 (1981)

Hunnius, W., Müller, K. and *Winner, C.:* Düngen wir richtig im Blick auf die Qualität von Hackfrüchten? Landw. Forschung *32*, 54, Kongressband (1978)

Kahnt, G.: Ackerbau ohne Pflug. Ulmer Verlag, Stuttgart, 1976

Kämpf, R.: Sind Fruchtfolgerichtlinien im spezialisierten Ackerbau noch aktuell? DLG-Mittlg. *2*, 62–64 (1976)

Kämpf, R.: Fruchtfolge aktuell. Verlagsunion Agrar, 4.Aufl., 1980

Keller, E.R.: Ausdehnung des Ackerbaues – Pflanzenbauliche Betrachtungen über Fragen der Fruchtfolge. Schweiz. Landw. Monatsh. *57*, 73–90 (1979)

Keller, E.R.: Der Boden als Grundlage für die Erzeugung von Nahrungs- und Futtermitteln – Erhaltung seiner Ertragsfähigkeit auf lange Sicht. Schweiz. Landw. Forschung *19*, 3/4, 209–222 (1980)

Keller, E.R., Delucchi, V. and *Kern, H.:* Pflanzenproduktion und integrierter Pflanzenschutz – Herausforderung durch die Zukunft. Schweiz. Landw. Monatshefte *59*, 332–352 (1981)

Keller, E.R. and *Baumgartner, M.:* Beeinflussung von Qualitätseigenschaften durch Genotyp und Umwelt, dargestellt am Beispiel der Kartoffel. Der Kartoffelbau *1*, 12–15 (1982)

Kofoed, A.D.: Askov 1894: Fertilizers and manure on sandy and loamy soils. Ann. agron. *27*, 583–610 (1976)

Liste, H.J., Ehrenpfordt, V. and *Smukulski, M.:* Ertragswirkung getreidespezifischer Fruchtfolgeglieder, dargestellt anhand des 'Internationalen Fruchtfolgegliederversuches'. Arch. Acker- u. Pflanzenbau u. Bodenkunde, Berlin, *18*, 6, 395–405 (1974)

Loomis, R.S., Rabbinge, R. and *Ng, E.:* Explanatory models in crop physiology. Ann.Rev. Plant Physiol. *30*, 339–367 (1979)

Maillard, A.: Entretien de la fertilité du sol à long terme sous l'enjeu des assolements, des amendements fertilisants et des traitements herbicides. II. Bilan comparatif des variations de quelques paramètres bio-chimicophysiques du potentiel de rendement d'un sol après cinq années d'essais. Thesis ETH-Z No. 6925 (1981)

Malet, Ph.: Modelling in Mediterranean area: adjustment problems of crop models. Proc. 15th Coll. Int. Potash Inst. (1980)

Nystrom, S.: The effect of crop rotation on yield variation in the light of results from some long-term experiments. Lantbrukshogskolans Med. A, Nr. 251 (1975)

Penning de Vries, F. W. T.: Simulation models of growth on crops, particularly under nutrient stress. Proc. 15th Coll. Int. Potash Inst. (1980)

Pidgeon, J. D.: A preliminary study of minimum tillage systems (including broadcasting) for spring barley in Scotland. Soil & Tillage Res. *1*, 139–151 (1980/81)

Pommer, G.: Bayer. Landesanstalt für Bodenkultur und Pflanzenbau, Freising (BRD), persönliche Mitteilung, 1982

Prummel, J.: Kalidüngung und Kartoffelqualität. Der Kartoffelbau *32*, 3, 73–76 (1981)

Rixhon, L.: Impact des techniques modernes sur les bases traditionelles de l'agriculture. Schweiz. Landw. Forschung *18*, 3, 135–152 (1979)

Schönrock-Fischer, R. and *Sachse, B.:* Untersuchungen zum Auftreten von Getreidezystenälchen *(Heterodera avenae* Woll.) in Abhängigkeit von Getreideanteil und Intensivierungsmassnahmen in der Fruchtfolge (1. Teil). Arch. Acker- u. Pflanzenbau u. Bodenkunde, Berlin, *24*, 6, 359–366 (1980)

Simon, W. and *Körschens, M.:* Die Eingliederung von Futterarten als Haupt- und Zwischenfrüchte in die Fruchtfolge. Int. Zeitschr. f. Landw. 47–51 (1981)

Srzednicki, G., Keller, E. R. and *Schwendimann, F.:* Planung und Anlage eines langdauernden Feldversuches zwecks Abklärung von Veränderungen in der Ertragsfähigkeit eines Bodens unter dem Einfluss von Fruchtfolge, Düngung und Herbizideinsatz. Schweiz. Landw. Forschung *17*, 89–107 (1978)

Steinbrenner, K. et al.: Einfluss des Getreideanteils in der Fruchtfolge auf Ertrag und Befall mit Fusskrankheiten *(C. herpotrichoides* und *O. graminis)*. Arch. Acker- u. Pfl.bau u. Bodenkunde, Berlin, *22*, 4, 259–267 (1978)

Vetter, H. and *Früchtenicht, K.:* Steigende Kosten – an Dünger sparen? DLG-Mittlg. *19*, 1042–1043 (1981)

Vez, A.: Observations dans les essais de rotation de cultures à Changins au cours des 10 dernières années. Revue Suisse Agric. *7*, 4, 113–118 (1975)

Vez, A.: Influence à long terme de diverses mesures culturales sur la teneur en matières organiques du sol et le rendement des cultures. Rev. Suisse Agric. *11*, 3, 125–128 (1979)

Vez, A.: Werden unsere Böden noch richtig bearbeitet? Schweiz. Landw. Monatshefte *58*, 12, 501–519 (1980)

Winner, C.: Zuckerrübenbau. Verlagsunion Agrar, 1981

Coordinator's Report on the 1st Session

The Basis for Optimum Yields

A. van Diest, Department of Soil Science and Plant Nutrition, Agricultural University, Wageningen/Netherlands*; Member of the Sceintific Board of the International Potash Institute.

In European agriculture, the ratio of input cost and output value is usually such that for maximum profit farmers should aim at yields lying between 90% and 100% of the maximum attainable. Prof. *Meyer*, in his contribution, pointed out that European farmers strive for these optimum yields by utilizing soils that generally were formed in the Pleistocene period and that consequently can be designated as relatively juvenile. Although comparatively speaking these soils are well endowed with mineral nutrients, we all known to what extent differences in native soil fertility in the past have affected soil productivity in Europe.

It is furthermore known that, in order to circumvent the low fertility levels of many soils, in various countries farmers have taken measures to concentrate the natural fertility of large areas of land onto small acreages on which the arable crops were grown. Prof. *Meyer* discussed how this type of what he calls 'concentration farming' has gradually given way to another type that he calls 'transformation farming'. In this latter type of farming, the soil is viewed as a body in which agricultural inputs are transformed into biomass. In this view, the intrinsic chemical assets of a soil are considered less important than the ability of that soil to serve as a medium in which roots can make optimum use of the inputs supplied by the farmer. These inputs are primarily nutrients and water, and as long as these materials are available at relatively low prices most European soils of adequate depth and favourable topography can excellently serve as rooting medium for agricultural crops.

In his paper, Prof. *Keller* has pointed out that in many instances with the presently available plant material and under the prevailing climatological conditions, yields have risen to values approaching the maximum that can be reached. Such high yields require, next to nutrients and water, the input of plant-protective chemicals and high-

Prof. Dr. *A. van Diest*, Dept. of Soil Science and Plant Nutrition, Agricultural University, De Dreyen 3, NL-6703 BC Wageningen/The Netherlands

quality seed, and of growth-supporting cultural measures, such as seedbed preparation. Equally important is Prof. *Keller's* statement that such high yields were produced by farmers spending on a particular crop only 15 to 30% of the time they had to spend on it 30 years ago. Such an astonishing increase in productivity of the average European farmer can be looked upon positively, but at the same time there are also negative aspects attached to this phenomenon. In the first place, the average European farmer has not gained much leisure time from this increase in productivity. On the contrary, the small margin between expense and income has forced him to greatly increase his productivity without granting him the assurance that such an increase will yield him a higher profit or a greater satisfaction in life.

It is, of course, a fact that the use of chemicals has made it possible for a farmer to considerably reduce the amount of time spent on seedbed preparation, on control of weeds, pests and diseases, and also on the nutrition of his crops. Here again, we meet the delicate balance between economy and ecology, as mentioned by Prof. *Keller*. I dare say, however, that in the past few years in Europe we have made progress in convincing legislators and the general public that the judicious use of agricultural chemicals enables our farmers to stay in business while producing food at amazingly low costs, without constituting a serious hazard to the maintenance of a reasonably clean and healthy environment. Emphasis must be laid on the term 'judicious use', as numerous examples are still at hand in which chemicals are used injudiciously and where short-term gains are accompanied by long-term damage imposed on our environment.

It is our task as *researchers* to constantly look for possibilities enabling farmers to obtain maximum benefit out of the use of chemicals, without serious damage being done to the environment. Likewise, it is our task as *consumers* to pay the price for measures imposed upon farmers preventing them from using certain chemicals in order to safeguard our environment.

One negative aspect of the increasing labour productivity of our farmers is that the number of people that can find employment in agriculture, has been constantly declining. In this connection, the question arises whether the vicious cycle of shrinking profits and consequently increasing need for a further rise in labour productivity can be broken through the involvement of unemployed workers, at least of those who would welcome an opportunity to make themselves useful in agriculture.

When indeed, the time has come that under the prevailing soil conditions many European farmers produce crops yielding close to the maximum attainable, it makes all the more sense to ask ourselves the question whether with our present crops we derive maximum benefit from growth factors other than the soil-bound ones, such as incident light. In the Netherlands, both with root crops, like potatoes and sugar beet, and with wintergrain crops, the quantity of light intercepted during a growing season lies in the neighbourhood of 50% of incident light. When after harvesting the wintergrain another crop is grown, the percentage can be improved, but with root crops the chances of improvement are more remote. Still, there is a great need of innovative thinking to enable our farmers to make more efficient use of the incident light without lowering their labour productivity.

Dr. *Spiertz* has pointed out some possible ways to improve the interception of incident light. This might be achieved by an enhanced rate of leaf initiation and leaf expansion, or by an extension of the period over which a leaf is involved in assimilation. The resulting increase in leaf-area duration can be very useful in raising the productivity of our crops.

Of equal importance are efforts to extend the grain-filling period of our cereals, and the period over which sugar accumulates in sugar beet, and starch accumulates in our potatoes. Associated with this is research aimed at lowering the rate of respiration in our cultural plants.

It is furthermore of interest to note, as Dr. *Spiertz* pointed out, that in N.W. Europe, the productivity of C-4 crops does not exceed that of C-3 crops. This finding brings into focus the potentialities of countries having a more continental climate, where higher temperatures and higher radiation offer extra opportunities for farmers to optimize their yields.

Looked upon from a N.W. European viewpoint, it is rather paradoxical to notice that there where nature is rather generous in matters like temperature and light, farmers are often less successful in exploiting those assets. It is of course true that in countries well-endowed with light and temperature, other growth factors and growing conditions are often less favourable. I am thinking in this respect of water and nutrients, of steepness and stoniness of the land, and of shallowness of the rooting zone.

Here, however, lie the challenges. It is far easier to supply additional water to thirsty crops and to supply additional nutrients to hungry crops than is to supply extra heat to shivering crops and extra radiation to light-starved crops.

We in the International Potash Institute have as our primary task to bring to the attention of the agricultural world the need for improvement of the nutrition of our crops. We know that we should not go about this in a single-minded fashion by drawing attention only to the need for more fertilizer use. But at the same time, we feel the obligation to point out that under many existing conditions of adequate presence of light and temperature, application of plant nutrients is one of the best investments to be made towards achieving optimum yields.

12th Congress of the International Potash Institute
June 1982 at Goslar/Fed. Rep. of Germany

2nd Session

Optimization of Animal Production Based on Optimum Crop Production

Co-ordinator *Dr. Th. Walsh*, Director, Council for Development in Agriculture, Dublin/Ireland; member of the Scientific Board of the International Potash Institute

The Efficiency of Nutrients and Energy in Plant and Animal Production Systems

C.C. Balch, National Institute for Research in Dairying, Shinfield, Reading/United Kingdom and *G.W. Cooke*, Rothamsted Experimental Station, Harpenden, Herts/United Kingdom*

Summary

The efficiencies of the systems considered here are defined as the proportions of inputs (which may be nitrogen [and other] fertilizers applied to crops, or energy and protein supplied to animals) which are present in the products of the system used as human food. Efficiency is generally improved by intensification which is secured by increased inputs. The appetite of livestock is the most important factor that limits the efficiency of conversion of animal feed to human food. When intake can be increased a larger proportion of the total diet is available to produce more meat or milk.

Crops grown for direct human consumption can produce several times as much energy and protein as do animals fed on the produce of the same area of farmland. The pathways of plant nutrients applied as fertilizers to barley and to grass used as animal feed are discussed. About one-quarter of the nitrogen in crops eaten by beef cattle or dairy cows can be recovered in meat or milk when the animals are managed intensively. Considerable amounts of plant nutrients contained in the feed eaten by livestock are excreted and must be returned to land efficiently to maintain soil fertility.

Comparisons between the efficiencies of production of populations of different species depend on rates of reproduction and replacement as well as on productive efficiency and feed intake. The highest efficiencies are achieved in producing milk, young mammals and eggs. In assessing the much lower efficiencies recorded for the less intensive forms of beef production, and for sheep, account must be taken of the abilities of ruminants to use fibrous food and to live on pasture produced on land that could not be used for arable cropping.

Although the developing countries have much larger populations of animals than the developed countries have, they produce much smaller quantities of meat and milk because growth rates are poor and erratic, and food is restricted in quantity and poor in quality. This situation will only be remedied by establishing more intensive production with a portion of the stock, and by improving the diet of the rest of the animals by pasture improvement, by adjusting stocking rates, better management, and by the provision of some supplementary feed.

Published estimates of the efficiencies of production systems vary considerably since they depend on the assumptions made. Much more research is needed on complete farming systems to measure the partial efficiencies of the components of the systems, to identify limiting factors, and to devise methods of overcoming these constraints. Mathematical models will be needed to provide quantitative predictions of the results of changes in production systems. This ability to forecast the effects of change is essential for making sound policy decisions on management and improvement.

* Dr. *C.C. Balch*, DSc., FIBiol, Deputy Director, National Institute for Research in Dairying, Shinfield, Reading RG2 9AT/United Kingdom

Dr. *G.W. Cooke*, CBE, FRSC, FRS, Honorary Scientist, Rothamsted Experimental Station, Harpenden, Herts AL5 2JQ/United Kingdom

In planning for higher efficiency account must be taken of the stage of development that has been reached. In well-developed agriculture precise biological information on the components of systems must be available before decisions can be taken that will be both biologically and economically sound. Less developed systems have a similar need for experimental information, but differences in the importance of the local factors affecting efficiency may lead to different paths to higher productivity.

1. Introduction

1.1 The efficiency of agricultural systems

All agricultural production results from the capture of solar radiation for the process of photosynthesis by plants rooted in soil. These plants provide the food of people, or of animals which, in turn, provide food for man. The overall efficiency of the process is low. *Spedding*, *Walsingham* and *Hoxey [23]* have given data for the conversion of energy in solar radiation to energy in the agricultural products from crop and from animal systems. For the first stage of crop production these data range from 0.7% conversion by a crop of grass yielding 12 t/ha of dry matter, to 0.2% conversion by wheat yielding 4.4 t/ha of grain, and to 0.12% for peas and field beans yielding 2.5 t/ha. The highest overall conversion of solar radiation by animals fed on crops and herbage quoted was 0.044% by baconer pigs; conversion by dairy cattle was 0.027%, while production of eggs from hens and of beef from suckler cattle achieved only 0.012%. The task of agricultural scientists is to make the whole process more efficient. This we do by identifying constraints on the various stages in the agricultural system; then by inputs (of fertilizers, feed, and pest and disease control chemicals) and by improved management systems, we plan to overcome these constraints. At the same time other scientists endeavour to raise, by selection and breeding, the genetic potentials of our plants and animals.

This paper follows the successive stages in agricultural systems involving the use of fertilizers to produce arable and herbage crops used for animal feed, through the the animal production phase, to the stage where human food is available. The emphasis is on the efficiencies of the system at the various stages.

1.2 Forms of production needed

Basically the world needs more foods of the same kinds that are now eaten, but with a trend towards improved nutritional quality, particularly more protein of good quality for poor people; this may come from plants or from animals. A greater energy density is required in some diets so that infants and young people are physically able to eat enough.

The contributions of different forms of agricultural production to World energy and protein supplies for people have been given by *FAO [10]:*

	percentage contributions to supplies of	
	Energy	Protein
Cereal grain crops	54	49
Plant products (roots, pulses, vegetables, oil seeds and nuts)	35	21
Animal products	11	29

Cereals provide roughly half of the world's energy and protein. Animal products supply a tenth of energy, but nearly a third of protein requirements.

In debates on world food supplies there is often criticism of the use of land to produce animal feeds because the overall efficiency of the conversion of plant products to meat, milk or eggs is low. Table 1, based on data published by *Spedding*, *Walsingham* and *Hoxey [23]*, shows calculated differences in gross energy and crude protein from crop production and from animal feeding systems. In discussing such data that involve ruminants we must remember that many countries have large areas of land which cannot be used for arable crops and are only suited to growing permanent herbage crops for ruminants. For example, one-third of the area of the U.K. is quite unsuitable for any crops other than pastures or rough grazing.

Table 1. Yields of gross energy and crude protein from crop production and animal production systems*

	Yield of dry matter t/ha	Gross energy produced GJ/ha	Crude protein produced kg/ha
Crop			
Ryegrass	12.0	222	2100
Wheat (grain)	3.8	70	469
Field beans (seed)	2.3	43	613
Maize (grain)	4.0	76	392
Rice (grain)	4.9	88	375
Potatoes (tubers)	5.8	102	522
Sugar beet (roots)	8.7	152	416
	Nature of animal product and yield kg/ha		
Animal			
Cattle: beef (suckler)	360 (carcass)	3.9	53
beef (on barley)	440 (carcass)	4.8	65
dairy	3386 (milk)	8.8	118
Sheep	462 (carcass)	7.5	65
Pigs	875 (carcass)	14.4	105
Broiler fowl	980 (carcass)	7.1	135
Laying hen	624 (edible fraction of the eggs)	4.1	74

* *Spedding*, *Walsingham* and *Hoxey [23]* give the sources of these data and describe the animal production systems adopted

1.3 Problems of intensification

Improvement in agriculture is generally synonymous with intensification – we require more product from each unit – whether a hectare of land, or a head of livestock. This requires scientific information so that the production processes can be controlled. Intensification has often been regarded as undesirable by many well-meaning people. In fact it is the only way to secure more efficient use of resources in plant and animal production.

The problem with plants in high-producing systems is usually that of ensuring that sufficient of the simple chemical ions that are plant nutrients, and sufficient water, should be present at root surfaces just when they are needed for uptake. The availability of nutrients and water to plant roots depends on the total amounts of the ions present in soil, on rates of diffusion of these ions, and on the porosity and hydraulic conductivity of the soil; these matters have been discussed elsewhere *(Cooke [7, 8])*. Parallel problems occur with animals. The most universal limitation to the efficiency of animal production systems is the appetite of the animals. If only they could eat more they could consume enough to make useful gains on poor quality feeds in extensive systems. But at the other end of the spectrum it is clear that when high-yielding cows can be induced to eat a little more concentrated food for a few weeks in early lactation the benefits in increased milk production will extend throughout the lactation *(Broster [5, 6])*.

The need for nutrients to be present in greater concentrations in diets, as greater production is expected from animals, is shown in Table 2 *(ARC [1])*. Not only has the total amount of feed eaten to increase greatly, but the concentration of crude protein (assumed to be of optimal degradability), and the concentrations of calcium and phosphorus, must increase in the diet as the total intake increases to meet the needs of the animal to grow more rapidly, or to give more milk. Planning a diet for a given level of production requires decisions based on the analyses of the feed available, on their content of metabolisable energy, and on the degradability of the protein in the rumen; mineral supplementation may be necessary.

Table 2. The effects of intensification of animal production on the concentrations of nutrients needed in the diets of a calf and a Jersey cow*

	Daily intake[a] of dry matter (kg)	Concentrations of nutrients in daily requirements				
		Crude protein[b]	Ca	P	Mg	Na
Type of stock		grammes/kilogramme in the dry matter				
Calf weighing 100 kg						
0.0 gain in weight per day kg	1.4	86	1.7	1.1	1.2	0.50
0.5 gain in weight per day kg	2.1	121	5.5	2.9	1.4	0.75
1.0 gain in weight per day kg	3.2	130	6.7	3.4	1.3	0.75
Jersey cow weighing 400 kg						
0 milk yield per day kg	3.8	87	2.5	2.2	1.9	0.7
10 milk yield per day kg	9.0	106	3.3	3.2	1.4	0.9
20 milk yield per day kg	14.5	119	3.5	3.5	1.4	0.9

* These data are given by *ARC [1]*

[a] All diets are with metabolisability $\left(=\frac{\text{metabolisable energy}}{\text{gross energy}}=q\right)$ of 0.6

[b] Protein is assumed to be of optimum degradability

1.4 Inputs to intensive systems

This paper is concerned with the efficiencies of inputs which must be maximal if optimal economic production is to be achieved. Discussion of efficiency is concentrated on the following topics: (a) Inputs of support energy to the whole system are briefly considered. (b) Inputs of plant nutrients to produce barley and grass are discussed in relation to the use of these crops for animal production. (c) Discussions of the factors affecting the efficiencies of different species of animals are followed by consideration of the efficiencies of integrated farm production systems. (d) Finally, the special problems of animal production in the developing countries are discussed.

2. Efficiency of fuel energy inputs

Following the 'energy crisis' which began when oil prices were sharply increased in 1973, it became fashionable to examine agricultural systems to determine how much energy was provided in the human food resulting, in relation to the total fossil fuel energy needed to produce it. Most systems producing crops grown out of doors for direct human consumption give products yielding more energy in food than was in the fuel energy used. Nevertheless, faced with threats to the long-term security of supplies of fuels for heating their homes, and for effortless transport, some of the urban community has criticised the energy used in modern intensive agriculture. *White [24]* has estimated that in U.K. this amounts to only 4.3% of the total national consumption of energy; the proportion used in agriculture in U.S.A. is similar. Particular criticism is directed against the manufacture of fertilizers which take 24% of the total support energy used by agriculture (and nitrogen accounts for 90% of the total energy used to make fertilizers). These critics appear to be unaware that fertilizers increase the productive capacity of land, and that the efficiency of the solar radiation captured by plants is thereby greatly increased. An even more important point is that the critics ignore the energy used to transport, store, process, sell and cook the food after it has left the farm. *White [24]* states that this amounts to nearly 15% of the total national use of energy – over three times as much as is used to produce the food grown on U.K. farms. The total energy used in animal production systems is considerably greater than the energy in the edible products. Table 3 shows an examination of energy inputs and outputs for several production systems listed by *White [24]*.

We will not pursue these arguments about the fossil fuel energy used in farming systems because the main points have been made adequately by other authors. The present input of fuel energy into agriculture is essential for the continuation of the modern intensive systems on which the world's food supply depends. In the end any conflict for the use of fossil energy will be between hunger on the one hand, and comfort and convenience in living and moving on the other hand. *Holmes [14]* summarised the situation as it now is: 'Of course we cannot eat fuel and, of course, animals provide valuable proteins, minerals and vitamins in the diet but it is probable that because of price alone much effort will be needed to devise modern but more energy-saving farming systems'. The constructive aspect of these criticisms of the energy used in agriculture as a whole, including the considerable proportion used to make N-fertilizers, is the warning of increased fuel costs in the future that must stir us to research on saving energy in farming systems, on exploring the use of alternative energy sources (including the products of agriculture), and on alternative ways of fixing nitrogen. These topics are discussed by *J.K.R. Gasser* later in this congress. The future of alternative fuel inputs, and alternative management systems, will depend on their costs and the returns that they offer.

Table 3. The use of fuel energy, and other support energy in agricultural systems[1]

	Energy[2] input GJ/ha/year	Energy in crop, or ME in product GJ/ha	Efficiency[3]	Protein output kg/ha/year	Energy to produce protein MJ/kg
Crops					
Wheat	19.3	60.0	3.12	495	39
Barley	17.6	46.2	2.63	364	48
Potatoes	52.0	69.3	1.33	460	113
Sugar beet (at the farm)	25.2	82.5	3.28	—	—
Onions	93.4	27.7	0.30	276	338
Tomatoes (in glasshouse)	1300	62.0	0.05	945	1360
Animal products					
Milk	32.5	18.5	0.57	201	162
Pig meat	18.0	11.4	0.63	76	238
Eggs	22.5	6.0	0.26	113	200
Poultry (broiler)	29.4	4.3	0.15	145	203
Beef (dairy herd)	10.4	3.2	0.31	40	257
Beef (beef herd)	10.6	2.4	0.23	31	348
Sheep meat	10.1	2.5	0.25	22	465

[1] These data are from *White [24]*
[2] Excluding the inputs of solar energy
[3] Efficiency is calculated from the ratio $\frac{\text{energy in crop or product (GJ/ha)}}{\text{energy input per year (GJ/ha)}}$

3. Plant nutrient cycles in farming systems

In this section we follow the pathways of plant nutrients used (a) to produce barley to feed a steer, and (b) to produce grass to feed a dairy cow. Both examples are based on published results of field experiments testing fertilizers on crops, and on published information on diets for livestock and on composition of animal products *(ARC [1], MAFF [19])*.

3.1 Barley produced to feed a steer

Spring-sown barley grown at Rothamsted in an experiment described by *Widdowson, Penny* and *Bird [25]* had a test of 113 kg/ha of N against no nitrogen. The yields and amounts of nitrogen in the crop were:

	Grain	Straw	Amount of N in crop kg N/ha			Recovery of N applied as fertilizer (%)
	kg/ha of dry matter		Grain	Straw	Total	
Without N-fertilizer	3.0	2.4	47	10	57	—
With 113 kg N/ha	5.0	4.9	92	28	120	56

The composition of the crop (concentrations and total amounts of nutrients) was:

	Grain % in dry matter	Straw	Grain kg/ha	Straw	Total
N	1.84	0.56	92	28	120
P	0.35	0.06	17.5	2.9	20.4
K	0.61	1.89	30	94	124

By the time that the barley crop had been produced 44% of the N applied as fertilizer had already been lost from the system. It is not realistic to calculate percentage recoveries of the fertilizer P and K applied as, under modern intensive cereal-growing systems, these nutrients are applied on a maintenance basis, the crop using reserves in the soil as well as fresh fertilizer. Nevertheless the crop removed 47 kg/ha of P_2O_5 and 149 kg/ha of K_2O and these amounts would be needed as fertilizers or manures to maintain soil fertility.
The steers fed on this barley were assumed to weigh 300 kg each and to gain weight at 1 kg per day. The diet was assumed to be:

Daily allowance	Metabolisible energy (MJ)	Crude protein (g)	Nitrogen (g)
3.3 kg of grain	45	380	61
3.3 kg of straw	24	116	18
Totals	69	496	79

Armstrong and *Brookes [2]* who proposed this diet considered that a daily supplement of 50 g of urea (i.e. about 22 g of N in this form) would be needed to correct the deficit of rumen-degradable protein in the barley. The 5 t/ha of barley grown on the N-fertilized plots, plus the same weight of straw, would provide feed for 1515 days for such animals, and therefore for 1515 kg of liveweight gain (LWG).

3.1.1 Recoveries of plant nutrients in animal product

The nutrients recovered were calculated from published information *[1, 19]* on the composition of LWG. *Nitrogen:* Of the 120 kg/ha of N in the crop only one-quarter (30 kg) was present in LWG that is potential human food (allowance was made for the N supplied by the urea supplement). Since only one-half of the N in the crop came from fertilizer (the remainder coming from soil) only one-eighth of the fertilizer-N will appear in the carcass (after allowing for tissues discarded in dressing the carcass, the final proportion of fertilizer-N that becomes available as protein in human food will be less, probably no more than 10%). *Phosphorus:* The barley supplied just enough P to meet the published *[1]* requirements of the animal. About 50% of the P in the barley eaten was excreted; this would need to be returned to the land in farmyard manure (FYM) or slurry. *Potassium:* The ration supplied three times as much K as the animal needed *[1]* and of the total ingested 80% or more was excreted; from a hectare of barley about 100 kg of K would be available in manure for recycling.

3.2 Grass produced to feed dairy cows

The field experiment at Wenvoe (South Wales) was one of a series described by *Morrison*, *Jackson* and *Sparrow [20]*. The grass received 450 kg/ha of N as fertilizer in six equal dressings and was cut six times each year.
Average results over four years were:

N applied kg/ha	Dry matter yield t/ha	N in crop kg/ha	N in dry matter %	Crude protein %
0	1.2	28	2.26	14.1
450	13.6	384	2.82	17.6

The grass also contained these concentrations of other minerals, as % in dry matter – Ca 0.70, Mg 0.23, K 2.8, Na 0.29, P 0.43.
Of the fertilizer-N applied 79% was recovered in the grass. In parallel work *Jackson* and *Williams [17]* showed that only 75% of total dry matter produced in this way was actually eaten when grass was grazed; a similar percentage of dry matter is often lost in making and using hay or silage. Therefore only 10 t/ha of grass dry matter would actually be consumed by the cows, this would recover 59% of the fertilizer-N applied. Assuming that the grass supplied 11 MJ of energy per kg of dry matter, and the metabolisability (q) was 0.6, the total metabolisable energy available (110 000 MJ/ha) would provide for the production of 21,568 litres of milk which would contain 108 kg of N *[1]*. Therefore 24% of the fertilizer-N applied would be available as protein for human food in milk.
This example is over-simplified as it assumes that cows will graze high quality grass, with no other food, in the most productive part of the year, making no allowance for weight change in the cow, or the production of a calf. In a more realistic example following *Holmes*, *Craven* and *Kilkenny [15]*, calculations were made for a cow maintained for one year on 0.4 ha of this grass plus 1 tonne of purchased concentrates. She yielded 5500 kg of milk in the year, gained 50 kg in weight, and calved again after 12 months. After allowing for the contribution of the N in concentrated food, and the production of the calf and its nitrogen content, the total N recovered in milk and calf would be about 20% of the fertilizer-N applied.

3.2.2 Recovery of other nutrients in milk

The 11 kg of this grass dry matter eaten daily by grazing, or as high quality silage, will provide as much magnesium, more phosphorus and calcium, and much more potassium, than the cow needs. Her milk will contain about 5% of the Mg, 7% of the K, 25% of the Ca, and 33% of the P, that was supplied by the grass.
Nearly all of the remainder of these mineral nutrients, and the nitrogen, that are not in the milk will appear in excreta. Over a 12-month period the cow's wastes will contain 160 kg N, 12 kg P, 100 kg K, 20 kg Ca and 12 kg of Mg. These large quantities, particularly of N and K, emphasize the need to make the maximum use of nutrients in wastes by returning them to land at times and rates which ensure the maximum efficiency of the nutrients in growing another crop. Furthermore, these wastes must

not be regarded as *liabilities* that create disposal problems, but as *assets* that have great value in maintaining soil fertility.

3.3 Nitrogen pathways

Nitrogen is a powerful link throughout the whole of systems which produce human food from animals fed on crops that are grown in soil; in many conditions in developed agricultural systems the supply of nitrogen governs yield and output of arable crops or grassland. The large increases in the prices of fertilizers in the last 10 years, and the need to avoid environmental pollution which nitrate causes when it moves from agricultural systems into natural waters, has made the efficiency of nitrogen fertilizers a priority topic for research the world over. Inorganic nitrogen is ephemeral in soil, nitrates are liable to be lost by leaching, or by denitrification; ammonium forms are liable to loss of ammonia on calcareous soils. There are also massive losses of ammonia from animal excreta, whether dropped on grazed grassland, or when voided indoors and handled as manure.

Research is being done to improve the efficiency of the N used in crop production by tests of alternative forms of N-fertilizer, and improved times and methods of application. This work should be extended to whole farm systems involving animal production from crops; one measure of the efficiency of these systems would be the percentages of total N in the crop, and of fertilizer-N, which appear in the final product as protein that is used as human food.

The estimates made in Sections 3.1 and 3.2 indicate that 12% of fertilizer nitrogen used on barley was recovered in beef from a steer that ate the barley grain and straw, whereas 24% of the fertilizer-N given to grass that was the only feed of a dairy cow appeared in her milk. But of the *total* nitrogen in the crop the two kinds of livestock returned about a quarter in their product – beef or milk. This difference between the recoveries of *fertilizer-N* is accounted for by the difference in the responsiveness of the two crops; N-fertilizer increased the yield of barley grain by 67%, but the grass made very little growth without fertilizer-N and applying this nutrient increased the yield by *11 times*. Other authors have published estimates of the fertilizer-N recovered from animal production systems: in one example *Holmes [12]* calculated that only 7% of the fertilizer-N used on grass was recovered in milk. *Greenhalgh [11]* has concluded that 12.5% of the N applied in fertilizer to pasture might be recovered in milk, while the return in beef was only 7.5%.

Differences between the estimated recoveries of fertilizer-N in milk or beef calculated here, and the calculations of others that we have quoted, show that more work is needed to study the actual fate of fertilizer-N applied to crops through the whole system of soil to crop to animal to human food. Much will depend on the efficiency of the N at the first stage when it is applied to crop or grass. The experiments must be made under carefully-controlled conditions and sufficient ancillary work must be done to establish partial efficiencies of components of the system and to identify the factors that prevent greater efficiency being achieved. There is need for such work to be done in different regions because climate and soil have large influences on the recovery of nitrogen fertilizer by the crop. For example, in the series of experiments described by *Morrison, Jackson* and *Sparrow [20]* the recovery of applied-N over a four-year period ranged from 82% at one centre on heavy soil in a wet area, to only 46% at a centre on lighter soil in a dry area.

3.4 Transformations of energy and protein

To supplement the calculations made above on the transfer of nitrogen and minerals from plant material to human food, estimates of the conversion of the energy and protein in the feed used to energy and protein in human food were made using the information given by *MAFF [18]* on the composition of milk and beef. The results below show somewhat higher efficiencies than those calculated by *Holmes [13]* for similar production systems and summarised later in Table 7.

	Steer producing beef	Cow producing milk
	Percentage recoveries of nutrients in the feed in the product	
Gross energy	9	16
Metabolisible energy	16	28
Protein	27	24

4. The efficiencies of animal production systems

When predicting the responses of animals to particular feeding systems the first information that is required is on the composition and nutritive value of the feed together with a means of estimating how much the animals will eat. *The International Network of Feed Information Centers (INFIC [16])* has developed a system for the naming of feeds, and the collection, storage and exchange of numerical and factual information about feeds on a world-wide basis. Very many factors are concerned in determining the efficiency with which animal feed is converted to human food. *Balch* and *Reid [4]* have discussed the subject widely and some of the important points are stated in this section.

4.1 Losses of ingested nutrients

The factors which are responsible for losses of energy at various stages in animal systems are shown in Table 4. Losses are considerable, and inevitable; as the authors *[4]* say various factors then determine the speed and extent of growth, fattening and other forms of production: 'Although the animal has little choice but to utilise digested energy, it does not follow that it will be utilised for the form of production desired by the farmer or consumer'.

4.2 Feed intake

Limitation of intake by appetite is the single most important factor which usually sets the upper limit to efficiency of conversion. No matter how desirable an extra input may be on economic grounds, no improvement can be obtained if the animal refuses to eat more. Feed must provide: energy + protein + minerals (both macro- and micro-

Table 4. The main losses of energy, expressed as percentages of input, which influence the proportion of the dietary energy which becomes animal product*

	Inputs of energy at various stages			Losses of energy as percentages			
	Pig	Fowl	Ruminant	Cause of loss	from Pig	from Fowl	from Ruminant
Dietary energy	100	100	100	Gases	0 (0–0.3)	0	8 (5–12)
				Faeces	20 (5–40)	13–65	30 (10–60)
Digestable energy	80	80	62	Urine	2 (1–3)	—	4 (3–7)
Metabolisable energy	78	80	58	Heat and movement	16	20	23
Net energy *for Maintenance* Production energy *for Liveweight Gain* *for Milk*	62	60	35 / 41				

* The data are quoted by *Balch* and *Reid [4]* and are based on *Reid [22]*

nutrients) + vitamins. *Maintenance* of the animal production unit is the first call on nutrients. Production (of milk, eggs or liveweight gain, etc) results when input exceeds that needed for maintenance. The proportion of intake that is used for maintenance depends on level of production, as the following figures show:

	Percentage of intake for maintenance
Dairy cows: 10 kg milk/day	53
20 kg milk/day	36
Steers (growing)	52–63
Pigs (growing)	35
Laying hens: 200 eggs/year	67
300 eggs/year	57

The percentage of energy that is available for production varies with the amount of intake as compared with the energy needed for maintenance; thus when intake is twice the need for maintenance 50% of the energy is available for production, but when the ratio rises to six times maintenance, 83% is available for production. Deviations from linear relationships between intake and proportion of energy available for production depend on factors such as limitations to appetite and the reduction in digestibility at high intakes.

4.2.1 Appetite

Appetite has a vital role in determining food intake. *Voluntary intake* is regulated by several factors that are discussed here.

With diets of less than about 65% digestibility, voluntary intake in ruminants is limited largely by physical factors related to the rate of disappearance of digesta from the rumen. For some diets the digestibility of the feed provides a useful index to its intake; factors that influence the rate of breakdown of digesta will therefore influence the voluntary intake of that diet. Among such factors are the state of division and nutrient balance, particularly the content of rumen-degradable nitrogen *(Balch* and *Campling [3])*. With diets of more than 65% digestibility intake appears to be influenced to a greater extent by factors related to the maintenance of body homeostasis. These include nutrient balance and the rate of fermentation of substrate in the rumen. With many types of stock intake is reduced by high environmental temperatures. This is a serious limitation to the efficiency of animal production in tropical countries.

4.2.2 Digestibility

The efficiency of digestion is expressed as the net amount of energy, nitrogen, or other nutrient removed from the feed during its passage through the gut. Digestibility is affected by a number of factors:

a) Plane of nutrition – as intake increases digestibility either falls or remains constant. With long forages there may be little change, but fine chopping or grinding can diminish it.
b) Dietary balance must be correct, for example there may be a need for extra nitrogen in digesting cellulose.
c) Grinding feed improves the digestibility for non-ruminants and may be essential. With ruminants, grinding commonly depresses digestibility.

4.2.3 Efficiency of utilisation of products of digestion

All digested nutrients enter blood or lymph and homeostasis mechanisms then act to keep blood composition constant within certain limits; if this control breaks down, metabolic disorders result. Therefore, it is beneficial to feed regularly, for then utilisation becomes most efficient. Other factors are important: *Balance* in the diet is essential for efficiency, thus energy supplies cannot be fully effective unless all other nutrients (*e.g.* the correct proportions of amino acids) are present. *Temperature* can affect the feed conversion efficiency with poultry. *Ruminant digestion* is complicated; factors that affect the pathways of microbial digestion, and the formation of acetic, propionic and higher fatty acids, affect the utilisation of the products of digestion and the composition of the product; for example, a fall in the proportion of acetate and an increase in butyrate diminishes the fat content of milk. For these reasons it is difficult to state precise values for the utilisation of energy.

4.3 Dietary nitrogen

This component of feed presents special problems in ruminants. Proteins are degraded to simpler compounds and to ammonium-N. Amino acids are synthesised by rumen bacteria to form microbial protein. The efficiency of this process has a crucial effect on the efficiency of nitrogen metabolism.

Energy is the primary nutrient and response to protein depends on energy intake. When protein is limiting it is used with maximum efficiency and its biological value (determined by the amino acids it contains) then becomes important. If energy is adequate the response to protein is linear (recalling Liebig's 'law of limiting factors' stated in the last century for factors affecting plant growth), though at very high levels protein may be toxic. The upper limit of response to both energy and protein is set by the voluntary intake of food but *Balch* and *Reid [4]* state 'no animal can use energy and protein with maximum efficiency at the same time'. Therefore it seems most important to have the energy input right, if necessary sacrificing protein balance. Nitrogen inputs can be made more efficient by protecting proteins so that they pass through the rumen and are digested in the intestine. Adding starch to the diet assists in retaining ammonia that may be released in the rumen. Ruminants can use non-protein nitrogen (notably urea); often these materials are less efficient than protein, but sometimes they are as good. Rumen synthesis may not, however, be adequate for high-yielding dairy cows where the milk itself may contain more than 1.2 kg of protein daily. If a diet is so short of protein (or other nutrients such as minerals or vitamins) that the energy taken in cannot be used, the animal will respond by reducing its intake. Systems are now being developed to calculate the amount of nitrogen that ruminant diets need to contain (a) in the non-protein-nitrogen or rumen-degradable form to permit optimal growth of rumen microorganisms, and (b) as protein that will escape degradation in the rumen and supplement the supply of microbial protein reaching the intestine. The perfection of such schemes will aid the improvement of the efficiency of feed utilisation *(ARC [1])*.

4.4 Overall efficiency

Balanced diets offer the optimal utilisation of energy. Defining and securing these may be difficult and *Balch* and *Reid [4]* comment: 'Maximisation of economic profitability involves difficult compromises between reducing safety margins and the increased risk of lowered production due to a lowered energy intake or to an inadvertent deficiency'. In attempting to achieve the desired form and amount of production, several factors are of 'supreme importance': (a) a high food intake with efficient utilisation for production; (b) food intake control, most important in maintaining body homeostasis; (c) selection of an animal that has the ability to give the desired product; thus pigs should have the ability to convert dietary energy into protein and not fat, cattle should have ability to convert the available energy into milk or protein (*i.e.* lean meat). Cows that can 'buffer' their production by converting body fat into milk early in lactation have advantages over other cattle.

5. Comparisons of the efficiencies of species of animals

Balch and *Reid [4]* have discussed the efficiencies of different classes of livestock. They emphasise, 'The efficiency of any one enterprise, herd, breed or system is the result of a large number of component partial efficiencies varying interdependently and independently. Attempts to improve the efficiency of animal production depend heavily on correct definition of the main limiting factors in each situation'. For example, good returns from feed cannot be expected from a system handicapped by a low reproductive rate. They cite the results of comparisons between breeds which showed that many times more females were required in tropical breeds to sustain a given level of production than were necessary with Holstein cows. For example, the Hariana breed from India used only 11.5% of feed energy directly for production as compared with 43.8% of energy used by Holsteins for milk production. High-yielding cows have the ability to convert feed to milk with high efficiency (63–68%) whereas the efficiency with which fat is laid down is 10–20% less. However, cows must be fed so that they develop some reserve of fat during the later stages of lactation, this is because a good dairy cow draws on body reserves of fat to keep up high levels of yield early in her lactation. Therefore efficiency in the use of food must be assessed over the whole lactation rather than over a short period.

Similarly poultry have been bred for specific purposes. The breeds used for broiler production have high food intakes and achieve high weights rapidly with a more efficient use of the food than can be achieved by the breeds which have been established for egg production.

5.1 Scale of performance

Wilson [26] expressed efficiency as 'the proportion of the specified nutrient which, in the specified time, is converted into a product for consumption or use by men'. His calculations of the biological efficiencies of protein production by animals performing at different levels are summarised in Table 5. This Table shows the well-known superiority of dairy cows in converting feed protein to protein in human food; it also shows well the increased efficiency that results from intensifying production to higher levels and gives a theoretical ceiling.

Balch and *Reid [4]* also discussed this subject. They gave estimates (which are shown in Table 6) of lifetime conversion of dietary energy into protein and energy of animal product. The calculations were based on the assumptions of several partial efficiencies

Table 5. The efficiency of animal systems in converting dietary protein to protein in animal product in developed countries*

	'Average'	'Improved' (or top 5%)	Theoretical ceiling
	Percentage of dietary protein converted to protein in animal product		
Product			
Milk	23	34	45
Beef (steer)	6	8	10
Pork	12	16	20
Lamb	3	9	12
Eggs	20	30	36
Broiler meat	20	30	—
Rabbit meat	11	17	20

* This table is based on a presentation by *Balch* and *Reid [4]* of data published by *Wilson [26]*

Table 6. The lifetime efficiencies with which dietary energy is converted into protein and the energy resulting from various animal production systems*

	Lifetime production of	
	Protein (g per MJ digestible energy)	Energy (% of digestible energy consumed)
Production and level of output		
Pork (91 kg at slaughter)		
2.72 kg feed per 0.45 kg of gain	1.20	—
1.81 kg feed per 0.45 kg of gain	1.53	18
1.13 kg feed per 0.45 kg of gain	2.07	—
0.91 kg feed (a) per 0.45 kg of gain	2.89	—
(a) the limit with no losses		
Broiler meat		
1.59 kg at 12 weeks	2.84	12
1.59 kg at 10 weeks	3.27	14
1.50 kg at 8 weeks	3.80	16
Eggs		
200 per year	2.41	12
Milk		
3600 kg per year	2.51	22
5400 kg per year	3.06	27
9072 kg per year	3.90	35
Beef		
499 kg at 15 months	0.69	6

* The data were published by *Balch* and *Reid [4]*

which were published by *Reid [21, 22]*. These results show very clearly the large gains in efficiency (and therefore in profit to the farmer) when the efficiency of feed conversion can be increased with pigs, when broilers reach the required weight in a shorter period, and when milk yields can be considerably increased.

5.2 Value of animal products

Balch and *Reid [4]* have pointed out the great variability in the composition of animal products. The fat content in the empty body can vary from 1.1 to 61.5% in pigs, and from 1.8 to 44.6% in cattle. The composition of the fat-free body is, however, much less variable. The value of animal protein produced, considered as human food, depends on its 'biological value' which is determined by its amino acid composition. FAO data quoted for these biological values are:

Beef and veal	74.3	Hens' eggs	93.7
Chicken	74.3	Cows' milk	84.5
Pork	74.0		

5.3 Choosing between animals

5.3.1 Efficiency of production

In considering the best system of animal production to adopt, decisions must be based on the long-term performance of whole populations of animals; this subject has been studied by *Holmes [13]*. He took account of (a) reproductive index (the annual mass of live young, born or hatched, compared with the mass of the dam); (b) replacement index (based on the average life of the female and the number of progeny; (c) productive efficiency and the feed intake of the animal (relative to its maintenance requirement). *Holmes* derived efficiencies as proportions of (a) protein, (b) metabolisable energy (ME), and (c) gross energy (GE) in feed which were returned as edible nutrients, and also the yields of protein per unit of energy through lifetimes calculated from hatching or birth to slaughter, or from the point of lay with chickens, or the beginning of lactation with cows. The highest efficiency of protein production by single animals through their productive lives was from young mammals (pork, early lamb, veal) and by egg production; the lowest efficiency was with the less intensive systems of beef production and with sheep. On the basis of protein yield per MJ of metabolisable energy all intensive production gave similar results of 2.5–3.4 g protein per MJ of metabolisable energy. When measurements were made in terms of gross energy, the non-ruminants are more efficient because their diets are higher in metabolisability.

In making full comparisons of species account must be taken of food costs for rearing chickens to point of laying, for rearing cows to calving, for maintaining female breeding stock and rearing replacements. The value of carcasses at the end of their productive life must also be taken into account; from the production of eggs, milk, and poultry and pigs these carcasses have high values. The examples of the efficiencies of feed for breeding populations in Table 7 were given by *Holmes [13]*. (His paper states the assumptions that were made for the calculations.) In terms of conversion of crude protein to edible protein, egg production had the highest efficiency; but on the basis of energy conversion, milk production was slightly superior. Efficiency is improved when the numbers of young produced per year are increased. Improved genotypes, better feeding, and better management, will all increase the efficiency of feed conversion.

Holmes [13] concluded that common farm animals can achieve similar feed efficiencies. The high cost of rearing and maintaining the females who produce a small number of progeny each year generally reduces feed efficiency severely; dairy cows are the exception. Normally milk, even with associated beef production, gives high yields which may be equalled or exceeded by egg production, and by poultry meat if all of this (including the skin) is eaten. A dairy herd gives the best return from concentrated feeds, particularly if they are used at low rates.

5.3.2 Comparisons based on unit areas of farmland

Some comparisons of the food produced by arable crops and by several animal farming systems have already been given in Table 1. *Holmes [13]* made detailed calculations of production from animals fed on the produce of 1 hectare of land, assuming average yields of 4 t/ha of barley, 6 t/ha of grass dry matter for sheep, and 7 t/ha for dairy cows.

Table 7. The efficiencies of feed given to breeding populations and the edible energy and protein to be obtained from these animals fed on the produce of 1 hectare of land[1]

	Annual production kg/ha		Edible protein		Edible energy			Grammes of protein per MJ of ME eaten
	Carcass	Eggs	% of crude protein eaten	Yield kg/ha	% of energy[2] eaten		Yield MJ/ha	
					ME	GE		
Eggs	85	1250	22	138	19	12	8900	2.9
Broiler	1225	—	17	137	14	10	7500	2.6
Bacon								
12 piglets/year	745	—	14	80	16	11	7700	1.7
24 piglets/year	900	—	18	98	19	13	9300	2.0
Sheep								
1.4 lambs/year	268	—	4.0	32	6	3	3500	0.5
2.8 lambs/year	423	—	6.2	50	9	5	5500	0.9
Suckler cow								
0.9 calves/year	255	—	4.4	35	5	3	2800	0.6
1.8 calves/year	365	—	7.4	50	7	4	4100	0.9
Milk	Carcass	Milk						
with low concentrates	60	3940	19	138	20	11	11500	2.4
with high concentrates	52	4100	20	142	21	12	11790	2.5
with high concentrates plus veal[3]	100	3900	20	144	20	12	11500	2.5
with cereal beef[3]	135	3100	18	120	18	10	9700	2.2

[1] These data were published by *Holmes [13]*
[2] ME = metabolisable energy, GE = gross energy
[3] Using surplus calves that were not needed for replacements

Table 7 gives some of these results. Milk and egg production give the most protein per hectare, and milk the most energy. However, such conclusions are over-simplified. Although beef cattle and sheep produce much less, they can use poor grass or live on land that would not otherwise be in agriculture; also ruminants use fibrous foods and non-protein nitrogen. In practice, British cattle get 20–40 per cent of their metabolisable energy from concentrates; sheep get only 6 per cent of their energy from concentrates and *Holmes* describes them as the only true grassland animals.

6. The efficiency of nutrients and energy in production systems in developing countries

The countries classified by *FAO [9]* as 'developing' have only about 60 per cent as much protein available to their people as have the countries classed as 'developed'; some data are given in Table 8. While over half of the protein in developed countries is of animal origin, less than a quarter of the smaller total in developing countries is from animal sources.

Table 8. Amounts of protein available to people in regions of the world* in 1975–1977

	Total	Vegetable sources	Animal sources
	grammes of protein available per head per day		
World	69	45	24
Africa	59	47	12
North-Central America	93	36	56
South America	66	37	29
Asia	58	46	12
Europe	96	43	53
Oceania	96	33	62
All developed countries	98	43	55
All developing countries	58	45	12

* These data are from *FAO [9]*

6.1 Animal production in developing countries

These great differences in the animal food available to people in developed and developing countries are not due to a shortage of animals in the latter countries. As Table 9 shows developing countries have twice as many cattle and buffaloes and more pigs, sheep, goats and chickens. But the Table also shows that meat production from cattle and buffaloes is twice as great in the developed countries (from half as many animals). Indigenous pigmeat production is 65% greater in developed countries; only with sheep and goat meat do the developing countries produce a little more (from nearly twice as many animals). Annual milk production is shown in Table 9. *FAO [9]* data show that a few countries average more than 5000 kg of milk per cow annually; the three highest figures are Israel (6733 kg), USA (5386 kg) and Sweden (5281 kg). The differences between milk yields in developed and developing countries are large – nearly five times as much milk comes from each cow in the developed countries. The 'best

Table 9. Numbers of livestock and the production of meat, milk and eggs in developed and developing countries in 1980*

	All developed countries	All developing countries
Number of livestock, millions		
Cattle	425	791
Buffaloes	0.8	131
Pigs	339	459
Sheep	527	593
Goats	24	435
Chickens	3030	3363
Production of meat, millions of tonnes		
Beef and buffalo	31.3	15.4
Sheep and goat	3.6	4.1
Pig meat	33.7	21.4
Poultry meat	20.2	9.0
Milk production		
No. of cows, millions	114	108
Yield of milk, kg/year/cow	3127	657
Milk produced, millions of tonnes	357	71
Hens' eggs produced, millions of tonnes	17774	9683

* These data were published by *FAO [9]*

country' average (in Israel) is 3½ times the world average milk yield, is over twice the average in developed countries and is ten times greater than average production in the developing countries. This situation is parallel to that disclosed by *FAO [9]* figures for crop yields in regions of the world, but the differences in milk production are much larger than corresponding differences in crop yields.

6.2 The need for improvement

There are several causes of the low productivity outlined in the previous section: (a) Reproduction rates, measured by young animals produced per female per year, are low. (b) Rates of growth, expressed as months to maturity, or months to first offspring, are generally low and the rates of growth through this period are erratic. (c) Gains per unit of food consumed are low because the quality of the food is poor. (d) Production of milk is small per unit of energy or protein consumed because the feed provides only a small margin over the requirements for maintenance. (e) There are few offspring to benefit from the energy and protein intake. This leads to the conclusion that, judged by the effective use of energy and protein resources, intensive methods will give by far the higher returns. These can, initially at least, be applied to only a proportion of the livestock. Improvement of the condition of the majority of the animal population must result from work to improve local grasslands and forage crops and the use of wastes from arable crops grown for human food.

As people in developing countries become more prosperous many will demand increased food from animal sources. Better quality protein to benefit children will be supplied economically by milk (with meat as by-product) and by eggs and poultry meat. Poultry and pigs farmed intensively require cereals and other foods that can be eaten by man; intensive milk production often requires cereals and oil-seed residues.

These diversions of human foods to animals are only justified if production systems are efficient. In practice all *intensive* animal production in developing areas is likely to involve confined and hand-reared stock.
However, we must remember that the developing countries already have large populations of livestock, most of which are producing little human food. The justification for retaining these livestock, and endeavouring to increase their productivity, is that there are large areas in all climatic regions that are suited only to producing animal food from pastures because, if cultivated, the soils quickly erode, or because physical characters of the land preclude cultivation altogether. The productivity of the pastures on these areas should be improved by liming and seeding where necessary, by fertilizing, and by improved management. The basic problems are to improve the health and nutrition of the existing livestock. A *reduction* in numbers of animals per unit area should be considered. This would provide a more generous allocation of existing supplies of feed to each animal, leading to a greatly increased output of animal products, and to a consequent rise in the efficiency of feed conversion. Besides these scientific problems of converting plant and animal nutrients into human food, it will be necessary to consider how to overcome constraints on the use of animal products that are set at present in some areas by uncontrolled factors such as availability of the foods, custom, prejudice and religion.

6.3 The provision of protein

Animal products have an important role in supplying high-quality protein. Although the efficiency of conversion of energy in food must always be the major consideration, since protein is the important component lacking in many diets, it is worth giving up some energy to produce animal protein, provided that it is done with reasonably high efficiency.

6.3.1 The production of milk

Under many conditions in developing countries protein is the most valuable nutrient in milk. We have also shown earlier that the most efficient production of protein, and of energy, that can be obtained from ruminants, is provided by the dairy cow. Very considerable problems will have to be overcome in the improvement of pastures, and in the management and feeding of the stock that consume them, to achieve the potential that these animals have. Much greater use of grasslands can be achieved if it is feasible to produce milk throughout the growing season. Where the growing periods are short the greater use has to be made of preserved forages and supplementary concentrates for the cattle. In addition the production of milk products (dried milk, cheese and butter) for human consumption throughout the year has also to be concentrated in this period.
Under many conditions it will be important to consider the efficiency with which either the total nutrient input, or the nutrient content of the supplementary feeds, are converted into milk. The return for a whole year is the important criterion, though production of milk will vary in volume according to the range of inputs at different seasons. With all breeds, but especially with the specialist dairy breeds, losses of body weight will be severe at the lower levels of nutrient intake. In the short term the

efficiency of conversion of, for example, dietary energy into milk energy may appear best in conditions of underfeeding. This, however, would be a misleading indicator for policy decisions for at least two reasons. Firstly, on a lifetime basis, underfeeding will result in little output to set against the total cost of maintenance during long rearing and non-productive periods. Secondly, it is well established that underfeeding with energy during lactation results not only in reduced milk yields, but also in a reduction in protein content of the milk.

7. General discussion

Large amounts of plant nutrients are needed to grow the yields of herbage and arable crops required for intensive farming systems. It is difficult to ensure high efficiency in the use of these nutrients when they are applied as fertilizers. However, the problems in securing high efficiency in the use of the plant products as nutrients for farm animals are even greater. The results of research and development give us the ability to make reliable *quantitative* predictions of the likely result of any change in production systems. It must be stressed that this ability to make accurate predictions is essential for making sound policy decisions at all management levels, from an individual farm, to a country. The few examples that we have been able to give will illustrate the extreme complexity of the factors influencing the efficiency with which nutrients derived from plants are converted into animal products. Accurate predictions of the efficiency of any one production system will require considerable research on the particular partial efficiencies of the components of the system and the use of sophisticated mathematical models. The emphasis must always be, firstly on the identification of constraints in production systems, and secondly on research to overcome them. It is very important to identify the hierarchy of limiting factors, to know their relative importance, and to estimate the effects of progressively removing constraints. From the ideal package of improved practices that will be proposed the governments and farmers concerned will have to chose those components that are practicable and which give the best economic returns.

The results of the many published calculations on the efficiencies with which farm animals convert their feed to human food depend on the assumptions made about the systems studied. There are wide ranges in the published values. The methods used are valuable as models for further investigations, but *Balch* and *Reid [4]* point out how vulnerable all estimates of efficiency are to incorrect assumptions used in the calculations. Correct decisions depend on actual experimentation with alternative systems: 'In the absence of adequate experimental evidence it is all too easy for an existing unimproved method to be compared with the best that can be obtained by sophisticated techniques under ideal conditions.'

It is essential to have physiological efficiencies determined from long-term experimentation so that the examination of economic circumstances can have a scientific basis. Nevertheless it must be emphasised that it would be naive to base final management decisions solely on these efficiencies; all factors must be considered. For example, the efficiency of beef cattle and sheep in converting crude protein to human food is low (Tables 5 and 7); however, such animals can subsist for much of their lives on food that is 'nutritionally unavailable, and in some cases physically inaccessible to other meat-producing animals' *(Balch* and *Reid [4])*.

It will be unwise to base policy decisions on crude approximations and gross generalisations about the overall efficiency of certain processes. For example, because the efficiency of conversion of dietary nitrogen into animal protein has been found to be low in a particular situation, it should not be assumed that this efficiency will be so low in some other situation that animal production has to be discouraged. A more enlightened approach will be to consider the value of animal products in terms of essential amino acids, readily available calcium, vitamin B_{12}, etc, in addition to the demand for a more varied and interesting diet. Any disincentives to more effective animal production, such as religious bars on the consumption of certain species, or social insistence on stock numbers as indices of wealth, irrespective of the condition of the animals, must be overcome by education.

In many situations a carefully planned, but limited supplementation of basic feeds will improve the output of animal product. In some areas large amounts of poor quality forages, or even byproducts, are available in forms that can be utilised only by ruminants, albeit with low efficiency because of the low digestibility of the materials. It is possible to calculate the benefits from supplying limited amounts of energy, protein, and/or certain minerals; these may markedly improve the output of product and may decrease generation time. In such circumstances it seems more appropriate to consider the efficiency of conversion of the supplementary nutrients into additional product than to be concerned with the overall conversion of the total nutrient intake.

8. The way ahead

In considering ways of improving efficiency it is necessary to differentiate between the situations in countries with well-developed agricultural economies and other countries. In developed economies, economic forces will continue to push agricultural methods towards increased economic efficiency. This may well differ from optimum biological efficiency expressed as efficiency of energy or protein utilisation. Nevertheless the information required from research workers in order to achieve that economic efficiency, will be largely biological. This information will take the form of data on the component factors in production processes, expressed in relationships that can be incorporated into mathematical models for predicting production response to given changes in input or management.

In less-developed countries, policies will have to be guided by less-precise data. Although the same biological factors will be involved, their relative importance will be very different, and giving different answers where there are enough data. The agriculturalist's, and biologist's, problem will be to determine what modifications to the prediction models will be required for use in developing countries.

9. References

1. *ARC* The nutrient requirements of ruminant livestock. Published for the Agricultural Research Council by Commonwealth Agricultural Bureaux, 1980
2. *Armstrong, D.G.* and *Brookes, I.M.:* Protein requirements of ruminants: The ARC proposals. In: Energy and protein requirements of ruminants. Proceedings of the Fourth Study Conference of the Scottish Agricultural Colleges, Perth, pp. 26–44, 1980

3. *Balch, C.C.* and *Campling, R.C.:* Regulation of voluntary food intake in ruminants. Nutr. Abstr. Rev. *37*, 669–686 (1962)
4. *Balch, C.C.* and *Reid, J.T.:* The efficiency of conversion of feed energy and protein into animal products. In: Food production and consumption: the efficiency of human food chains and nutrient cycles. Eds. *A.N. Duckham, J.W.G. Jones* and *E.H. Roberts*, pp. 171–198, North-Holland, Amsterdam: American Elsevier, New York, 1976
5. *Broster, W.H.:* The effect on milk yield of the cow of the level of feeding before calving. Dairy Sci. Abstr. *33*, 253–270 (1971)
6. *Broster, W.H.:* The effect on milk yield of the cow of the level of feeding during lactation. Dairy Sci. Abstr. *34*, 265–288 (1972)
7. *Cooke, G.W.:* Some priorities for British soil science. J. Soil Sci. *30:* 187–213 (1979)
8. *Cooke, G.W.:* Whither soil research? Annual Report of the Macaulay Institute for Soil Research for 1979, pp. 124–154 (1980)
9. *FAO:* Production Yearbooks for 1979 and 1980, Vols *33* and *34*. Food and Agriculture Organisation of the United Nations, Rome (1980, 1981)
10. *FAO:* The state of food and agriculture, volumes for 1970–1979. Food and Agriculture Organisation of the United Nations, Rome (1970–1979)
11. *Greenhalgh, J.F.D.:* A forward look at technical possibilities for grassland. In: Grassland in the British economy. CAS Paper No 10. Ed. *J.L. Jollans*, pp. 51–63, Centre for Agricultural Strategy, Reading University, Reading RG6 2AU, 1981
12. *Holmes, W.:* The use of nitrogen in the management of pasture for cattle. Herb. Abstr. *38*, 265–277 (1968)
13. *Holmes, W.:* Choosing between animals. Phil. Trans. Roy. Soc. Lond. *B281*, 121–137 (1977)
14. *Homes, W.:* Grass, the dairy cow and agricultural efficiency. Tenth Hannah Lecture. Annual Report of the Hannah Research Institute for 1980, pp. 65–75, 1980
15. *Holmes, W., Craven, J.* and *Kilkenny, J.B.:* Application on the farm. In: Grass, its production and utilization. Ed. *W. Holmes*, pp. 239–268, Blackwell Scientific Publications, Oxford, 1980
16. *INFIC:* International Network of Feed Information Centres. INFIC Publication No 1. International Feedstuffs Institute (IFI), Utah State University, Logan, Utah 84322, USA, 1978
17. *Jackson, M.V.* and *Williams, T.E.:* Response of grass swards to fertilizer nitrogen under cutting or grazing. J. agric. Sci. Camb. *92*, 549–562 (1979)
18. *MAFF:* Manual of nutrition. Ministry of Agriculture, Fisheries and Food. HMSO, London, 1978
19. *MAFF:* Energy allowances and feeding systems for ruminants. Ministry of Agriculture, Fisheries and Food. Technical Bulletin 33 (Reference book 433), HMSO, London, 1975
20. *Morrison, J., Jackson, M.V.* and *Sparrow, P.E.:* The response of perennial ryegrass to fertilizer nitrogen in relation to climate and soil. Technical Report No 27. Grassland Research Institute, Hurley, Maidenhead, 1980
21. *Reid, J.T.:* Speculations on future production of meat, milk and eggs. *In:* Proceedings 1970 Correl Nutrition Conference for Feed Manufacturers, Buffalo, New York, pp. 50–63, 1970
22. *Reid, J.T.:* Potentials for improving production efficiency of dairy and beef cattle. *In:* Economic and social impacts of improving agricultural production efficiency. Proceedings of Agricultural Research Institute *21*, 87–100. National Academy of Sciences, Washington (1973)
23. *Spedding, C.R.W., Walsingham, J.M.* and *Hoxey A.M.:* Biological efficiency in agriculture, pp. 355–369, Academic Press, London, 1981.
24. *White, D.J.:* Energy in agriculture. Proc. Fertil. Soc. Lond. *203*, 5–30 (1981)
25. *Widdowson, F.V., Penny, A.* and *Bird, E.:* Results from the Rothamsted Reference Experiment. II. Yields of the crops and recoveries of N, P and K from manures and soil, 1971–1975. Report of Rothamsted Experimental Station for 1979, Part 2, pp. 63–75, 1980
26. *Wilson, P.N.:* The biological efficiency of protein production by animal production enterprises. In: The biological efficiency of protein production. Ed. *J.G.W. Jones*, pp. 201–209. Cambridge University Press, London, 1973

The Importance of the Chemical Composition of Forage for Optimizing Animal Production

A. Kemp, Centre for Agrobiological Research, Wageningen, The Netherlands

Summary

Increasing grassland production changes the chemical composition of the forage. The importance of the chemical composition for optimizing animal production is generally accepted. The wide range in concentrations of chemical constituents in the forage is not always such as to allow ruminants to convert it efficiently into animal products which are acceptable for human consumption.
This paper deals with some aspects of:
- Optimizing forage production and alterations in chemical composition.
- Chemical composition of forage in relation to animal production.

1. Introduction

Forage production involves the conversion of environmental inputs such as light energy, CO_2, water and soil nutrients to provide digestible energy and other nutrients for ruminant livestock. Crop growers try to improve this conversion in relation to seasonal inputs or constraints, the efficiency of the crop in responding to these factors and how far these can be modified by growing systems to optimize forage production. Animal nutritionists consider the *physical constitution* and the *chemical composition* of the harvested material in relation to *animal requirements*. Scientific standards for feed evaluation are used in practice to optimize animal production.
It is estimated that forages provide more than 90% of the feed energy consumed by herbivorous livestock. So, forages can make an important contribution to *world food supplies* in the future by providing greater amounts of meat and dairy products. An important part of the total forage production is produced on *grassland* and a high percentage of the grass production is utilized by grazing milking cows and beef cattle. In many countries grassland production has increased considerably. In the Netherlands for instance, during the last 30 years the use of nitrogenous fertilizer has increased from 50 to 250 kg N per ha of grassland per year, resulting in an *increase in grass production* of over 40%. This change in forage production led to a considerable change in concentrations of chemical constituents in the forage.

* Ing. *A. Kemp*, Centre for Agrobiological Research, P.O. Box 14, NL-6700 AA Wageningen/ The Netherlands

hand, NO_3^--contents occur which are so high that nitrogen uptake no longer leads to an increase in the dry matter production, but only to undesired nitrate accumulation in the crop.

The literature on nitrate uptake and *nitrate accumulation* by plants is very comprehensive, though specialists in this subject state that the overall picture is not yet clear. In this paper we give only a rough indication of *some important principles.*

Nitrate taken up by the plant, is reduced to *nitrite* and *ammonia*, and is then converted to protein mainly in the above ground plant parts. The rate of photosynthesis is important in this. Under normal conditions the reduction is so rapid that nitrite and ammonia do not accumulate. *Nitrate accumulation* thus implies that the rate of

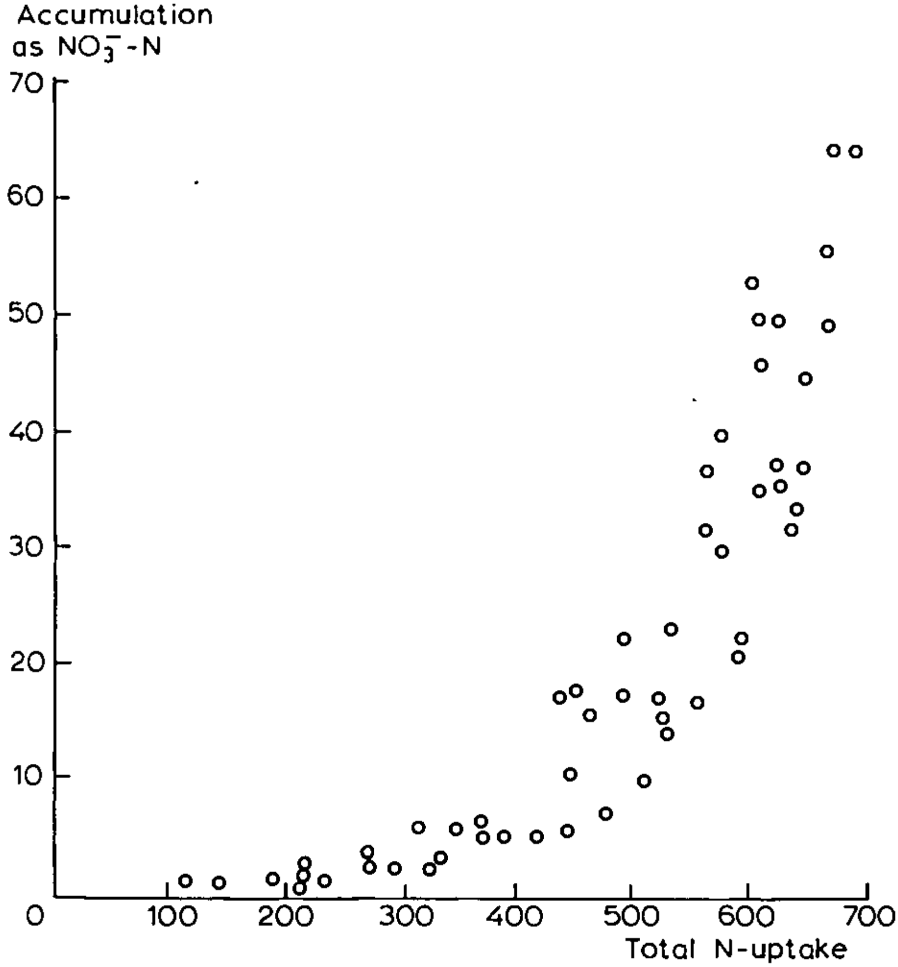

Fig. 2. Relationship between the total nitrogen uptake by grass and the part of this accumulated as nitrate-nitrogen (kg/ha per year).

assimilation has not kept pace with the rate of uptake. Applying more nitrogen than required for optimum plant production may lead to undesirable nitrate accumulation. Accumulation may also occur with an adequate supply of nitrate, if *growth* is retarded, *e.g.* by shortage of water, light or nutrients other than nitrogen. Nitrate uptake may also exceed reduction in the plant with an insufficient supply of *trace elements* necessary for the reduction process or by treating the grass with herbicides. For more information readers are referred to *Wright* and *Davison [22]*.

As to the influence of trace elements, *molybdenum* is an essential element for nitrate reduction in the plant. So, a shortage of molybdenum may lead to accumulation of nitrate. However, nitrate accumulation may occur also with a sufficient supply of molybdenum but as a consequence of the inhibition of the *enzymatic reductase activity* by addition of *tungsten, Heimer et al. [7]*. It is interesting that molybdenum and tungsten also affect nitrate accumulation in ruminants according to the same mechanism *(Korzeniowski et al. [12, 13])*. According to the literature, the *accumulation* of nitrate is determined to a great extent by the amount of *nitrate absorbed* by the roots. This is illustrated very clearly in Figure 2, which shows the relationship between the total nitrogen uptake by grass and the part of this accumulated as nitrate-nitrogen.

The *accumulation of nitrate* increases distinctly with *increasing uptake of total nitrogen.* This increase is not rectilinear and nitrate accumulation occurs especially at total N-uptakes of over 400 kg of nitrogen per ha per year. The scatter is partly due to differences in moisture content of the soil, temperature, light intensity, state of growth, etc. Below a level of total N-uptake of 400 kg, about 5 kg nitrogen or less is accumulated as nitrate, being about 1% or less. The highest accumulation may be about 10% of the total N-uptake.

It is worthwhile to consider these results in relation to the total N-uptake required for optimization of grass production. It appears from Figure 1 that about 400 kg of nitrogen per ha per year is necessary for optimum grass yield. Several experiments have shown that at annual applications of 400–450 kg of nitrogen about the same amount of nitrogen is taken up by the grass. As nitrate accumulation begins to increase sharply at levels from 400–500 kg uptake (Figure 2), it can be concluded that nitrate accumulation occurs mainly after excessive nitrogen dressings. The relationship shown in Figure 2 also illustrates clearly that it is important to bring the *nitrogen dressings* as much as possible *into agreement with the requirement* for optimal growth, to prevent severe nitrate accumulation.

2.3 Macro elements

Although potassium, sodium, calcium, magnesium, chlorine, phosphorus and sulphur are all essential for plant and animal production, in this paper attention will only be paid to the elements which are *not always sufficient* in the forage to meet the animals requirements, *viz. magnesium* and *sodium*. This will be done very briefly because little new information has become available recently.

On sandy soils, the sodium and the potassium *status of the soil* have a great effect on the sodium content of grass. The more potassium in relation to sodium, the lower the sodium concentration in the forage, although differences in *potassium* and *nitrogen dressings* and the *botanical composition* of the sward may cause great variations. As far as magnesium is concerned, the magnesium content of the soil does not reliably predict the magnesium content of the grass. Only magnesium contents of sandy soils lower than 50 mg per kg dry soil appear to result in lower magnesium concentrations in the grass. The greater part of the variation of the sodium and magnesium contents of herbage is explained by differences in magnesium, sodium, potassium and nitrogen dressings and by changes in the botanical composition of the sward. Heavy fertilization with potassium decreases the sodium and magnesium contents of the herbage. On the other hand, nitrogen dressings increase both sodium and magnesium more or less depending on the potassium and sodium status of the soil and the potassium dressings. The more potassium is available to the plant, the higher the increase of potassium and the lower the increase of sodium by nitrogen fertilization. Improvement of grassland production by means of nitrogen dressings and good management leads to a sward mainly consisting of grasses, little clover and herbs which contain more sodium and magnesium.

It follows from the above that the sodium and the magnesium *contents of the herbage* give more reliable information on the sodium and magnesium supply of the animals than *soil testing*.

2.4 Trace elements

Trace elements can be divided into three groups: the *essentials*, the *possibly essentials* and the *non-essentials*. According to *Underwood [20]* at the present time 10 trace elements are known to be essential for the higher animals, *viz. iron, iodine, copper, zinc, manganese, cobalt, molybdenum, selenium, chromium* and *tin*. However, in studies on interrelationships between chemical composition of forage and animal production more aspects than essentiality alone may be of importance, *viz. toxicity aspects* and the *transmission* of elements from the feed into *animal products* consumed by human beings. In the scope of this paper, only a few illustrations will be given briefly, in which variation in trace element contents in the forage may affect animal production. These will refer to copper, cadmium and lead: copper being an essential element, cadmium possible essential and lead a non-essential constituent.

Although the uptake of trace elements by plants is influenced by *type of soil, acidity of the soil, fertilizer treatment*, etc., there are important differences in uptake between the elements. This is shown in Table 1 *(Hemkes*, unpublished data). On permanent grassland, treated with 0 (S_0), 6000 (S_1), 12,000 (S_2) and 18,000 (S_3) kg dry matter of sewage sludge per ha, the increase of cadmium in the grass is much more pronounced than that of copper, while copper was accumulated more easily than lead. This sequence in uptake and the small increase in lead was also demonstrated by other workers.

Differences in the accumulation of these metals may also be caused by various amounts of nitrogen given as ammonium nitrate-limestone. Table 2 shows the accumulation of cadmium, copper and lead in grass of the S_1 plots treated in early spring and after each cutting with 0 (N_0), 30 (N_1), 60 (N_2) and 90 (N_3) kg of nitrogen per ha.

The sharp increase in the cadmium concentration in the grass is very striking as the contents on the heavily fertilized plots are more than twice as high as in the grass from the zero plots. There is only a small increase of the copper contents and the lead concentration did not change significantly.

Table 1. The influence of different applications of sewage sludge on the accumulation of cadmium, copper and lead in grass (mg/kg dm)

	S_0	S_1	S_2	S_3
Cadmium	0.1	0.8	1.5	1.7
Copper	5.8	9.3	11.6	12.9
Lead	2.5	3.1	3.4	4.0

Table 2. The influence of nitrogen dressings (0–90 kg/ha) on the uptake of cadmium, copper and lead by grass (mg/kg dm)

	N_0	N_1	N_2	N_3
Cadmium	0.5	0.7	1.0	1.2
Copper	8.9	9.2	10.2	10.5
Lead	3.1	2.9	3.1	3.1

Especially under grazing conditions, the grass may be contaminated more or less *with soil.* Because the concentration of trace elements in the soil is generally much higher than in the grass, the trace element content of the grass harvested may be much higher than the content of the grass. Contamination by air or water pollution may also be important. Moreover, the total intake of trace elements by grazing animals can be increased considerably by soil consumption. An example of the influence of contamination on the copper and lead contents of herbage from the experimental plots mentioned above, is given in Figure 3.

From May to February the copper contents of the grass did not change very much and remained within a normal range from about 8 to 12 mg/kg dm. However, there was a sharp rise in the lead concentration, which started at the end of the growing season.

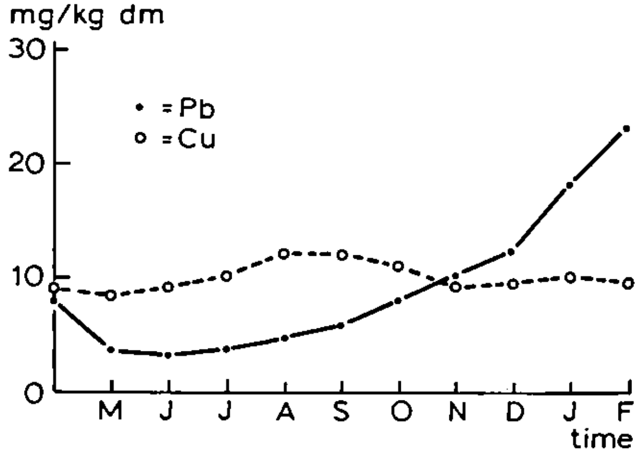

Fig. 3. Seasonal variation in the copper and lead content of grass.

In February the highest values of almost 25 mg/kg were observed. The cadmium concentration is not shown in Figure 3, but there was no significant increase during the winter. The explanation of the significant increase in lead content of the grass during late autumn and winter has probably to do with the influence of *air pollution.* Contamination of the grass by soil can be excluded because no differences were found in lead contents of the grass from the undressed and heavily dressed plots with sewage sludge. Moreover the copper and cadmium concentrations of the grass did not change. So, the most probable explanation for the higher lead concentrations in late autumn and winter is the contamination with lead by air. Supposing that the lead concentration in the air did not change much, it is understandable that the influence of this on the lead contents of the herbage is more pronounced *in late autumn* and *winter* than during the growing season, because in wintertime the herbage is relatively old and therefore contaminated for a longer period. Figure 3 illustrates clearly, that the intake of lead by grazing animals may be much higher in wintertime than during periods when herbage is growing more rapidly.

3. Chemical composition of forage in relation to animal production

In the foregoing some illustrations were given of factors affecting the *chemical composition* of forage which results in a great variation in the concentration of chemical constituents. This chemical composition is not always in agreement with the *animals requirement* necessary for optimizing animal production. *Deficiencies* as well as *excesses* may have a *harmful effect.*

At the beginning of this century, *Bertrand [2]* developed a rule which stated that every essential element has a whole spectrum of actions, depending on the dose and the nutritional state of the animal in respect to the element in question. *Mertz [16]* discussed *Bertrands rule* in a paper on essential trace elements and illustrated it as shown in Figure 4.

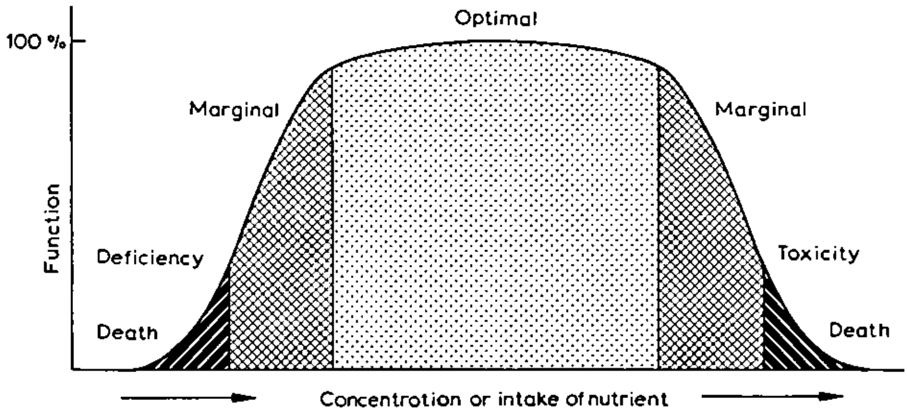

Fig.4. Dependence of biological function on tissue concentration or intake of a nutrient *(Bertrand [2], Mertz [16]).*

Bertrand's rule states that a function for which a nutrient is essential, is very low or absent in a theoretical, *absolute deficiency*, and increases with increasing exposure to the essential nutrient. This increase is followed by a plateau representing the maintenance of *optimal function* through homeostatic regulation, and a decline of the function toward zero as the regulatory mechanisms are overcome by increasing concentrations that become *toxic*, *Mertz [16]*. The principle of Bertrand's model is probably applicable to all essential nutrients. Each essential nutrient has its own specific curve which differs from that of other nutrients, for example by the extent of the plateau. The requirements of copper for example and the amounts which are potentially toxic are very close to each other. On the other hand the toxic levels of zinc are very much higher than the concentrations in the ration which are sufficient to meet the animals requirement. In the interpretation of the relationship between the concentration or intake of a nutrient and the biological function (Figure 4), it must be taken into account that the absorption of a certain element may depend on the presence of other constituents. This is very striking for copper, because molybdenum and sulphur are so important for the absorption of copper that a particular level of intake of this element can lead to signs either of copper deficiency or of copper toxicity in the animal *(Underwood [20]*. Chemical criteria for evaluating forage for optimizing animal production have long been used. *Standards* on the *requirements* of energy, protein, macro and trace elements are used all over the world. Considering the chemical composition of forage in relation to the animals requirement, two aspects are important, *viz.* the *concentration* of the nutrients in the forage and the *amount of dry matter* which is consumed by the animal. However, little information is available on the factors affecting the dry matter intake. Up to now, it has not been possible to estimate the dry matter intake based on chemical criteria in the forage. Consequently, the nutritive value of forage is expressed in terms of the concentration of nutrients in the forage and does not give predictions on the dry matter intake.

In this chapter, the importance of the chemical composition of forage will be illustrated by giving some examples of the following topics:

1. The animals *requirement* for maintenance and production in relation to the chemical composition of the ration.
2. The susceptibility to *deficiencies* and excesses which may result in depressed growth or milk production and in disease symptoms.
3. The *accumulation* of constituents in animal products which might be harmful to human beings.

3.1 The energy and protein supply of milking cows during grazing

Not only the dry matter production, but especially the crude protein yield of grassland is considerably increased by the use of more nitrogen. To meet the energy requirement of milking cows as far as possible with pasture grass, it is necessary to have always sufficient young and energy rich herbage available. Chemical criteria are used *to predict* the *digestibility* of the organic matter of forages. The development of in vitro techniques to estimate the so called '*in vitro* digestibility' of organic matter, improved this way of determining nutritive value considerably *(Tilley* and *Terry [19])*.

In high producing milking cows under grazing conditions, the daily intake of fresh grass must be very high to meet the energy requirement because the dry matter content of the grass is low. Because the digestibility of the organic matter decreases as the herbage grows older, the herbage must be grazed in a *young stage of growth*. As more nitrogen fertilizer is applied, the ratio between digestible organic matter and digestible crude protein changes, resulting in *more protein* in relation to organic matter. Comparing these alterations in chemical composition of the herbage with the protein requirement of high yielding cows, Figure 5 gives an illustration of the differences between the protein requirement and the estimated daily intake of crude protein at various nitrogen doses and at milk yields of 4000 and 6000 kg/lactation period (*Kemp et al. [10]*).

When comparing the daily intakes of crude protein at the various nitrogen levels with the daily requirement of milking cows, it is found that throughout the grazing period the *crude protein* intake is much *in excess* of requirement. On the fields receiving much nitrogen the crude protein excess in spring and in autumn is about equal and amounts to roughly 1500 g per cow per day. With an average dose of 200 kg N per ha, the excess of crude protein will average some 1000 g per animal per day throughout the grazing season. These excesses are greater if the herbage is utilized by beef cattle because the protein requirement of these animals is lower.

There are two approaches to improve the ratio between energy and protein in herbage rations, *viz. the supply* of *supplementary* feed which is high in energy and low in protein and the *extraction of protein* from the grass by fractionation. The last approach opens the possibility to utilize the surplus of herbage protein produced in the grazing season more efficiently during the housing period, because in wintertime protein generally has to be bought to meet the animals demand. *Wieringa et al. [21]* found that fractionation of herbage offers the possibility to use at least a part of the excess protein

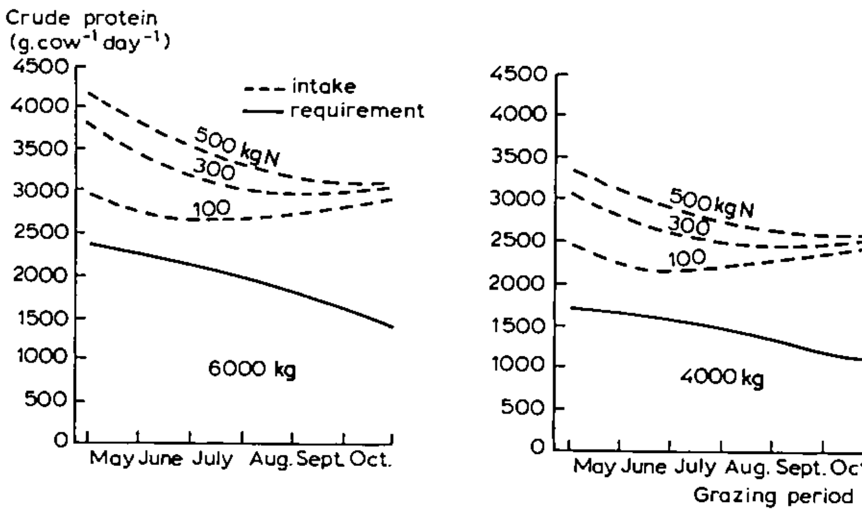

Fig. 5. Comparison of crude protein requirement with the crude protein supply for cows with different milk yields (6000 resp. 4000 kg/lactation period) and with various nitrogen applications to the pasture (100, 300, 500 kg N/ha).

as a food or feed component. *Pressed herbage*, fed to dairy cows, proved to result in *increased dry matter* intake and in *better performance*. However, more work has to be done to improve the fractionation machinery and the preservation of the protein. The increased dry matter intake and a better animal performance by feeding pressed grass indoors goes hand in hand with the advantage of increasing the herbage output by up to 20% due to the absence of grazing losses. This also has to be taken into account when economic calculations about such a system of utilization are to be made.
Milk production per cow is still increasing and more supplementary feed has to be supplied to highly productive dairy cows during the grazing season. The energy supply is the limiting factor because the *intake capacity* of the grazing cow, especially under *wet conditions*, is not adequate. In the future it will become more and more important to develop grassland utilization systems focussed on an *increased dry matter intake* of forage.

3.2 Nitrate in the plant, the animal and in animal products

As shown in Figure 2 up to 10% of the total nitrogen content of herbage may consist of nitrate nitrogen. During the last 10 years detailed observations have become available on the relationship between the *nitrate intake* and the incidence of *nitrate toxicity* in cattle.
The intake of nitrate rich forage by ruminants results in *nitrite* formation in the rumen, due to the activity of nitrate reducing microbes. The nitrite is partly absorbed into the blood leading to the conversion of hemoglobin into *methaemoglobin* which is incapable of oxygen transport *(Gamgee [4])*. Moreover nitrite in the blood results in lowered blood pressure *(Ashbury* and *Rhode [1])*. *Malestein et al. [14]* found that the supply of nitrite to cows *in partu* caused a drop in maternal blood pressure, whereas heart rate and respiration rate increased. The oxygen capacity of the blood decreased and the oxygen supply to the foetus was adversely affected after nitrate intake by pregnant cows. When the oxygen transfer to the foetal blood decreases too sharply, intra-uterine death and abortion may result. *Van Broekhoven* and *Stephany [3]* found that in ruminants which had consumed nitrate, the *nitrosamine concentration* in the rumen fluid increased at the same rate as the nitrite concentration increased though on a much lower level. In normal cows 2–3% of the hemoglobin is converted into methaemoglobin. Symptoms of nitrate poisoning occur when 50% or more of the hemoglobin has been converted into methaemoglobin. According to *Wright* and *Davison [22]* the first cases of nitrate poisoning in practice were reported in 1895 by *Mayo [15]* who established nitrate poisoning in cattle in Kansas, USA, following the feeding of corn stalks (corn stalk poisoning). Nowadays, it occurs regularly, in many countries. In the Netherlands nitrate poisoning in bovines occurred regularly after feeding turnips and rape. Recently there have been many cases after feeding hay or pre-wilted silage from leys heavily dressed with slurry and nitrogen fertilizer. Sometimes nitrate contents of over 6.0% NO_3^- in the dry matter are found in the rations.
In order to obtain more information about the relationship between *nitrate intake* and the formation of methaemoglobin in the blood and, hence, on the acceptable doses of nitrate which can be supplied without risk, the results of over 40 feeding trials are summarized in Figure 6. The experiments were carried out with dry or lactating Friesian cows and the rations consisted of hay which was always consumed within

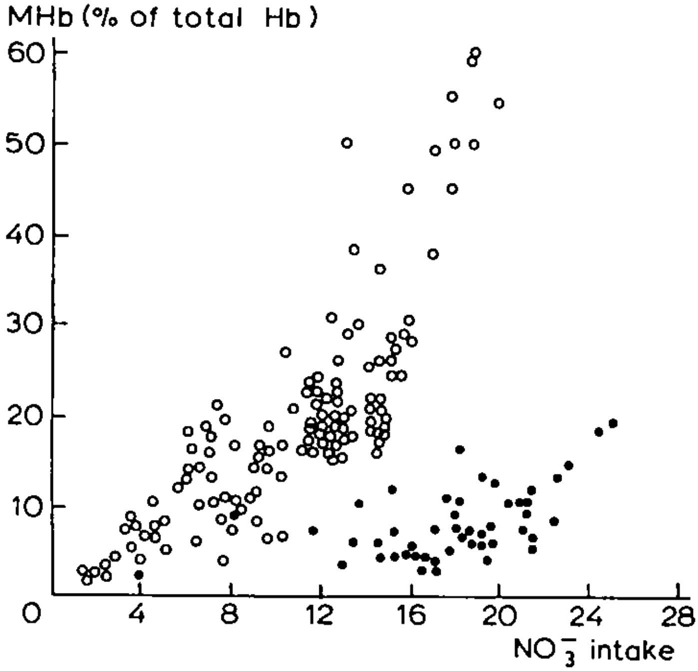

Fig.6. Relation between nitrate intake with hay (o) and with freshly mown herbage (•), (grammes NO_3^- per 100 kg bodyweight per meal) and the formation of methaemoglobin (% of Hb) in cows.

one hour, turnips or freshly mown grass, upon which the cows were allowed to feed up to two hours per meal. The cows were fed twice a day. The nitrate contents in the forage ranged from below 0.50 to over 6.0% NO_3^- in the dry matter *(Kemp et al. [9])*. In a system of feeding hay or prewilted silage twice daily the methaemoglobin values remain at a normal level, if no more than 3 g of NO_3^- per 100 kg bodyweight per meal are supplied. To be on the safe side of the methaemoglobin values being on a normal level again at the next feeding, the NO_3^- intake should be no more than 10 g per 100 kg bodyweight per meal. If 15 g of NO_3^- or more per 100 kg bodyweight per meal are consumed the risks of severe clinical symptoms and even death will rise rapidly. Figure 6 also shows that amounts of nitrate supplied in freshly mown grass cause much lower methaemoglobin values than those supplied in hay or prewilted silage. This is mainly due to the difference in *the rate of intake* of the nitrate containing hay and fresh herbage and to the difference in the rate at which the nitrate in the consumed feed *is released in the rumen* liquid *(Geurink et al. [5])*. On a dry matter basis hay and prewilted silage is consumed per kg dry matter much more rapidly than that from fresh herbage. Experiments have also shown that in the rumen fluid the nitrate is released more rapidly from the cells of the hay than from the more or less damaged cells of the fresh herbage. As a result the NO_3^- from fresh grass enters the rumen more gradually and so the formation and the absorption of NO_2^- takes place at a lower rate. To keep the methaemoglobin values in the blood within the normal range of 2–3%, a NO_3^--content of 0.75% in the dry matter of hay or prewilted silage may not be exceeded. In fresh herbage the *maximum acceptable* NO_3^--content is 1.50% in the dry matter. In herbage which is utilized by grazing, a NO_3^--content of 2.0% or somewhat higher can be accepted because the rate of dry matter intake under grazing is slower than that of freshly mown herbage fed indoors. When critical levels of nitrate in herbage are expected, it is safer to utilize this by grazing as hay or prewilted silage.

In 1932 *Seekles* and *Sjollema [17]* already pointed out that nitrate supply to milking cows increased the *nitrate* concentration in the *milk*. Data from our own experiments are summarised in Figure 7 *(Kemp et al. [9])*. There is a positive relation between the NO_3^- intake with the forage and the nitrate concentration in the milk produced within 12 hours after feeding. The nitrite concentration in the milk, not mentioned here, had also increased, but to a much lower level. At high NO_3^- intakes, nitrate concentrations in the milk may rise to about 1 mMol per litre.

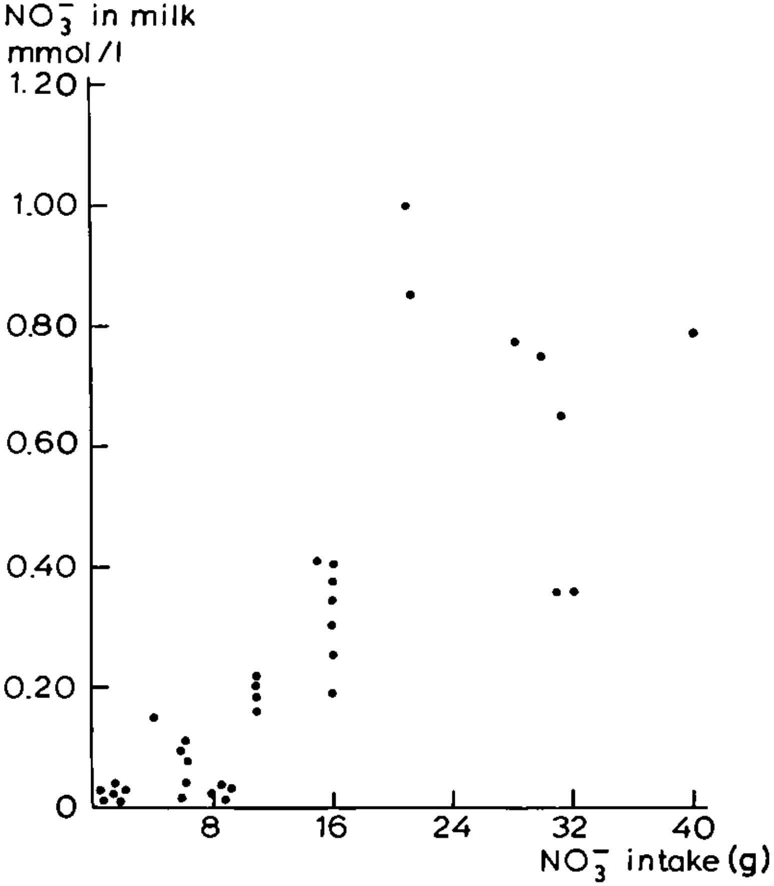

Fig. 7. Relation between nitrate intake (grammes NO_3^- per 100 kg bodyweight per meal) and the nitrate concentrations in the milk produced within the first twelve hours after feeding.

3.3 Prevention of nitrate poisoning

In the Netherlands very high NO_3^--contents in the herbage occur mainly after excessive applications of nitrogenous fertilizers and slurry. However, Table 3 shows clearly that also at N rates of 400 kg per ha per year which generally result in maximum grass production, 17% of the samples showed critical levels of nitrate, *viz.* higher than 0.75% NO_3^- in the dry matter. Table 3 summarizes the NO_3^--contents of almost 5000 herbage samples from 24 experimental fields on permanent grassland with different nitrogen applications over 8 years *(van Steenbergen*, pers. comm.).

Table 3. Influence of nitrogen dressings on the nitrate content of herbage *(v. Steenbergen* pers. comm.)

N rate kg/ha	Number of samples	Percentage of samples with NO_3^- content		
		<0.75	0.75–150.	> 1.50
0	732	100	–	–
100	818	100	–	–
200	878	99	1	–
300	867	95	5	–
400	879	83	16	1
500	799	60	33	7

At a level of 400 kg N per ha per year the number of samples with nitrate contents exceeding 1.50% is negligible. Summarizing the data shown in Table 3, it can be concluded that nitrate poisoning in cattle can be already prevented to a great extent by giving *nitrogen applications* which do *not exceed* the amount necessary for *maximum production*. However, in a number of cases the nitrate content will be to high if the herbage is fed in the form of hay or prewilted silage.

Since both the nitrogen requirement of a crop and the nitrogen supply from the soil are difficult to predict, a fertilizer regime directed at maximum grass production will regularly cause increased methaemoglobin values or clinical toxicity symptoms. In these cases, prevention may be directed to adapting the feeding system and in this the amount of nitrate consumed, the rate of nitrate intake and the rate of release of nitrate from the forage into the rumen fluid play important parts.

Figures 8 and 9 show the *amount* of hay, prewilted silage and freshly mown herbage respectively, that may safely be supplied per meal based on the relationship between nitrate intake and the formation of methaemoglobin in the blood *(Geurink et al. [6])*. The figures have been divided into three parts: a nitrate intake level at which poisoning symptoms do not occur; a nitrate intake level at which slight to clear clinical symptoms occur; and a nitrate intake at which severe symptoms may occur and usually lead to death. To maintain a normal methaemoglobin content in the blood while feeding hay or prewilted silage containing 5% NO_3^- in the dry matter (Figure 8), no more than 0.06 kg dry matter per 100 kg bodyweight may be supplied per meal (3 g NO_3^- intake per 100 kg bodyweight). Feeding 0.2 kg dry matter per 100 kg bodyweight of the same forage would result in about 20% methaemoglobin in the blood. An intake of 0.3 kg will lead to a methaemoglobin level of about 50% and usually to severe clinical symptoms. When the nitrate content is 0.75% in the dry matter, a maximum of 0.66 kg dry

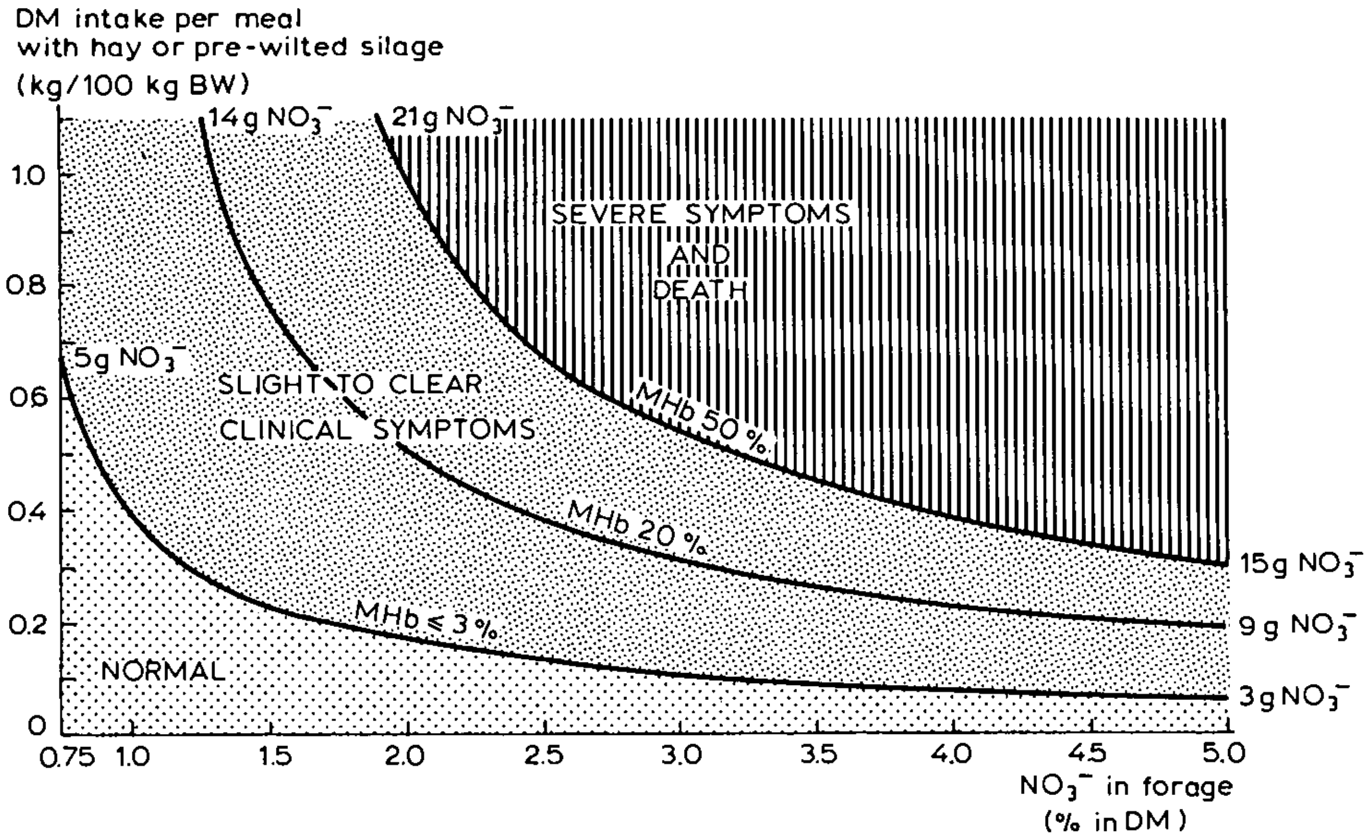

Fig. 8. The nitrate content (x-axis) and the dry matter intake (y-axis) of preserved grass in relation to the formation of methaemoglobin in cows.

matter per 100 kg bodyweight may be consumed per meal and still maintain a normal methaemoglobin content (intake of 5 g NO_3^- per 100 kg body weight). About 60 min. will be required for that amount of intake. Under these conditions the nitrate intake rate and the formation of methaemoglobin is so slow that it is in equilibrium with the

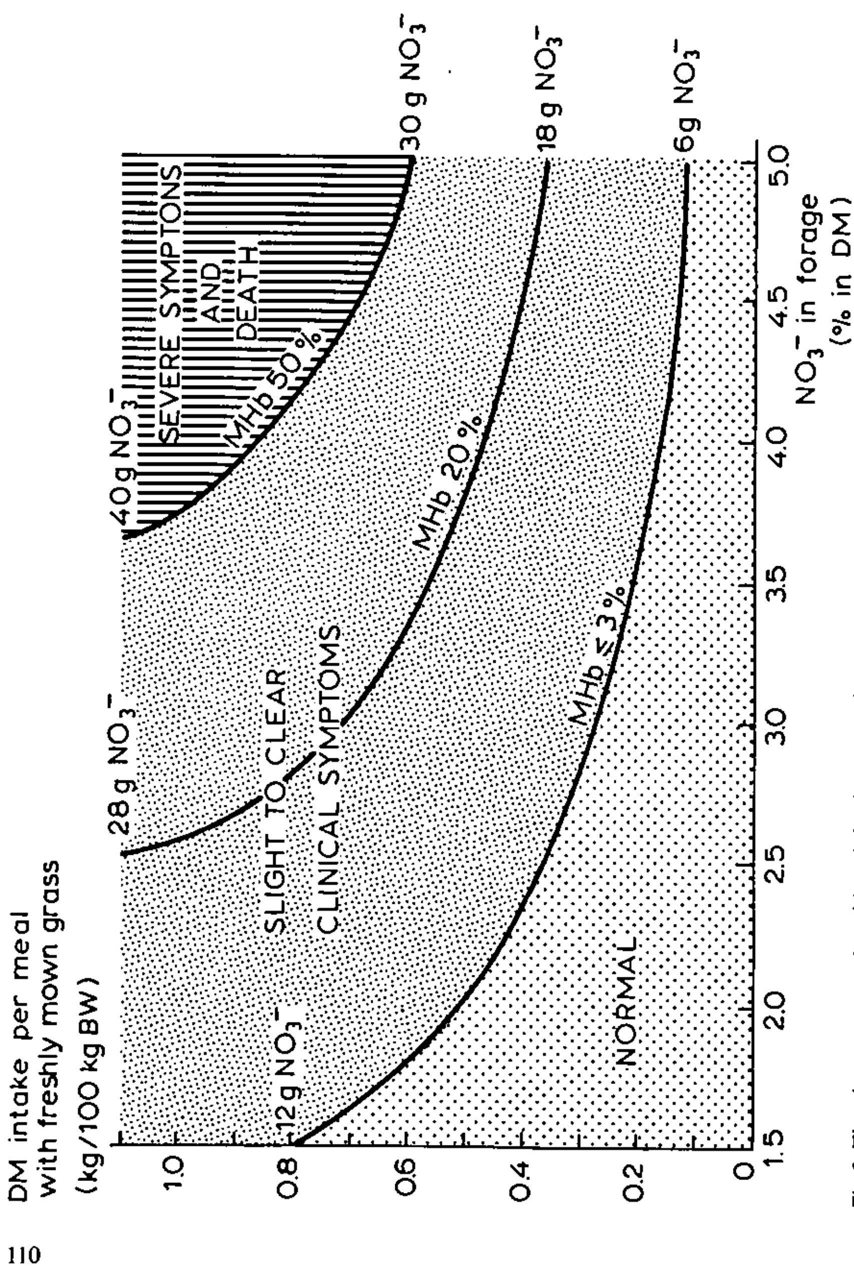

Fig. 9. The nitrate content (x-axis) and the dry matter intake (y-axis) of freshly mown herbage in relation to the formation of methaemoglobin in cows.

reduction. Therefore hay and prewilted silage with a nitrate content up to 0.75% may be supplied *ad lib* without increasing methaemoglobin in the blood. A meal of forage containing more than 0.75% NO_3^- in the dry matter can be fed no more than every 60 min. The amount per feeding can be determined from Figur 8.
The maximum acceptable amounts of nitrate in freshly mown herbage are given in Figure 9 in the same way. With this forage containing 1.50% NO_3^- in the dry matter, a normal methaemoglobin content in the blood is maintained if no more than 0.8 kg dry matter per 100 kg bodyweight is supplied per meal (intake of 12 g NO_3^- per 100 kg bodyweight). For this amount of intake about 2 hours will be required.
Another very interesting approach in preventing nitrate poisoning in cattle is focussed on the prevention of the formation of *nitrite* accumulation in the *rumen* by inhibition of the enzymatic activity of nitrate reductase. *Molybdenum* is known to be indispensable for the action of this enzyme. Recently, *Korzeniowski et al. [12, 13]* demonstrated both *in vitro* and *in vivo*, that the addition of sodium tungstate to a nitrate rich forage can considerably inhibit nitrate reductase activity in the rumen resulting in considerably less nitrite formation. However, for practical application of tungstate as a prophylactic against nitrate poisoning, all potential hazards concerning possible dangers to the animal, to the consumer of animal products and to the environment should be carefully considered.

3.4 Macro elements

3.4.1 Magnesium:

For many intensive high producing grassland systems the *magnesium supply* is insufficient to meet the requirement of dairy cows. Even in wintertime, when the rations consist mainly of home grown forage, attention has to be given to the magnesium supply. A shortage of available feed magnesium leads to the occurrence of *hypomagnesaemia* and hypomagnesaemic tetany *(grass tetany)*. Detailed experimental observations led to conclusive evidence that a *low magnesium intake* and *low availability* of the feed magnesium are the main factors in causing hypomagnesaemia. In contrast with calcium, phosphorus and sodium, adult animals cannot mobilize body magnesium to prevent a fall in the blood levels in cases of a dietary shortage. Therefore, hypomagnesaemia and tetany can be induced within a few days in contrast with deficiency symptoms caused by a shortage of calcium, phosphorus or sodium.
Figure 10 shows schematically summarized data of balance trials with over 60 cows fed on rations consisting of freshly mown herbage from permanent grassland with different fertilizer treatments and of hay and concentrates *(Kemp [11])*. The higher the intake of apparently available magnesium (Mg in feed minus Mg in faeces), the more magnesium is excreted in the urine, dependent on the level of milk production. A dry non-pregnant cow requires 2.5 g of available magnesium per day, to keep intake and excretion in balance (R_0= maintenance requirement). The excretion of magnesium in the urine in this case is 2.5 g/day, so retention is zero. For each 10 kg of milk 1.2 g of available magnesium have to be supplied to meet the requirement, R10, R20, etc. (R available magnesium = 2.5 + 0.12 M). Lower intake results in decreased excretion in the urine and negative retention. When urinary excretion is lower than 10 g/day

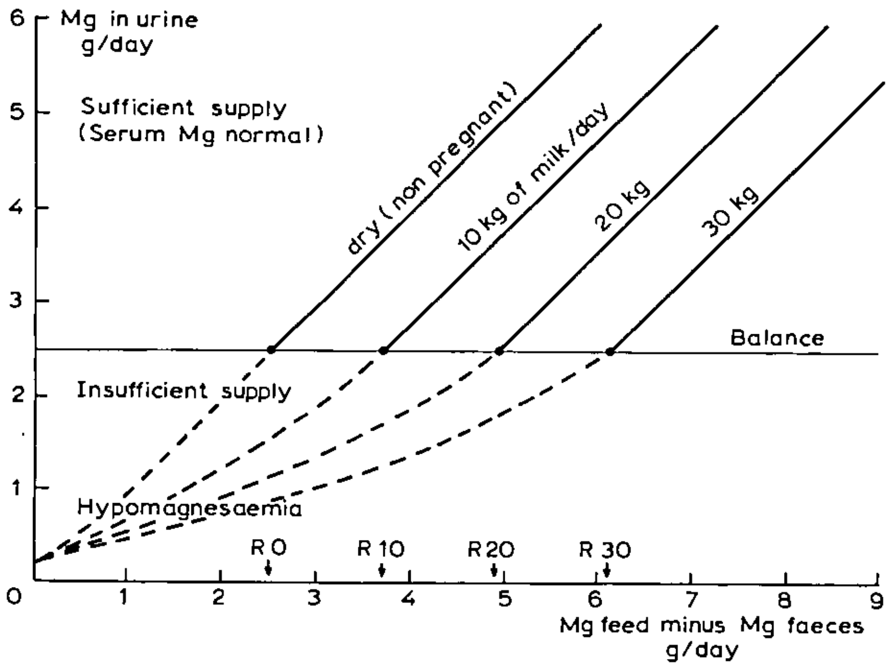

Fig. 10. Relationship between the intake of 'available' magnesium and the urinary excretion in milking cows on different levels of milk production.

hypomagnesaemia and tetany may occur. However, magnesium absorbed in excess of requirement is excreted in the urine proportionally and retention remains zero.
The relationship between magnesium intake on the one hand and *urinary excretion* and *serum magnesium values*, on the other hand, leads to the conclusion that urinary magnesium excretion is a better measure of *magnesium status* and *magnesium supply* of the animals than the blood serum magnesium concentration. For practical purposes, even the magnesium concentration in random samples of urine gives more information than serum magnesium levels. In the Netherlands the following *standards* for estimating the *magnesium supply* of cows are used:

Mg in urine (mg/l)	Mg supply
More than 100	Adequate to liberal
20–100	Inadequate
Less than 20	Severe deficiency, danger of tetany

It follows from the above, that all factors affecting dry matter intake, magnesium content of dry matter and magnesium availability (ranging from 5–35%) play a part in hypomagnesaemia and tetany. Therefore, fluctuations in botanical composition of the forage, climatic and soil conditions and fertilizer treatment may be important. This illustrates the complexity of the problem. The prevention of hypomagnesaemia and tetany have to be focussed on a sufficient supply of magnesium to meet the requirement for maintenance and production. On light sandy soils, it is possible to increase the magnesium content of the herbage considerably by means of magnesium dressings. However, during tetany prone periods, oral administration of extra magnesium is necessary to be safe.

3.4.2 Sodium:

The sodium content of herbage is not always sufficient to meet the requirement of milking cows. Supplying herbivores with additional salt is a very old custom in many areas. The sodium requirement for maintenance and production of an adult milking cow is 6.0 g of dietary sodium per day and 0.50 g per litre of milk. With a milk yield of 25 to 30 kg a day the sodium requirement is adequately met with a normal dry matter intake, when the sodium content in the ration is 0.15% (*Smith* and *Aines [18]*, *Kemp* and *Geurink [8]*).
However, in contrast with magnesium, ruminants always have ways of delaying the consequences of deficient supply. Immediately after cutting the *sodium supply*, excretion in the *urine* falls sharply. When daily excretion falls below 2.5 or 3 g, the balance turns negative total excretion being greater than dietary intake. Depletion of sodium from the body begins, manifested particularly as a fall in the sodium level in *saliva* and a corresponding rise in potassium. The composition of *rumen fluid* changes in like manner most of its sodium being derived from saliva (Figure 11) (*Kemp* and *Geurink [8]*). This sodium acts as a *mobile reserve* that can be drawn on in periods of deficient supply. This reserve allows even highly productive cows to be fed for several months on a sodium deficient diet without clinical signs. However, when this reserve is depleted the cow shows depressed appetite, produces less milk, loses weight, tends to lick objects and has a dry staring coat.

Because of this reaction to *deficiency*, long before clinical signs appear, the best criterion for assessment of *the sodium status* is the concentration of sodium and potassium in saliva:

In saliva (mg/100 ml)

Na	K	Na supply
>300	< 50	Sufficient
300–200	50–150	Insufficient, without clinical signs
200–100	150–250	Insufficient, clinical signs may occur
<100	>250	Severe deficiency, clinical signs occur

Direct supplementation to deficient cattle improves the sodium imbalance within a few days (Figure 11). However, ways should be found of avoiding sodium deficiency by adjusting fertilizer treatment. The herbage sodium can be increased easily by dressing grassland with salt or sodium containing fertilizer.

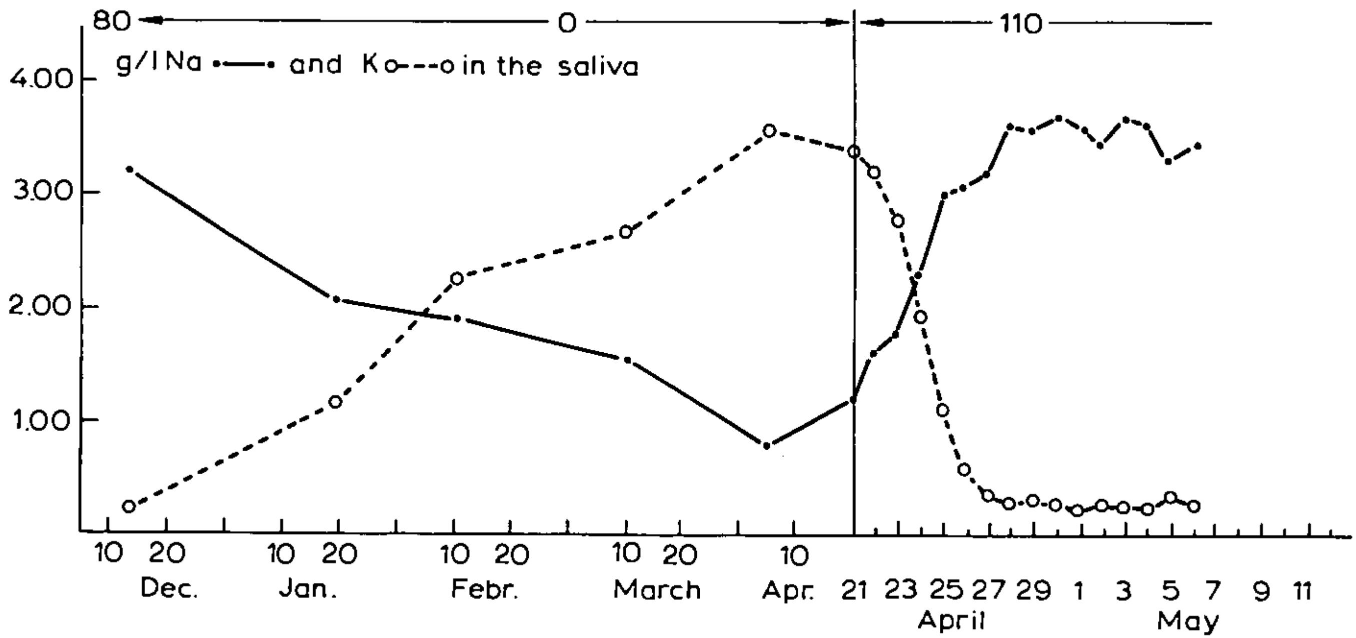

Fig. 11. Concentration of sodium and potassium in the saliva of milking cows on rations low in sodium (0.05% in dm) with and without additional NaCl (→O→ = 0 g of NaCl per day).

3.5 Trace elements, copper, cadmium and lead

3.5.1 Copper:

Copper is an *essential* element for various metabolic purposes. A mobilizable store of copper is present in the liver. If the supply is inadequate, clinical signs appear first and are more severe in yearlings and heifers, because during growth animals require more copper than during adulthood. Cattle require much more copper than non ruminants or sheep.

Copper absorption and utlilization in the animal can be markedly affected by several other elements and dietary components. Not all factors affecting copper utilization are yet known. Therefore the copper requirement cannot be given with great accuracy. An important factor inhibiting copper absorption seems to be *sulphide* in the *rumen*, resulting in the formation of insoluble copper compounds. Intensification of grassland management causing higher protein and sulphur contents of the grass results in a decrease in copper availability. Moreover in many countries, the content of molybdenum in herbage is a major factor depressing the copper status of the animal.

Methods of preventing copper deficiency are focussed on the application of copper containing fertilizer to increase the copper content of the forage, or on oral administration of additional copper, or on subcutaneous or intramuscular injections of slowly absorbed organic copper complex *(Underwood [20])*.

Sheep are much more susceptible to copper toxicity than cattle. In sheep it may occur after consumption of concentrates containing more than 15–20 mg/kg copper or while grazing pastures heavily contaminated with copper containing pig-slurry.

3.5.2 Cadmium and lead:

Especially during recent years much information has become available about the adverse effects of cadmium and lead in forage on animal production, although the picture is not yet clear. Comparing the lead and cadmium contents in the forage with the toxic levels for ruminants, perhaps it may be concluded that the toxic levels are higher or much higher than the maximum concentration in non-contaminated forage. However, it is suggested that differences in contamination are the most important factors in explaining the great variation in the cadmium and lead contents of the forage. There are indications that the cadmium and lead contents in milk are affected by cadmium and lead in the diet. Accumulation of these metals in the body occurs mainly in the kidney, the liver and the bones.

In forage production in the future, it might be necessary to pay more attention to the transmission of these elements to animal products. *Preventive measures* have to be taken to keep the concentrations of cadmium and lead in forage within the maximum acceptable levels.

4. References

1. *Ashbury, A.C.* and *Rhode, E.A.:* Nitrite intoxication in cattle: The effects of nitrite on blood pressure. Am. J. vet. Res., *25*, pp. 1010–1013 (1964)
2. *Bertrand, G.:* Eigth Int. Congr. Appl. Chem. NY 28, pp. 30 (1912)
3. *Broekhoven, L.W. van* and *Stephany, R.W.:* Environmental aspects of N-nitroso compounds. IARC Sci. Pub. 19, pp. 461–463 (1978)

4. *Gamgee, A.:* Researches on the blood. On the action of nitrite on blood. Physiological Transactions of the Royal Society, London, pp. 589–625, 1868
5. *Geurink, J.H., Malestein, A., Kemp, A.* and *Klooster, A.Th. van 't:* Nitrate poisoning in cattle. 3. The relationship between nitrate intake with hay or fresh roughage and the speed of intake on the formation of methaemoglobin. Neth. J. agric. Sci. *27*, pp. 268–276 (1979)
6. *Geurink, J.H., Malestein, A., Kemp, A., Korzeniowski, A.* and *Klooster, A.Th. van 't:* Nitrate poisoning in cattle. 7. Prevention. Neth. J. agric. Sci. (in press, 1982)
7. *Heimer, Y.M., Wray, J.L.* and *Filner, P.:* The effect of tungstate on nitrate assimilation in higher plant tissues. Pl. Physiol. *44*, pp. 1197–1199 (1969)
8. *Kemp, A.* and *Geurink, J.H.:* Nieuwe inzichten in de natriumbehoefte en de natriumvoorziening van melkkoeien. Tijdschr. Diergeneesk. *91*, pp. 580–613 (1966)
9. *Kemp, A., Geurink, J.H., Malestein, A.* and *Klooster, A.Th. van 't:* Grassland production and nitrate poisoning in cattle. Proc. Int. Symp. Europ. Grassl. Fed., Gent, pp. 910–915, 1978
10. *Kemp, A., Hemkes, O.J.* and *Steenbergen, T. van:* The crude protein production of grassland and the utilization by milking cows. Neth. J. agric. Sci. *27*, pp. 36–47 (1979)
11. *Kemp, A.:* Effect of fertilization on biological availability of magnesium in ruminants. Proc. 'John Lee Pratt' Intern. Symp. Kentucky U.S.A. (in press)
12. *Korzeniowski, A., Geurink, J.H.* and *Kemp, A.:* Nitrate poisoning in cattle. 5. The effect of tungsten on nitrite formation by rumen microbes. Neth. J. agric. Sci. *28*, pp. 16–19 (1980)
13. *Korzeniowski, A., Geurink, J.H.* and *Kemp, A.:* Nitrate poisoning in cattle. 6. Tungsten (wolfram) as a prophylatic against nitrate-nitrite intoxication in ruminants. Neth. J. agric. Sci. *29*, pp. 37–47 (1981)
14. *Malestein, A., Geurink, J.H., Schuyt, G., Schotman, A.J.M., Kemp, A.* and *Klooster, A.Th. van 't:* Nitrate poisoning in cattle. 4. The effect of nitrite dosing during parturition on the oxygen capacity of maternal blood and the oxygen supply to the unborn calf. Vet. Quart. *2*, pp. 149–159 (1980)
15. *Mayo, N.S.:* Cattle poisoning by nitrate of potash. Kansas agric. expt. Stat., Bull. *49*, pp. 1–18 (1895)
16. *Mertz, W.:* The essential trace elements. Science *213*, pp. 1332–1338 (1981)
17. *Seekles, L.* und *Sjollema, B.:* Untersuchungen über die Ätiologie der Grastetanie. I. Mitteilung. Die Aufnahme, Umsetzungen und Ausscheidung von in Lösung zugeführtem Kaliumnitrat beim Rinde. Die Zusammensetzung des Blutes bei der Nitratvergiftung. Arch. f. Tierheilk. *65*, pp. 331–342 (1932)
18. *Smith, S.E.* and *Aines, P.D.:* Salt requirements of dairy cows. Bull. *938*, Cornell Univ. Ithaca, New York (1959)
19. *Tilley, J.M.A.* and *Terry, R.A.:* A two-stage technique for the *in vitro* digestion of forage crops. J. Brit. Grassl. Soc. *18*, pp. 104–111 (1963)
20. *Underwood, E.J.:* Trace elements in human and animal nutrition. Academic Press. New York and London, 1971
21. *Wieringa, G.W., Meer, H.G. van der* and *Geurink, J.H.:* Production and utilization of energy and protein in grass in relation to nitrogen rate, green crop fractionation and dairy feeding systems. Proc. Int. Symp. Europ. Grassl. Fed., Wageningen, pp. 103–111, 1980
22. *Wright, N.* and *Davison, D.L.:* Nitrate accumulation in crops and nitrate poisoning in cattle. Adv. Agron. *16*, pp. 197–247 (1964)

The Role of Fertilizers in Improving Herbage Quality and Optimization of its Utilization

J.Salette, Laboratory of Grassland Agronomy Angers-Lusignan, INRA, Angers/France*

Summary

The paper discusses the effects of fertilizer application on the main quality criteria of the nutritive value of grassland herbage, how they vary and how they are related to the increase in production: nitrogen content, energy content and mineral content. A method of analysis is proposed based upon the dynamic evolution of these criteria during growth, essentially concerned with the laws of dilution. Finally, the possibilities for improving herbage utilization are discussed mainly in connection with the factors which limit the utilization of pastures. The paper discusses the possibility of using models to predict the qualitative composition of herbage at any given point during regrowth.

1. Introduction

Quality is a variable and complex concept. It is usual to consider two aspects: one, expressing in terms of chemical composition the nutritive value (energy and nitrogen contents and the contents of minerals and vitamins); the other in terms of intake. The two aspects are complemented by the efficiency of conversion through animal metabolism.

Dairy cattle have most often been used to evaluate forages because the product (milk) is easily measured over short periods in quite simple experiments. In grazing, the problem is more difficult because the increase in herbage production necessitates an increase in the stocking rate; the increase in production and improvement in quality lead to an increase in the number of grazing days. Thus, in the case of meat production, several investigations have shown a relation between application of fertilizer and live-weight gain per hectare.

When quality is assessed by making simple laboratory measurements it is relatively easy to identify the reaction to fertilizer treatment. On the other hand, when animals are used the results are affected by the method of forage utilization and by the increased quantity of herbage allowance: applying fertilizer increases the quantity of grass and it is then essential that the surplus production should be effectively consumed by the animals or by feeding more animals *(Demarquilly [18], Raymond* and *Spedding [51])*. Furthermore, at pasture, the results may differ according to whether they are expressed on the basis of production per animal or on production per unit area *(Mott [46])*, the main problem lies in adjusting the stocking rate to the herbage available and to its rate of growth.

* *Dr. J. Salette*, Station d'Agronomie, Centre de Recherches d'Angers, Beaucouzé, F – 49000 Angers/France

This paper focuses on the problem of relating herbage nutritive value to the use of fertilizers: in the first place nitrogen which, through controlling the rate of grass growth, is the decisive element in managing pasture to provide the daily and seasonal needs of the herd; in the second place, the other elements which are applied to improve mineral nutrient levels in the soil or to correct imbalance and to restore the minerals removed from the soil, which are increased by the increased by the increased growth brought about by applying nitrogen.

Besides assessing the effects on the chemical composition of the crop, it is obviously necessary to analyze the effects of the fertilizer on herbage utilization and the consequences on the optimization of production through agricultural grassland systems.

These problems have been given much attention as is evidenced in many excellent papers from different countries: *van Burg et al. [8]*, *Demarquilly [19]*, *Fleming [22]*, *Perigaud [50]*, *Raymond* and *Spedding [51]*, *Reid* and *Horvath [52]*, *Whitehead [64]*. The complexity of the subject is increased because variability due to stage of growth and to season is often greater than that due to fertilizer. The full understanding of these problems calls for the study of how the quality criteria vary during growth of the grass and different fertilizer levels. Results at a given date are not enough; they are incomplete and may be misleading. It is further necessary to master these problems on simple plant populations like monospecific swards, before turning to the more complex situation in grass-legume mixtures or in natural grasslands.

Finally, it is necessary to consider the matter in relation to an improved grassland management through the growing periods and in relation to the needs of the animal which indeed vary according to the different periods of the year.

2. Variability in nitrogen content of grasses

2.1 Nitrogen content and form of nitrogen

Is is most important not to compare effects between different parts of the response curve to N rates: in the case of a pure grass sward on a soil low in N, the response in yields is at first linear and one can identify the following successive effects on N content of the herbage:

a) a slight decrease in N content due to dilution through an initial very large yield response.

b) a steep increase in N content.

c) an increase in N content partly due to soluble N (organic and nitrate).

d) an increase due almost entirely to soluble N (organic and nitrate).

e) an increase only in soluble N, sometimes including ammonium which is an indication of disequilibrium in uptake and metabolism.

Yield increases through the phases a)–c). Phases a) and d) are considered abnormal, and correspond respectively to an extreme N deficiency or excess.

Phase e), which is rare, indicates toxicity and is accompanied by yield reduction, while there is no yield increase in phase d). Many results in the literature appear contradictory because they relate to different phases [*e.g.* a), b) and d)]. It must be noted that literature very seldom deals with low N dressings. The N content of herbage harvested young, at the beginning of regrowth and intensively fertilized is often in excess of the animal's needs: a crude protein content of 16% (2.6% N) suffices for the maintenance and production needs of a cow giving 25 l milk and largely satisfies the needs for animal growth. However, even at high levels of fertilizer, herbage N contents are not sufficient at growth stages corresponding to late grazing or even to silage cuts at an early stage (Tables 1 and 2). Similarly, N contents are not silage cuts at an early stage (Tables 1 and 2). Similarly, N contents are not always sufficient in summer and autumn (a problem discussed in Sections 3 and 5).

High rates of N used to accelerate growth lead to very high N contents in the herbage and to the accumulation of residual N in the soil; a succession of grazing and mowing could contribute to optimizing fertilizer and forage use.

Above a certain level, an increase in N causes in addition to the increase of protein N, an increase in soluble N, nitrate or organic (amides, free amino acids, amines). They are of less value to the animal than protein N because they are not so efficiently

Table 1. Effect of nitrogen rates on the optimization of grassland use during the period 'end of winter-beginning of spring'. Tall fescue *(cv.* Ludelle), compared at two yield levels: for grazing, 1,5 t ha^{-1} dry matter, or for a silage cut, at 5 t ha^{-1} dry matter. Experiment at Lusignan *(Salette* and *Lemaire [unpublished 1979])*. The largest amount of N was chosen so that growth was not limited by N supply

	1,5 t dry matter ha^{-1}			5 t dry matter ha^{-1}		
Fertilizer level	N_1: 60 (60+0)*	N_2: 120 (60+60)*	N_3: 180 (60+120)*	N_1: 60 (60+0)*	N_2: 120 (60+60)*	N_3:180 (60+120)*
Stage of growth	vegetative, ear height 10 cm	vegetative	vegetative	flower opening	ear emergence	vegetative, ear height 10 cm
Date	24 April	9 April	2 April	25 May	4 May	26 April
Time saving by nitrogen use						
– between 60 and 120 kg N ha^{-1}....	15 days		7 days	21 days		8 days
– between 60 and 180 kg N ha^{-1}....		22 days			29 days	
Crude protein (% dry matter) ...	12.2	20.3	25.6	6.6	10.8	15.4
In vitro dry matter digestibility (D. value)........	74	81	83	59	69	74
Nitrogen uptake kg ha^{-1}..........	30	47	62	50	90	125
Residual nitrogen in soil (kg ha^{-1}).....	30	73	118	10	30	55
Apparent recovery of N between 60 and 180 kg, %		27			62	

* Fertilizer applied twice: previous autumn and February (kg N ha^{-1}, as ammonium nitrate)

Table 2. Spring growth of Italian ryegrass *cv.* Tiara, sown previous October, in a good nitrogen level soil. Three rates of nitrogen applied on 15th February, respectively 50, 100, 150 kg N ha^{-1} using ammonium nitrate. Results for four successive cuts as dry matter yield (DM) in t ha^{-1}, total nitrogen content in the dry matter (N) and total soluble carbohydrate content in the dry matter (TSC)

Cutting date	28 March			19 April			2 May			11 May		
Stage of growth	vegetative			vegetative, ear height 10 cm			stem elongation			ear emergence		
	DM	N	TSC	DM	N	TSC	DM	N	TSC	DM	N	TSC
N_1	1.9	2.76	19.2	3.9	2.00	29.2	4.9	1.42	28.2	5.5	1.40	26.2
N_2	2.1	3.30	13.7	4.5	2.40	22.8	5.3	1.62	26.2	6.2	1.54	21.4
N_3	2.5	3.96	9.5	4.9	3.01	18.4	5.7	2.23	19.1	6.6	1.92	18.2

transformed into microbial protein by the rumen microorganisms unless accompanied by an energy supplement *(Demarquilly et al. [20], Holmes [31], INRA [33])*. Such herbages may have a lower efficient N content, expressed as digestible protein in the intestine (PDI) than herbages receiving less adequate fertilizer. Figure 1 shows how the content of different forms of N changes during the growth of Italian ryegrass.
Nitrate N contents increase with the level of N applied above a high N rate. They are high for two or three weeks following application, in practice during the early weeks or regrowth; after this, they decrease throughout growth. The phenomenon is analogous for growth following sowing as indicated in Figure 2 which shows the relations between soluble N, NO_3-N and total N during growth of an Italian ryegrass. A certain nitrate N content is recognized as an indication of good nitrogen nutrition *(van Burg [7]*, 0.15% NO_3-N). Nitrate N contents are often higher in autumn, or in other cases where weather conditions limit grass growth while there is an abundant nitrogen supply in the soil. Variation in NO_3 content and the risk of nitrate toxicity have been much studied *(van Burg et al [8], Deinum* and *Sibma[16], Griffith [24], Kemp et al. [36], Nowakovski [47])*. In practice, the risks are slight on grasslands receiving less than 400 kg/ha/year in split applications where NO_3-N content rarely reaches 0.25%. Moreover, the risks are reduced in grazing or in using cut forage by staggering feeding to avoid too rapid an ingestion of nitrate. Besides, profusely tillering species grazed or cut at frequent intervals show lower NO_3-N contents *(Deinum* and *Sibma [16])*.
In a general way, deficiency in energy content, nitrogen and phosphorus can be important causes of infertility *(Brochart [6])*. One should keep in mind that in practice most grassland is under-fertilized. This applies in Europe and in France *(Salette [54])* and even more so in the tropics: the N content of Pangola grass *(Digitaria decumbens)* is often below 1%; it can be considerably increased with fertilizer but always remains. below the levels obtained in temperate regions under comparable agricultural conditions. They vary much with season and are related to the ratio leaves/stems plus stolons *(Salette [53, 56]*, Figure 3*)*. The contents are often too low for productive animals and the digestibilities are also low *(Chenost [9])*.

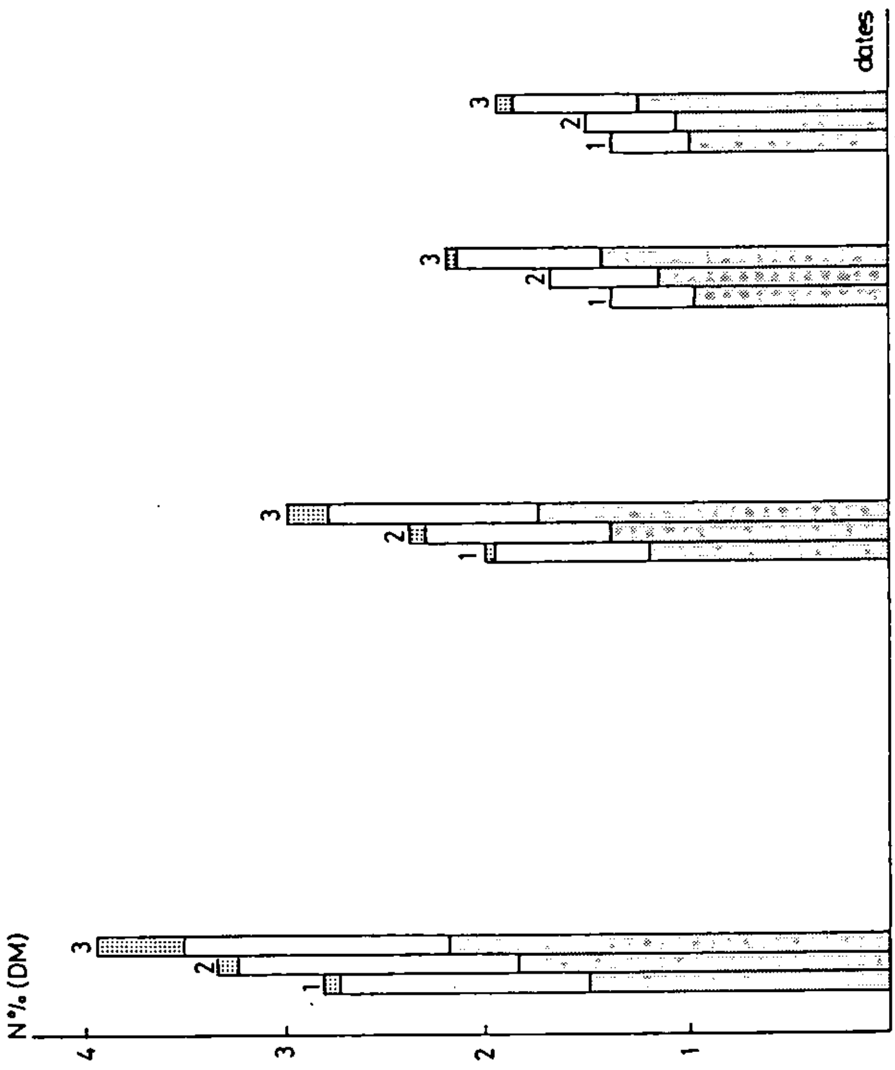

Fig. 1. Content and distribution of the three main forms of nitrogen in grass at successive cutting dates. Spring growth of Italian ryegrass, *cv.* Tiara, sown previous autumn. Three nitrogen rates applied in February as ammonium nitrate: (1): 50; (2): 100; (3): 150 kg N/ha^{-1}.

- nitrate nitrogen
- organic soluble nitrogen
- protein nitrogen

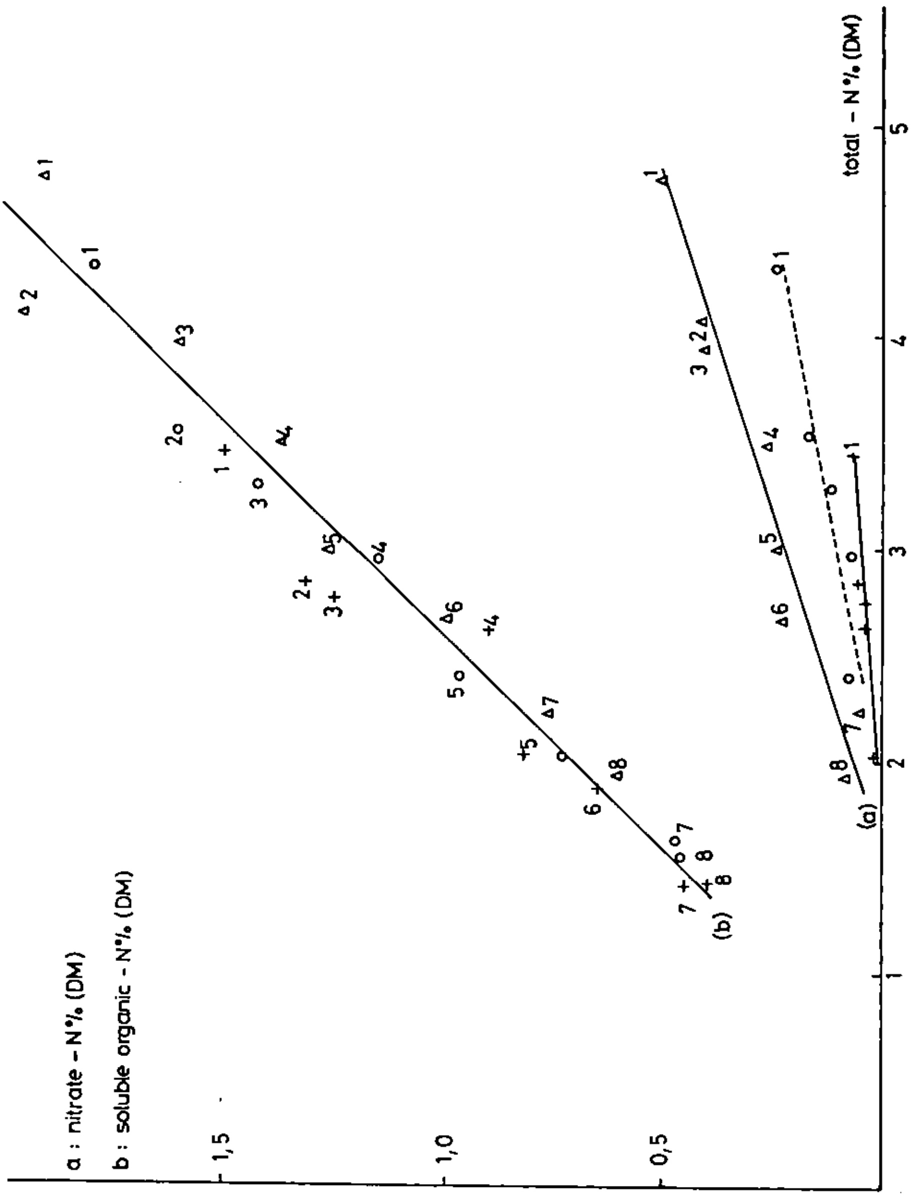

Fig. 2. Evolution during spring growth of soluble organic nitrogen and nitrate nitrogen contents in dry matter, *versus* total nitrogen content, for eight successive cuts in Italian ryegrass: 4th; 21st; 28th March, 4th; 19th; 26th April and 2nd; 10th May, respectively for cut numbers 1 to 8. Other cultural data as in Figure 1.

+ – 50 kg $N.ha^{-1}$
o – 100 kg $N.ha^{-1}$
△ – 150 kg $N.ha^{-1}$

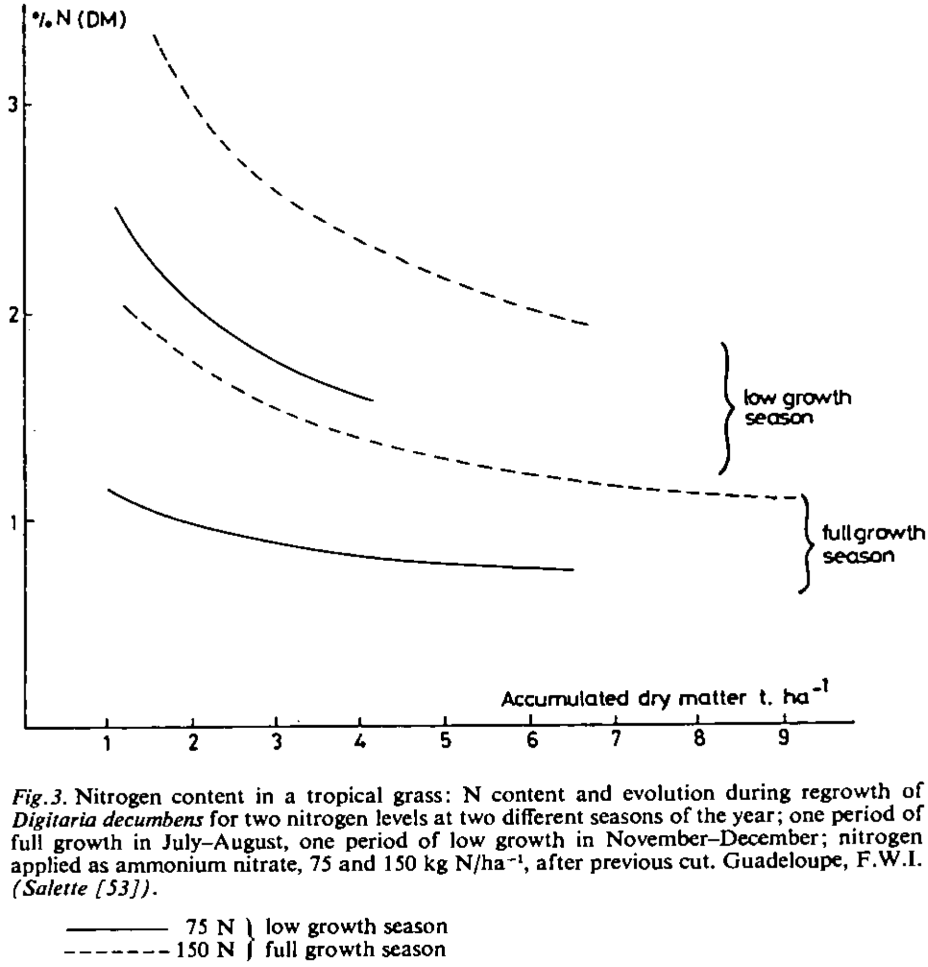

Fig.3. Nitrogen content in a tropical grass: N content and evolution during regrowth of *Digitaria decumbens* for two nitrogen levels at two different seasons of the year; one period of full growth in July–August, one period of low growth in November–December; nitrogen applied as ammonium nitrate, 75 and 150 kg N/ha^{-1}, after previous cut. Guadeloupe, F.W.I. *(Salette [53])*.

——— 75 N } low growth season
------- 150 N } full growth season

2.2 Effects on other plant constituents

Generally speaking, increasing the N supply decreases often markedly the content of soluble carbohydrates *[Alberda [1], Jones et al. [34], Lefebvre* and *Joliet [41], Nowakowski [47], Waite [63])*, while it does not affect the cell-wall carbohydrate content. There is often an improvement in soluble carbohydrate content later in sward growth. Table 2 gives results for Italian ryegrass sown in autumn and cut at various stages of growth in the following spring. Low soluble carbohydrate content could adversely affect the quality of silage, but there are no definite conclusions on the subject.

The increase in nitrogen content is accompanied by a decrease in dry matter content of the herbage: herbage cannot at the same time be high in nitrogen and high in dry matter (*Behaegue* and *Carlier [2]*, *Demarquilly [18]*, *Salette* and *Dumas [57]*). This can raise problems in conservation: more herbage mass and hence more difficult to dry, an increase in ensilling losses. It should also be noted that a low dry matter content may lead to a reduction in dry matter intake, because of the increased fill

3. Energy value expressed by digestibility

There have been a number of studies comparing the *in vivo* and *in vitro* digestibility of herbage, from plots receiving different levels of N fertilizer; it appears that there are in this case no differences in digestibility (Review, *Demarquilly [19]*). However, when soil fertility is very low it seems reasonable to suppose that an increase in N supply would have a positive effect on digestibility through enabling the plant to grow properly (with similar effects on the rumen flora).
In any case it does not seem entirely logical to compare on the same dates, the digestibility of forages which have received different levels of N fertilizer. In practice, ni-

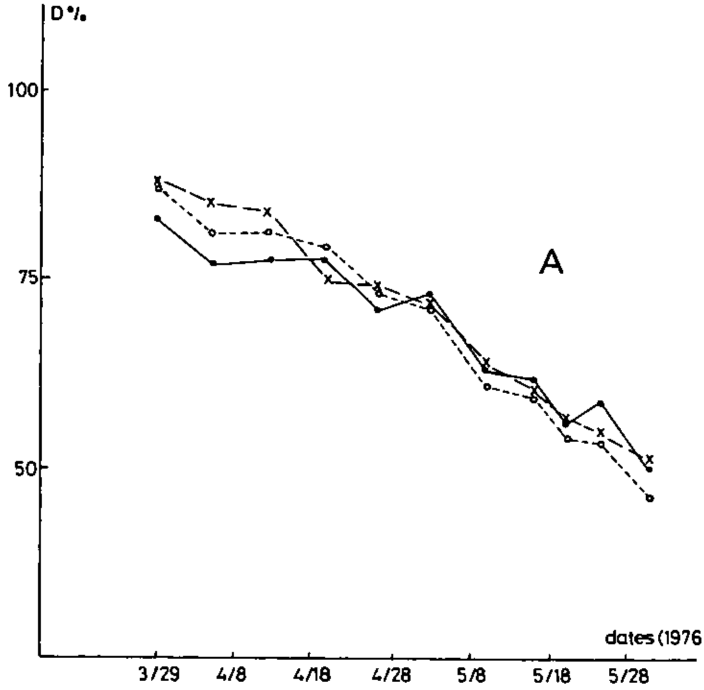

Fig.4. Variation of *in vitro* dry matter digestibility (D %) during regrowth of grasses for different nitrogen levels: spring growth of tall fescue *cv.* Ludelle (N levels and other data as in Table 1).

Fig.4a. Evolution of D % during regrowth days: D % differences are not significant when comparisons are made on the same day.

trogen's main effect consists in accelerating growth: swards receiving more N would be utilized earlier, the cutting or grazing are practically decided at the moment when a given level of dry matter yield has been reached. Thus, we have compared digestibility *(in vitro* digestibility of dry matter) throughout regrowth as related to accumulated dry matter (Table 1; Figures 4a and 4b). Figure 4b shows clearly that at a low rate of N fertilizer (N_1) digestibility over grass growing falls off more than it does at high rates (N_2, N_3; values as in Table 1). Comparing the slopes of the curves we find values of –5.5, –4.1 and 3.2 digestibility points per tonne of dry matter increase for tall fescue and –4.8, 3.2 and 2.5 points for cocksfoot respectively at N_1, N_2 and N_3, for spring growth in April and May. Similar results have been obtained for other species and in other years *(Salette* and *Lemaire*, unpublished). During reproductive growth, the rapid lignification of stems results in steeper slopes; while, in the vegetative phase, the diminution is mainly due to change in the ratio of younger to older leaves. At the end of winter digestibility may improve with the starting of growth: we have found that the digestibility of a natural pasture could improve during the first 3 or 4 weeks when the old autumn leaves having moderate to good nutritive value are replaced by new leaves with a very high value.

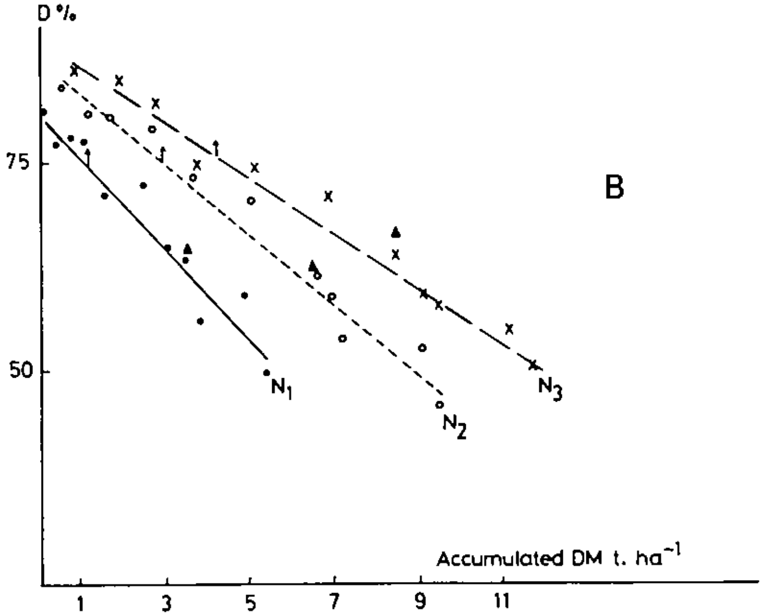

Fig.4b. Evolution of D % *versus* the accumulated herbage dry matter during growth (dry matter t/ha^{-1}).
– stages of development: ↑ : ear at 10 cm height
▲ : ear emergence
These stages are at approximately the same date for the different N treatments
– *fertilizer used:* ●——● N=60 kg N ha^{-1}
○——○ N=120 kg N ha^{-1}
×——× N=180 kg N ha^{-1}

4. Mineral composition

4.1 General aspects

The effect of fertilizer treatment on mineral composition is very complex and may appear confusing because it depends on so many factors which cannot all be controlled at the farm level: type of natural flora or sown sward, method of utilization, return of excreta, trampling, climate, availability of water, level of N and other fertilizers, soil type, season, stage, reproductive phase, age of growing grass, and age of sward. Several authors have reviewed this subject (*van Burg et al. [8], Bouchet* and *Guéguen [5], Coppenet [13, 15], Fleming [22], Guéguen [27], Périgaud [48, 50], Reid* and *Horvath [52], Whitehead [64]).*
It is not easy to determine the mineral requirements of animals, mainly because of interference with other elements and because of reserves stored in the animal body, principally in the bones (Mg frequently causes problems because the animal cannot store it). The needs vary according to the type of animal and the objectives of production.
Basing calculations on the amounts ingested one can lay down thresholds for minimum herbage content and, from herbage analysis, make judgements as to its adequacy for supplying the animal's needs *[Guéguen [27]).* The best known are mineral requirements directly related to production, for example, P, Ca, Mg and Na for milk. As well as a deficiency threshold we can similarly define a toxicity threshold for animals, where the intervals between deficiency and toxicity are relatively small, so that it is necessary to exercise caution in correcting deficiencies (Cu in particular). Besides, the needs of animals which vary according to the level of production and age necessitate avoiding imbalance in the diet. Fertilizer can make a contribution to maintaining this equilibrium in the herbage and this is particulary important where mineral supplements are not fed.

4.2 Variation due to fertilizer treatment

Fertilizer affects mineral composition both directly and indirectly.

4.2.1 Direct effects

Increasing the supply of an element usually increases its concentration in the plant. There is a relationship between the increase in yield due to its application and its content in the herbage *(Smith [60])*: it is possible to have, first, a yield increase with a decrease in content followed by both increase in yield and in mineral concentration and an increase in concentration with no further increase in yield above a so-called critical level and giving luxury consumption; finally, the concentration may increase with a decrease in yield, indicating toxicity. This is similar to the effects of nitrogen discussed above. Below the threshold defined as 'critical value', application of the element will increase yield.
The critical values for mineral content related to herbage growth actually differ from animal needs; for some elements the former are above the latter, this is mainly the

case for potassium. On the other hand, for P, Ca, Mg, Na and for the main trace-elements, the values required by the animal are above those required by the plant; thus in the case of P, there will be a yield response provided that plant content is below 0.15–0.18% in dry matter, a level which is scarcely sufficient to cover animal maintenance needs. For some elements (Mo, Se, Cu) 'normal' plant contents may be toxic for animals. Again, plants have no definite need for Na, I and Se; while the animal does not seem to need definite amounts of other elements like B which is indeed very necessary for legumes.

4.2.2 Indirect effects

Between mineral elements in the soil and an applied element there may be uptake interactions which means either antagonism or synergy. Thus K is antagonist to Mg. The plant content of most mineral elements, if soil supplies are adequate, is usually increased by nitrogen fertilizer, but if supplies are inadequate the effect of nitrogen will be the reverse due to dilution in the increased herbage mass. The effect should not be confused with antagonism. Several examples can be given, particularly for phosphorus *(Coppenet [13,15], Lambert et al. [39])* and for other major elements *(van Burg et al. [8], Salette et al. [58])*.

4.3 Other causes of variability

These induce much wider variations than those connected with mineral nutrition. In practice, seasonal variation is very important: contents may be above animal requirements at some times of year and much below at others *(Coppenet [13,15], Fleming [22], Périgaud [50])*. These seasonal variations are caused by differences in the behaviour of the elements in the soil and differences in plant uptake caused by climatic changes and, also, by changes in the physiological status of the plant, *e.g.* change from vegetative to reproductive phase, changes in the tillering pattern and the rate at which leaves appear and expand.

Variations with the age of regrowth through dilution in the increased mass of plant material are even larger: thus, contents can change by a factor of one to two for K and P *(Coppenet [15], Guéguen [27], Guéguen* and *Fauconneau [28]*, *cf.* also section 5.2.). Finally there are large differences between herbage species: differences between legumes and grasses, between species, and between varieties *(Coppenet [13], Périgaud [50])*.

4.4 Reminding of other animal need points

The two elements concerned in antagonism and synergy are nitrogen and potassium, and this can explain variations in plant behaviour on soils which are, according to chemical analysis, normally fertile *(Behaegue* and *Carlier [2], van Burg [8], Chevalier [10])*. Phosphorus content of herbage can be raised by 10–25% by applying nitrogen or phosphatic fertilizer *(Coppenet [15], Ferrando et al. [21], Lambert et al.*

[39]). There are numerous and complex effects by soil constituents which may immobilize phosphate (organic matter, iron and aluminium hydroxides, lime). Moreover, except before seeding, fertilizers can only be broadcast on the soil surface and this does not favour the efficiency of an element which is slightly mobile. It is difficult to attain mineral herbage contents sufficient for high producing animals *(Guéguen [27])* and the year-to-year variation is very large. Over large areas where extensive or semi-intensive stock farming is practised, whether in the tropics or in temperate zones, soils are generally not sufficiently well supplied with P to produce anything but yields below the potential, and frequent P deficiencies for the grazing animals, all the more so as they will not receive any mineral complement.

Magnesium has been much studied, particularly in W. Europe, because of its importance in tetany. A higher Mg content is needed when N and K fertilizers are increased, the permissible level being 0.15–0.20% Mg in dry matter. Usually the content is a little above this value, but there is much fluctuation. Grass is supposed to respond in yield where its Mg content is below 0.10% Mg. Several authors have closely studied the magnesium problem in intensive livestock farming: *Behaegue* and *Carlier [2]*, *van Burg et al. [8]*, *Coppenet [15]*, *Wolf [65]* and, for semi-intensive management, *Dejou* and *de Montard [17]*. Low herbage magnesium can be corrected, to some extent (10–20%), by applying magnesium sulphate or dolomitic limestone and by careful management of potash fertilizer. Dusting the grass with magnesia has also been used in severe cases to produce a quick result. Legumes on the whole have a higher Mg content than grasses, usually sufficient for the animal needs. The same applies for Ca.

Calcium content depends essentially on Ca availability in the soil and pH. Many grassland soils should be limed. Grasses are often not well supplied wth Ca *(Coppenet [13]*, *Gross* and *Jung [25]*, *Périgaud [48]*, *Salette et al. [58])*; herbage from mixed swards is higher in Ca as is the case for Mg *(Behaegue* and *Carlier [2]*, *Chevalier [11])*.

In soils of low calcium status the available Ca can be lowered by applying N. *(Coppenet [15]*, *Dejou* and *de Montard [17])*.

It can be interesting for grazing animals to increase the sodium content of herbage by applying sodium salts *(Hasler et al. [29]*, *Henkens [31])*. The Na content of white clover is always high though the tropical legumes and lucerne contain only traces. Some grass species contain very little Na (timothy, fescue) while cocksfoot and ryegrass *(Coppenet [13])* and some tropical grasses like *Digitaria* present high Na contents *(Salette et al. [58])*. Sodium content is also raised by applying nitrogen, provided the soil is well supplied with Na *(Behaegue* and *Carlier [2]*, *Coppenet [31]*, *Salette et al. [58]*, *Wolf [65])*.

Some soils contain insufficient sulphur to supply the needs of crops and animals, but more usually, the herbage contents are sufficient: values published by *Behaegue* and *Carlier [2]* are very high. The same is the case for chloride. Values quoted by *Behaegue* and *Carlier [2]* and *Salette [55]* are all above the critical value 0.1% given by *Whitehead [64]*. *Juste et al. [35]* have indentified severe S deficiency in lucerne on calcareous soils in the West of France.

As far as trace-elements are concerned, the problem is more complex, and much work has been published on the subject. Parent rock on which the soil is formed has an important influence and consideration of this can contribute to identify the areas where deficiencies are likely to occur *(Fleming [22], Lamand* and *Bellanger [38], Périgaud [48,49])*. In contrast to the major elements, critical values are not referred to animal needs but rather to herbage levels at which no signs of deficiency have been found, which presupposes a precise knowledge of the troubles caused by each deficiency. The problem is complicated by diverse interactions emphasized by differences in individual animal behaviour. There are, on the one hand, direct deficiencies caused by insufficient supply of the element, and, on the other hand, more complex deficiencies induced by unfavourable pH or interference by other elements, for example S/Mo and Cu; Ca/Cu; Ca/Mn; N/Cu; P/Zn. Both soil application and spray application may be considered *(Coppenet [14], Fleming [22])* and it is important to avoid reaching toxic levels, sufficiency and toxicity thresholds being separated by only a small margin, which is even narrower in the case of Cu. It is not easy to correct deficiencies *(Périgaud [48, 49])* and mineral supplement is no panacea, it is generally better to give animals a mineral complement despite possible practical difficulties *(Guéguen [27], Lamand* and *Bellanger [38])*. Let us remember that it is often necessary to apply Mo to legumes *(Juste et al. [35])*.

4.5 Practical applications

Despite the fact that the assimilation by the animal of the various elements is not necessarily proportional to their contents in the herbage (P and Mg in very young herbage was claimed to be less available to the animal than in older herbage, though the content of the latter is lower) in practice one has to proceed on the basis of norms characterizing the needs of the animal.

There is a particular problem in the case of performance livestock for which a mineral supplement is needed, above all in P, Ca and Na, along with an energy supplement and, sometimes nitrogen. But, at medium levels of milk production and for young animals, well fertilized grass usually supplies enough minerals; for beef cattle and low yielding dairy cows mineral supplementation can be useless. In every case it is advisable to control herbage mineral contents: on the basis of individual farms in very intensive systems and for semi-intensive and extensive systems through homogeneous soil type areas. For trace-elements considerations can be based on geological knowledge and information from analytical surveys may indicate the likelihood of possible deficiencies.

One may quote as an example of this kind of approach the normogram giving deirable levels of Mg in relation to N and K used in the Netherlands (in *van Burg et al. [8])*.

An information bank is being considered in France from the results of herbage analysis *(Bouchet* and *Guéguen [5])*.

As well as its importance in terms of nutritive value for the animal, herbage analysis has an importance in supplementing information given by soil analysis as indicating the nutritional status of the herbage. For potassium, *De Montard* proposes to use the K/N ratio rather than simply K content as this correlates well with cumulated deficiencies induced by successive cuts *(Dejou* and *de Montard [17])*. It is possible on well manured swards *(Salette et al. [58]* and research in progress) to relate contents of K, P and, in some cases, some other elements like Na and Ca, to N content of the dry matter by a linear regression:

$$\text{mineral\%} = a + b\,(\text{N\%}) \quad (1)$$

In this way one can graphically relate the content of the considered mineral to that of nitrogen and thus eliminate the effects of dilution by nitrogen and the effect of age

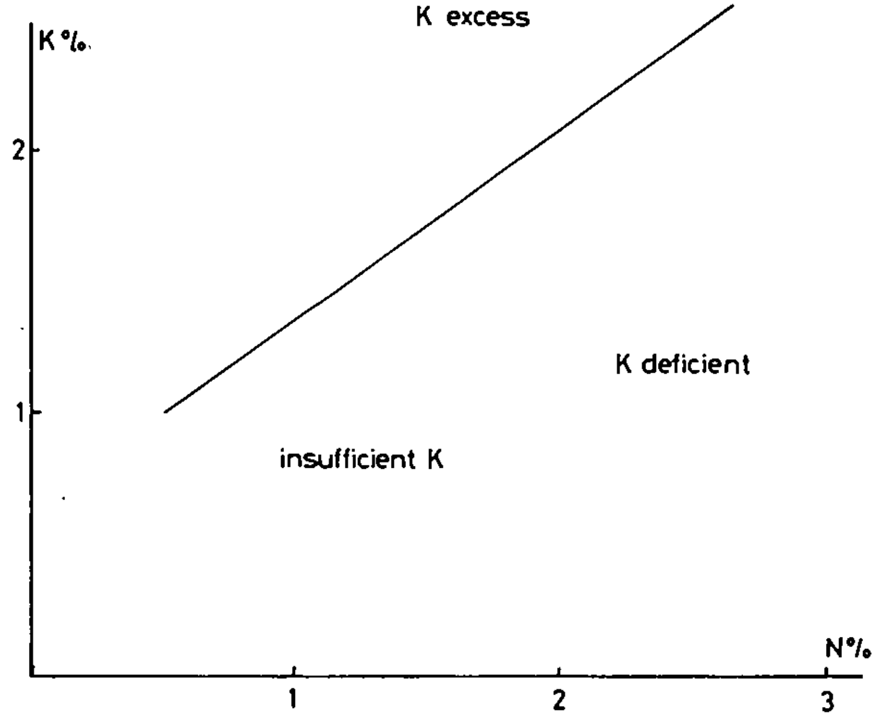

Fig.5. Relation between the K and N dry matter contents in grasses. Established linear regression for *Digitaria decumbens* grown in five different experiments with good K supply, all in the same vertisol type soils: K % = 0,71. N % + 0,64 (r = 0,62). Variation in the values is mainly due to effects of season, yield, and nitrogen levels *(Salette et al. [58])*. A result of a grass analysis of K and N values giving a point close to the reference line should be interpretated as corresponding to soils correctly supplied with K as opposed to points in insufficient or excess zones.

Table 3. An example of relation between mineral content and nitrogen content of grass (tall fescue *cv.* Ludelle), during its spring regrowth. All correlations are highly significant *(Salette, Robichet, Lemaire [unpublished])*

Nitrogen level (kg N ha^{-1})	Equation		
60	K % = 0.301	N % + 1.598	r = 0.888
120	K % = 0.434	N % + 1.683	r = 0.957
180	K % = 0.433	N % + 1.969	r = 0.953
all levels confounded	P % = 0.082	N % + 0.105	r = 0.964

of the regrowth. We are now studying how far such an approach can be used to establish standards for normal, excessive, insufficient or deficient mineral nutrition by relating the value for a particular sample to pre-determined standards (Figure 5). It will be necessary to test out various equations corresponding to differing soil conditions under which the dynamics of the elements differ.

The interpretation must also be done with due regard to the stage of growth and knowing the level of biomass production. The interest of this approach is confirmed by the dilution equations (*cf.* section 5.) and by the close relations between mineral and nitrogen contents throughout the course of regrowth (Table 3).

5. The dynamics of dilution during sward regrowth

We have stressed that any criterion relating to a particular physiological status of the plant, such as N content or mineral content, changes during regrowth of the sward. It is usual to refer such variation to the age of the regrowth, as in Figure 4a. There are several defects in such a procedure mainly because of the irregularity of growth over time. It therefore appeared worthwhile to try to refer such criteria to the actual stage of growth of plant itself, *i.e.*, the accumulated dry matter yield (Figure 4b).

5.1 Nitrogen content

We have been able to show *(Salette* and *Lemaire [59])* that change in N content during regrowth can be described by the equation:

$$N\% = \alpha\,(DM)^{-\beta} \quad (2)$$

where DM is the herbage mass dry matter at a given time, and N% the DM nitrogen content at the same moment. This relationship varies with the nitrogen nutrition, cultivar and season. From the point of view of nutritive value of the herbage, N% can be related to two closely associated aspects: the level of nitrogen nutrition which is given approximately by the rate of N fertilizer applied, and the stage of regrowth which is represented by the herbage dry matter at the same moment. Figure 6 shows an example for 4 levels of N applied to tall fescue summer vegetative regrowth, irrigated during dry periods by ref. to PET (6 successive cuts). Maximum dry matter yield is obtained with 100 kg/ha N, while the crude protein content needed for a high yielding dairy cow (16% DM) can be obtained at herbage yields below 1.6, 3.5, and 5.8 t/ha dry matter *i.e.*, before 19 July, 2 and 19 August respectively at 50, 100 and 150 kg/ha N applied at the beginning of growth. In spring, the dilution is much more rapid but N contents are higher for summer growth. It would be interesting to develop models for the plant behaviour in relation to nitrogen and season and to test predictive values as compared to the actual production and composition of different swards. It would also be interesting to examine the effect of N dressings applied not only at the beginning of growth *i.e.* just after the previous defoliation, but also during the regrowth.

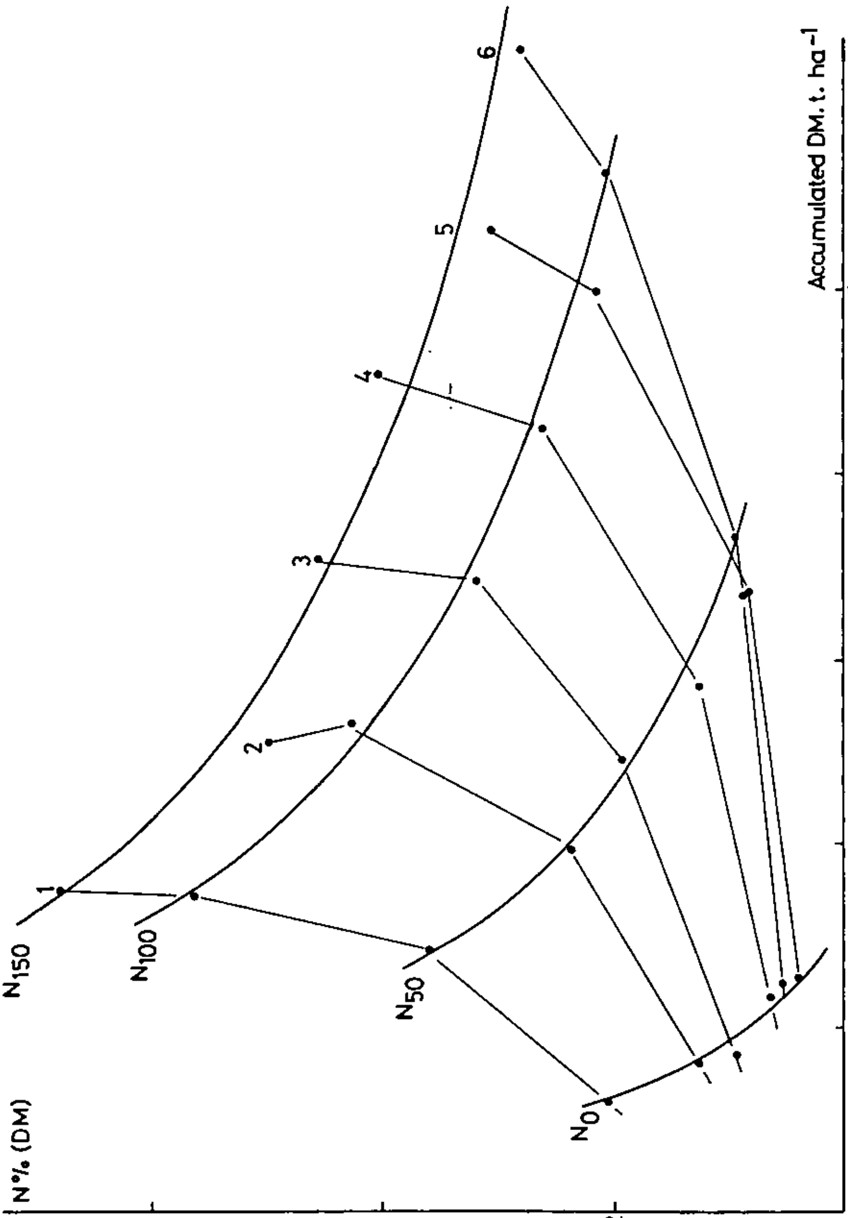

Fig. 6. Forms of nitrogen dilution curves for a tall fescue sward regrowth at 4 nitrogen levels: N_0, N_{50}, N_{100}, N_{150}, respectively nil, 50, 100, 150 kg N/ha^{-1} as ammonium nitrate. Summer regrowth with some irrigation. Numbers 1 to 6 refer to six successive cuts on July 18th, 25th; August 1st, 8th, 16th, 24th. The points joined by lines represent harvests at same cutting date *(Lemaire* and *Salette*, Lusignan *[1977, unpublished])*.

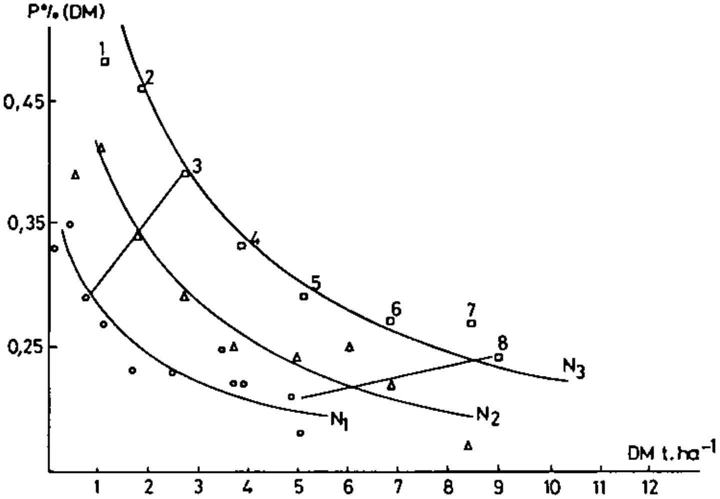

Fig. 7a. P dilution for a spring growth of tall fescue *cv.* Ludelle (other data as Table 1, and Figure 4). The influence of nitrogen varies over the growth, higher for young stages (point nb 3, at April 8th) than older ones (point nb 8, at May 11).

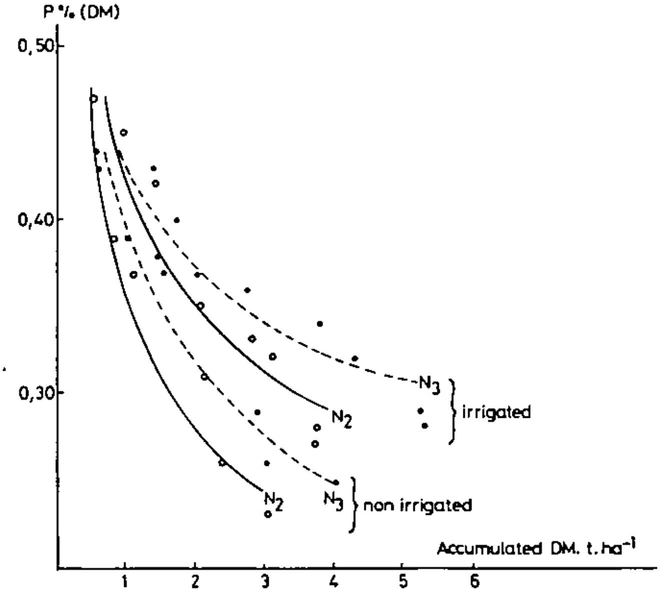

Fig. 7b. P dilution with irrigation for a summer growth of cocksfoot, *cv.* Lucifer. Two nitrogen rates N_2, N_3, respectively 60 and 120 kg N/ha^{-1} applied as ammonium nitrate after previous cut, and divided into irrigated and non irrigated plots. For increasing P content, the effect of water supply is much higher than the small nitrogen effect.

Fig. 7. Phosphorus dilution during grass regrowth: Phosphorus dry matter content (P % dry matter) evolution during the regrowth plotted *vs.* accumulated herbage dry matter (DM t/ha^{-1}).

5.2 Minerals

A similar procedure leads to analogous results for mineral content which can be described by equations like those used for N showing the physiological similarity between the uptakes of dfferent nutrients as related to stage of growth. The problem, which we are now investigating, concerns the relations between mineral and N contents as described above (section 4.5). It is possible to propose a model for 'normal behaviour' of the plant which, under given environmental conditions, can be used to make predictions. Furthermore, the values predicted by 'normal behaviour' can be compared with actual values and used for a better diagnosis of the mineral status of a given type of sward.

For instance, Figures 7a and b show change in P content of tall fescue respectively in spring and summer regrowths at different levels of N fertilizer applied at the start of regrowth. Figure 7a shows that this method gives a good account of the effect of N on P content of herbage. The effect of N is more marked early in growth (point 3, 12.4.76) than later (point 8, 17.5.76) while comparisons at the same yield of dry matter can also be made. Table 4 gives some of the dilution equations for K, P, Ca, Mg and S for two species. Such relationships have also been established for several other grass species. However, there are some minerals which do not always behave in this way: Ca contents may even increase during summer growth, while Mg and Na contents may show little variation with stage of growth.

Table 4. Mineral dilution equations for spring growth in tall fescue and cocksfoot at different nitrogen levels over two years *(Salette, G. Robichet, J. Lemaire [unpublished results])*. All relations are highly significant with correlation coefficient r between 0,88 and 0,99. *(same experiment as in Table 1.)*

Nitrogen level		Tall fescue *cv.* Ludelle	Cocksfoot *cv.* Lucifer
K % (1976)	N 60	$K = 2.360\ (DM)^{-0.125}$	$K = 2.844\ (DM)^{-0.063}$
	N 120	$K = 3.412\ (DM)^{-0.196}$	$K = 3.639\ (DM)^{-0.099}$
	N 180	$K = 4.550\ (DM)^{-0.237}$	$K = 4.560\ (DM)^{-0.124}$
K % (1977)	N 60	$K = 3.041\ (DM)^{-0.265}$	$K = 2.854\ (DM)^{-0.094}$
	N 180	$K = 5.395\ (DM)^{-0.388}$	$K = 4.384\ (DM)^{-0.210}$
P % (1976)	N 60	$P = 0.289\ (DM)^{-0.231}$	$P = 0.318\ (DM)^{-0.101}$
	N 120	$P = 0.429\ (DM)^{-0.429}$	$P = 0.370\ (DM)^{-0.200}$
	N 180	$P = 0.622\ (DM)^{-0.441}$	$P = 0.527\ (DM)^{-0.398}$
Ca % (1977)	N 60	$Ca = 0.391\ (DM)^{-0.295}$	$Ca = 0.423\ (DM)^{-0.180}$
	N 180	$Ca = 0.438\ (DM)^{-0.215}$	$Ca = 0.486\ (DM)^{-0.199}$
Mg % (1977)	N 60	$Mg = 0.161\ (DM)^{-0.314}$	$Mg = 0.087\ (DM)^{-0.191}$
	N 180	$Mg = 0.303\ (DM)^{-0.389}$	$Mg = 0.174\ (DM)^{-0.365}$
S % (1977)	N 60	$S = 0.247\ (DM)^{-0.182}$	
	N 180	$S = 0.292\ (DM)^{-0.214}$	

5.3 Possible applications

The analysis of mineral and N contents throughout any regrowth gives much more information than simple comparison of values obtained for isolated punctual cuts.

Thus, it is possible to compare the rates of change of any studied criterion *(e.g.* P content or N content) and this gives a better account of the possibilities offered by the different plant populations under study. There are obvious practical difficulties: the need for much more determinations over growing time and the need to measure herbage DM mass at each sampling.

A better comparison of behaviour in N and mineral contents between genotypes can be made by comparing curves than by comparing points. The method allows better judgments to be made as between herbage mineral content between different swards and as to what might be possible in the way of controlling mineral composition and the value of fertilizer treatments based on soil analysis and how the animal mineral requirements may be satisfied.

Moreover, by transforming the dilution equation (Eq. 2) by multiplying both members by herbage mass (DM), it is possible to express the nitrogen uptake of the sward (N_{uptake}, in kg. ha^{-1}):

$$N_{uptake} = \alpha\,(DM)^{1-\beta} \quad (3)$$

In this way a better estimate of the amounts of N and similarly amounts of mineals removed from the soil in each or cumulated grazings or cuts is obtained which will help to determine the quantity of every nutrient which has to be returned to the soil by fertilization.

6. Optimizing herbage utilization and quality

6.1 Problems of a better use through grazing

The optimization of grassland use through a good adaptation of the compromise yield × quality is the first objective for the cattle breeder. Not every herbage is eaten by animals, so pasture evaluation must take account of intake. The best quality herbage is that of which the animal eats the greatest quantity. But there is a great lack of information about the factors of intake, probably because this is a difficult problem to solve. The first problem is that of how the animal behaves in its reaction to the herbage offered, particularly in grazing; up to what stage of growth is herbage eaten with only a small acceptable rejected proportion? How far can the sward be eaten down without the animal performance being adversely affected? The latter is easier to determine with dairy cows. The growing sward herbage intake by the grazing animal is limited in two ways *(Gillet*, quoted in *[43])*:

- A quantitative limit imposed by the height of sward above which much waste and rejects become inevitable. Herbage mass ($DM \cdot ha^{-1}$) corresponding to this stage depends on species, season and grazing method; the corresponding date in the regrowth weeks varies with the rate of nitrogen applied.
- A qualitative limit, more easily identified in the spring since it is related to stem elongation, lignification and heading; this occurs for each variety at a definite date in each region. It is more difficult to identify for further vegetative regrowths in which it depends upon criteria which, themselves, vary with the age of regrowth, season, and fertilizer level.

We have begun a theoretical study of the grazing potential of spring growth by taking account of the dominant effect of N in terms of growth rate *i.e.*, saving time in obtaining a given herbage mass *(Minderhoud et al. [44])*. This has highlighted the importance of nitrogen rate in relation to its effect on grass growth rate and thus on the date of commencing defoliation in spring and how long this first grazing could be continued, taking account of the limits previously defined *(Lemaire* and *Salette [43])*. Table 5 which expands the results given in Table 1, shows how nitrogen rate use can lead to optimize spring grazing management. Early grazing makes possibe economy in conserved forage, though it may not permit the highest stocking rate due to a longer

Table 5. Influence of nitrogen supply on the possible management of spring grazing: example with tall fescue *(growth data as in Table 1, Lemaire and Salette [43])*

	N_1	N_2	N_3	
Possible date for starting grazing (1,5 t DM ha^{-1})	April 24	April 9	April 2	
'Effective' simulated date for grazing	April 24	April 9	April 2	April 9
Possible grazing period (number of days)	7	21	23	16
Average herbage offered (kg DM/ha^{-1})	1.600	2.600	3.250	3.750
Calculated number of grazing days (days/ha^{-1}) ..	107	173	213	250
Average stocking rate (m^2·cow·day)	93	57	47	40
Grazing area needed per cow (m^2)	650	1.200	1.030	640

Table 6. Effect of nitrogen on stocking rates, liveweight gain and number of grazing days, in two pure grass swards used for beef production in Le Pin (Normandie) *(Beranger [3])*

Type of sward	Nitrogen fert.: kg N ha^{-1} year^{-1}	Stocking rate: animals ha^{-1}	Number grazing days ha^{-1}	Liveweight gain (kg): per animal	per hectare	Percent fat animals
Meadow fescue	80	2.8	470	0.99	498	95.8
	180	3.7	620	1.11	721	96.7
	280	4.3	711	1.02	754	87.0
Perennial ryegrass	200	5.1	915	0.91	905	84.6
	300	5.7	992	0.93	1027	88.8
	400	6.3	1080	0.92	1104	90.9

number of grazing days possible. Generous N fertilizer produces more growth utilized by grazing, and consequently a silage cut will be needed to achieve full utilization. This table shows how complicated pasture management may be and emphasizes the importance of fertilizer for increasing the number of grazing days. This has been stressed by many authors and is illustrated by results obtained by *Béranger [3]* with beef cattle, in Table 6.

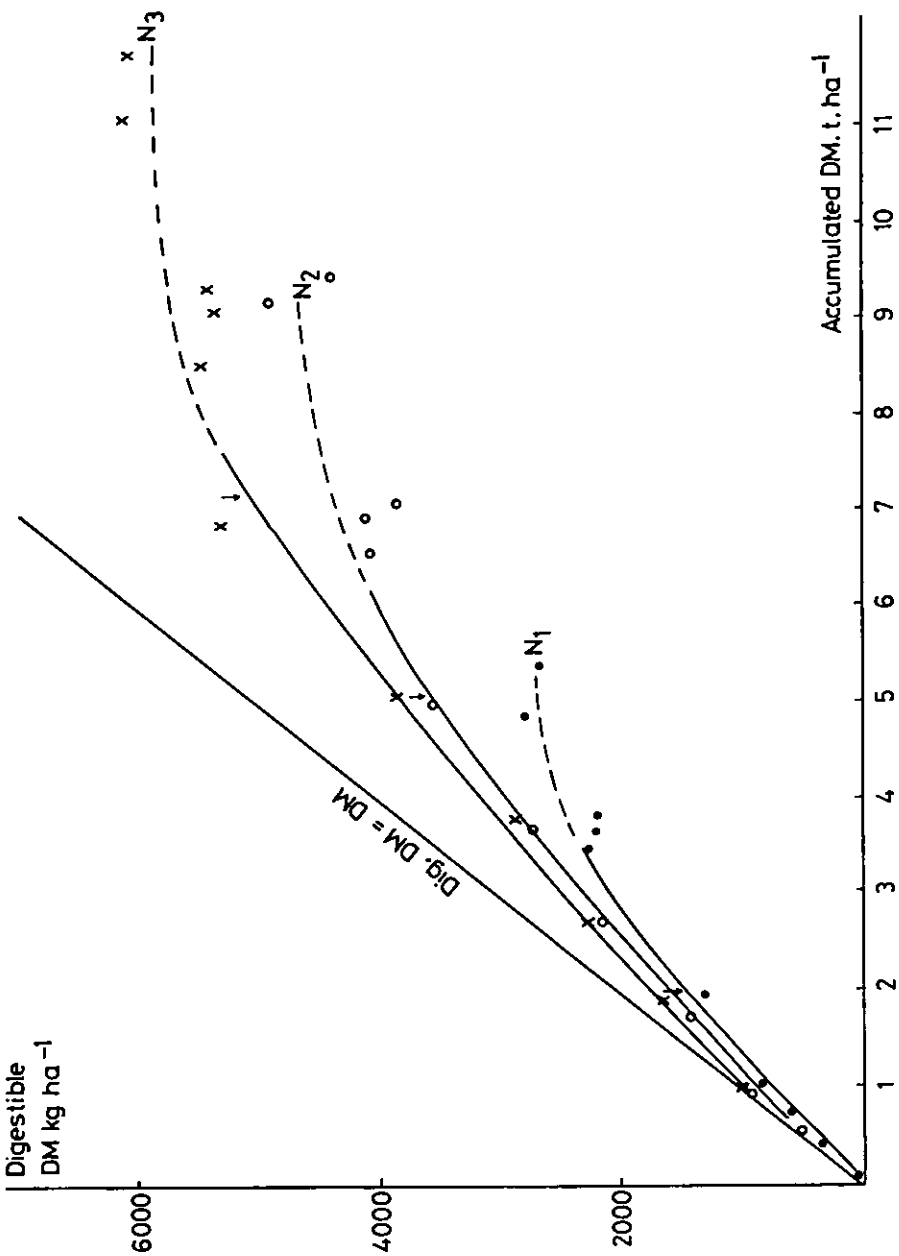

Fig.8. Accumulation of digestible dry matter (kg/ha^{-1}) during a growing period; plotted *versus* growth (represented as herbage dry matter accumulation DM t/ha^{-1}). Effect of three nitrogen rates, N_1, N_2, N_3, on spring regrowth of tall fescue (other data as in Table 1).

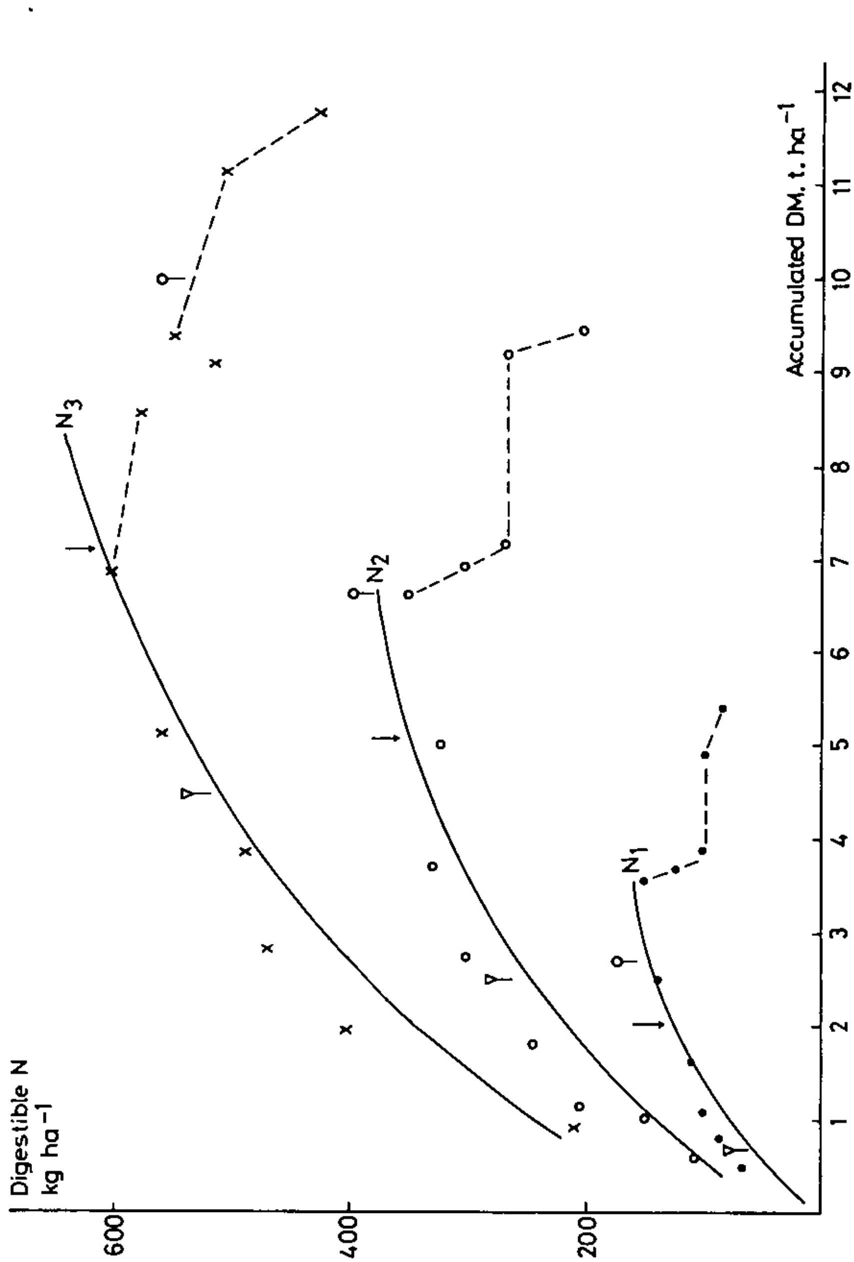

Fig. 9. Accumulation of digestible protein (dig. N, kg/ha^{-1}) during a regrowth period, plotted *versus* growth (represented as herbage dry matter accumulation DM t/ha^{-1}). To be compared with same tall fescue sward results in Figure 8. Some quality values were placed on this curve:
- Dry matter digestibility at 70%: ↓
- Total crude protein content 16%: △
- Total crude protein content 10%: ○

6.2 Possibilities of predicting and controlling herbage nutritive value

The optimization of the utilization of successive grazings involves the problem of maintaining herbage quality as the yield increases during regrowth. The problem should be expressed in terms of kinetics of regrowth (section 5) by reference to energy and nitrogen contents and their variation as related to the level of N applied (which affects the rate of growth).

By knowing the digestibility of dry matter at successive stages we can transform the growth curve DM $\cdot$ ha^{-1} = f (time) and obtain:

– (i) 'herbage digestible DM $\cdot$ ha^{-1}' = f (time)

or into a curve relating digestible dry matter to stage of growth, expressed as a function for the dry matter accumulation:

– (ii) 'herbage digestible DM $\cdot$ ha^{-1}' = f (DM)

Similarly, using the equations for the dilution of nitrogen content (section 5.1) the variation in digestible nitrogen with growth can be expressed. Using the relations between digestible nitrogen (DCP) and total nitrogen proposed by *Demarquilly et al. [20]* we have obtained for the results on the growth of fescue given in Table 1, the following equations:

$$\text{for } N_1 : DCP\% = 9{\cdot}2\ (DM)^{-0.775} \qquad r = 0{\cdot}970 \quad (4)$$

$$\text{for } N_2 : DCP\% = 43{\cdot}2\ (DM)^{-0.910} \qquad r = 0{\cdot}978 \quad (5)$$

From these curves, we can deduce the limits of date or DM herbage mass beyond which a given value of digestible DM or N contents can no longer be maintained. Figure 9 shows variation in herbage digestible N as a function of growth. This curve can be compared with Figure 8 which represents variation of harvestable energy. The relation herbage digestible N (kg/ha) = f (dry matter/ha) can be calculated from the Eq. 3 described in section 5.3 above. From values calculated from N content analysis of successive cuts in spring we obtain the following equations: (tall fescue, other data as in Table 1, 6 first cuts with the simplified relation DCP = (N × 6.25) – 4.5 according to *Demarquilly [20]*)

$$\text{for } N_1: DCP \cdot kg\ ha^{-1} = 83.02\ (DM)^{0.662} \qquad r = 0{,}963 \quad (6)$$

$$\text{for } N_2: DCP \cdot kg\ ha^{-1} = 156.7\ (DM)^{0.474} \qquad r = 0.939 \quad (7)$$

$$\text{for } N_3: DCP \cdot kg\ ha^{-1} = 260\ (DM)^{0.446} \qquad r = 0{,}936 \quad (8)$$

From the curves in both Figures 8 and 9, it appears that after a certain growth stage, beyond point no. 6 in successive cuts, in this case at ear emergence, quality falls off sharply and the curves inflect showing a break in their regularity.

In order better to adapt the use of such curves to grassland management we can include points corresponding to particular values. For example in Figure 9, 16% and 10% for DCP and 70% for dry matter digestibility.

These correspond to different yields in relation to the rates of N applied. This clear illustration of the relationships between N fertilizer and quality criteria offers possibilities for the control of quality as grassland is intensified. It would be interesting to be able to determine with experimental animals at what points on the curves the qualitative and quantitative limiting values above described (*cf.* section 6.1, and Table 5) are situated and the corresponding evolution of the intake. Such an investigation should be undertaken for the main types of grassland in a given region (species and cultivars, associations, etc.) and at different seasons. With using grazing animals on plots receiving contrasting treatments this type of approach could yield much valuable information for the improvement of pasture utilization.

6.3 The problems of grass-legume swards

We do not deal at length with these, as a very important work has been done on them. The main objective in managing these swards is to maintain a balanced botanical composition: nitrogen applied at more than moderate rates reduces the proportion of legumes and so may reduce the feeding value as well as palatability (*Demarquilly [19], Voigtländer [62]*). On the basis of the difference in seasonal growth patterns between the grasses and white clover, *Laissus [37]* proposed a method of applying N at the beginning of spring to favour grass growth before the summer without prejudicing the later growth of clover. Competition for minerals is important as it affects the balance of the association and its longevity; phosphorus is less easily taken up by legumes though their requirements are high; the same applies for potassium, grasses being able to take up less available forms which are not accessible to legumes (*Coïc* and *Bosquet [12], Chevalier [11], Steffens* and *Mengel [61]*).
Potassium fertilizer is a useful tool for controlling botanical composition and, hence forage quality, since the nutritive value is made up from the average of components of a very different composition. Palatability of grass-legume mixture is often better than that of either constituent separately. The main problem is to maintain the composition over the long term, especially under grazing.

7. Conclusions

The fertilizer policy needed to try and optimize grassland production should be considered in three stages. First, it is necessary to maintain or improve soil fertility, which constitutes a capital, and in this respect, we can remind that much grassland is situated on less fertile soils low in available P, K and Ca and fertilizers must be used to raise their fertility potential. Second, it is necessary to decide on the rate of nitrogen fertilizer to adapt growth to suit the daily needs of the herd and the climatic conditions. Finally, it is necessary to apply sufficient fertilizer to compensate for nutrients removed through harvests and grazings and other losses and to maintain the soil fertility status as well as the nitrogen and mineral balance of the herbage at the desired levels. The measures needed for optimized production will differ according to the production purposes of the farming system, they will vary between farms and between regions which both show a great heterogenity. It is necessary to match sward management and herd management; thus the type of animal (breed, genetic potential, requirements) suited to the most intensive systems are more demanding as regards herbage quality. The place of grass in the diet is the dominant factor in evaluating the benefit of the fertilizer use which should increase grass production without lowering its quality too much. We have seen how model equations could assist in matching herbage production to the different needs of different animals. However, many farmers, perhaps because they are insufficiently informed about the possible production and quality potential of their grasslands, buy from outside the farm protein and energy supplement which sometimes or several times exceed the requirements at some periods of year and only serve to decrease the amount of herbage consumed, and this is not a good choice. Furthermore, an easier management possibility is also a quality factor being facilitated by an adequate nitrogen use.

The main question is relating to nitrogen rest on the dynamics of dilution through regrowth of the grass and its seasonal variation; the grass may be too rich in N or it may contain too little. When nitrogen is used to achieve a given level of production at an earlier given time, the gain in time will correspond to the use of higher dressings. This can be compensated if the corresponding residual N in soil is being used by late silage cuts. Variation in herbage quality through the year raises other problems, *e.g.* improved utilization of autumn growth. It is most important to match the concentrates to the daily herbage allowance in order to better control factors which affect its composition and more local experimentations are needed to elucidate these matters. One result could be to make possible large economies in bought-in feeds and nitrogen fertilizer. Too many farmers who use intensive methods are inclined to apply too much fertilizer in order to be sure that they have enough to meet any eventuality, while, at the other extreme, even in European countries, alongside these there are millions of hectares of under-developed lands suffering from a great lack of fertilizers...

The low soluble carbohydrate content of grasses poses a further problem; how far would it be possible to improve this *e.g.* by plant breeding? It may be that the reason this has not been more investigated lies in the analytical problem of measuring in a reliable manner large series of samples.

In connection with mineral equilibrium within the plant and more generally as regards chemical composition, we have mentioned the concept of 'normal plant composition behaviour'. More precise information in this field will help to improve an adequate herbage diagnosis of mineral and nitrogen content in relation to fertilizer treatment.

In a general way the problem of herbage quality is to satisfy the demands made by a farming system by adapting fertilizer usage to improve time management and sward productivity: the timing of regrowth, the timing of grazing and time management. The essential objective is only to produce grass which we know how to use. It is not a simple matter as is the growing of grass for dehydration. Optimization of pasture utilization is a problem in 'variable geometry'.

References

1. *Alberda, Th.:* The effect of nitrate nutrition on carbohydrate content in *Lolium perenne.* Proc. 8th Inter. Grassl. Congr., p. 612–617 (1960)
2. *Behaeghe, T.J.* and *Carlier, L.A.:* Influence of nitrogen levels on quality and yield of herbage under mowing and grazing conditions. Europ. Grassland Feder. 5th Gen. Meeting Uppsala, p. 27 (1973)
3. *Beranger, C.:* Unpublished results cited by *Demarquilly [19]* (1971)
4. *Blaxter, K.L. et al.:* The effects of nitrogenous fertilizer on the nutritive value of artificially dried grass. J. agric. Sci. Camb. *76*, 307–319 (1971)

5. *Bouchet, J.P.* and *Guéguen, L.:* Constituants minéraux majeurs des fourrages et des aliments concentrés. *In:* Prévision de la valeur nutritive des aliments des Ruminants, INRA Publ., 189–202 (1981)
6. *Brochart, M.:* L'infécondité nutritionnelle chez les vaches. *In:* Regards sur la France. Les maladies animales. Leur incidence sur l'économie agricole. Ed. S.P.E.I., Paris, 295–330, 1972
7. *Burg, P.F.J. Van:* Nitrate as an indicator of the nitrogen nutrition of grass. Proc. 10th Intern. Grassl. Congr., 267–272 (1966)
8. *Burg, P.F.J. Van et al.:* Nitrogen and intensification of livestock farming in EEC countries. Proceedings of the Fertilizer Society Meeting, 23 April 81. London, 1981
9. *Chenost, M.:* Le Pangola et l'élevage intensif en climat tropical humide. Colloque sur l'intensification de la production fourragère en milieu tropical humide et son utilisation par les ruminants. Guadeloupe, CRAAG, Ed. INRA, Paris, 1974, 52–59, 1971
10. *Chevalier, H.:* Fertilisation azotée, phosphatée et potassique de la prairie temporaire exploitée au rythme de la pâture. Fourrages, *62*, juin 75 (1975)
11 *Chevalier, H.:* Fertilisation azotée et potassique d'associations de ray-grass d'Italie et de trèfle violet. Un exemple expérimental. Publ. SCPA, Dossier K_2O, *20*, 9–27 (1981)
12. *Coïc, Y.* and *Bosquet, J.:* Influence de la nutrition potassique et de la nutrition azotée sur le rendement et la composition minérale de plantes de prairie (dactyle et trèfle blanc) cultivées seules ou en mélange. Ann. Phys. vég., *3*, 243–260 (1959)
13. *Coppenet, M.:* Sur les variations de la composition minérale des graminées fourragères exploitées en régime de pâture. C.R. Ac. Agric., *50*, 330–344 (1964)
14. *Coppenet, M.:* Effet des sels de cuivre et de cobalt sur l'enrichissement des plantes fourragères en ces deux oligo-éléments. C.R. Acad. Agr., *13*, 923–937 (1970)
15. *Coppenet, M.:* Fertilisation intensive et qualité des fourrages. Bull. Techn. Inform., *283*, 583–591 (1973)
16. *Deinum, B.* and *Sibma, L.:* Nitrate content of herbage in relation to nitrogen fertilization and management. Proc. Int. Symp. Grassland Fed. on the role of nitrogen in intensive grassland production, Wageningen, Pudoc, 95–102 (1980)
17. *Dejou, J.* and *de Montard, F.X.:* Effet positif des fertilisations potassique et magnésienne dans les sols volcaniques du Massif Central. Publ. SCPA, Dossier K_2O, *21*, 13–24 (1982)
18. *Demarquilly, C.:* Influence de la fertilisation azotée sur la valeur alimentaire des fourrages verts. Ann. Zootech., *19*, 4, 423–437 (1970)
19. *Demarquilly, C.:* Fertilisation et qualité du fourrage. Fourrages, *69*, 61–84 (1977)
20. *Demarquilly, C., Grenet, E.* and *Andrieu, J.:* Les constituants azotés des fourrages et la prévision de la valeur azotée des fourrages. *In:* Prévision de la valeur nutritive des aliments des Ruminants, INRA Publ., 129–154 (1981)
21. *Ferrando, R., Lagneau, F.* and *Gervy, R.:* Fumure phosphatée et fertilité de la vache laitière. 5e Cong. Intern. Reprod. Anim. et Fécond. Artific., Trente, II, *39*, 304–310 (1964)
22. *Fleming, G.A.:* Mineral disorders associated with grassland farming. International meeting on animal production from temperate grassland. Dublin, 88–95, 1977
23. *Grenet, E.* and *Demarquilly, C.:* Utilisation de l'azote des fourrages verts par le mouton en croissance: influence du stade de végétation, de l'espèce fourragère, de la fertilisation azotée et de l'addition d'orge. Ann. Zootech., *26*, 481–501 (1977)
24. *Griffith, G. ap:* The nitrate nitrogen content of herbage. II. Effect of different levels of application of sulphate of ammonia on the nitrate content of herbage. J. Sci. Food Agric., *11*, 626–629 (1960)
25. *Gross, C.F.* and *Jung, G.A.:* Season, temperature, soil pH, and Mg fertilizer effects on herbage Ca and P levels and ratios of grasses and legumes. Agronomy J., *73*, 629–634 (1981)
26. *Guéguen, L.:* Etude de la composition minérale de quelques espèces fourragères. Influence du stade de développement et du cycle de végétation. Ann. Zootech., III, *8*, 245–268 (1959)
27. *Guéguen, L.:* Les besoins en minéraux chez les ruminants. *In:* Prévision de la valeur nutritive des aliments des Ruminants, INRA Publ., 1981
28. *Guéguen, L.* and *Fauconneau, G.:* Etude sur les variations des teneurs en matières azotées et en éléments minéraux de la fétuque des prés. Ann. Zootech. *10*, 2, 69–87 (1961)

29. *Hasler, A., Lehmann, V.* and *Besson, J.M.:* Einfluss einer Na-Düngung auf den Natriumgehalt von Wiesenfutter. Schweiz. landw. Forsch., *13*, 37–50 (1974)
30. *Henkens, Ch.H.:* Factors influencing the sodium content of meadow grass. Neth. J. Agric. Sci. *13*, 21–47 (1965)
31. *Holmes, W.:* The use of nitrogen in the management of pasture for cattle. Herbage Abstracts, *38*, 4, 265–277 (1968)
32. *Huguet, L.* and *Gillet, M.:* The influence of nitrogen fertilizer and autumn management on the quality of green herbage. 5th Gen. Meeting of European Grassl. Fed., Uppsala (1973)
33. *INRA:* Alimentation des Ruminants. Principes de nutrition, valeur nutritive des aliments et besoins alimentaires des animaux. Ed. by INRA Publications, route de St Cyr, 78000 Versailles, 1978
34. *Jones, D.I.H., Griffith, G. ap* and *Walters, R.J.K.:* The effect of nitrogen fertilizer on the water-soluble carbohydrate content of perennial ryegrass and cocksfoot. J. Brit. Grassl. Soc. *16*, 272–275 (1961)
35. *Juste, C., Delas, J.* and *Tauzin, J.:* Carence en soufre de la luzerne en sol de Charente. III. Interaction soufre-molybdène dans un essai réalisé en vases de végétation. C.R. Acad. Agric. *57*, 1134–1139 (1971)
36. *Kemp, A. et al.:* Grassland production and nitrate poisoning in cattle. Proc. 7th Gen. Meeting, Europ. Grassland Fed., Ghent *9*, 1–9 ,15 (1978)
37. *Laissus, R.:* Ajustement de la fertilisation azotée des prairies pâturées, en vue d'utiliser les potentialités du trèfle blanc. Acad. Agric. France, 599–615 (1981)
38. *Lamand, M.* and *Bellanger, J.:* Stratégie du dosage des oligoéléments dans les fourrages et les aliments composés, interprétation des résultats. *In:* Prévision de la valeur nutritive des aliments des Ruminants, INRA Publ., 203–212 (1981)
39. *Lambert, J. et al.:* La fertilisation phosphorique et la conduite rationnelle des herbages en région tempérée. Phosphore et Agriculture, *76*, 4–16 (1979)
40. *Larvor, P.:* Enquête sur les facteurs agronomiques et zootechniques de la tétanie d'herbage dans le Nord de la France. Ann. Zootech. *13*, 3, 277–288 (1970)
41. *Lefèbvre, J.M.* and *Joliet E.:* Etude des variations de la composition protidique et glucidique des parties aériennes du dactyle. Ann. agron. *18*, 5, 529–543 (1967)
42. *Lefèbvre-Drouet, E.:* Etude des variations de la composition minérale, protidique et glucidique des racines et des parties aériennes du dactyle (influence de la fertilisation potassique). Ann. agron. *21*, 4, 385–402 (1970)
43. *Lemaire, G.* and *Salette, J.:* Conséquences du rythme de croissance de l'herbe sur la conduite du pâturage au printemps. Possibilités de prévisions. Fourrages, *85*, 23–37 (1981)
44. *Minderhoud, J.W. et al.:* Effect of high levels of nitrogen fertilizer and adequate utilization of grassland productivity and cattle performance, with special temperate regions. Proc. 12th Intern. Grassland Congr. Moscow *1*, 1, 99–121 (1976)
45. *Moore, J.E.* and *Mott, G.O.:* Structural inhibitors of quality in tropical grasses. *In:* *A.G.Matches* (Ed.), Antiquality Components of Forages. CSSA Special Publ. 4, Crop Science Society of America, 53–98, 1973
46. *Mott, G.O.:* Grazing pressure and the measurement of pasture production. Proceedings of the VIIIth International Grassland Congress, Reading, England, 606–611 (1960)
47. *Nowakowski, T.Z.:* Effects of nitrogen fertilizers on total nitrogen, soluble nitrogen and soluble carbohydrate contents of grass. J. Agric. Sci. *59*, 387–392 (1962)
48. *Périgaud, S.*: Liaisons carentielles entre sols, végétaux et animaux. Ann. Nutr. Alim. B327–B378 (1971)
49. *Périgaud, S.:* Oligo-éléments et qualité des fourrages. Influence de la fumure minérale. Fourrages, *57*, 43–60 (1974)
50. *Périgaud, S.:* Influence de la fertilisation sur la composition minérale des fourrages et la satisfaction des besoins en minéraux des ruminants. Bull. Tech. CRZV, Theix, INRA, *21*, 4, 4–46 (1976)
51. *Raymond, W.F.* and *Spedding, C.R.W.:* Nitrogenous fertilizers and the feed value of grass. *In:* Proceedings of the First General Meeting of the European Grassland Federation Wageningen, 151–160 (1965)
52. *Reid, R.L.* and *Horvath, D.J.:* Soil chemistry and mineral problems in farm livestock, a

review. *In:* Animal Feed Science and Technology, *5*, 95–167. Elsevier Scientific Publishing Company, Amsterdam, 1980

53. *Salette, J.:* Seasonal pattern of forage growth and related characters in humid tropical conditions. Colloque sur l'intensification de la production fourragère en milieu tropical humide et son utilisation par les ruminants. CRAAG, Guadeloupe, Ed. INRA, Paris, 1974, 93–99, 1971
54. *Salette, J.:* La fertilisation de la prairie: principes, problèmes et perspectives. Fourrages, *62*, 177–202 (1975)
55. *Salette, J.:* Sulphur content of grasses during primary growth. Symposium on Sulphur in Forages, Wexford, Ireland, Publ. Sulphur Institute, 143–152, 1978
56. *Salette, J.* and *Dumas, Y.:* Constantes de comportement de *Digitaria decumbens* Stent.: Relation entre la teneur en azote et le rapport feuilles/tiges; influence de différentes conditions de milieu. C.R. Acad. Sc. Paris, *271*, série D, 200–202 (1970)
57. *Salette, J.* and *Dumas, Y.* and Constantes de comportement de *Digitaria decumbens* Stent.: Relation entre les teneurs en azote et en matière sèche; influence de différentes conditions de milieu. C.R. Acad. Sci. Paris, *271*, série D, 324–326 (1970)
58. *Salette, J., Dumas, Y.* and *Sobesky, O.:* Eléments d'écologie des herbages à Pangola dans divers milieux des Antilles françaises. II. Données sur les éléments minéraux chez *Digitaria decumbens* cultivé dans divers milieux. L'Agronomie tropicale, *28*, 833–845 (1973)
59. *Salette, J.* and *Lemaire, G.:* Sur la variation de la teneur en azote des graminées fourragères pendant leur croissance: formulation d'une loi de dilution. C.R. Acad. Sc. Paris, *292*, 875–878 (1981)
60. *Smith, P.F.:* Mineral analysis of plant tissues. Ann. Rev. Plant Phys. *13*, 81–108 (1962)
61. *Steffens, D.* and *Mengel, K.:* Comparaison de l'absorption du potassium interfoliaire des minéraux argileux par le ray-grass anglais et le trèfle violet. Publ. SCPA, Dossier K_2O, *20*, 5–8 (1981)
62. *Voigtländer, G.:* Nitrogen fertilisation and yield of permanent Grassland. Proc. 1st Gen. Meeting European Grassl. Fed. Wageningen, 93–104 (1965)
63. *Waite, R.:* The water-soluble carbohydrates of grasses. IV. The effect of different levels of fertilizer treatment. J. Sci. Food Agric. *9*, 39–43 (1958)
64. *Whitehead, D.L.:* The role of nitrogen in grassland productivity. Bull. 48, Comm. Bur. Pastures Fld. Crops, Hurley, England, 202 p., 1970
65. *Wolf, H.:* Beeinflussung des Natrium- und Magnesium-Gehaltes im Weidegras. Wirtschaftseigene Futter *17*, 3, 190–197 (1971)

Co-ordinator's Report on the 2nd Session

Optimization of Animal Production Based on Optimum Crop Production

Th. Walsh, Council for Development in Agriculture, Dublin/Ireland*;
Member of the Scientific Board of the International Potash Institute

Background

Looked at in the context of the subject of this Congress, there is a highly significant difference between measuring the efficiency of nutrient use in crop production compared with animal production systems. In the former, the yield and quality of the crop produced can be measured directly, while in the case of the animal the primary production, *i.e.* pasture or crop used for fodder or feed, is consumed and transformed into a saleable animal product *i.e.* meat, milk or wool. In the ultimate analysis, it is the amount of such product produced by the fertilizer input, that determines the efficiency of nutrient use. In effect the intervention of the animal very much complicates the position.

This complexity is clearly shown in the papers presented at the session, efficiency being largely determined by the way pasture is utilized – the sort of animals being fed, how they are managed, how pastures are grazed, seasonal aspects of yield, the nature of supplementary feed, animal health, market prices and a host of other factors. An important principle in animal management determining efficiency, is that the animal must have sufficient feed over its whole productive lifetime. In pasture growth on the other hand there are seasonal peaks and troughs and these must be managed to meet animal needs. The added complication that nutrients ingested in grass or feed may be deposited by animals in the form of urine or faeces or returned in the form of slurries and other residues, with the possibility of loss, brings into focus the question of nutrient recycling. There also arises the question of gains through a number of sources, *i.e.* nitrogen through legumes; sulphur, nitrogen and other nutrients in rainfall; deep rooting plants; and oxygen and carbon dioxide through respiration and photosynthesis. On the other hand losses can arise through erosion, leaching, excretion and respiration. These factors are all of importance in the optimization of nutrient use, while in addition the actual quantity of product produced must come into the picture. In dairying, for instance, the quality of the herbage available is of very great importance: a slight lowering in the digestibility of the dry matter in silage may lower milk yields in a significant way – such, for instance, as can occur from delaying harvesting beyond the optimum time, even a day or two. A striking example of this was provided a few years ago by one of my

* Dr. *Th. Walsh*, Director, ACOT, Council for Development in Agriculture, Frascati Road, Blackrock, Co. Dublin/Ireland

colleagues *(McCarrick*)*. He showed that from applying the same quantity of nutrients to a pasture, part conserved as hay and part as silage, animals fed the latter had a much higher carcase gain per unit liveweight gain than those fed on hay. A similar effect is noted by *Kemp* in his presentation here. The highly complex nature of the whole system has been clearly illustrated by *Salette* when dealing with the factors which influence variability in the mineral composition of herbage. He has, for instance, listed such factors affecting composition as soil differences and climatic changes, the physiological state of the plant tillering pattern rate and time of regrowth, interaction between nutrients, and dilution effects.

In the circumstances and because of the extent of the subject being covered, it is impossible in this co-ordination paper, to deal in any sort of meaningful way with the many important issues raised in these papers. Of themselves they are essentially a condensation of much factual material and research. At best one can deal with a few of the main topics raised and these are now discussed.

The importance of grass as a crop in intensive animal production systems

In the paper by *Balch* and *Cooke* it is shown that in terms of energy fixed, pasture is very much ahead of other crops. While the given figure of 12 t/ha of dry material is high, some recent data from this country has shown a level of some 18 t/ha from Italian rye grass swards for silage. In terms of cost per unit of energy and protein, grass is also pre-eminent, and consequently for the efficient low cost production of animal products, is a primary and highly valuable resource.

All three papers presented are largely concerned with intensive animal production. In this connection the main production factor concentrated on is nitrogen. This is only right, as this nutrient is the major yield and quality producer. It is shown in the papers that response to nitrogen can be evaluated in many ways and these have been adequately dealt with, with emphasis on the complicated nature of response effects. In this respect alone these papers contain much valuable material.

One must direct special attention to the interaction of nitrogen with many other elements, *e.g.* phosphorus, potassium, magnesium and practically all the essential trace elements. In the case of P, as pointed out by *Salette*, N at high levels of application can dilute the phosphorus content of herbage, to a point where the latter would be insufficient to meet the needs of high producing dairy cows. It would be rewarding to pursue these interactions further, as without sufficient other nutrients either major or trace, nitrogen response effects could be limiting. For instance, sulphur deficiency cannot be made good by nitrogen application, but rather the opposite – an experience which has emerged very clearly from recent work in my own country.

A point which does not emerge clearly from the papers is that relating to the effect of nitrogen on the soil as such, and indeed the demands, which under the impact of high N use can be made on some soils, especially trace element-wise, where some of these under existing soil conditions, may be near deficiency level, but were sufficient to meet the demands of low production, traditional agriculture. While the vital role of nitrogen is understandably a major theme of all these papers, in our experience where forage

* *McCarrick, R.B.:* Proceedings 10th International Grassland Congress, Helsinki (1966)

production is so important, the role and behavior of potassium would also have merited special attention – without it production rapidly declines.

The recycling of nutrients – a key factor

In most animal production systems there is a wide scope for nutrient loss. This is clearly shown in the paper by *Balch* and *Cooke* – only some 10% of the nitrogen applied in fertilizers being recovered in meat. However, it is emphasized by the authors that with the high amount of nutrients released from the animal in the form of faeces and urine, great care must be taken to recover these nutrients and recycle them for soil fertility building. The patchy effect of urine and dung deposited by animals on pastures under grazing is well known to everyone, leading to differential growth in pasture and setting problems in management. It is of interest that the growth of coarse grass produced in this way from cattle excrement can be efficiently utilized by sheep, giving a substantial yield benefit in mixed grazing sytems.

It would be difficult to over-emphasize the need for effective management of these animal voided nutrients. Indeed, the approach of *Balch* and *Cooke* and the other authors, revolves around an understanding of nutrient balance effects in soil under intensive pasture management conditions. As yet, however, we know little enough about how different soils are affected in relation to such matters as organic matter content and its mineral composition and distribution, and oxidation/reduction conditions, so important to many aspects of nutrient release and pasture growth.

The complexity of these systems

Balch and *Cooke* draw attention to a host of factors important in intensification and of how input/output energy and nitrogen relationships are involved in such systems. The critical role of animal appetite is emphasized, while attention is given to the economic significance of a per unit area or per animal response approach, there being a substantial difference in this respect between meat and milk production. Stocking rate and system of grazing *(i.e.* rotational paddock grazing or set stocking) are other key efficiency based considerations and here animal behavior studies are important, *i.e.* how much energy does an animal expend in the actual process of grazing. The complexity of the components involved and their highly interactive nature clearly emerges from this and other papers. The need, therefore, to take a farm system as a basic unit in the context of which component research should be undertaken is important. There are, in fact, very few examples of a research approach along these lines as of now.

The importance of effective management

Kemp's paper presents another very important aspect of intensification. In all our countries the quality of forage is fundamental in the provision of an adequate level of nutrition throughout the lifetime of the animal. In this respect nitrogen has a major

role in the production of silage or hay for forage purposes during the winter period. Where production peaks, as in most of our countries, in April and May, it is important to have management systems designed to use this peak production, either through higher stocking or conservation as forage. This requires effective management, basically of fertilizer inputs realizing that, at best, only some 80% of the grass crop produced will be harvested. *Kemp* lays special stress on the excess use of nitrogen, and in this respect in dealing with the effects of nitrate accumulation in tissue he has opened up an important field for further consideration. It is important to note the wide range in nitrate nitrogen content of herbage, *i.e.* varying from 0.1 to 10% NO_3 – levels which could follow the use of high nitrogen or nitrogen supplemented slurries.
Kemp has also drawn attention to the important management fact, that the nitrate supplied in freshly mown grass, can give rise to much lower methaemoglobin values in blood than those arising from hay or pre-wilted silage. This is an important point in herbage utilization.

The mineral content of herbage

He has also placed special emphasis on macro and trace elements, dealing especially with problems which have emerged in his own country in relation to hypomagnesemia and sodium deficiency. In my own country we have had special experiences in this matter. In both his paper and that of *Salette*, there is considerable stress on trace element aspects of deficiency and toxicity, the difference in plant and animal requirements in this respect being especially significant. It is a fact that while this subject is very important and that while now much is known about the specific effects of important trace elements, very little in the way of systems based quantitative data is available, *i.e.* the effects systematically evaluated quantitatively in terms of animal products through a complete production cycle. This is a major deficiency. (The papers of both *Salette* and *Kemp* deal with seasonal variation in the mineral content of herbage, both major and trace.) These variations are shown to be important, leading to seasonal occurrence of some deficiency problems. This information is especially relevant also when pasture herbage analysis is proposed as a diagnostic method, the simple question arising as to from what part of the plant and what stage of growth should the sample be taken.

More attention to nitrogen fixation by legumes desirable

In considering these papers in the context of the optimum use of fertilizers on pastures, there is one aspect, which while mentioned, has not perhaps received sufficient attention. It is accepted that the manufacturer of nitrogenous fertilizers is very demanding on energy sources. On the other hand, legumes properly managed can be significant to both the nitrogen and energy economy of pasture systems. While the antagonism between fertilizer N and legume N is well established, I would like to have seen some aspects of those management practices which can help to make the best of both forms in a complementary fashion addressed in these papers. In my country we have a special need to optimize the use of nitrogen from legumes in efficient pasture production. There is a management dilemma, however. In order to produce early grass for grazing and to ensure high yields of high DMD silage, nitrogen must be used. We also need, however, to ensure the best possible contribution from clovers in terms of containing production costs.

Obviously a two sward system has advantages in this respect, but this requires new management knowledge. This is a field where more research is urgently required, not alone because of the low energy and low cost aspects of grass-legume swards, but also because of the known superior feeding value of such swards. In this respect potassium, because of the higher requirement of clover for this nutrient, is of major importance, while trace elements have also an important role in the fixation process. An immediate objective must be to step up the efficiency of the fixation process. Again, one might have expected in this session some attention to those other forms of nitrogen fixation in the rhizosphere of some plants, now the subject of increasing attention in warmer climates.

Natural pastures as ecological complexes

By and large the papers presented have dealt with the monoculture of pasture plants. While under intensive conditions this is a developing trend, much grassland development work is concerned with multispecies pastures, where ecological concepts of competition and interaction intervene, and where under such conditions the optimization of fertilizer use becomes more difficult. For instance, as mentioned before, legumes have higher potassium requirements than rye grasses, while also under certain soil conditions, clover plants have, for instance, a capacity to absorb higher amounts of Mo than grasses, inducing hypocuprosis in ruminants. The same applies to a number of other elements, some plants in effect being accumulators.

These ecological considerations are of special importance when considering changes in the management of pastures and range and difficult lands in many parts of the world, where to intensify production, management practices may require the confinement of animals to smaller areas than under extensive grazing. For instance, cobalt deficiency has occurred in sheep under such circumstances, as their capacity to hunt for cobalt efficient plants under natural grazing conditions is reduced. In essence, under natural conditions the good farmer or the good adviser must be a good ecologist, *i.e.* be able to intelligently read the pasture flora as a basis for management information.

Making effective use of the world's potential pasture land

Much of what has been presented in these three papers deals with animal farming systems under intensification. However, *Balch* and *Cooke* have rightly pointed out the need, world developmentwise, to consider in a more comprehensive way the systems required to optimize production under extensive agriculture – in hill, mountain and wasteland areas where traditional systems of production still hold back the economic and social well-being of many people. The very size of what has to be tackled in this respect is daunting. For instance, *half* of the land area of the world is in the tropical region of 30° N–30° S, which carries *half* of the world's ruminant animal population, but which now produces less than *one-third* of the world's meat and *one-sixth* of the world's dairy production. It is imperative now that this problem should be tackled, as there are important benefits to be derived, not only in relation to increasing the quantity of human food in deficient areas, but also its quality in terms of animal protein – a major need.

Final remarks

It has been very difficult to deal adequately with papers of such a comprehensive and important nature as these, in this short co-ordination document. The papers clearly show not only the problems inherent in the development of efficient animal production systems, but they also point up the solutions which are gradually emerging from the research under way. These papers constitute a highly important reference source either for the student, the teacher, the adviser or the research worker, and I have no doubt that as they become available they will be used extensively and rewardingly as a valuable reference source.

12th Congress of the International Potash Institute
June 1982 at Goslar/Fed. Rep. of Germany

3rd Session

New Policies in Crop Utilization and Fertilizer Use

Co-ordinator *Prof. Dr. I. Arnon*, Settlement Study Center, Ramat Gan/Israel; member of the Scientific Board of the International Potash Institute

Alternative and Renewable Sources of Energy

W. Seifritz, Swiss Federal Institute for Reactor Research, Würenlingen/Switzerland*

Summary

The paper reviews the use of biomass as a source of energy and shows from a number of examples, particularly the growing of sugar beet for the manufacture of ethanol, that this way of producing fuel is not desirable.
On a world basis it is possible that there might be a confrontation between the needs for 'food' and 'technological' calories of which there is already a hint in the so-called 'energy crop strategy'. In conclusion, given the present world food supply position, the intensification of food production should be given priority over attempts to produce fuel from biomass and we should not aim to use the photosynthetic process to provide technical calories.

'*While the affluent are trying to fill their gas tanks the poor are worrying about food shortages.*'

('Newsweek', July 14, 1980)

1. Introduction – the basic questions

Some 10 000 years ago mankind began to practice a settled agriculture in the Middle East. The energy inputs for this extensive form of agriculture were first and foremost the energy provided by the sunlight (for the photosynthetic processes of plant growth), the labour of his own hands and the muscle-power of animals for sowing and harvest. The use of domestic animals to assist in cultivation was only justified from the energetic point of view because the food requirements of the animals did not overlap man's own needs. In today's intensive and highly mechanised farming, the muscle power of man and animals, and even the energy from the sun, no longer play such a dominant role as in the early more extensive husbandry. Nowadays the main energy inputs into agriculture are made up from fertilizers, pesticides, agricultural machinery, fuel and wages to the extent that the required enery input per unit time in these forms is greater than the food energy which can be harvested.
Modern agriculture is – from the purely energetic point of view – an endothermic process. Even so, agriculture is still a perfectly sensible pursuit because a calorie of food energy is infinitely more valuable than a calorie of primary energy. For instance, a steak with trimmings in a restaurant costs about DM 15 and has an energy content

* Prof. Dr. Ing. *W. Seifritz*, Swiss Federal Institute for Reactor Research, CH-5303 Würenlingen/Switzerland

of about 1000 Kcal. Its 'energy price' is thus about 13 DM per kWh – more than one hundredfold the price of electricity or pretty nearly three hundred times the price of crude oil at $ 34/bbl*.

The example shows that, despite the inherent negative energy balance, it is sensible to use agriculture to transform coal, oil, gas or nuclear energy into food calories – man cannot use primary energy directly.

To show how the agricultural energy balance works out in the production of protein, so essential for man, several examples can be given from practical agriculture (Table 1).

Table 1. Energy yield of various crops [1]

Crop	Food energy yield (10^6 Kcal)*	Labour (man hours)	Ratio: Kcal protein output to Kcal fossil fuel energy input
Soya bean	7.6	15	0.49
Potato	20.2	60	0.24
Rice	21	30	0.1 (!)
Wheat (USA)	7.5	7	0.29
Wheat (India)	2.7	615	1.54
Hay	8.6	16	0.26

* US-values per hectare

Practically all the 'harvest ratios' are below unity, underlining the endothermic nature of intensive agriculture as postulated above.

The energy conversion looks even worse for the production of animal protein as shown by the examples in Table 2 *[1]:*

Table 2. Output: Input energy ratios for animal products

Produce	Protein output Fodder input ($\times 10^{-3}$)	Protein output Fossil energy input ($\times 10^{-3}$)
Milk	33.3	28
Eggs	50	76
Pork	40	28
Beef	8.2–6.1	12.9–99
Lamb	5.3	62

Egg production makes the best use of fodder and energy inputs, but, even in this case, to obtain utilisable animal protein requires generally 10 to 40 times the amount of fossil energy. These ratios are further illustrated in Figures 1 and 2 which relate to US conditions. US agriculture uses about 12% of total national energy supply, roughly 1 kW per inhabitant *[2]* and one US farmer can today grow enough food for 50 people not engaged in agriculture. Within a period of 30 years (1940–1970) the labour requirement of US agriculture has reduced by a factor of four, while at the same time its energy requirement grew by 2½ times. So human and animal muscle power has been replaced by mechanisation.

* 1bbl = barrel = 159 l

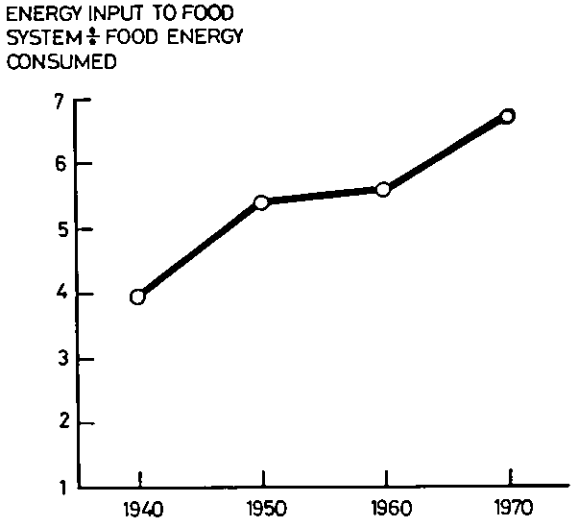

Fig. 1. Energy input to food energy consumed by years

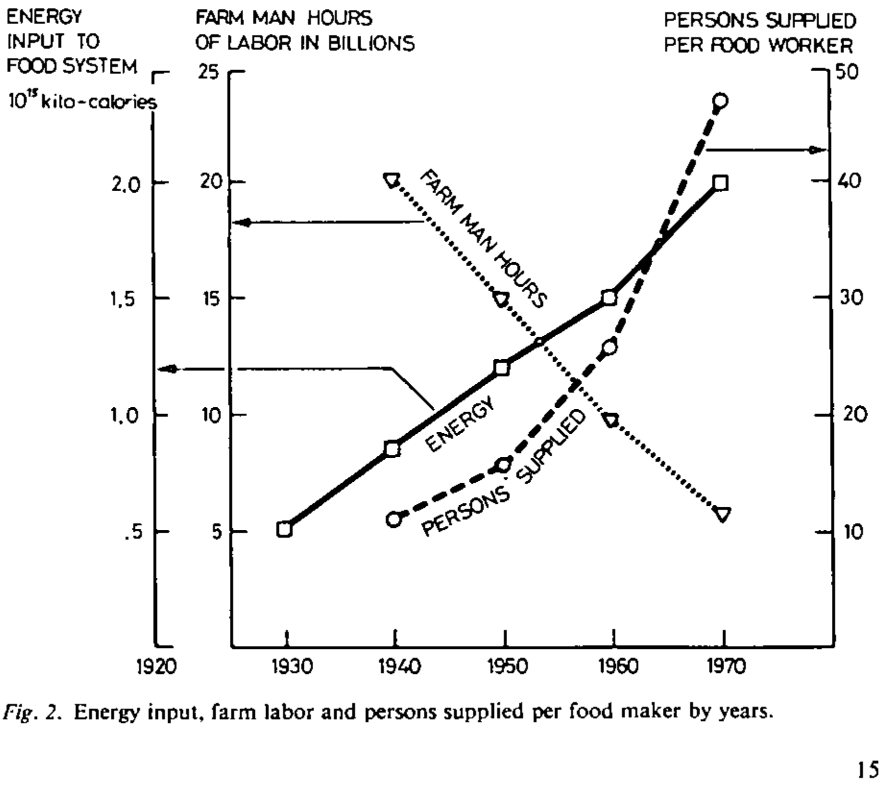

Fig. 2. Energy input, farm labor and persons supplied per food maker by years.

One other relationship may be of interest in this connection: in terms of incident sunlight (at this latitude about 120 W/m^2 through the year) the efficiency (Combustion heat of biomass/energy incident sunlight) of crops varies from a few per thousand to a maximum of a few per cent. A good average value for the growing season would be about 0.9%, or an average over the year of 0.6%.
As a converter of sunlight energy into the heat content of wood, the Swiss forest has an efficiency of only about 1 per thousand.
In the face of such low energetic efficiencies, does it make any sense to talk in these days about using renewable biomass to produce technical calories rather than high value food calories? Whether this might prove to be of practical value in contributing to energy conservation would depend on the answers to the following questions:

a) Would the production of one 'biomass calorie' (for example in the form of wood, ethanol, methanol or biogas) require more or less than one 'primary calorie', in other words is a conversion factor sufficiently good? The conversion must be much more efficient than unity, since the argument used in the case of food calorie production no longer holds: a biomass 'fuel' calorie is only marginally, or not at all, to be valued above a calorie of primary energy. This is particularly true if the 'utility' of the biomass calorie is the same as the primary energy (*e.g.* if both are liquid fuels). Furthermore in contrast to food, biomass energy gives no particular pleasure; there is no pleasurable sensation when producing biomass fuel.

b) Because the photosynthetic efficiency of biomass production is low the land surface required to make any significant contribution to energy supply would be very large. Is there sufficient land? For example to maintain a power of roughly 30 MW (corresponding to about 40 Million litres of ethanol per year – the typical size of an alcohol factory being two orders of magnitude smaller than a typical future coal liquefaction plant) a sugar beet area of exactly 100 km^2 is necessary.

c) The production of biomass energy must compete with the growing of food. If the former were to take priority over the latter we should be entitled to ask the question 'Will the automobiles of the rich be permitted to eat the bread of the poor?'

The examples discussed below lead to the conclusion that in our latitude the production of biomass energy is neither energetically nor economically sound. It might nevertheless be justifiable simply as a means of providing work in some sectors of agriculture or in some agricultural areas but even then one would be disregarding the fact that it is not energetically efficient. In any case the potential of biomass fuel is very limited and can never be considered to substitute oil completely.

2. Examples of ethanol production

The classical way of converting biomass into liquid fuel is by fermentation of sugar and starch containing crops to ethanol. The method can be compared with the production of methanol by the gasification of coal; in both cases the product is an alcohol. Table 3 lists ethanol yields obtainable from the most important crops in US agriculture *[3]:*

Table 3. Alcohol yields of crops

Crop	Average yield (t/ha)	Ethanol yield l/ha
Corn	6.2	2002
Wheat	2.2	739
Grain sorghum	3.9	1169
Potatoes	32.25	2797
Jerusalem artichoke	22.2–49.4	1684–4677
Sugar beet	50.9	3853
Sugar cane	90.2	5191
Sweet sorghum	—	4677
Rice	5.7	1712
Oats	2.0	477
Rye	1.7	514

Taking about 5600 Kcal per liter (7100 Kcal/kg: $\rho = 0.79$ g/cm^3) as the energy content of ethanol, the most interesting crop for our latitudes, sugar beet, has an average energy yield of 0.28 W/m^2. Taking the average annual insolation of the Federal Republic of Germany as about 120 W/m^2 this corresponds to a photosynthetic efficiency of less than 3 per thousand. This figure expresses the very low production of biomass energy per unit area of land.

It is a complicated matter to establish whether alcohol production yields more energy than has to be put into the system in the form of primary energy; the answer depends upon the method of calculation, as indicated:

a) Sugar cane has the advantage over beet that the by-product (bagasse) can be burned to provide energy for the distillation process. In the case of sugar beet there has to be an energy input.

b) Several authors do not account for the energy input hidden in the capital investment, equipment, transportation, labor, etc.

c) The ethanol yield is compared with energy input, such as for instance oil only *[4]* whereas there are, in fact, various other energy inputs (coal, electricity, nuclear power) while the energy element in capital investment is not taken into account. In such a way one can arrive at any result one desires.

The reckoning can only be economically sound if it takes into account not only the obvious energy inputs (like fuel for harvesting machinery etc.) but also the energy involved in capital, wages, housing of machinery and so forth.

These considerations become particularly important when one compares the Brazilian sugar-cane programme and a proposal for a German sugar beet project. Wage levels, land availability and general living standards are so different that the conclusion will be entirely different in the one case from the other.

To cover only 20% of the Brazilian fuel demand would require – even though several harvests per year are possible – the planting of sugar cane on an area the size of Belgium. Today an area of about 5059 km^2 (just about ten times the area of Lake Constance) in Brazil is devoted to growing sugar cane and cassava for alcohol production *[5]*. Brazilian conditions are 'favourable' for such an enterprise: cheap labour, climate suitable for sugar cane, and almost limitless cheap land. Such conditions do not apply here.

Neither should one disregard the environmental consequences of ethanol production; each litre of ethanol from biomass results in 12 litres of poisonous waste which today in Brazil is mostly discharged into the rivers *[5]*.

Most of the alcohol produced in the USA is manufactured from grain. According to the *American Institute of Chemical Engineers*, the resultant price for ethanol (inclusive of current subsidies) is US $ 0.42–0.45 per litre, equivalent at 1 US $ = 2.35 DM to 1.1 DM per litre. The energy content of ethanol is only 60% that of petrol, so this figure corresponds to petrol at 1.8 DM/l as compared to today's price of 60 Pf (price exclusive of tax).

3. The example of Euphorbia lathyrus

Melvin Calvin of the *University of California* thinks it would be possible to produce a petrol substitute from a type of caper spurge *(Euphorbia lathyrus* L.) which produces a carbohydrate-rich whitish sap. He gives the energy yield as the equivalent of 10 bbl per acre per annum at a price of $ 40/bbl, *i.e.* 3929 l oil at $ 0.25/l.

The energy yield per unit surface is calculated as:

$$\frac{3929\ \text{l oil}}{\text{ha}} = \frac{4.57\ \text{kWh}}{\text{m}^2 \cdot \text{year}} = \frac{0.52\ \text{W}}{\text{m}^2}$$

The average German motorist covers 15 000 km in a year and his average petrol consumption is 10 l/100 km. The average power thus corresponds (1 l petrol ~ 10 000 Kcal) to about 2 kW. If this motorist were to obtain his fuel from a *Euphorbia* plantation it would be necessary to reserve for him an area of 2 kW/(0.52 W/m^2) = 0.385 ha. at a cost price of only 10 DM/m^2 the charge for completing the purchase alone would be almost 40 000 DM which is about double the price of his car. Quite apart from this aspect there is not enough land to supply the fuel needs of a substantial part of motorists.

In 1980, the Federal Republic used 47.5 mio t coal equivalent (SKE) as oil, taking the equivalent (1 SKE = 7000 Kcal) that is about 44 GW. If this amount of oil were to be replaced by *Euphorbia* or sugar beet (av. energy yield 0.4 W/m^2) we should require an area of 110 000 km^2 [44 GW/0.4 W/m^2] which is half of the total area of the Federal Republic.

These examples show how demanding of land is the production of energy from biomass. The underlying cause is the naturally inefficient photosynthetic process.

4. Petrol from sugar beet in Western Germany?

Discussion of the possibility of producing fuel from biomass in the Federal Republic can, for various reasons (relatively high photosynthetic efficiency, suitability of the climate, available infrastructure, etc.) only realistically be based on the sugar beet crop. The chair of marketing research at the University of Bonn has carried out a study *[6]* from which emerges:

Even using the best available techniques, an alcohol factory at the present level of prices and costs could pay the farmer only 14.4 DM per tonne for roots if it were to make any profit. In the most recent beet campaign the farmer received 94.4 DM for A class roots (with full guarantee) and 67.1 DM for B class roots (with limited guarantee).

A decisive point is the fixing of a price for ethanol. The author has proposed 0.82 DM per litre but this is too low for profitable production from beet. To compete with sugar production would require a price of 1.48 DM/l to correspond with the producer price for B roots, or 1.76 DM for A roots. True enough the present price of ethanol is higher than the proposed 0.82 DM (1.34 DM per litre) but if there were large scale production from beet, the price on the market would be appreciably depressed, say the authors.

According to this study ethanol from sugar beet would only be competitive if the price of oil were again to rise three- or fourfold. But this increase in energy cost would lead to a sharp rise in the price of agricultural produce. The price of sugar would also rise sharply making ethanol production again uneconomic. Evidently alcohol production would only be possible with state involvement (prohibitions, compulsory purchase).

The study further concludes that it would not pay to breed a variety of root especially for fuel production, as plant breeders have proposed; the present varieties are well-suited. Again, it would be uneconomic to give up the export of surplus sugar in favour of ethanol production; the losses involved in export subsidies being in general less costly than the subsidisation of ethanol manufacture. There would be no benefit to the German trade balance.

Result: The winning of ethanol from sugar beet must remain a dream, at least for the Federal Republic and the European Community. Although technically possible, it does not make economic sense. The future outlook, even if price relationships change, gives little hope of profitability. The practical possibility of exploiting modern biotechnology and gene manipulation for the breeding of special 'energy' crops can at the present stage be dismissed as pure speculation.

5. Energy from waste?

The biomass available today in the Federal Republic (forest litter, wood by-products, straw and animal excrement) is equivalent to about eight million tonnes coal equivalent per year *[7]*. It is conceivable that the use of 5 mio t of the annual total of 25 mio t straw could theoretically substitute coal equivalent for about 70% of German agriculture's heating oil requirement (ca. 1.3 mio t).

Timber residues in the Federal Republic correspond in energy content to about 4 mio t heating oil per year *[7]*: However, the costs of collection, transport, storage and preparation of straw and wood militate against the systematic use of these residues. Available straw-burning equipment is said to be not yet efficient. Further, the use of biogas from plant and animal wastes as tractor fuel is not yet thought to be economic.

On the other hand the heat made available by the cooling of milk is already used for heating water on about 8000 farms.
Result: Even the agricultural lobby sees little prospect for the economic use of biomass energy.

6. Biomass energy: Food hunger versus energy hunger

Irrespective of arguments about the economics or the demand for land, for me, the strongest counter-argument against a world-wide drive to use more biomass for the provision of energy is the inevitable conflict with food production. The slogan, 'Is the rich man's car to be allowed to steal the bread of the poor?', is widely heard. The *World Bank* is itself concerned that there is a possibility that too much food will be sacrificed to provide fuel: 'It is necessary to raise an alarm' *[8]*.
Such thoughts are underlined by the following calculation which I often quote in this context. This refers to ethanol from grain (wheat) *[3]:*

$$\frac{2.57 \text{ gallons}}{\text{bushel}} \triangleq \frac{94.4 \text{ gallons}}{\text{ton}}$$

$$\triangleq \frac{357 \text{ litres ethanol}}{\text{tonne wheat}}$$

$$\triangleq \frac{215 \text{ litres petrol equiv.}}{\text{tonne wheat}}$$

As noted above, the average motorist uses about 1500 l petrol per year, which means a 'wheat equivalent' of 1500/215 $\sim$ 7 tonnes wheat per year which could better be used as a food supplying protein for mankind. Even worse a tonne of wheat contains 120 kg protein *[1]* or, *1 kg protein corresponds very nearly to 2 l petrol* – world protein supplies in 1975 totalled 122 million tonnes.
The question now arises as to which is more important in view of the world food problem, particularly in the developing countries; protein or fuel? To feed the motorcars of the rich countries with biomass ethanol from grain would use 1.5 t grain per head of the population – almost 8 times as much per head as is available as food in the Third World.
A committee of experts called together by *FAO* in summer 1980 tackled the theme '*Energy Cropping versus Food Production*' and the problem was further considered by the *Agricultural Committee* of *FAO (COAG)* in April 1981 and again by the *Committee for World Food Security (CFS) [9]*.
The *COAG* concluded that 'energy cropping' except in a very few countries was up to now only in the experimental stages but that the 'use of food materials to provide energy would be in some cases disadvantageous to the food-importing countries and particularly so to the poorer sections of their populations'. Further development depended upon the general price structure for energy on progress in conversion technology and in crop potential, in which there would be expected to be very large differences from country to country. The core of the *COAG* report stated: 'The

potential competition between food production and the provision of 'green' energy is directly relevant to the problem of the security of world food supply'. The *FAO* Secretariat was enjoined to monitor carefully the problems involved (particularly changes in price and availability).

The *Committee for World Food Security* agreed with this conclusion. The USA delegation reported that only about one per cent of the grain supply of the USA was being used for ethanol manufacture and that the underlying policy considerations were under active review.

Now, a concluding word on the energetic role of fertilizers: as is known, arable crops can convert 600 kg nitrogen per hectare into organic substance, and, under the most favourable circumstances as much as 1600 kg *[12]*. These quantities of N are not available in any natural soil and must be supplied by fertilizers. Each kilogramme of N applied to a crop can produce a grain yield increase of 10 kg. The manufacture of N fertilizer depends up to 90 per cent on the chemical reaction between atmospheric nitrogen and hydrogen derived from fossil fuels – natural gas or oil. The energy required to produce one tonne N as fertilizer is about 1.5 t coal equivalent (= 10 500 Kcal) and, in turn, this will produce 10 t grain. Thus oil and gas are important raw materials of agriculture. The desperate world food situation means that there is no practical alternative to the use of fertilizers. The slogan 'back to nature' can solve none of agricultures energy problems.

Figure 3 represents diagramatically the contribution of energy in its various forms to agriculture *[12]*. A good 70 per cent of the energy used in German agriculture is made up from fertilizer and fuel alone. Fortunately, the fossil energy input to fertilizer manufacture could be substituted by nuclear energy (electrolysis of water with nuclear electricity) so that nuclear energy can contribute (indirectly) to crop production.

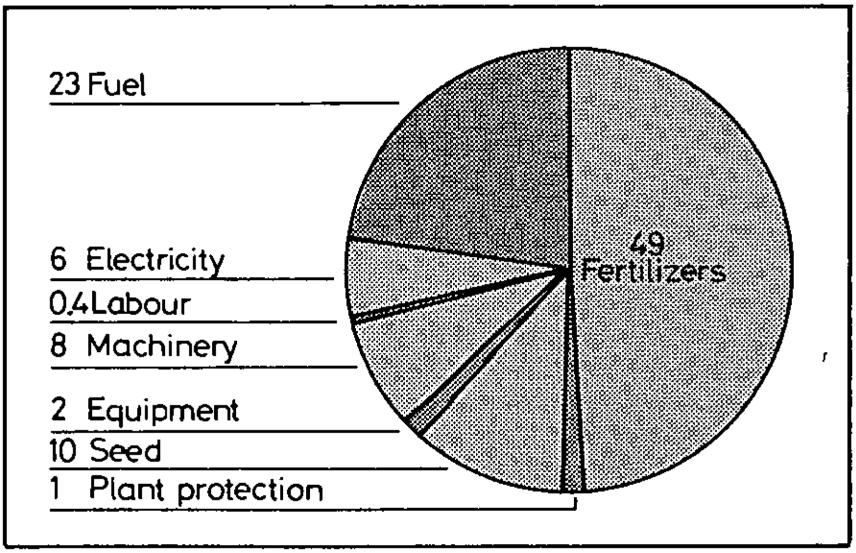

Fig. 3. Energy inputs to plant production (per cent).

7. Conclusion

So long as mankind is not in the position to provide enough food for the needs of the world, the question of the use of biomass to provide energy can only be considered with extreme reserve. It is possible to conceive of a situation in which large areas of the developing world might be devoted to the production of biomass energy for example to provide for the fuel needs of the industrialised countries under the slogan 'Fuel for the World' while, in those countries the populations are inadequately fed and the slogan is 'Bread for the World'. This ambivalence is illustrated in the following figure (Figure 4).

The outlook for world food supply can be summed up in the following *[11]:*

By the year 2000, projections show that there will be 2000 million more mouths to feed than there are in the world today. Today with world population at 4.4 billion it is estimated that 23% of the population of the developing countries (approaching 750 million people) is seriously under-nourished *(per capita* calorie supply below basal metabolic requirement) *[12]* 15 million hungry souls, mostly children are added

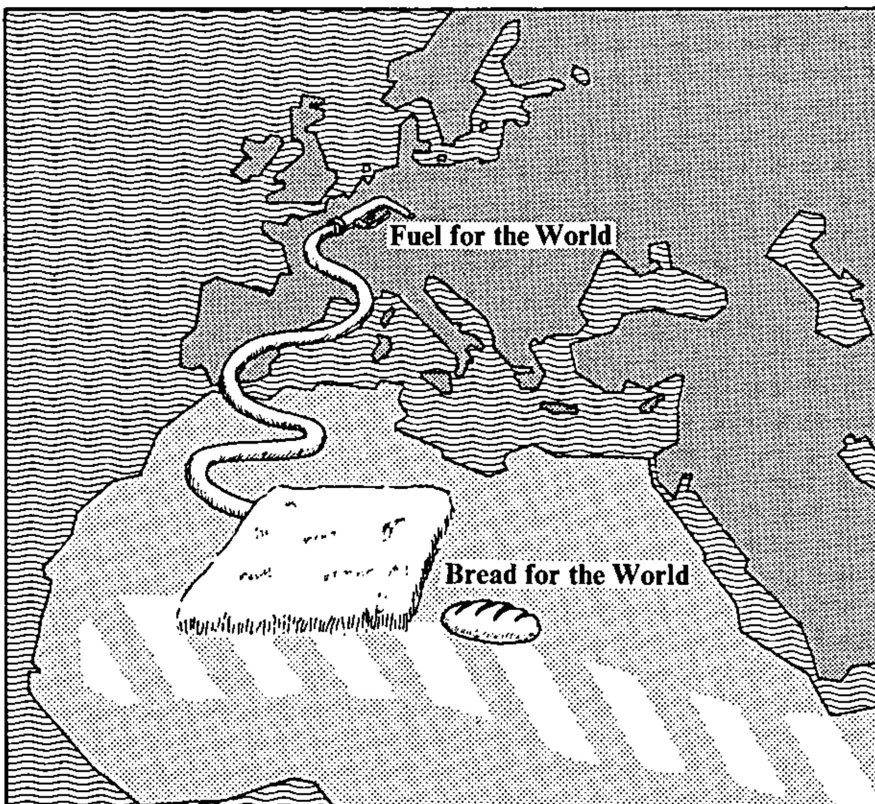

Fig. 4. Biomass for 'Fuel for the World' or for 'Bread for the World'?

to this total each year. Food production must be increased in the future at least in proportion to the increase in population and this increase in production must be brought about through intensification of development and increasing productivity per unit area of land by making full use of scientific and technological advances. More and more help must be given to the countries of the Third World.

It may be that there are regional market niches, *e.g.* the *Common European Agricultural Market*, where it might be imaginable to use a part of the capability of agricultural overproduction in order to produce biomass fuel. And I admit also that we cannot solve the world food problem by feeding the Third World with the agricultural surplus production of the European Market. However, we all know that this agricultural 'market' is far away from a free market with competition and with an artificial price level for agricultural products far beyond the prices of the world market: it is indeed a 'custom-house' to maintain a respectable standard of living for the Western European farmers.

I have the gloomy vision that if we allow bureaucracy to take over the boatswain's whistle over a biomass fuel production program we will not only build up 'butter, milkpowder and meat mountains' but also expensive 'ethanol lakes' to the detriment of the consumer. In other words there is no guarantee for somewhat free market conditions.

Faced as we are with the severe problem of how to provide for the food needs of the world it is abundantly clear that – globally speaking – the 'still available agricultural area in the world must be used for the production of food calories' and should not be used for the production of 'technical calories'. Other ways must be found to provide the latter and it is suggested that nuclear energy should make an increasing contribution even in the developing countries.

8. Acknowledgement

I am most grateful to Prof. Dr. *M. Taube*, EIR, Würenlingen, who has drawn my attention to a number of references which add weight to this contribution.

9. References

1. *Pimentel et al.:* Energy and Land Constraints in Food Protein Production. Science, *190*, pp. 754 November (1975)
2. *Combel, A.B.:* Energy Resource Demands of Food Production, Energy. *I*, pp. 133–142, Pergamon Press, 1976
3. Harvest & Ethanol Yields from Selected Feedstocks. SERI/SP-755–1033 (1981)
4. *Chambers, R.S. et al.:* Gasohol
5. Brazilian Alcohol: In the Tank not on the Table, Technology Review, pp. 10, May (1980)
6. Treibstoff aus Zuckerrüben wird ein Traum bleiben, FAZ, Oct. 26 (1981)
7. Nutzung von Biomasse: Noch Zukunftsmusik, Landwirtschaftliche Rentenbank, Frankfurt (VWD) June 23 (1981)
8. Food for Fuel for Thought. Newsweek, July 14 (1980)
9. Energie aus Nahrungsmitteln, Neue Zürcher Zeitung, Nr. 109, Mai (1981)
10. Autofahren mit Alkohol oder elektrischem Strom – Daten und Fakten der Energiediskussion 6, IZE, Bonn
11. Schwäb. Zeitung, 6. Februar (1981)
12. *Voss, G.:* Energie-Wege aus der Krise, Dt. Instituts Verlag, Köln, 1981
13. *FAO:* Agriculture toward 2000, FAO Rome, 1981

Economic Aspects of Alternative Crop Utilisation with References to Lower Saxony

K. Meinhold, Institute of Agricultural Economy, FAL,
Braunschweig/Federal Republic of Germany*

Summary

The cultivation of crops to provide raw material for ethanol manufacture is already a practical proposition in suitable parts of Lower Saxony. Using the best available methods of cultivation and manufacture and full utilisation of residues the overall energy balance is positive and the ethanol can compete with industrial alcohol. Fossil energy prices will rise further over the mid- and long-term suggesting that there will be a place for ethanol as an additive to motor fuel. The development of efficient methods for growing and processing these crops therefore deserves serious attention. There is no conflict with food production because food is already in surplus in the EEC. Exporting food grown in the EEC cannot solve the world food problem because prices here are well above those on the world market. The problems of the developing countries will be solved rather by technical aid and more efficient use of their own resources.

1. Introduction and scope of the investigation

Economic and social development in industrial countries was supported up to 1972 by unlimited supplies of fossil energy obtainable at prices which did not reflect the fact that, in the long term, these resources were limited. There is no doubt that, so long as large scale substitution is not possible, fossil energy will continue to become scarcer and more expensive *(Pearce et al. [12], RWI [16])*. It is not therefore surprising that, in spite of lack of certainty as to future demand and future energy supply, all studies of the energy problem have suggested that:

- Energy demand per head of the population should be reduced
- Strategies must be evolved to satisfy present and future energy demands
- Renewable sources of energy should be actively investigated and the technology for the conversion of energy crops and biomass should be developed.

* Prof. Dr. *K. Meinhold*, Institut für Betriebswirtschaft, Bundesforschungsanstalt für Landwirtschaft (FAL), Braunschweig-Völkenrode/Federal Republic of Germany

For the Federal Republic of Germany, with its negative balance of payments imposed by the need to import energy, there is a need to reduce energy consumption and to reduce dependance on imports by re-structuring the energy supply and developing indigenous sources of energy.
Using crops to supply energy amounts to indirect use of the sun. The following discussion is based on the assumptions

- that we are concerned with only one energy carrier – ethanol to be used industrially or as an additive for motor fuel;
- that the raw materials are crops and their residues;
- that only one technology, *i.e.* the fermentation of materials containing sugar and starch, will be used.*

We are thus excluding from the discussion the possibility that there might be competition between agricultural and forest products or that the latter might, at least partially, replace the former.

Answers are needed to the following questions:

1. What are the most important aspects in the EEC regarding the provision of energy by crops and its economics?
2. What prices could be offered to farmers in Lower Saxony for the raw materials for ethanol production?
3. In the light of present technology and in so far as this may be improved in the future, what are the costs of manufacture of ethanol?
4. At what price can ethanol be offered on the market?

2. Energetic and economic aspects of the production of energy crops in the EEC

It is sometimes said that to use crops as a source of energy and to produce biomass calories is, in our latitudes, neither economically nor energetically sensible. We need, however, to examine the bases for such an opinion and we find that the underlying assumptions and examples are still unproven.

To take the points one by one:

1. The proposition that modern agriculture is an 'endothermic process' is false. It is unreasonable to lump together direct plant production and the present practice of converting through the animal – at low efficiency – some plant products into meat,

* The use of cellulose for ethanol production has so far been frustrated by the poor economics of methods for conversion.

fat and milk in order to satisfy the demands of a population for the food to which they are accustomed, and at a luxury level. Informed people are however aware that the growing of crops shows a high positive energy balance, while animal production is carried out at the whim of the consumer. Neither are the facts altered by reference to the energy balance, *e.g.* by *Pimentel et al. [13, 14]* if one leaves out of the reckoning, quite inadmissably, carbohydrate and fat, and considers only protein. Such argument shows a lack of knowledge of the meaning of energy balance and an ignorance of human physiology. Fundamental to such reasoning is that the energy value of crops is calculated on the basis of 'food calories' related to energy input. It is more correct, in arriving at the true balance to include in the energy output also the energy content of by-products such as leaves and roots which are transformable into high grade energy. For example: while only the sugar of sugar beet is transformed into ethanol, cellulose and the other decompasable constituents of the roots and leaves can be used to produce biogas for use in the conversion process. Technology has been developed for this purpose and the overall energy balance is positive. Further examples could be given.

2. It is often said that the production of biomass would require much land and that there is competition between biomass calories and food calories. The question, whether the motor car of the rich shall be allowed to eat the bread of the poor has been posed with much emotion. As to the argument about land requirement it can be stated that the requirement for producing technical calories is rather less than that for food calories. On the one hand, unit area of land can produce more energy calories than it can food calories while even now more efficient energy crops are already available than the conventional varieties used for food. This holds for sugar beet, potatoes and also for maize in the production of corn cob mix. Neither is it just 'pure speculation' that plant breeding can produce better varieties. As to the argument about the confrontation between food and energy, it is quite clear so far as concerns the Fed. Rep. of Germany and the EEC as a whole that from 1985 to the end of the decade some 10 million tonnes of grain more than the EEC needs will be produced. By the end of the decade milk production will be 125% of requirements. Translating these surpluses into land area, by the mid-eighties they will be equivalent to 7 or 8 million ha and all this production is subsidised (to the tune of 30 milliard DM in the EEC) for disposal on the world market. This kind of financial burden is no longer tolerable. Consequently until the growing of energy crops requires the whole of this area, there can be no real competition between food and energy production if also external agricultural trade remains the same in relation to industrial exports and present and future biological, chemical and technical progress is used for the benefit of agriculture. A more important problem for the EEC, than the confrontation between food and energy, is that one of finding ways to reduce the food surpluses which we can no longer afford to finance.

3. Another argument is that 'so long as mankind is unable to feed the population of the world at an acceptable level we should put aside the utilisation of biomass to provide energy'. Such utterances are much applauded by the ignorant but they are in no way convincing. It may fairly be said that the under-nutrition which obtains over wide areas in the world has less to do with actual food shortage but with the lack of purchasing power and with problems of distributing available supplies,

neglect of the agricultural sector in the policies of the developing countries and uncontrolled population growth. The solution of this problem should be sought in the intensification of agriculture in these countries and a greater concentration on food crops at the expense of export-oriented plantation agriculture, which only too often uses the most productive land for cotton, tapioca and fruit and vegetables for export to the industrial countries.

Even when we look at this problem from the purely humanitarian point of view, we have to think about the most efficient route of food aid. It is then tolerably clear that the direct use of food grown in the EEC or in the Federal Republic of Germany, characterised as it is by high prices and high production costs, by exporting it into the world market could only make a modest contribution to the solution of the problem of hunger. It is suggested that there are better ways of helping. There is no argument but that aid to the developing countries should be expanded but at the same time this aid should be directed towards fostering self-help and should first and foremost concentrate on developing the agriculture of these countries. Such an objective should be pursued with urgency so that the agriculture of these countries should not be neglected by the policy makers because of the availability of foods to which their populations are not accustomed. Aid should be regarded as an integral part of economic policy.

4. Finally it should be made clear that nobody has suggested that the EEC motorist should switch entirely from petrol to ethanol and that we are talking only of its use as an additive – a less damaging additive than those used up to now. Anyway the production of biomass energy should be guided by the same principles that have attached to the use of nuclear energy: we could do without either if we could foresee that abundant fossil energy would be available at yesterday's prices. Unhappily, this is not the case and we shall be obliged to benefit from both alternatives even though we may have some reservations about this. Furthermore, the use of biomass energy – and the use of nuclear energy – is environmentally less undesirable than intensive use of fossil energy.

This debate is, however, relevant only if the production of energy by this route should prove to be competitive with fossil energy – *i.e.* imported oil – and, in this connection, we should bear in mind the following:

1. The agricultural production capacity so far used for food production should only be partly and gradually transferred to the production of energy and then only in so far as the energy produced in this way is competitive with imported fossil energy and is profitable to the farmer.

2. A more comprehensive transfer of resources from food production to energy production would be defensible only if the resultant social benefit were worth more than the social cost and if it resulted in an overall reduction in the cost of agricultural support.

3. Cost-benefit analysis to answer the second question is not yet available. The answer depends upon the availability of minimum cost technology for the energy conversion on an industrial scale and on raw material prices, which should be based on the

opportunity cost calculated from the least competitive food crop. Only then can sensible decisions be made about:

- Strengthening of the European balance of payments situation by the substitution of oil imports by the local production of energy while ensuring exchange rates with other countries, especially with reference to a possible increase in the price of oil.
- Stabilisation or reduction of the budgetary cost of agricultural support through a transfer of agricultural resources from over-production to the provision of energy.

Tho cost-benefit analysis carried out by *Wolffram* and *Hantelmann [19]* does not pay adequate attention to these considerations and therefore gives no answer to the question as to whether energy cropping would be economic on the basis of the individual farm or for the economy as a whole. Their analysis suffers from the defect that it is confined to sugar beet and, above all, because energy crop prices are based on market prices for foodstuffs. The following makes an attempt to bring us nearer to an answer to the question of the economic viability of growing crops to provide energy.

3. The economics of the production of energy crops, conversion, utilisation of residues and methodology

3.1 Production

Considering that up to now, agriculture has used soil, labour and capital solely for food production, that in view of the current overproduction, no higher quotas for food crops can be allocated and there is little prospect of increasing the demand for, for example, seed and table potatoes at present prices, than the economic viability of growing energy crops should be considered on the basis of their own variable cost plus the gross margin of the least competitive branches of food production which they substitute *(Weinschenck [18])* rather than on the basis of market prices from a heavily subsidised agriculture as *Gieseler [2]*, *Misselhorn [10]* and *Wolffram [19]* among others, have done. If an alcohol factory were to buy beet or potatoes at the supported market prices (A and B prices for beet, and the starch-potato price) it could hardly be competitive. Moreover, the production of energy crops were burdened with unjust support at the same degree as food production.

3.2 Cost of transport and factory costs

The possibility for reducing the overhead costs of the ethanol factory by the economies of scale has to be compared with the resulting increase in transport costs. Other things being equal, the intersection of the two cost-curves determines the size of the factory. If overheads and thus the cost of production per litre are to be reduced, full advantage must be taken of the degressive effects of the larger factory. Capital costs reduce by some 50% as the capacity is increased from 30000 to 240000 l/day *(Meinhold et al. [8])*. Costs of labour reduce in a similar fashion.

As a starting point for this investigation, a capacity of 120 000 l/day has been assumed, which, using the technology suitable for processing a range of raw materials, offers possibilities for optimising the use of capital and labour*. Since there is, at present, some uncertainty in the matter of capital cost of a multicrop factory, calculations have been made in Table 1 for a range of 45 to 65 mio. DM for a factory of such a size.

Table 1. Cost of production of ethanol at different levels of capital investment

		Capital					
Capital required	Mio. DM	45.0		55.0		65.0	
of which buildings	Mio. DM	11.25		13.75		16.25	
of which machinery	Mio. DM	33.75		41.25		48.75	
Daily output	l	120000		120000		120000	
Duration of campaign	days	330		330		330	
Annual output max.	l	39600000		39600000		39600000	
Utilisation of residues		Drying		Drying		Drying	
Personnel		50		50		50	
		Mio. DM/year	DM/l	Mio. DM/year	DM/l	Mio. DM/year	DM/l
Interest on capital[1]	10%						
AfA buildings	n=20	1.321		1.615		1.909	
AfA machinery	n=10	5.492		6.713		7.934	
Repairs (per cent of	buildings 2.0%	0.225		0.344		0.325	
capital requirements)	machinery 3.0%	1.012		1.238		1.463	
Total		8.05	0.203	9.910	0.250	11.631	0.294
Personnel costs	50 AK at 50000 DM	2.5	0.063	2.5	0.063	2.5	0.063
Energy cost	10 MJ/l a.a.	5.5	0.139	5.5	0.139	5.5	0.139
DM/l oil equiv.	0.5 DM/l						
Raw material sugar : starch = 1 : 1		2.772	0.07	2.772	0.07	2.772	0.07
Overhead costs	2.5% of capital requirements	1.125	0.023	1.375	0.028	1.625	0.033
Cost of production I		19.947	0.504	22.057	0.557	24.028	0.607
Use of by-products	10 MJ/l a.a. drying cost	5.5	0.139	5.5	0.139	5.5	0.139
Realisation	25 DM/t[2]	−6.7	−0.169	−6.7	−0.169	−6.7	−0.169
Cost of production II		18.747	0.47	20.857	0.53	22.828	0.58

[1] Amortisation
[2] 0.65 kg DM/l a.a.; mixture of beet, potatoes and grain; reckoned on substitution value

* In contrast to this, minimum cost in a pure grain distillery is given by about 600000 to 800000 l/d *(Meekhof et al. [7])*.

3.3 Product and by-product evaluation

Ethanol from crops competes directly with industrial alcohol based on fossil energy and, if it is used as a fuel additive, with petrol *(Johnston [4], Reinefeld* and *Hoffmann [15], Menrad [9], Scheller [17])*. In determining the competitive ability of crop-ethanol we must take into account both the price for industrial alcohol and its substitution value as an additive at actual refinery gate prices of petrol.
There are alternative ways of utilising the considerable amount of stillage from the conversion process (which, since it contains valuable protein is hardly to be reckoned poisonous). Therefore the investigation takes account of its use as feedstock and as a source of biogas *(Kleinhanss [5])*. We do not go into the possibility of using it for irrigation, since there might be undesirable environmental effects *(Hennings et al. [3])*.

3.4 Modelling to optimise raw material production and conversion to ethanol

Linear programming has been used in this study. The model has been designed so that as well as determining the competitiveness of ethanol, it includes yet uncertain coefficients, particularly as regards conversion, which, through sensitivity analysis, may suggest further improvements in processing technology.

3.5 Remarks on the methodology for deriving competitive prices for ethanol at a regional level

The raw material demands of a factory of the size envisaged above will exceed what can be provided by a small community and calculations must be based on larger units (regions). Two questions have to be answered:

1. What would be the regional competitive price for ethanol that would justify the establishment of an ethanol factory?*
2. What prices could be paid for sugar and starch raw materials to the farmers and what would be the average gross margins per hectare with or without an ethanol factory?

In arriving at the regional competitive prices for ethanol and in making proposals for the manufacture of ethanol from crops which might compete with fossil fuels, we have changed step by step the level of energy prices in a wide range – with which the prices of motor fuel and fertilizers are both connected – for ethanol as a raw material of the chemical industry and for ethanol as a petrol additive related to refinery prices of petrol. Out of the total of 46 urban and rural districts in Lower Saxony, 35 have been included in the comparative analyses.

* The regional cost of ethanol manufacture that would justify to establish at least one factory will be designated 'competitive price'.

4. Results of the investigation

Figure 1 shows for the 35 regions the ethanol prices at which at least one factory could be operated. It shows:

1. In regions where at the present time, because of relatively unfavourable conditions only few root-crops (sugar beet and potatoes) are grown for the market and only moderate grain yields are obtainable, assuming that our datas in the model are right and the technical problems are soluble, ethanol production would be competitive at a market price of 1.15 DM/l for synthetic alcohol and would yield a return to the farmer some 200–500 DM per hectare more than that obtainable from growing food crops. The economically optimum length of campaign for the factory would be, according to the ethanol price, 83 to 100% of the theoretically maximum 330 days.

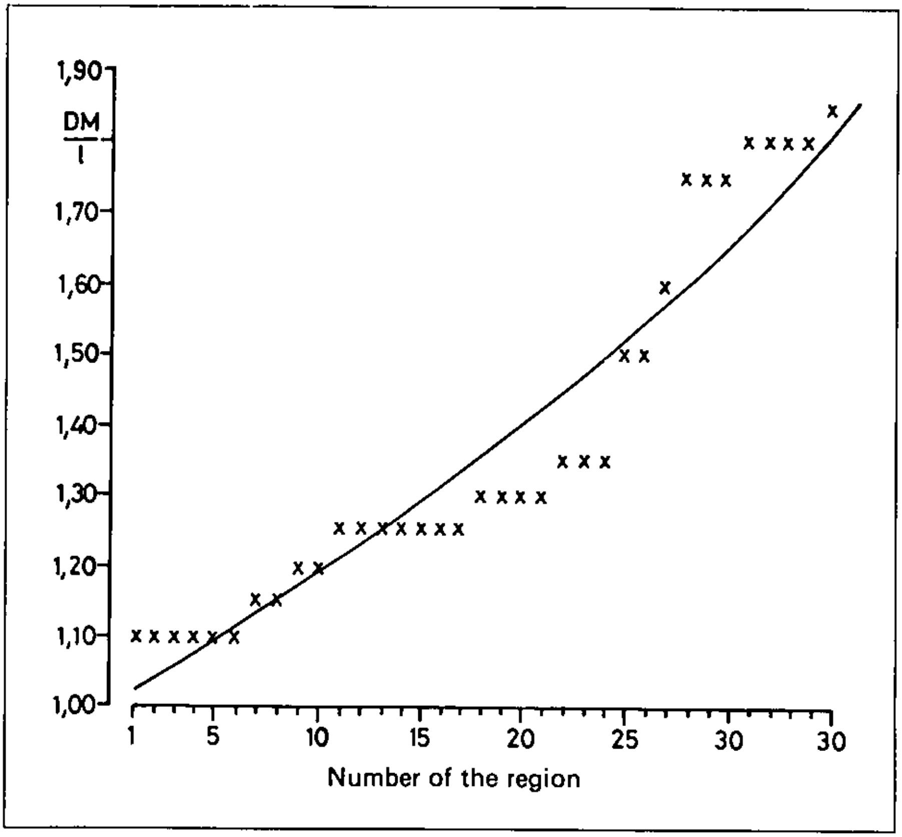

Fig. 1. Range of production costs for ethanol in Lower Saxony.

2. In the regions where root-crops are now mainly grown, the farmers benefit from the high prices paid for beet for manufacturing refined sugar. Beet cultivation is often carried out to the limit of rotational tolerance. The growing of potatoes for starch manufacture does not now compete with the high yields of winter barley and winter wheat that can be grown. The use of sugar beet for ethanol production in such regions would reduce income per hectare by 35–40%. An ethanol factory in such a region would be unable to pay prices which would compete with the subsidised growing of sugar beet for sugar production.

The eight regions most promising for ethanol manufacture (see Figure 1) were submitted to further analysis with regard to the following questions, up to now not completely answered:

1. What influence would increases in raw material yield have on the price obtainable for ethanol?
2. What would be the significance of an actual decrease in grain prices and what are the possibilities for using corn cob mix from maize as a cheaply to store raw material?
3. What might be the effect of technical progress in the field of conversion on the price of ethanol?
4. How will the present uncompetitiveness of ethanol as a fuel additive be altered by an increase in the price of petrol from fossil raw materials?

The effect of changes in such exogenous factors is illustrated in Table 2. Regarding grain prices it is assumed that:

- the farmers only receive the intervention price less handling charges;
- there is an intention, as has been much discussed recently*, to bring down grain prices in the EEC to the level of the world market.

The decreases in labour and energy requirements of processing of 10–20% are within a range which can already be regarded as fairly certain *(Misselhorn [11])*. It has to be established that, with utilisation of the by-products a positive energy balance is achievable in the winning of biomass energy against a balance of $\lesssim 1$ as in the case of fossil energy.
With regard to the future trend in energy prices, even if world energy demand remains constant over the coming years, which seems unlikely since population is increasing, it seems certain that prices will increase, the satisfaction of this demand will require the utilisation of sources in which the costs of extraction will be higher than they are today *(Bischoff [1])*. Therefore an increase in energy prices of 3% per year, measured in real terms, might be a reasonable assumption for the future.
The answers to these four questions are grouped in three sections.

* Guideline paper of the EEC commission *[6]*.

Table 2. Variation of parameters used in the model

		Basic solution	Variant 1	Variant 2	annual change % over 5 years Variant 1	over 5 years Variant 2	over 10 years Variant 1	over 10 years Variant 2
1. Raw material yield			%	%				
– potatoes		Average	+20	+33	+3.7	+5.9	+1.8	+2.9
– beet		1978–80	+20	+33	+3.7	+5.9	+1.8	+2.9
– maize			+20	Ø 1978–80	+3.7	±0	+1.8	+2.9
2. Grain price	DM/dt	Av. producer price 1980/81	intervention price 1981/82 43.90 DM/dt	90% of intervention price	–	–	–	–
3. Energy price	DM/l oil equiv.	0.45	0.60 (+33%)	– –	+5.9	–	+2.9	–
– Diesel fuel agricultural price	DM/l	0.75	0.90	–	+3.7	–	+1.8	–
– N fertilizer	DM/kg	1.75	2.00	–	+2.7	–	+1.3	–
4. Technical progress in ethanol manufacture								
– capital invest.	Mio. DM	65.0	58.5 (–10%)	52.0 (–20%)	–2.0	–4.4	–1.1	–2.2
– labour number		50	45 (–10%)	40 (–20%)	–2.0	–4.4	–1.1	–2.2
– energy need (excl. electricity)	MJ/l a.a.	9.7	8.7 (–10%)	7.8 (–20%)	–2.0	–4.4	–1.1	–2.2

4.1 Determination of the economic thresholds for ethanol production in the 8 regions under varying conditions

The minimum production cost of ethanol varies between regions over the range 1.09–1.47 DM/l absolute alcohol (a.a.) (see Table 3). Variations within the regions under similar conditions are 0.05–0.10 DM/l. More important however, is the change in threshold price for ethanol between versions 1–7. It is seen that:

1. The cultivation of maize and its use as corn cob mix (CCM) reduces the required minimum price by an average of 0.16 DM/l a.a.
2. An increase of 20% in the yield of crops grown for energy production, a grain price corresponding to the present intervention price, and a reduction in the capital cost and labour need in the factory would further reduce this price by 0.19 DM to 1.12 DM.
3. A further reduction of 10% in the grain intervention price would only reduce the price by 0.02 DM/l a.a.
4. An increase in the cost of energy of 33% over five years (from 0.45 to 0.60 DM/l of heavy oil) would result in an increase in the threshold price by about 0.09 DM. This

Table 3. Dependence of average competitive price per l a.a. on relevant factors in 8 regions of Lower Saxony

Ver-sion	Energy	Changes Crop production				Manufacture			Min. price	Change
	Energy cost DM/l oil equiv.	Raw material yield	Grain price	CCM with-out	with	Capital Mio. DM	Labour piece AK	Energy MJ/l a.a. without electricity	DM/l a.a.	DM/l a.a.
1	0.45	ø 78–80	ø 1981	×		65	50	9.7	1.47	
2	0.45	ø 78–80	ø 1981		×	65	50	9.7	1.31	–0.16
3	0.45	+20%	intervention price 1981/82		×	–10%	–10%	9.7	1.12	–0.19
4	0.45	+20%	90% of intervention price		×	–10%	–10%	9.7	1.09	–0.02
5	0.60	+20%	intervention price		×	–10%	–10%	9.7	1.18	+0.09
6	0.60	+20%	intervention price		×	–20%	–20%	–20%	1.11	–0.07
7	0.60	+33% (root crops only)	90% of intervention price		×	–20%	–20%	–20%	1.10	–0.01

means that as oil prices rise, the competitive position of ethanol would improve. This finding is by no means insignificant for the future of renewable energy sources. If a 33% increase in energy price, which, above all affects the cost of fertilizers and fuel for the growing and transport of the raw materials, results in only an 8% increase in the ethanol price, this must be a significant indication of the overall positive energy balance of the whole process for providing biomass energy.

5. A further reduction in capital and labour requirement would reduce the threshold price for ethanol to 1.10 DM/l despite the increasing cost of energy.

It is quite clear already that the sort of changes envisaged above are capable of achievement within the next few years and that, where conditions are suitable, we shall arrive at the situation where biomass energy will be truly competitive with fossil energy.

4.2 The effect of ethanol manufacture on the farmer's income

These effects can only be estimated rather crudely for lack of precise data and on account of methodological difficulties. However, it does appear that, in the case of one of the eight regions, if the growing of raw materials for energy is not taken up, then, as energy prices rise and under the conditions we have assumed, the average gross margin per hectare will decline from 1800 to 1640 DM. On the other hand, if the idea is taken up the gross margin for 9000 to 10000 ha – this area is needed for such a factory – could be increased by about 200 to 500 DM/ha. In this connection it is pointed out that with an alcohol yield of 4000 l/ha a.a. (corresponding to 35 t/ha

potatoes or 40 t sugar beet) an increase in price of only 0.05 DM/l would result in an additional revenue to the farmer of 200 DM/ha which is equivalent to an additional payment for the required labour of 5 DM/hour.
The earnings per hectare above are calculated on the basis of the present minimum price for ethanol which results in the following prices paid to farmers for the raw material: 66–90 DM per t for starch potatoes, 122–166 DM for CCM, 44–61 DM per tonne for sugar beet (present 1982/83 price for B-sugar beets 60 DM/t) and 21–31 DM/t for fodder beet (Table 4). Further income could be derived from the utilisation of high protein residues as fodder.

Table 4. Purchase prices for starch and sugar under varying conditions (average of 3 regions and ignoring by-products)

Version	Starch potatoes 18% starch		CCM 36% starch		Beet 16% sugar		Beet 10% sugar	
	DM/dt	DM/kg starch	DM/dt	DM/kg starch	DM/dt	DM/kg sugar	DM/dt	DM/kg sugar
1	9.87	0.55	–		5.60	0.35	3.06	0.31
2	9.33	0.52	16.60	0.46	6.11	0.38	–	
3	8.50	0.47	13.12	0.36	4.63	0.29	–	
4	7.17	0.40	12.18	0.34	4.74	0.30	–	
5	8.47	0.47	13.21	0.37	4.75	0.30	–	
6	8.63	0.48	13.22	0.37	4.75	0.30	–	
7	6.56	0.36	14.60	0.41	4.36	0.27	2.06	0.21

4.3 Optimisation of raw material provision and utilisation of residues

The raw material requirement of the factory over the 330 day campaign is determined within the model by the cost of preparation, availability, the cost of conversion and the proceeds from by-products. Raw material availability is determined by restrictions imposed by rotational requirements and its storage properties outside the growing period. The raw materials considered here differ as regards their production and storability and it is not surprising that for the Federal Republic as a whole, where conditions are so variable, minimum production costs can only be derived by considering together starch and sugar containing materials. It is naive, as some do, to talk always as though sugar beet were the only crop suitable for energy production.
As emerges from Table 5, for each of the five time intervals, there is a raw material which dominates the others. For period I, because of early maturity it is the potato, for period II sugar beet and for III–V ensiled corn cob mix. For long-term storage, chemical methods (ensiling) are to be preferred owing to the energy demand involved in other methods (ventilation of large stacks or stores). The use of root-crops from frost-free winter storage can only make sense if storage costs are compensated by very high yield or if, as the case for fodder beet, the roots can be stored in the field. Storability of raw materials reacts on the utilisation of the factory capacity and thus the minimum average costs of production are given by corn cob mix.
The optimal utilisation of factory waste – first of all the stillage –, so significant for the economic viability of the whole process, was determined in the model by reference

Table 5. Raw material requirements and factory efficiencies for periods I–V of the campaign (average all regions)

Version	Period I 1.8.–14.9.	II 15.9.–13.12.	III 14.12.–23.3.	IV 24.3.–2.5.	V 3.5.–21.6.	Efficiency %
	without Corn Cob Mix					
1	FK/BK	ZR	FR	FR	–	83
	with Corn Cob Mix					
2	FK/BK	ZR	CCM	CCM	CCM	100
3	FK/BK	ZR	CCM	CCM	CCM	100
4	FK/BK	ZR	CCM	CCM	CCM	100
5	FK/BK	ZR	CCM	CCM	CCM	100
6	FK/BK	ZR	CCM	CCM	CCM	100
7	FK/BK	ZR	ZR/FR/CCM	FR/CCM	CCM	100

FK Substandard table potatoes
BK Distillery potatoes
ZR Beet 16% sugar
FR Beet 10% sugar
CCM Corn cob mix

Table 6. Optimum use of waste at varying prices for food crops and energy

Version	Energy price DM/l oil equiv.	Potatoes	Beet 16%	Beet 10%	Grain	CCM
1	0.45	Fodder (FM)	Biogas (BG)	Burning (VB)	Fodder (FM)	Fodder (FM)
2, 3, 4	0.45	FM	BG	–	–	FM
5, 6	0.60	FM	BG	–	–	BG
7	0.60	FM	BG	BG	BG	BG

to the present price relationship between agricultural products and energy. Some results are given in Table 6 but these are somewhat problematic due to uncertainty about the composition of the waste and uncertainties as to how the biogas process may develop. It seems clear, however, that in spite of increasing energy prices it would be best to use it for biogas; this seems more economical than other possible uses. To answer the question whether the farmers of Lower Saxony should undertake the growing of energy crops under the ruling conditions of prices and costs, we have to distinguish between two possible uses for ethanol:

1. How competitive would bio-alcohol be with synthetic alcohol based on oil and required for industrial purposes?
   Synthetic alcohol was traded in 1981 at prices between 1.35 and 1.40 DM/l. Comparison of the above mentioned minimum price shows that biomass ethanol would compete if present day technology were put to work and the factories were built. However, the total market for industrial alcohol over the past few years has been only about 100000 tonnes. The capture of such a small market would do little to solve the problems of agriculture and of the surpluses.

2. The more important outlet for bio-alcohol is as a fuel. Here, alcohol can be used as an additive to low grade petrol or as a fuel in its own right. We cannot here go into all the details touching the substitution value of ethanol. Ethanol from crops is not at present competitive. However, the following deserves attention: Taking a price of 0.45 DM/l oil equivalent for the provision of process heat for ethanol production, we can assume a cost for motor fuel without tax of about 0.65 DM/l. At such energy costs the minimum price for ethanol under the best conditions would be about 1.09 DM/l – a difference of roughly 0.40 DM/l. If motor fuel were to rise to a price equivalent to that of industrial energy – about 33% –, its price would stand at 0.86 DM/l while ethanol, making full use of the technical progress mentioned herein, could be offered at about 1.10 DM/l, approximately halving the price differential against petrol. As the price of fossil energy rises, bio-alcohol will become increasingly competitive so that addition to motor fuel at about 10% will become a realistic proposition.

5. References

1. *Bischoff, G.:* Probleme der Weltenergieversorgung – Ausblick nach der Weltenergiekonferenz München 1980 (unpublished)
2. *Gieseler, G.* and *Schnell, Chr.:* Gärungsalkohol aus Agrarprodukten als Biokraftstoff. (Im Auftrag des BMFT), Dornier-System GmbH, Friedrichshafen 1980
3. *Hennigs, H., Kleinhanss, W.* and *Meister, H.:* Grundlagendaten und Verfahrensansätze zur Verwertung niederwertiger Energieträger und Reststoffe bei der Ethanolerzeugung. Arbeitsbericht des IfBw. Nr. 6, Braunschweig-Völkenrode (1981)
4. *Johnston, P.J.:* Ethanol – an Alternative to its Use as Fuel. Int. Sugar J. *82*, pp. 41–44 (1980)
5. *Kleinhanss, W.:* Wirtschaftlichkeit der Biogaserzeugung. Berichte über Landwirtschaft, *Bd. 58*, No. 4, p. 560 (1980)
6. *Kommission der EG:* Leitlinien für die europäische Landwirtschaft. KOM (81), 608, 23.10.1981
7. *Meekhof, R., Gill, M.* and *Tyner, W.:* Gasohol: Prospects and Implications. USDA, Agricultural Economic Report No. 458
8. *Meinhold, K., Hollmann, P., Kleinhanss, W.* and *Kögl, H.:* Ethanol aus nachwachsenden Rohstoffen – Analyse der Wettbewerbsfähigkeit unterschiedlicher Standorte Niedersachsens. Manuskript zur 22. Jahrestagung der Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaues e. V., Stuttgart-Hohenheim 7.–9. 10. 1981
9. *Menrad, H.:* Äthanol als Kraftstoff für Ottomotoren. Automobiltechnische Zeitschrift (ATZ), *81*, No. 6 (1979)
10. *Misselhorn, K.* and *Starcosa GmbH:* Ethanol als Energiequelle und chemischer Grundstoff. Branntweinwirtschaft No. 1, pp. 2–8 (1980)
11. *Misselhorn, K.:* Agraralkohol hat grosse Möglichkeiten. Branntweinwirtschaft, No. 10, pp. 326–330 (1981)
12. *Pearce, D.:* World energy demand and crude oil prices to the year 2000. Journal of Agricultural Economics, *XXXII*, No. 3, pp. 341–354 (1981)
13. *Pimentel, D. et al.:* Energy and Land Constraints in Food Protein Production. Science, *190*, p. 754 (1975)
14. *Pimentel, D. et al.:* Food production and the energy crisis. Science, *182*, pp. 443–449 (1973)
15. *Reinefeld, E.* and *Hoffmann, R.D.:* Chemikalien aus Saccharose. Zuckerindustrie, *105*, No. 8, pp. 736–743 (1980)

16. *Rheinisch-Westfälisches Institut für Wirtschaftsforschung:* Wirtschaftsprognose. Handelsblatt (Wirtschafts- und Finanzzeitung), No. 7, p. 4 (1982)
17. *Scheller, W. A.:* The Nebraska Two Million Mile Gasohol Road Test Program. University of Nebraska, Lincoln 1979
18. *Weinschenck, G.:* Die optimale Organisation des landwirtschaftlichen Betriebes. Paul Parey, Hamburg und Berlin 1964
19. *Wolffram, R.* and *Hantelmann, H.:* Die Rentabilität der Äthanolerzeugung aus Zuckerrüben. Agra-Europe (Dok.), *22*, No. 40, pp. 1–24 (1981)

Optimum Nutrition of Some Non-Food Plants

C.O.Tamm and *A.Aronsson*, Dept. of Ecology and Environmental Research,
The Swedish University of Agricultural Sciences, Uppsala/Sweden*

Summary

The nutrient requirement of a plant has to be related to its performance in relation to nutrient supply, usually described by an optimum curve. Recognizing that this curve is empirical, *i.e.* has to be established experimentally for each species, nutrient levels in the plant are kept constant or nearly so during the experimental period.
In young plants this means exponential growth and exponentially increased nutrient additions. In adult trees in the forest growth is no longer exponential, and both growth rate and internal nutrient concentrations vary with season and between years. It is, however, shown that nutrient concentrations and growth-rate can be controlled well enough to make long-term optimum nutrition experiments possible.
Stem growth data and total above-ground production figures from such experiments are presented. Much of the strong increase in yield is attributed to changes in resource allocation in the trees (new foliage favoured, less directed to fine root production). Increase in leaf biomass is however, a useful strategy up to a maximum value only. Increased photosynthetic activity might increase yield further, but only with 10 to 20 percent (in pine), while leaf area might increase with 100 percent or more from unfertilized to well fertilized.
Nutrient regime changes also affect ecosystem functions other than tree growth, such as decomposition rate and consumption (by changes in palatability of the plant material). The species composition of the ground vegetation also changes with nurient additions, often to highly productive communities with low diversity.

Introduction

There is a very simple answer to the problem associated with the title of this paper: Non-food crops require the same plant nutrients as food plants, and their optimum supply is often, but not always, within the same range as that for horticultural and agricultural crops.
However, forest trees and other plants growing in ecosystems less intensively managed than arable land are often better adapted than food crops to an environment low in plant nutrients, the export of nutrients with the harvested crop may be lower, and it may be impossible or undesirable to supply fertilizers to the sites in the amounts

* Prof. Dr. *C.O.Tamm* and Dr. *A.Aronsson*, Dept. of Ecology and Environmental Research, The Swedish University of Agricultural Sciences, S-750 07 Uppsala/Sweden

needed for optimum growth. There are thus reasons to discuss separately the nutritional problems associated with trees and other plants growing in semi-natural systems and harvested mainly for fiber or other products with low nutrient contents. Nutritional strategies of different plant types have also been discussed by *Chapin (11)* and others. As the space available is limited, we refrain here from a discussion of ecological specialists such as heavy metal or salt tolerant plants.

Before a closer analysis can be done, we need a definition of the concept 'nutrient requirement' which term is often used in a loose way. When a definition is used it is usually based upon a so-called optimum curve, where increased supply of a nutrient increases the growth of the plant up to a certain level, called optimum, after which there is usually a decrease in growth or vigour. The optimum is the point where the plant requirement of the nutrient in question is satisfied, under the conditions studied. The optimum curve – and the nutrient requirement – is thus an empirical result, and as such limited to the experimental conditions under which it was obtained. If desirable also other characteristics of the optimum curve can be used in the definition of the nutrient requirement, *e.g.* the requirement at half yield, or the curve slope at this point. Attempts have been made to give the optimum curve a theoretical foundation, the most notable one by *Mitscherlich*, the 'Law of Diminishing Returns'. Other attempts have used some basis of calculation other than yield for the dependent variable and nutrient addition for the independent one. Nutrient concentrations in substrate or foliage have been used for the latter, and various types of relative growth measures have been tested for the independent variable. The amount of a nutrient in 100 leaves is a variable sometimes occurring, but the introduction of product of a growth measure (leaf weight) and a concentration can hardly contribute to the clarification of the theoretical analysis.

Recently *Ingestad [18, 19, 20]* has questioned the use of traditional optimum curves, approximated by second degree functions or by Mitscherlich functions. He adjusts the supply of nutrients to the actual uptake of the plant instead of working with nutrient solutions of different concentrations, exchanged at intervals. As young seedlings grow exponentially, the nutrient supply also has to be exponential. He can then control the growth rate of a plant by adding a balanced amount of all nutrients to the solution at the desired rate. The growth rate can be kept constant over periods of several weeks (Figure 1). If total growth in his experiment is plotted against total nitrogen added he obtains a curve only slightly curved (convex towards the x-axis). If total growth is plotted against plant nitrogen concentrations, an exponentially rising curve is obtained (Figure 2). In both cases the increase is stopped abruptly by a sharp decline at plant (and solution) concentrations above optimum.

An interesting observation in *Ingestad's* experiments is that plants growing at rates 20 percent of the optimum rate, or even slower, have a healthy appearance, without visual deficiency symptoms. His optimum-rate growing plants grow much faster than plants in conventional solution cultures.

Ingestad's experiments are made under laboratory conditions, very different from those for plants growing under more natural conditions. However, natural selection between plants has often favoured those able to survive and propagate in an environment where high concentrations of growth-limiting nutrients are rare, but a more or less continuous replacement of absorbed nutrients takes place by organic matter mineralization. A young plant grows exponentially, both above and below ground, and the access to

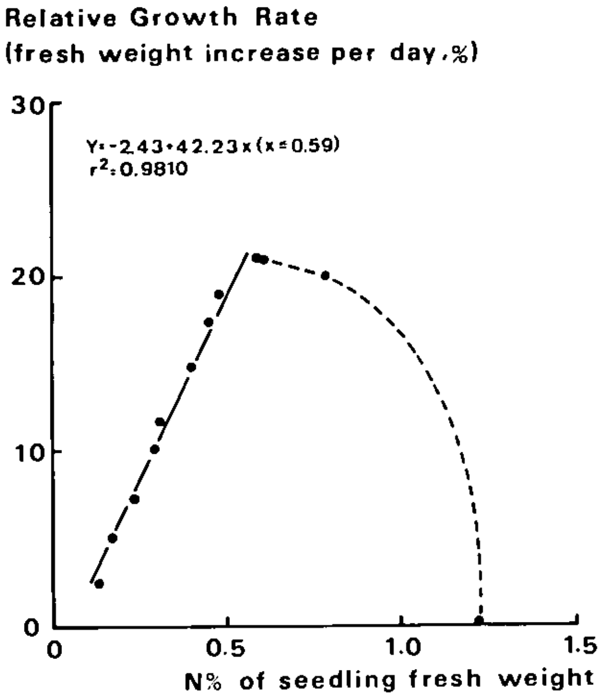

Fig. 1. Growth rate of birch seedlings *(Betula verrucosa* Ehrh.) plotted against plant nitrogen concentration (from *Ingestad [19])*.

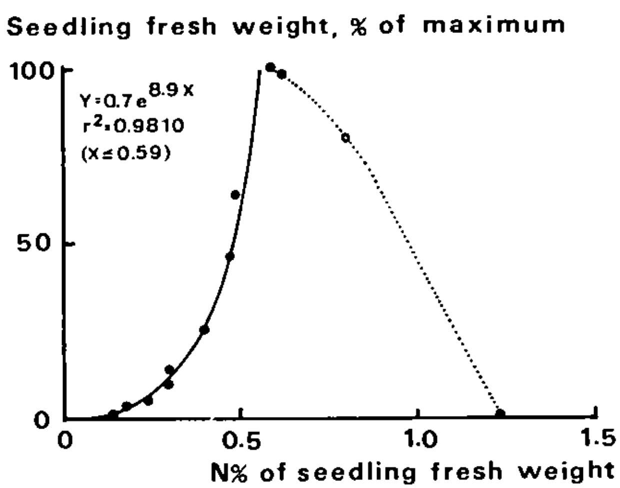

Fig. 2. Accumulated growth of the birch seedlings in Figure 1, plotted against plant nitrogen concentration. Experimental period 21 days (from *Ingestad [19])*.

nutrients may thus, at least in some cases, change exponentially with time. *Ingestad's* ideas on plant nutrition therefore have direct implications also for plants growing under outdoor conditions with low nutrient concentrations.

Nutrient conditions in closed tree stands

Forest stands differ from young seedlings in solution culture experiments in several respects.

One complication is that much nutrient uptake by trees is transmitted by mycorrhizal fungi, but this may not necessarily affect the fundamental principles of nutrient requirements. Ectotrophic mycorrhiza, typical for most coniferous trees, is commonly considered of greater importance for the tree at low levels of phosphorus and probably nitrogen than at near optimum conditions *(Björkman [7, 9])*. There is, however, on forest sites almost always keen competition for nutrients between trees, between trees and lesser vegetation, and between tree roots (and their mycorrhiza) and microorganisms.

Another difference is self-shading which changes the exponential growth curve to a sigmoid one.

In a closed forest canopy, the foliage biomass is approximately constant from year to year. Textbooks maintain that there is a culmination of stem growth and leaf biomass at canopy closure or shortly afterwards, but the decline from this maximum is usually a slow process *(Kira* and *Shidei [21])*. Dominant trees may increase their biomass (particularly of woody parts) for most of their lives, while unlucky individuals are suppressed, decrease in amount of foliage, and eventually succumb.

Like annual crops, deciduous trees renew their foliage each year, but the nutrients required for the new foliage are only partly taken up from the soil. Much is redistributed from other organs *(e.g.* branch, stem and root phloem and vascular rays). In evergreen plants, including conifers, much nutrient (and carbohydrate) is stored in older leaves *(Tamm [30], Rutter [28], Ericson [12], Chapin [11])*.

Due to this redistribution of mobile nutrients (N, P, K, Mg), the timing of the nutrient supply to the roots becomes somewhat less crucial as compared with seedlings or annual crops which have to cover almost all their nutrient requirement from the substrate in a short time. However, one of the points stressed by *Ingestad* is of equal importance here: reliable information on the importance for growth of the internal nutrient level in the plant can only be obtained if the internal level is kept constant or at least under control. Experiments were started in 1957 with the aim of studying growth effects in coniferous stands with controlled nitrogen regimes *(Tamm [31])*, and have later been extended to include other nutrients and treatments. Because of the seasonal redistribution of both carbohydrates and nutrients between needles of different ages, it is virtually impossible to maintain constant nutrient levels during the active growing perid *(Aronsson* and *Elowson [3])*.

Our aim has therefore been to maintain the autumn nutrient concentrations in the needles as constant as possible (particularly for nitrogen). Figures 3 and 4 give examples of the results obtained. Whether a constant autumnal needle concentration (as far as it is obtained) really means a constant nutrient status is a question not yet answered. *Waring* and *Youngberg [35]* maintain that needles on poor sites are more

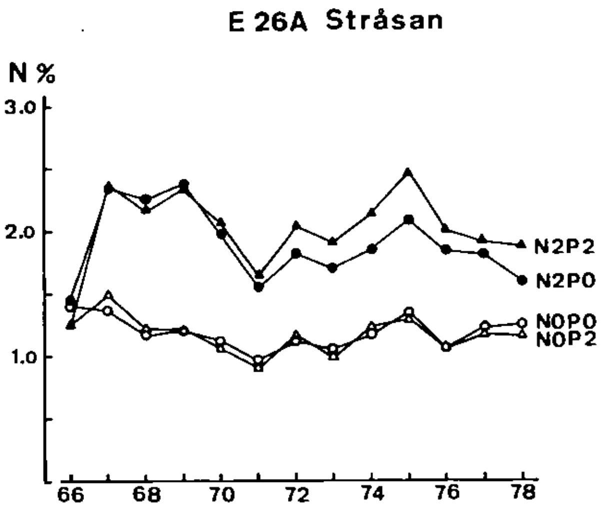

Fig. 3. Autumn concentrations of nitrogen (% D.W.) in current spruce needles in four of the experimental treatments in the Stråsan experiment, fertilized annually from 1967 onwards.

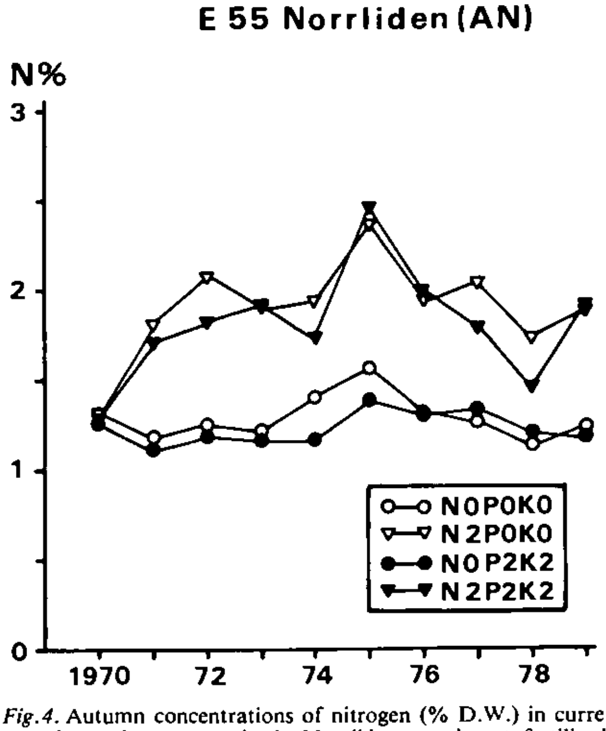

Fig. 4. Autumn concentrations of nitrogen (% D.W.) in current pine needles in four of the experimental treatments in the Norrliden experiment ,fertilized annually from 1971 onwards.

depleted of nutrients than needles of the same tree species on better sites during the active growing period. There are also several studies showing different nutrient levels in young and old trees *(Fiedler et al. [13], Höhne [16], Höhne* and *Nebe [17], Miller et al. [25])*. It is not quite clear to what extent such differences in leaf nutrient concentrations between trees of different age really mean differences in nutrient requirement. *Miller et al. [25]* point at the differences in relative proportions of sources and sinks for nutrients in trees of different sizes, a phenomenon also related to the theory of *Waring* and *Youngberg [35]*.

In our opinion, the creation of curves such as those in Figure 3 and 4 with separate internal nutrient levels for different treatments and with no or small changes with time, is the most important prerequisite for a quantitative assessment of nutrient optimum in a forest stand (or other perennial vegetation growing in dense stands). Conventional fertilizer experiments with one or a few applications may well demonstrate in a qualitative way that nutrients are growth-limiting, but cannot tell us the optimum.

Stem growth in tree stands at different nutrient regimes

Foresters are usually only interested in tree stem growth for the reason that it is comparatively easy to measure and that it constitutes the commercially most interesting part of the tree. We shall here first discuss stem growth and in a later section take total tree production into consideration.

Figure 5 shows, for sample trees *(Picea abies* Karst.) from six plots (three treatments) of the Stråsan experiment, that the annual basal area increase rises slowly with time, and that the fertilized trees grow better than unfertilized ones. There are no data for the three first years of the experiment, because all trees had not by then reached the measuring height (1.3 m above ground). The poorer growth of the treatment N2P1 in 1976 may be caused by lower summer precipitation than usual in 1975–1976, affecting heavily fertilized trees with their much larger crowns (see below) more than unfertilized ones *(cf. Aronsson* and *Tamm [4])*.

Figure 6 shows, for the same treatments (but based on non-destructive measurements on a much larger number of trees), the height development. Apparently height growth in spruce also responds to changes in nitrogen regime, although with lower percentage figures than basal area or diameter growth. In Scots pine *(Pinus sylvestris* L.) the height growth response to nitrogen is usually even smaller. The curves in Figure 6 do not deviate much from linearity, but the trees may still be in the exponential growth phase as volume increases much faster than height. Over a limited period of time, however, it appears permissible to approximate tree growth in the experiment with a straight line.

Figure 7 shows the stem volume growth 1972–1978 as a function of the average needle nitrogen level. As all needle nitrogen concentrations, basal area growth and height growth appear to be in a steady phase (apart from some between-year-variation as just described) we believe that the optimum curves in the diagram give reliable information about the optimum nitrogen concentrations in spruce needles, given the conditions under which the experiment was made (climate, genotype, sampling time, etc.). Despite the great variation it also seems clear that there is nitrogen-phosphorus interaction in the experiment. We shall come back in the next section to the question of the stand growth at optimum.

Experiments similar to the Stråsan spruce experiment have also been carried out with Scots pine *(Tamm et al. [34], Holmen et al. [14])*. Figure 4 shows the foliage nitrogen concentrations in one of the pine experiments, and Figure 8 the stem volume growth as function of the foliage nitrogen concentration. The curves are also here optimum type curves with a drop in growth at supra-optimum levels. In this case there seems to be a negative interaction between nitrogen and PK-fertilizer, not yet fully explained. The negative interaction is not observed with urea as source of nitrogen, but the growth response to urea is lower than that to ammonium nitrate, as in most other Swedish experiments.

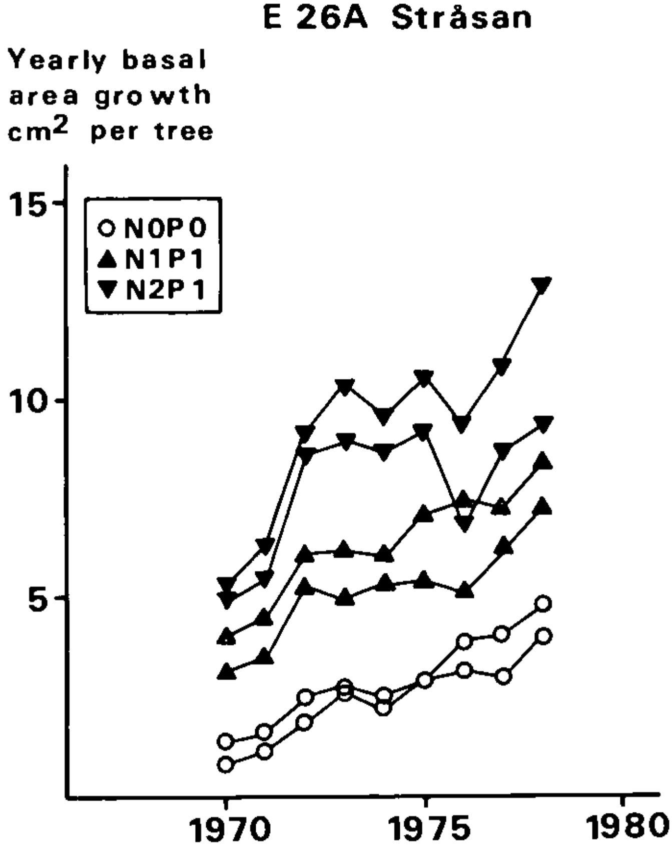

Fig.5. Basal area growth of harvested sample trees from control and two fertilized treatments in the Stråsan experiment. Each curve represents one plot and 4 trees (6 control trees).

Energy cost in increasing stem yield production

As mentioned above the stem yield has so far been the main forest product of commercial interest. The effectiveness of fertilization in increasing stem growth may be measured in different ways *(e.g.* in increased stem volume per kg nitrogen added, in economic terms, etc.). Another way to measure the fertilization effect is to compare the energy content of the harvest increase with the energy used for manufacturing and distribution of the fertilizer and for harvesting additional timber. We will make a crude estimate for the N1-treatment at E 26 A, Stråsan. All values for the energy content of different materials and operations are taken from two reports published at the *Department for Economics and Statistics, Agricultural College of Sweden,* Uppsala, 1975 *(Renborg* and *Uhlin [27]).*

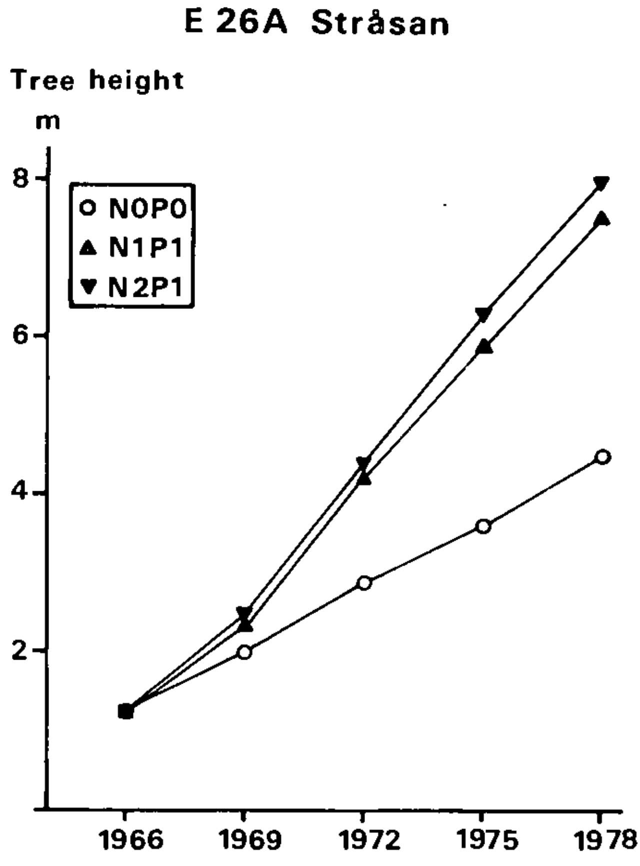

Fig. 6. Height growth development in three of the treatments in the Stråsan experiment. Each curve mean of measurements of four plots, each with about 100 trees.

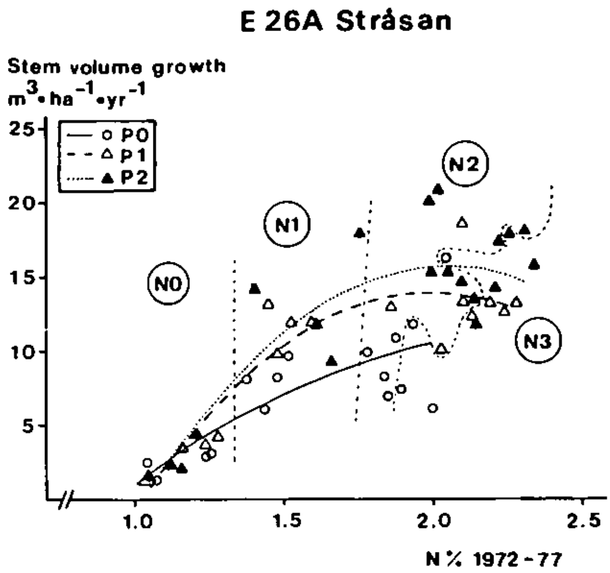

Fig. 7. Yearly stem growth 1973–1978 in the Stråsan experiment, plotted against needle nitrogen concentration. Each dot represents one net plot 20 × 20 m.
N1 means an annual dose of nitrogen as ammonium nitrate as follows: 60 kg·ha^{-1} 1967–1969, 40 kg 1970–1976, 30 kg 1977–. N2 and N3 mean two respectively three times N1.

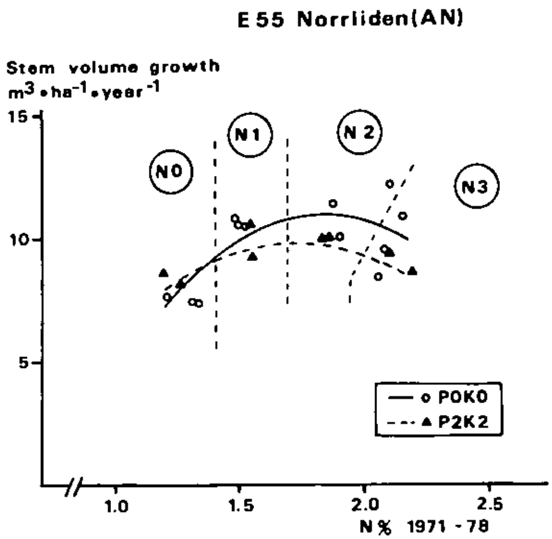

Fig. 8. Yearly stem growth 1972–1979 in the Norrliden experiment, plotted against needle nitrogen concentration. Each dot represents one net plot 20 × 20 m.
N1 means an annual dose of nitrogen as ammonium nitrate as follows: 60 kg·ha^{-1} 1971–1973, 40 kg 1974–1976, 30 kg 1977–. N2 and N3 mean two respectively three times N1.

Unfertilized plots have for the period 1973 to 1978 a production of about 2.5 $m^3 \cdot ha^{-1} \cdot year^{-1}$. But these plots have not yet a closed canopy and it may therefore be more fair to assume a production of about 5 $m^3 \cdot ha^{-1} \cdot year^{-1}$ when the canopy has closed. This would agree with the site index, translated to mean annual production *(Hägglund* and *Lundmark [15])*. For the N1-treatment the stem production is about 11 $m^3 \cdot ha^{-1} \cdot year^{-1}$ *(cf.* Figure 7). The increased production by fertilization is then 6 $m^3 \cdot ha^{-1} \cdot year^{-1}$ and with an energy content of 6.70 GJ ($6.70 \cdot 10^9$ joule) per m^3 wood this gives an energy production of 40.20 $GJ \cdot ha^{-1} \cdot year^{-1}$.
In order to get this increased production we have to put in energy in fertilizers, etc. A yearly dose of 30 kg $N \cdot ha^{-1}$ (2.07 GJ) and 20 kg $P \cdot ha^{-1}$ (0.16 GJ) each third year gives a fertilizer 'cost' of 2.12 GJ. For transport and spreading the fertilizers the estimated value is 0.23 GJ annually and the harvesting of the extra 6 m^3 wood will cost us 0.90 GJ. According to this estimate the input of energy will be 3.25 GJ, which means an output of energy 10 to 15 times more than input. If a larger part of the biomass (branches, needles) is harvested the benefit/cost relation in energy terms would be still more favourable as the harvesting costs are moderate. Stump removal requires the use of heavy machinery, and consequently more energy, at least if stump harvest is made as separate operation.

Stem yield and total yield at optimum nutrient supply

Of course data on 'optimum stem yield' can be taken from curves like those in Figures 7 and 8. The ecological significance of such curves is, however, doubtful, as the proportion of growth allocated to the stem changes with the age of the stand *(Kira* and *Shidei [21])* and also with the nutrient regime *(Axelsson [5]* and Table 1). In fact, young pines allocate only a small proportion of their photosynthate to stem growth *(Ågren et al. [1], Linder* and *Troeng [24])*.
Therefore attempts have been made to determine total above ground production in two optimum nutrition experiments *(Tamm [32], Albrektson et al. [2])*. Figure 9 shows the above ground production at Stråsan, plotted against the amount of needles. It appears as if maximum total yield was obtained at foliage biomasses around 15–20 metric tons per hectare. This figure may change somewhat, when a new sampling is made, as the amount of needles did increase between 1973 and 1978, but there is little doubt that further increase of needles above a certain level will not increase yield if at all possible. Heavily shaded needles are shed in a dense stand and fertilized plots are already so dense that there is virtually no ground vegetation.
We do not have good measurements of spruce photosynthesis in Sweden, but *Linder* and *Troeng [23]* have made such measurements in Scots pine, both fertilized and irrigated and non-fertilized. Their conclusion is that a better nutrient status increases the rate of photosynthesis, but only slightly. The great growth response after fertilization must therefore be explained by differences in allocation of photosynthates. Further confirmation on this point has been provided by *Persson [26]* in the same experimental area in which *Linder* and *Troeng* made their measurements. He found fine root production to be almost as large on the control plots as on the irrigated and fertilized ones (Table 1), in spite of a four-fold increase in above-ground production. Moreover, the fine roots accounted for more than one third of the total tree production

on the control plots against less than 15 percent on the irrigated and fertilized plots. It has been evident for some time that one effect of an application of a growth-limiting nutrient is an increased allocation of carbohydrates to leaves, resulting in increased leaf area index. This in turn leads to increased total production in stands not fully utilizing incoming light, as is often the case on poor sites. Very dense stands would then only respond to fertilization if the photosynthetic rate increases, and this response, if any, will be of a low magnitude.

The new results on changes in resource allocation to above and below-ground production indicate another response mechanism *(Axelsson [5], Tamm [33], cf.* also *Waring et al. [36]), viz.* that the increased stem growth after fertilization is to some extent related to a lower production of fine roots.

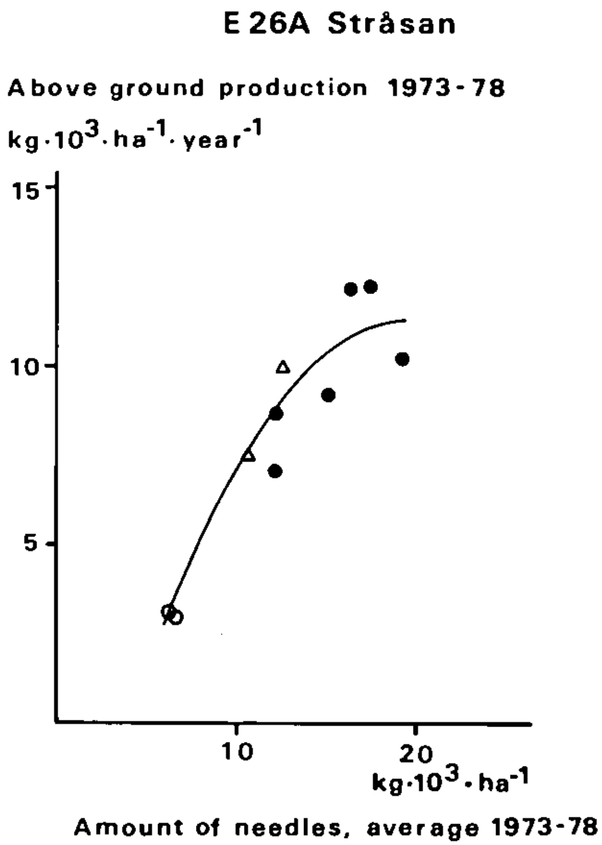

Fig. 9. Above-ground production in the Stråsan experiment plotted against needle biomass. Each symbol represents one plot.
Open rings: no fertilizer added
Open triangles: treatment N2PO
Filled dots: treatments N1–N3 with P1

Table 1. Annual biomass production, kg·ha^{-1}·years^{-1}, in a 20-year-old Scots pine stand at Ivantjärnsheden, Middle Sweden. Fine root estimates for 1975–1976, from *Persson [26]*, other estimates for 1979, from *Axelsson [5]*

Treatment	Needles	Branches	Stems	Stumps	Roots		Sum
					>2 mm	<2 mm	
Control	850	510	570	120	590	1390	4 030
Irrigated and fertilized .	2940	3750	2180	590	1300	1630	12 370

	Ratio Needles / Fine roots	Ratio Needles + branches + stems / Roots
Control	0.61	0.98
Irrigated and fertilized .	1,80	3,03

As very few reliable estimates are available on root growth in fertilized tree stands, we have to be cautious about conclusions on the true optimum production of forest ecosystems. However, for many practical purposes there is already progress if we can establish the above-ground production at optimum leaf area, in the way described in Figure 9.

As far as known, no other ecosystem than the 'optimum fertilized' spruce plot has been found to produce as much dry matter as 10 to 12 metric tons per hectare and year under climatic conditions similar to those of the Stråsan site (lat. N. 61°, altitude 350 m). Under more favourable climatic conditions certain clones of Salix species have shown very high yields in so-called energy-forest plantations. In 1981 the harvested yield (stemwood and stembark) ranged between 15 and 17 metric tons per hectare on the best plots in the southern part of Sweden (*G. Sirén*, personal communication).

Linder and *Lohammar* (in prep.) have made a theoretical calculation, based upon photosynthesis measurements, suggesting maximum energy forest yields around 15–20 metric-tons per hectare in South and Middle Sweden and 10–15 tons along the Bothnian coast (in a climate comparable with that at Stråsan). To this figure should be added about 3 tons leaf biomass to obtain comparability with the Stråsan data.

Changes in ecosystem characteristics with improvements in nutrient regime

So far we have discussed one aspect only of the changes in ecosystem functions with changes in nutrient regime, viz. the primary production of the dominant green plant. But ecosystem functions comprise a number of processes, most of which are affected by changes in canopy density or availability of ions in the soil solution.

The density and dark green colour of a fertilized stand means a change in albedo (the relation between reflected and incoming light of a surface), an important factor in energy budget calculations. A dense stand also suppresses all or most lesser vegetation, as has happened at Stråsan. Before the stand closed, there was a stimulation of certain components of this vegetation, such as fireweed (*Chamaenaerion angustifolium* L.

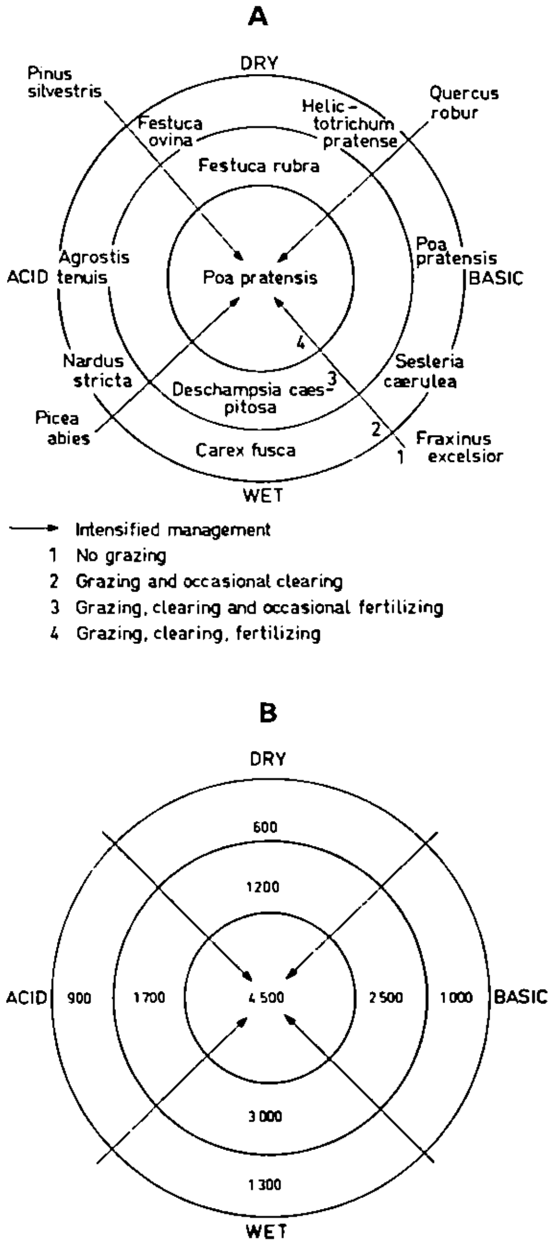

Fig. 10. Vegetational dynamics (A) and net primary production above ground (B) of semi-natural grasslands in Fennoscandia. Vegetation represented by quantitatively important species and production in kg·ha^{-1}·year^{-1} (herbs and grasses only, from *Steen [29]).*

Scop.) and raspberry *(Rubus idaeus* L.), see *Albrektson et al. [2])*. At Norrliden, where the canopy consists of Scots pine, a light-demanding species, fertilization has also favoured some herbs and grasses, notably *Chamaenaerion angustfolium* and *Deschampsia flexuosa* (L.) Trin. The lesser vegetation has changed in a way similar to what happens after clear-felling.
Such qualitative changes in vegetation are common when fertilizers are applied to mixed communities of plant species. The famous permanent plots at Rothamstead illustrate the fertilizer-induced shift from a relatively low-productive but diverse meadow vegetation to a very productive tall-grass community consisting of very few species *(Williams [37])*. For Swedish conditions *Steen [29]* has illustrated the consequences for both species composition and yield when various types of woodlands are transformed to pasture with increasing intensity of management (Figures 10A and B).

Plant nutrients are important also for other organisms than the green plants. There is evidence that the supply of nitrogen and phosphorus may limit the growth and activity of decomposers *(Berg* and *Staaf [6])*. In any case both consumers and decomposers are affected by the quantitative and qualitative changes in their food, as the amount and chemical composition of the plant material changes. Sometimes consumers or pathogens may respond in a very specific way to fertilization. Fertilized foliage is, *e.g.*, preferred by moose *(Björkman [7], Brantseg [10])*. Several fungi, particularly mycorrhiza-formers, might be disfavoured by nitrogen fertilization according to *Björkman*'s 'barter theory' *[7, 9]*.
An improvement in nutrient regime means a higher availability of nutrients in the soil, and consequently higher risks of leaching losses. Plant roots are effective in holding back essential nutrients, but some of the leaching may take place in winter or at snow-melting, when root activity is low. Some of the retention is caused by microorganism uptake rather than by root uptake. Most microorganisms prefer ammonium ions to nitrate as a source of nitrogen. If now the nitrogen regime approaches optimum for the green plants, there are good chances for nitrification in the soil. Available ammonium nitrogen is a prerequisite for nitrification. The nitrate formed can be taken up by plant roots, but is not absorbed on the soil colloids and is not much used by microorganisms. There are thus considerable risks of leaching losses. Naturally fertile sites seem to have higher leaching losses than poor sites, but even highly productive natural ecosystems usually adjust their production to the amounts of nutrients available. This means that most boreal forests, including many with high site-index, usually respond positively to added nitrogen, meaning that they are on the lower side of the optimum.
Some forests in the temperate and tropical belts may instead be limited by phosphorus or some other nutrient. It seems an urgent task to study the nitrogen budget of ecosystems limited by other nutrients than nitrogen but exposed to the increased atmospheric supply of bound nitrogen now occurring in Central Europe and Northeastern USA. If the nitrogen not used by the ecosystem is leached, we can expect increasing problems with ground water; if it is denitrified, we may have less local problems but possibly interference with the ozone layer in the upper atmosphere which protects the earth from dangerous short wave radiation. A third possibility is increased storage of organic nitrogen, but the accumulation will sooner or later lead to increased mineralization.

References

1. *Agren, G.I., Axelsson, B., Flower-Ellis, J.G.K., Linder, S., Persson, H., Staaf, H.* and *Troeng, E.:* Annual carbon budget for a young Scots pine. *In: Persson, T.* (ed.) Structure and function of Northern Coniferous Forests. – An Ecosystem Study, Ecol. Bull. (Stockholm) *32*, 307–313 (1980)
2. *Albrektson, A., Aronsson, A.* and *Tamm, C.O.:* The effect of forest fertilisation on primary production and nutrient cycling in the forest ecosystem. Silva Fenn., *11* (3), 233–239 (1977)
3. *Aronsson, A.* and *Elowson, S.:* Effects of irrigation and fertilization on mineral nutrients in Scots pine needles. *In: Persson, T.* (ed.) Structure and function of Northern Coniferous Forests. – An Ecosystem Study, Ecol. Bull. (Stockholm *32*, 219–228 (1980)
4. *Aronsson, A.* and *Tamm, C.O.:* Effects of irrigation on young stands of pine *(Pinus silvestris* L.*)* and spruce *(Picea abies* Karst.). *In: Ranneby, B.* (ed.) Statistics in theory and practice. Essays in honour of Bertil Matérn. Umeå, 1980
5. *Axelsson, B.:* Site differences in yield – differences in biological production or in redistribution of carbon within trees. Swedish University of Agricultural Sciences, Dept. of Ecology and Environmental Research, Uppsala, Report 9 (1981)
6. *Berg, B.* and *Staff, H.:* Decomposition rate and chemical changes of Scots pine needle litter. II. Influence of chemical composition. – *In: Persson, T.* (ed.) Structure and function of Northern Coniferous Forests. – An Ecosystem Study, Ecol. Bull. (Stockholm) *32*, 373–390 (1980)
7. *Björkman, E.:* Über die Bedingungen der Mykorrhizabildung bei Kiefer und Fichte. Symb. Botan Upsal. *VI*, 2, 1–191 (1972)
8. *Björkman, E.:* Älgen som finsmakare. Skogen *46* (14), 293 (1953) (In Swedish)
9. *Björkman, E.:* Forest tree mycorrhiza – the conditions for its formation and the significance for tree growth and afforestation. Plant and Soil *32*, 589–610 (1970)
10. *Brantseg, A.:* Skoggjødsling og viltet. – Jakt-, fiske-, friluftsliv *95*, 216–219 (in Norwegian) (1966)
11. *Chapin, F.S. III.:* The mineral nutrition of wild plants. – Ann. Rev. Ecol. Syst. *11*, 233–260 (1980)
12. *Ericson, A.:* Effects of fertilization and irrigation on the seasonal changes of carbohydrate reserves in different age-classes of needle on 20-year-old Scots pine trees *(Pinus silvestris)*. Physiol. Plant. *45*, 270–280 (1979)
13. *Fiedler, H.-J., Wunderlich, H.* and *Höhne, H.:* Über den Einfluss des Baumalters und der Standortsform auf die Ausbildung und den Nährelementgehalt der Kiefernnadeln. Arch. Forstwes. *16* (6/9), 609–616, Berlin (1967)
14. *Holmen, H., Nilsson, Å., Popović, B.* and *Wiklander, G.:* The optimum nutrition experiment Norrliden. A brief description of an experiment in a young stand of Scots pine *(Pinus silvestris* L.). Dept. of Forest Ecology and Forest Soils, Royal College of Forestry, Stockholm. Research Notes *26*, 34 pp. (1976)
15. *Hägglund, B.* and *Lundmark, J.-E.:* Handledning i bonitering med Skogshögskolans boniteringssystem. Skogsstyrelsen, Jönköping, 1981 (in Swedish)
16. *Höhne, H.:* Über den Einfluss des Baumalters auf das Gewicht und den Elementgehalt 1- bis 4jähriger Nadeln der Fichte. Arch. Forstwes. *13* (3), 247–265, Berlin (1984)
17. *Höhne, H.* and *Nebe, W.:* Der Einfluss des Baumalters auf das Gewicht sowie den Mineral- und Stickstoffgehalt einjähriger Fichtennadeln. Arch. Forstwes. *13* (2), 153–167, Berlin (1964)
18. *Ingestad, T.:* Nitrogen and plant growth; Maximum efficiency of nitrogen fertilizers. Ambio *6*, 141–151 (1977)
19. *Ingestad, T.:* Nitrogen stress in birch seedlings. II. N, K, P, Ca, and Mg nutrition. Physiol. Plant. *45*, 149–157 (1979)
20. *Ingestad, T.:* Addition rate and concentration. Relative addition rate and external concentration; Driving variables used in plant nutrition research. Review article for Plant, Cell and Environment (in press).
21. *Kira, T.* and *Shidei, T.:* Primary production and turnover of organic matter in different forest ecosystems of the Western Pacific. Jap. J. Ecol., *17* (2), 70–87 (1967)
22. *Linder, S.* and *Lohammar, T.:* Växter som solfångare – en förnybar energikälla (Plants capturing sunlight – a renewable source of energy). Forskning och Framsteg 17 (in Swedish) (in press)

23. *Linder, S.* and *Troeng, E.:* Photosynthesis and transpiration of 20-year-old Scots pine In: *Persson, T.* (ed.) Structure and function of Northern Coniferous Forests. An Ecosystem Study, Ecol. Bull. (Stockholm) *32*, 165–181 (1980)
24. *Linder, S.* and *Troeng, E.:* The seasonal variation in stem and coarse root respiration of a 20-year-old Scots pine *(Pinus sylvestris* L.). Mitt. Forst. Bundesversuchsanst., *142*, 125–139, Wien (1981)
25. *Miller, H.G., Miller, J.D.* and *Cooper, J.M.:* Optimum foliar nitrogen concentration in pine and its change with stand age. Con. J. For. Res. *11* (3), 563–572 (1981)
26. *Persson, H.:* Fine-root dynamics in a Scots pine stand with and without near-optimum nutrient and water regimes. Acta Phytogeographica Suecica, *68*, 101–110 (1980)
27. *Renborg, U.* and *Uhlin, H.-E.:* Resursflöden i svenskt jord- och skogsbruk 1956 och 1972 med tonvikt på energiströmmar. Dept. of Economics and Statistics, Agricultural College of Sweden, Uppsala, Report No. 64 and 65 (1975) (in Swedish)
28. *Rutter, A.J.:* Studies in the growth of young plants of *Pinus silvestris*. I. The annual cycle of assimilation and growth. Ann. Bot. Lond. (N.S.) *21*, 399–426 (1957)
29. *Steen, E.:* Dynamics and production of semi-natural grassland vegetation in Fennoscandia in relation to grazing management. Acta Phytogeografica Suecica *68*, 153–156 (1980)
30. *Tamm, C.O.:* Studies on forest nutrition. I. Seasonal variation in the nutrient content of conifer needles. Medd. från Stat. Skogsforskningsinstitut *45* (5), 1–34 (1955)
31. *Tamm, C.O.:* An attempt to assess the optimum nitrogen level in Norway spruce under field conditions. Stud. for. suec. *61*, 1–67 (1968)
32. *Tamm, C.O.:* Experiments to analyse the behaviour of young spruce forest at different nutrient levels. Proceedings of the First Int. Congr. of Ecology. September 8–14. The Hague. pp. 266–272 (1974)
33. *Tamm, C.O.:* Nutrient cycling and productivity of forest ecosystems. From: *A.L.Leaf*, ed. Proceedings. Impact of intensive harvesting on forest nutrient cycling. State Univ. of New York, College of Environmental Science and Forestry, Syracuse, N.Y. 1979, pp. 2–21, 1979
34. *Tamm, C.O., Nilsson, Å.* and *Wiklander, G.:* The optimum nutrition experiment Lisselbo. A brief description of an experiment in a young stand of Scots pine *(Pinus silvestris* L.). Dept. of Forest Ecology and Forest Soils, Royal College of Forestry. Stockholm. Research Notes, *18*, 25 pp. (1974)
35. *Waring, R.H.* and *Youngberg, C.T.:* Evaluating forest sites for potential growth response of trees to fertilizer. Northwest Science *46* (1), 67–75 (1972)
36. *Waring, R.H., Thies, W.G.* and *Muscato, D.:* Stem Growth per Unit of Leaf Area: A Measure of Tree Vigor. Forest Sci., *26* (1), 112–117 (1980)
37. *Williams, E.D.:* Botanical composition of the Park Grass Plots at Rothamstead 1956–1976. Rothamstead Expt. Sta., 61 pp., 1978

New Dimensions in Agricultural Engineering

J. K. R. Gasser, Agricultural Research Council, London/United Kingdom*

Summary

The agricultural engineer has to apply existing engineering knowledge to improve agricultural productivity, involving: i) the development of new machinery, ii) recognising the need for instruments to provide measurements of important parameters and designing these, and iii) the application of control engineering principles to improve farming systems. In recent advances much use has been made of the many developments in electronics and computing, particularly the microcomputer. Special attention is paid to the role of the engineer in improving the efficiency of energy used as fertiliser.
Examples are given of the development of machines and controls for improving the direct drilling of cereals and the harvesting and transport of potatoes.
Major advances have been made in livestock engineering and examples related to the welfare and feeding of pigs, cattle and poultry are given.
Two major challenges for the future are the use of straw and the re-cycling of animal wastes.

1. The role of the engineer in agriculture

Agriculture is concerned with the production of food, and engineering has been identified with farming from the time that early man used a pointed stick to assist in planting his crops or a crook-shaped stick to help in managing his animals. Initially the necessary power was provided by man himself, then by his draught animals, a phase that continued for several thousand years, and most recently by the use of engines using fossil fuels, initially steam powered and now almost entirely internal combustion (or electric motors for some fixed installations, with electricity from fossil fuel powered stations).
The availability of power has had several consequences for agriculture; it has enabled man to do work more quickly and therefore to cultivate larger areas with less labour input. In the earlier paper *(Gasser [9])* the time required for the cultivation of one hectare of rice was shown to decrease from 837 man hr to 30 man hr as the system changed from subsistence farming to intensive temperate agriculture. The increased

* Dr. *J. K. R. Gasser*, Scientific Adviser, Agricultural Research Council, 160 Great Portland Street, London W1N 6DT/United Kingdom

speed of operation from the use of machines also allows operations to be done more timely and increases the flexibility of management. For example, in the UK the modern combine harvester allows such rapid harvesting of cereals, which coupled with minimum cultivation techniques now available for cultivating and drilling cereals, that it has allowed a very marked increase in the proportion of winter sown cereals. This has two major benefits. First the yield is greater from winter than from spring sown cereals, second the farmer is able to spread the work over a longer period. Other consequences of the decreased amount of workers' time required for the production of one hectare of crop are that fewer people are required in agriculture, the standard of living of the agricultural community is improved and food is produced more cheaply. Initially the machines were controlled by man, but with the development and application of control engineering, more automation has become possible with improved control and efficiency. This is particularly true in the livestock sector. The engineer can provide the farmer with the means to improve the way in which he uses the fossil energy on which modern farming depends in the capture and utilisation of solar energy which represents the basic renewable energy resource. In discussing the role of the engineer in improving agricultural efficiency, this paper considers the fossil fuel energy input to agriculture, especially that required for fertilisers, and how the engineer can improve the use of this energy for crop production, harvesting and storage and animal production and to decrease losses of energy from the system.

2. Energy use in UK agriculture

White [24] reviewed the use of energy in agriculture and calculated the primary energy consumed in UK agriculture in 1978. Table 1 shows his estimates of the amounts and proportions for the various inputs. The largest single input was for fertilisers (23%) and as fertiliser consumption, particularly of nitrogen, continues to increase, the present value may be taken as one-quarter of the energy used in agriculture in the UK. Another substantial input is imported feedstuffs (13%) and the effects of this energy which has been produced by the expenditure of fossil energy elsewhere cannot be ignored in considerations of energy use.

Table 1. Primary energy consumed in UK agriculture 1978 *(White [24])*

Item	PJ	per cent
Solid fuel	1.2	0.3
Petroleum	70.0	17.5
Electricity	37.2	9.3
Fertilisers	93.3	23.4
Machinery	40.0	10.0
Feedstuff processing (off-farm)	52.5	13.2
Chemicals	8.5	2.1
Buildings	22.9	5.7
Transport, distribution and services	16.3	4.1
Miscellaneous	4.3	1.1
Imported feedstuffs	53.2	13.3
Total	399.4	100.0

2.1 Efficiency of energy use

From the inputs given in Table 1, the non renewable energy required to produce a given crop can be calculated, such as fuels to power machines, to dry crops, to provide fertilisers and control chemicals, as well as the provision of machinery and buildings. Where crops are used for feeding to animals, similar calculations can be made of the total energy input to provide animal products. This energy is called support energy. A measure of the efficiency of agriculture is the ratio 'E' of the energy contained in the product to the support energy used to produce it

$$E = \frac{\text{Energy output}}{\text{Support energy}}$$

White [24] provided values of E for a number of commodities based partly on his own calculations and partly on those calculated earlier by *Leach [11]*. The main differences were in values for animal products. Table 2 gives values of E for a number of crops and animal products. These values must be interpreted with caution because they do not take account of factors such as the need to process some crops before consumption and that forage crops are not eaten directly by man and have to be processed through a ruminant. Also Table 2 only gives the values for the primary or desired product and ignores secondary products such as cereal straw or the recycling of energy in animal wastes. However, some general conclusions may be drawn. For example, cereals and potatoes show a net return of energy greater than the support energy used and therefore the considerable energy input as fertiliser to the production of these crops is justified. Vegetable crops which provide some essential dietary requirements as well as variety are energy intensive and glasshouse crops, such as tomatoes, are very demanding of support energy. The alternative is to grow tomatoes in a more favourable climate and transport them to Northern Europe. *Stanhill [21]* in a study of the energy costs of six systems of protected tomato production found that the difference in energy required for heated protected crops in Northern Europe and unheated crops in the Mediterranean region approximately equals the energy used to transport the fruit by air. When crops are processed through animals to

Table 2. Estimates of agricultural use of support energy *(White [24])*

Commodity or product	Energy input or Support energy GJ ha^{-1} yr^{-1}	Energy output or ME GJ ha^{-1} yr^{-1}	E= ME/Support energy
Wheat	19.3	60.0	3.12
Barley	17.6	46.2	2.63
Potatoes	52.0	69.3	1.33
Carrots	25.1	32.5	1.30
Onions (bulb)	93.4	27.7	0.30
Tomatoes (glasshouse)	1300	62.0	0.05
Milk	32.5	18.5	0.57
Beef (from beef herd)	10.6	2.4	0.23
Pigs (pork and bacon)	18.0	11.4	0.63
Poultry (eggs)	22.5	6.0	0.26

produce animal products, the efficiency drops. Energy is converted most efficiently in the production of milk and pig meat.

2.2 Energy for marketing and food preparation

We have been discussing the primary agricultural production and further substantial processes are necessary for many products before agricultural products are consumed as food. Many operations require large inputs of energy such as transport, processing, packaging, retailing, and cooking in the home. *White [24]* provided information (derived partly from *Leach [11]*) on the total energy required for the food produced, imported and consumed in the UK in 1968. Table 3 gives these values which show that energy used by agriculture (including imported feedstuffs and off-farm processing) is about one-fifth of the total energy required to put food on the table. With the continued rise in food processing and production of convenience foods, energy use by the food and drinks industries will have increased and the proportion of total energy used by agriculture has become less. In more primitive societies, less energy is used in food processing but a greater proportion is required for cooking because the methods of heating are very inefficient.

Table 3. Primary energy involved in food production UK 1968 *(White [24])*

Item	PJ	per cent
Agriculture (less feedstuffs)	274	15.7
Feedstuffs processing (off-farm)	51	2.9
Imported feedstuffs	53	3.0
Food imports	260	14.9
Fish imports	13	0.7
UK fishing	33	1.9
UK food and drinks industries (less feedstuff processing)	476	27.3
UK food shops	139	7.9
Food storage	450	25.7
Total	1749	100.0

3. The use of energy as fertiliser in agriculture

Figure 1 shows the energy used in fertiliser production in the UK in 1978 and the corresponding input of energy as imported animal feedstuffs, together with their flow through the agricultural system to produce food and pathways of losses. Phosphorus and potassium are removed in agricultural products and the main losses are in sewage effluent and sewage sludge not returned to agricultural land. Nitrogen is easily lost through any one of a number of routes and since it requires much energy for its production, the efficiency of use and conservation of nitrogen are matters of great concern. Engineers have already contributed greatly in decreasing the amount of energy required to fix atmospheric nitrogen. *Lewis* and *Tatchell [12]* showed how the change of primary energy from coal to naphtha to natural gas had decreased the energy input from 123 to 86 to 73 MJ kg^{-1} N. More recent plant has achieved a figure of 64 MJ kg^{-1} N. Engineers are also making considerable efforts in improving the use of fertiliser-N as it flows through the system.

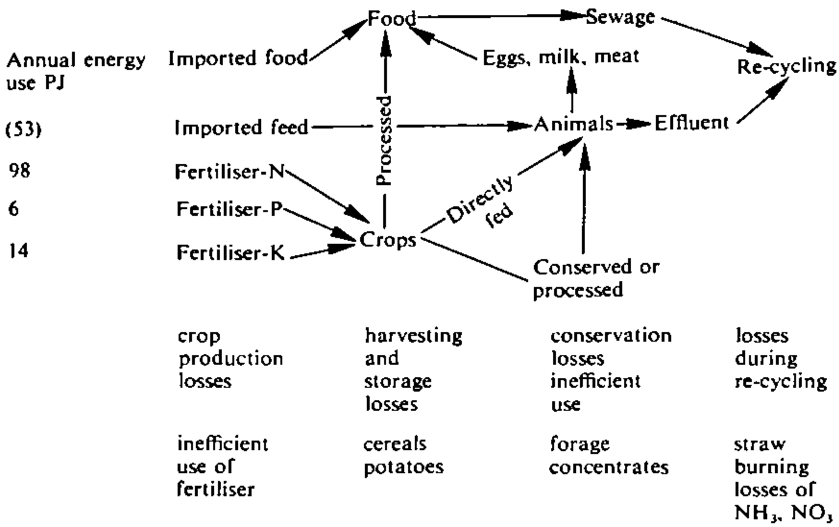

Fig. 1. A simplified scheme for energy inputs as fertilisers and feeding stuffs to agriculture, their use in food production, re-cycling, and loss.

4. Crop engineering

4.1 Direct drilling of cereals

Advances in the use of chemicals to control weeds, diseases and pests have allowed the development of new systems of crop production based on minimum cultivation or direct drilling of crops. Such more rapid techniques have greatly aided the recent trend towards winter sowing of cereals in the UK. One of the problems associated with direct drilling of cereals on heavy soils in wet conditions is the smearing of the sides of the slit which leads to poor crop establishment and can enhance the damage caused by slugs which travel down the slit. A lesser problem has been to apply fertilisers effectively when direct drilling because they cannot normally be incorporated in the soil. Figure 2 shows how these problems are overcome by the use of an 'A'-blade for sowing the seed and it can be adapted to place the fertiliser in the soil *(MacIntyre* and *Pascal [15])*. The seed is blown to the ends of the 'A'-blade and, if required, the fertiliser may be dropped in the centre, thus placing it in a position to allow better utilisation by the crop.

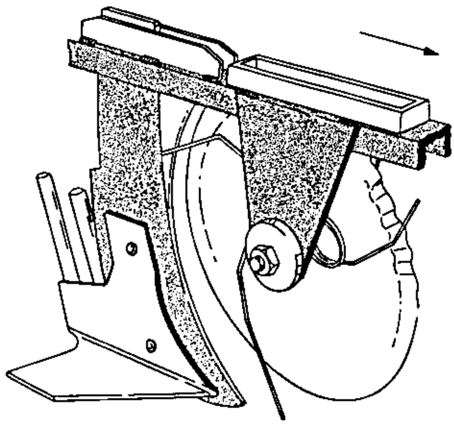

Fig. 2. 'A' blade coulter with trash-clearing device *(MacIntyre* and *Pascal [15]).*

4.2 Use of gantries in crop production

Cultivation is done for three main purposes, to create a favourable root environment for crop establishment and growth, to bury other plant material and weeds to remove competition to the crop and to restore or provide a level surface for subsequent farming operations. The development of direct drilling has shown that cereals may be sown successfully and yield well when sown into undisturbed soil and weeds may be controlled chemically. There remains the problem of maintaining a level surface when machinery has to pass across the land many times during the production of a crop. A solution to this problem has been suggested following the juxtaposition of two ideas developed separately. The use is well established of permanent tracks for wheels through cereals, called tramlines, to allow spraying and fertiliser applications with minimum damage to crops and loss of yields. These are already being considered experimentally as permanent tramlines, but present day techniques of growing crops still require the passage of some machinery across the soil. Another development for protected horticultural crops has been the travelling gantry. This has been developed to allow all crop operations to be done from a gantry carried on rails at the side of the house, so that the total ground area can be used productively. By substituting gantry tracks for tramlines in the field, all operations can be done without passing across the soil. Gantries spanning 15–20 metres are envisaged *(Matthews [13])* which by using new crop production techniques and specially developed machinery will mean little loss of productive area. Much automatic control and monitoring can be done using such a system.

4.3 Damage to potatoes during harvesting, transport and storage

4.3.1 Harvesting losses by damage

Potatoes are easily damaged by bruising and surface abrasion and the damaged areas become infected leading to loss of saleable crop. Potatoes are harvested by lifting the soil containing the tubers and separating them by a riddling action on a moving belt of rods called the web. Detailed investigations at the *Scottish Institute of Agricultural Engineering (SIAE)* have shown that a number of factors affect the amount of damage to the tubers. The ratio of the web speed to the forward speed is very important, as web speed increases relative to ground speed, i.e. the ratio becomes greater than unity so the damage increases. A meter to measure the ratio web speed/ground speed was produced and fitted to a potato harvester *(Carlow [4])*. Results of tests in the field given in Table 4 show that using the meter to obtain the optimum ratio, minimum damage was caused to the harvested tubers.

Because much damage occurs during the primary harvesting operation, *McGechan [14]* investigated the causes of damage during the removal of loose soil on harvesters. Figure 3 shows that horizontal motion removed soil more effectively than vertical motion at lower peak accelerations and caused less damage particularly with motion along the length of the bars. He concluded that potato harvesters need to be redesigned to remove soil using a horizontal shaking motion.

Table 4. The relationship between mechanical damage and web/forward speed ratio. Variety: King Edward. Soil: Light silt *(Carlow [4])*

Date	Run	Damage type	Ratio 1:1	1.2:1	1.4:1	1.6:1
24 October 1979	1	% Peeler	20	25	30	36
		% Severe	3	2	7	13
		Index	81	89	139	199
	2	% Peeler	16	23	29	40
		% Severe	5	3	9	11
		Index	83	90	150	197
1 November 1979	3	% Scuffed	3	4	3	–
		% Peeler	30	32	32	–
		% Severe	5	7	15	–
		Index	128	149	204	–
	4	% Scuffed	4	3	3	–
		% Peeler	28	34	20	–
		% Severe	6	6	17	–
		Index	130	147	212	–

4.3.2 Damage during transport

After harvesting, potatoes are normally transported in bulk to the store and again may be moved in bulk for grading and packing. When filling bulk containers with a conveyor and discharging from a fixed height, the initial drop is much larger than during the later stages of filling and the damage to potatoes is correspondingly greater. A simple device was developed to adjust the height of the conveyor by using an air-filled soft plastic ball to sense the surface of the trailer or top of the potatoes *(McRae [16])*. When the ball is deformed, a switch is actuated. This provides power to raise the conveyor for a fixed period of time (about 1.5 secs) after which the conveyor descends again. This cycling continues, and the number of cycles per minute can be adjusted. The effect is to maintain the average drop height at 168 mm at which distance damage would not be expected with few falls exceeding 250 mm, thus minimising the

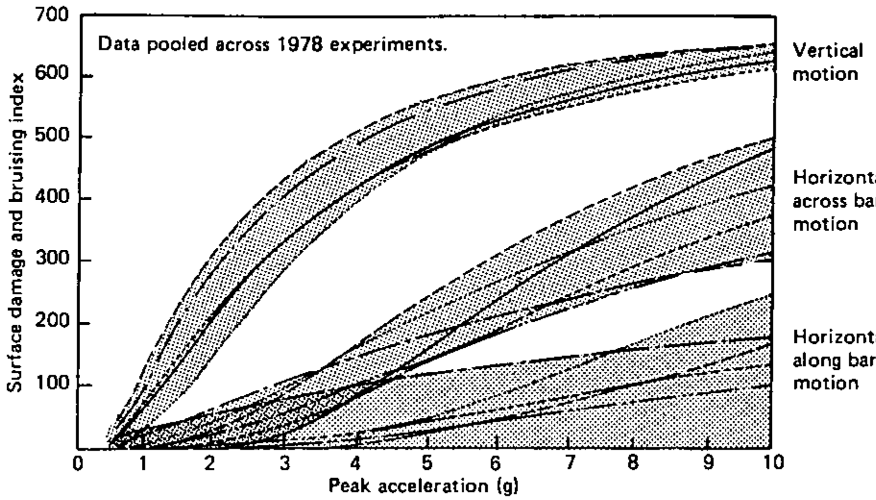

Fig. 3. Surface damage and bruising index of potatoes caused by varying peak acceleration. Shaded areas indicate the spread between the most susceptible and least susceptible varieties for each direction of motion *(McGechan [14])*.

Varieties

Record	————————	King Edward	- - - - - - - - - - -
Pentland Hawk	- - - - - - - - - -	Pentland Crown	— - — - — - —
Maris Piper	- - - - - - - - - - -	Desirée	— - - — - - — -

risk of damage. Thus by the use of a simple tranducer and control mechanism, damage is minimised without the need for the operator to adjust the conveyor height at frequent intervals. He is thus free to concentrate on other aspects of his work.

4.3.3 Measurement of forces on the potato

In order to relate damage to potatoes to the forces and pressures to which they are subject, some method of measuring these incidents is required. For example, for potatoes moving on the web of a harvester the instrument must move with and simulate the behaviour of the tuber. Over the past decade a number of instrumented simulated fruits and vegetables have been made but they were costly. A more economical device, which retained usefulness and reliability, was developed at SIAE over a period of 5 years *(Anderson [1])*. The artificial potato contains a sensor, a single hybrid integrated circuit and a rechargeable battery and responds to handling similarly to a tuber. The sensor can be either an accelerometer to measure accelerations experienced by the tuber or a pressure transducer to measure static loads. Ideally, the accelerometer should have omni-directional sensitivity, but using a single-axis accelerometer and making several passes enables a valid assessment to be made with the simpler and cheaper instrument. The other equipment needed is a frequency-modulated (FM) receiver, a stereo-cassette recorder, a demodulator and a pen recorder to provide a visual output. One channel of the cassette recorder is used for the signal from the artificial potato and the other is required for a commentary to record the position of the device along the machine and so allow the accelerations measured to be related to the motions causing them. Standard loads and forces are used to calibrate the equipment. The development of the artificial potato illustrates well how the solution of a problem requiring particular measurements may have to await the availability of the appropriate techniques before the investigation can be made.

5. Livestock engineering

5.1 Animal welfare

Modern intensive livestock production demands that animals are kept under conditions allowing the optimum conversion of food to animal products. Values given in Table 2 show that pigs convert effectively the grain and other feeds produced by the use of fertilisers into pork and bacon. To do this they must be appropriately housed and fed. Like many animals, when kept under cool conditions pigs generate extra heat by muscular activity using part of their food intake to maintain body temperature above its lower critical value thus decreasing the efficiency of feed conversion. Animals generate heat all the time and in warm conditions ventilation is essential to prevent heat stress. Thus a ventilation system is required which will maintain the internal temperature within the desired range, remove noxious gases and keep dust at a tolerable level. These conditions must be achieved throughout the normal range of external temperatures and wind speeds, which greatly influence ventilation conditions in naturally ventilated houses. Whether or not a stable airflow pattern is developed and its direction, for example in a building with an inlet in the ridge and extractor fans at the eaves, will depend on the external and internal temperatures.

5.1.1 Ventilation of an animal house

Bell [2] in the *Sixty-seventh Thomas Hawksley Lecture* summarised the work leading to the definition of conditions required for stable air-flow and their application to the design of a pig-fattening house. (Reprinted by permission of the *Council of the Institution of Mechanical Engineers* from Proceedings of the Institution).

Figure 4 shows the airflow patterns produced in a building when there are air inlets at the ridge and extract fans at the eaves. In describing the two cases illustrated it is convenient to discuss first the situation where the extract rate is the same in both cases. The velocity of air entering at the inlets will then be the same in the two cases and this will generate an 'inertial pressure', $P_1 \propto \rho_1 V_1^2$, where ρ_1 is the density and V_1 the velocity of the incoming air. The inertial pressure will tend to cause the air to follow its original trajectory on entering the building and this is what is happening in Figure 4a. If however, the incoming air is significantly colder than that inside (say, at night) there will be a density difference tending to cause the air to fall. This is what is happening in Figure 4b. The effect of the density difference is incorporated in the notion of a 'gravitational pressure', $P_2 \propto (\rho_1 - \rho_i)\,g$ where ρ_i is the density of the inside air.

In general the curvature of the path followed by a jet of air entering a building turns out to be dependent on the ratio P_1/P_2, and this ratio is incorporated in the Archimedes Number, A_r, which is given by:

$$A_r = \frac{l(\rho_1 - \rho_i)\,g}{\rho_1\,[V_1^2]}$$

where l is a characteristic dimension of the building. If the ratio is either very large or very small then one of the two pressures is strongly dominant and a simple, stable airflow pattern is obtained. If the ratio takes on intermediate values then the airflow pattern is both complicated and unstable.

This general understanding of the problem began to emerge in the late 1960s and early 1970s from studies, principally in Russia and West Germany, of the ventilation of factory buildings. *Carpenter* et al. *[5]* and *Randall [17, 18]* have applied it to the study of livestock buildings in an elegant series of experiments involving the investigation of airflow patterns by means of buoyant liquid film bubbles. Their experiments have shown that values of Ar in the range 30–75 should be avoided. In this range the air

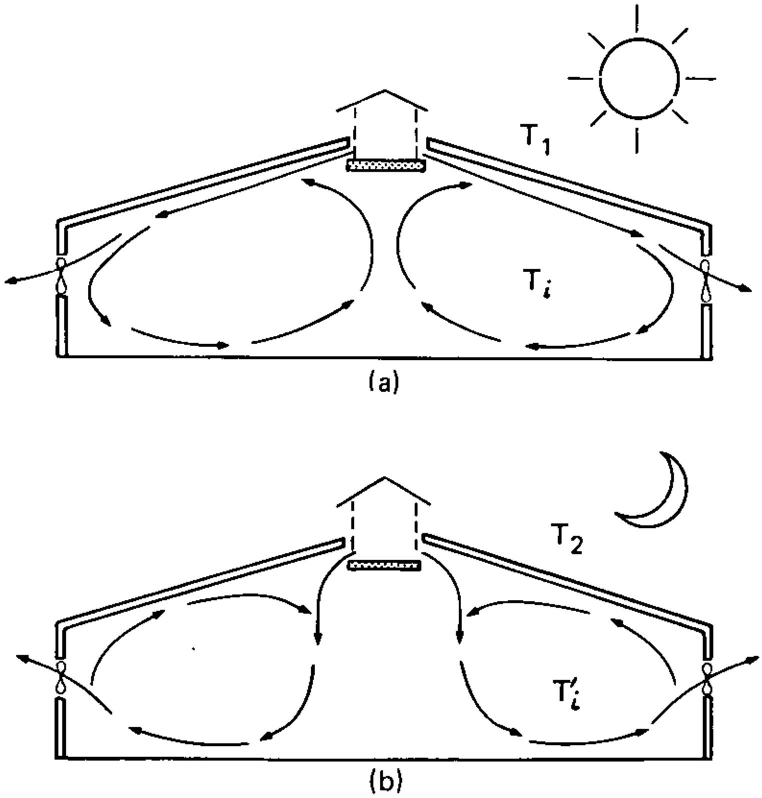

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Fig.4. Buildings ventilated by means of extract fans and ridge inlet.
(a) When outside temperature, T_1, is close to the inside temperature, T_i.
(b) When the outside temperature, T_2 is less than T_i *(Carpenter et al. [5]; Randall [17]; Randall* and *Battams [18])*.

circulation pattern is unstable. Satisfactory, stable ventilation systems may be obtained by using A_r values on either side of this range, the choice being a matter of which regime it is convenient to maintain in a particular case.

5.1.2 Application to the design of a pig fattening house

Randall [14] has selected the lower stable range (*viz.* A_r 30), where the inertial pressure is dominant, to design a ventilation system for a fattening piggery. Air enters the building via a long narrow 'high speed' (5 ms^{-1}) jet inlet along the ridge of the building. Such an inlet is affected very little by variations in wind pressure. The inertial pressure is such that the circulation pattern of Figure 4a is maintained down to incoming air temperatures as low as 0°C where the tendency of the air trajectory to curve downwards is still dominated and prevented by the high speed of the jet.

The 500 place building for fattening pigs which has been constructed to this design is effectively 12 m wide and 32 m long. A cross-section of this building is shown in Figure 5 where it will be seen that there is a central access passage, and dunging channels along each of the outside walls. A series of exhaust fans is spaced along the side walls just below the eaves. To avoid using them outside their most efficient range they are either switched full-on or off, any variations in air throughput necessary to maintain a given temperature being obtained by adjusting the number switched on. The double inlet which runs along the ridge of the building can be adjusted in proportion to the number of fans in operation so as to maintain an inlet velocity of not less than 5 ms^{-1}. Provided that the inlet runs the length of the building (either as a continuous slot or as a series of perforations) the fact that only one or two fans out of a total of twelve may be on during very cold weather, does not destroy the essentially two-dimensional nature of the air circulation pattern.

The temperature distribution in the building, like the air circulation pattern, is essentially a two-dimensional one, there being uniformity between corresponding points along the length. Within the cross-section, however, there is a small spatial variation of temperature due to the gradual warming up of the cold inlet air as it mixes with the internal air on traversing over the pigs in a direction from the dung channel

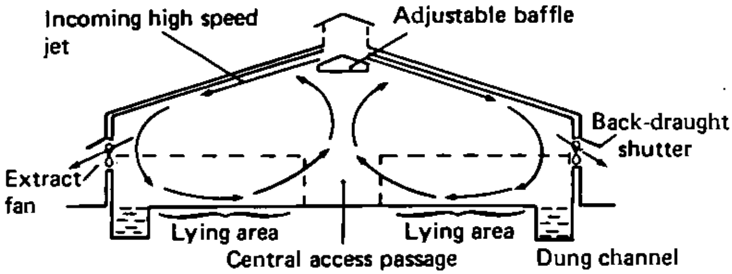

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Fig.5. Application of the high speed jet ventilation system in a pig fattening house *(Randall [19])*.

to the central passage. Although this temperature variation across the floor only amounts to 1–2°C, it has been arranged deliberately to occur in the sense described because of a remarkable influence it has on the pig behaviour. They unerringly find the warmest spot to lie in, even though there may be only a degree or so of advantage, and hence congregate towards the centre of the building. Defaecation they prefer to carry out where they will be unharrassed by others and so they seek out the less populous cooler regions near the outside of the building. In other words, they make use of the dunging area provided. This not only facilitates the removal of excreta but since the lying area is kept clean the pigs also keep cleaner and as a result are more healthy and put on weight more rapidly. All this may sound a little surprising but it is possible to demonstrate the remarkable influence of the air flow pattern and hence the temperature distribution by reversing the circulation direction. When the central area is just a degree or two below that at the 'dung channel' the pigs rapidly become less efficient converters of feedstuffs."

5.2 Animal feeding

5.2.1 Pigs

The piggery also incorporates automatic on-floor feeding of pelleted dry feed by using a recently developed conveying and weighing system *(Randall* et al. *[20])*. The pellets are conveyed pneumatically through a 75 mm diameter plastic pipeline and deflected sequentially into a series of weighing hoppers, one for each pen of pigs. When each hopper is filled to a pre-determined weight the weighing springs are extended to a position where the deflector is withdrawn and the pellets pass to the next hopper. When all the hoppers are full they are emptied simultaneously. The weight dispensed can be adjusted to the requirements of the pigs in each pen. This system of feeding causes less stress to the pigs, because they quickly recognise that feed is dispensed when the filling stops and do not become agitated as they do when waiting for food with manual pen feeding.

5.2.2 Ruminants

Ruminant diets typically have two major components – roughages to provide the necessary bulk for the rumen and additional high energy foods and proteins to balance the diet. The roughage may be fresh cut fodder as in zero grazing, conserved fodder as hay or silage, or low quality roughage such as straw. Concentrates include cereals, maize, soya bean meal and fish meal. Therefore, two very dissimilar components need to be weighed and mixed. A system involving feeding silage and barley for dairy cows is shown schematically in Figure 6 where the silage is metered from the silo, a pre-determined proportion of barley is added and the mixture is conveyed to a second belt from which the cattle eat *[Dawson* et al. *[8])*.
Further control would be possible if the moisture content of the silage were known, so that the concentrates could be added on a dry weight basis, thus maintaining a constant proportion of energy concentrate. The measurements have to be capable of

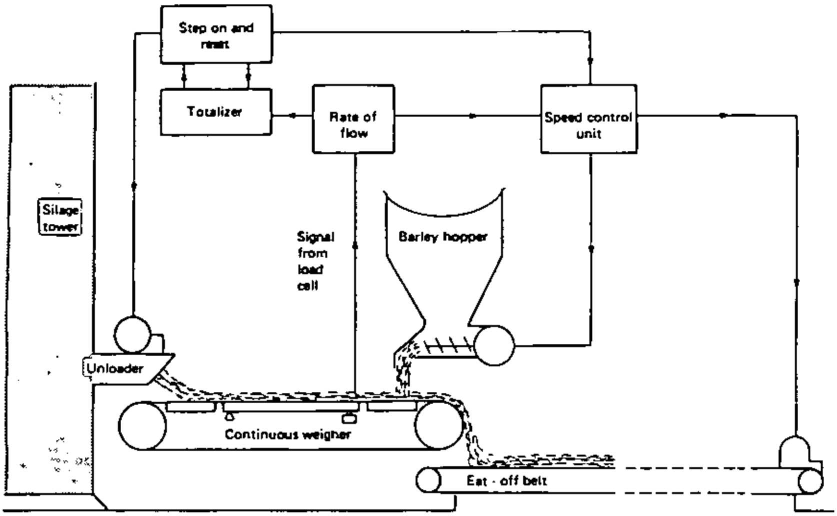

Fig.6. System for the continuous weighing of silage and metering barley to give a diet of constant composition *(Dawson et al. [8])*.

being taken continuously or at very short time intervals and in a form suitable for providing the necessary control signal. Recently, a moisture meter has been developed, primarily for use with forage, which uses reflectance ratios in the infrared as a measure of the moisture content *(Hooper [10])*. The infrared sources are specially developed solid-state lamps and the optical head is devoid of moving parts, so that the instrument is robust and potentially capable of working under the hostile conditions likely to be found on farms.

Successive reflectance ratios can be measured at intervals of one millisecond and the micro-processor will display the mean of from 16 to 4096 elements as required. Its further development may be expected and the necessary computer software written to allow its incorporation into a system such as that shown in Figure 6. Similarly, *Davis* and *Wilton [6]* described proportioning controls and dispensers for use in the preparation of cattle diets from ground straw with molasses, cereals and other additives. The speed of the auger feeding the straw mill governs the rates of discharge of the other components and thus maintains a constant proportion of straw to other ingredients. The control is exercised through geared printed circuit motors.

5.3 Monitoring dairy cattle

Dairy cattle normally enter the milking parlour twice daily when they are milked, receive concentrate rations and are seen by the herdsman, who can check their condition. The amount of concentrate fed will depend on the part of the lactation of the cow and feeding policy. Therefore for full automation automatic identification of each cow is required and as a prerequisite information is needed on the past performance. The milk yield has to be recorded and the record used to determine the amount of concentrate to be fed. As a check on condition, weighing is desirable. Figure 7 shows these functions schematically *(Bell [2])*. All these functions may be controlled by a mini-processor, if the necessary sensors are available to provide the information which may be displayed on a *Visual Display Unit (VDU)*. Additional information about each cow may be stored and recalled on demand such as date of calving, health record, likely date for next service, as well as the lactation curve from start to date of recall. This relieves the herdsman of many routine duties and allows him to concentrate on stockmanship because in a modern milking parlour, he may be able to devote less than one minute to each cow. The various components of an automated system have been developed separately and integration has had to await the production of suitable hardware for the control systems such as the micro-computer. However, full automation is not yet possible because there is not enough understanding of how the biological nature of each individual cow should be represented in the control box labelled Herd Management *(Burgess [3])*.

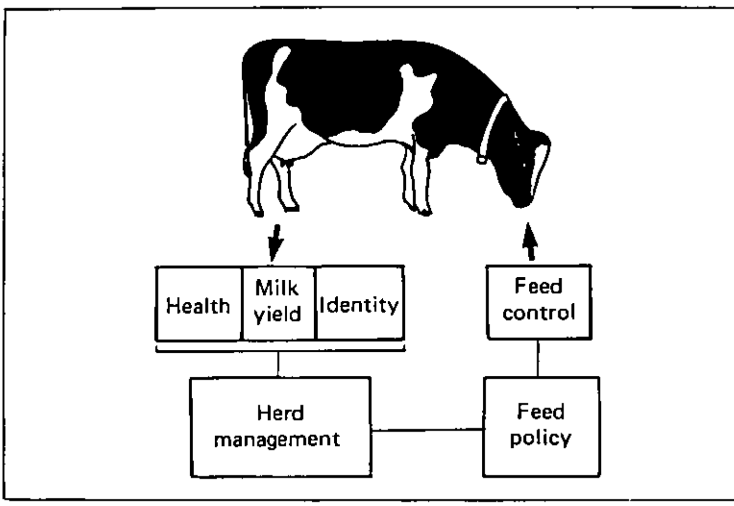

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Fig.7. Schematic diagram of information required and its processing in dairy parlour automation *(Burgess [3])*.

5.3.1 Animal identification and its uses

The automatic identification of cattle requires that the identifying device shall be recognised by an appropriate sensor and a control signal produced. Most systems use radio devices, one of which currently in use, employs a transponder carried on a collar round the cow's neck. When the cow walks through a loop aerial, for example in the form of a frame at the entrance to a rotary milking parlour or weighing platform, the transponder picks up a signal at a single freuquency and generates and returns a particular pulse train that is identified by a pulse code modulated (PCM) receiver *(Street [22])*. When the cow has been identified, the computer will provide the signals to carry out the necessary functions, such as record weight or milk yield and feed concentrates. The recording of milk yield also enables the removal of the teat clusters to be done automatically, because the increase in weight is measured as well as the total weight, and when the rate of increase falls below a pre-set value the teat cluster is allowed to fall *(Bell [2])*.

5.4 Feed dispensers

Dairy cows often receive their ration of concentrates in the parlour while they are being milked. Early designs of automatic dispensers delivered concentrates either on a volumetric or a timed basis. With the inevitable variation in bulk density between different feeds and different batches of the same feed, the accuracy was only within 5% of the desired amount for 25% of the measurements. Figure 8 shows the design of a simple gravimetric dispenser which overcomes these difficulties and is sufficiently cheap to be fitted to each stall of a herring-bone parlour *(Dawson* and *Turner [7])*. Each charge or shot is 0.5 kg, and is provided by filling the weighing bucket from the store of concentrates by means of a motor-driven screw auger. The motor is stopped by the movement of the balance closing a micro-switch, which also activates the solenoids to open the flap at the bottom of the weighing bucket thus discharging the concentrates to the manger. The time required to weigh and deliver one shot is about 9 seconds, with an accuracy of about 2%. The number of shots for each cow is controlled by the predetermined programme.

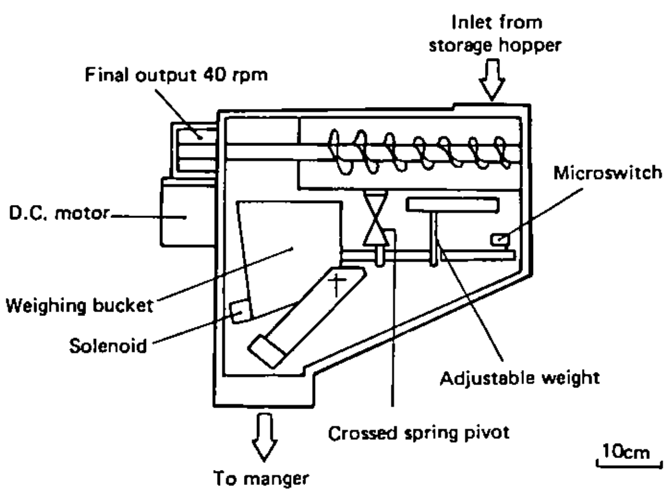

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Fig.8. Gravimetric weigher dispenser for feeding concentrate to dairy cows *(Dawson* and *Turner [7])*.

5.5 Poultry weighing

In contrast to cattle and pigs, which are normally kept in small groups, broiler chickens are kept as large flocks and there may typically be 20 000 birds in each house. Also chickens often have free access to food so that knowledge of feed supplied and of the average weight and range of weights of the birds is useful in checking the efficiency of feed conversion and deciding the marketing strategy during the later stages of growth, because birds of different weights are required for the fresh market, for deep-freezing or for sale as portions. With such a large population the average weight and range of weights may be determined from a random sample; individual weights are not required. The problem was to obtain and record cheaply a representative sample of weights. A system based on perches attached to strain-gauges offers some promise of success because the equipment is relatively inexpensive and provides a signal suitable for processing by a micro-computer *(Turner [23])*. The design of the perch is critical because it must attract sufficient birds to use it to provide a good statistical sample but not be so attractive that individual birds occupy it for long periods. The prototype system is controlled by a micro-computer which produces a daily histogram of the weight distribution. Figure 9 shows the average weights recorded automatically over the eight-week rearing period, compared with weekly weighings manually of about 100 birds. The two sets of weighings begin to diverge after 35 days apparently because the heavier birds become more reluctant to perch. However, once this divergence due to animal behaviour has been established both the average weight and its standard deviation can be forecast with reasonable accuracy. In order to produce information on the efficiency of food conversion, the amount of food

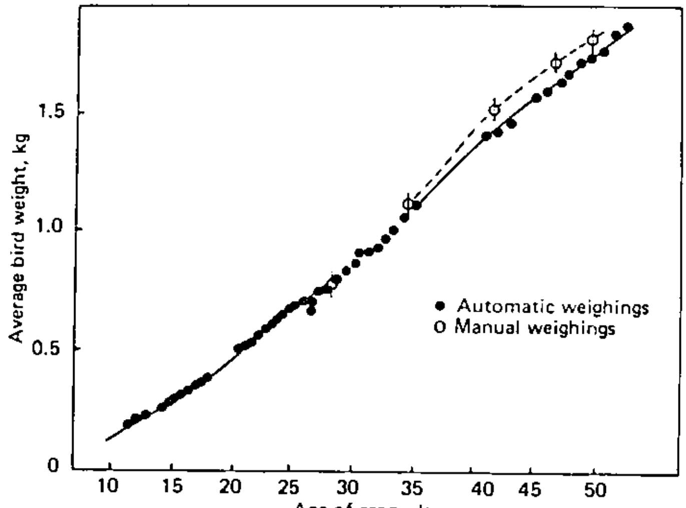

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Fig.9. The growth curve of broilers in a house containing 20,000 birds from daily automatic weighings and weekly manual weighings of 100 birds *(Turner [23])*.

consumed by the chickens in each house must be known. At present, commercial feeding methods do not provide this but means of obtaining this information are in progress. When it is available in a suitable form, the computer will be able to provide information on the daily food intake and feed conversion as well as totals over longer periods.

6. Challenges for the future

6.1 The use of straw

Fertilisers are used to grow crops and during crop production some plant parts are produced that are not desired. The outstanding examples are the stems of crops grown for their seeds. These include straw from cereals, stover from maize, stems from oil-seed rape, bagasse from sugar-cane, and pulp from sugar-beet. Sugar-beet pulp is widely used as an animal feed and bagasse is used as fuel to provide power for the sugar factories, which are good examples of ways in which secondary products from crops may be used. Cereal straw, presents a particular problem because it has little commercial value, is bulky, wide-spread and there is a large surplus. *White [24]* estimates that the average surplus in the UK, 5.4 mt, would provide 83 PJ (1.8 Mtoe) if burnt; that is almost equal to the energy used as petroleum in agriculture. Much of the surplus straw is burnt in the field with some benefit to the succeeding crop by clearing and cleaning stubble. However, the use of straw as a fuel on farms poses two questions for the engineer. One is the need to handle the straw from the field to the point of use, usually involving a storage phase, the other is provision of suitable furnaces to provide heat for the purposes required. Furnaces for burning straw are available but systems to allow economical use of the heat generated for all farm purposes are not available. A system using part of the energy in straw to dry the remainder of the cereal crop has been developed by *Wilton [25]*, where cereals are to be used for animal feeding.
In the potential use of straw as fuel, for animal feed, as feedstock for paper, chemicals, or building materials, the engineer has a role to play in meeting the challenge of making more efficient use of this material produced at considerable energy cost including fertilisers.

6.2 Recycling animal wastes

Values of E in Table 2 suggest that the production of animal products does not use support energy efficiently, including that used as fertilisers to produce feedstuffs. However, apart from the energy used for growth (or milk or egg production) animals require some energy for the maintenance of basic biological processes, but much of the ingested energy is voided as faeces and urine and is therefore available for recycling. For grazing animals or those kept outside, there is no control over the pattern of distribution and no effective measures can be taken to prevent losses of nutrients, particularly nitrogen. However, many cattle are housed for part of the year and most pigs and poultry all the time so that their wastes require to be collected and returned to the land (or otherwise used). In Table 5, the total quantities of nutrients contained in these effluents were compared with the corresponding amounts applied as fertiliser *(White [24])*. These quantities may be valued by comparing the available nutrients with the cost of the corresponding fertiliser supplies. All the potassium and about half the phosphorus in animal slurries are readily available to plants and losses from the system depend on the efficiency of collection, storage and spreading. For nitrogen however the situation is very different. Although the animal excreta from housed livestock contain an amount equivalent to more than one-third the N applied as fertiliser, only slightly more than half of this is available to plants and much is at risk during storage and spreading, so that the amount actually used by plants is no more than one-third of the total in the excreta or equivalent to one-ninth of the amount applied as fertiliser.

Nitrogen may be lost as ammonia gas to the atmosphere at all stages, and nitrate may be lost by denitrification and leaching. The efficient conservation and utilization of the nitrogen in animal slurries presents a great challenge to both engineers and biologists. The potential financial savings and better use of energy resources are both large and should provide the necessary stimulus for further work.

Table 5. Nutrient value of excreta from housed livestock UK 1979 *(White [24])*

Animal	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)
	'000 t		
Cattle	286	114	286
Pigs	69	46	34
Poultry	79	62	34
Total	434	222	354
% of purchased fertiliser	37	53	86

7. Conclusions

1. Engineers have made significant contributions to improved agricultural efficiency in the use of fossil fuel including that used to make fertilisers.
2. Many branches of engineering have been involved including mechanical engineering, instrumentation, control engineering, and operational research.
3. In many cases the advances have been made in response to socio-economic demands rather than in pursuit of technical advance.
4. Many challenges exist for the future to improve the utilisation of secondary products and the re-cycling of wastes.

Symbols of units used

M	= mega = 10^6
G	= giga = 10^9
P	= peta = 10^{15}
m	= metre
mm	= millimetre
kg	= kilogramme
t	= tonne = 10^3 kg
ha	= hectare
J	= joule = 0.24 calorie
Mtoe	million tonne oil equivalent equals about 45PJ
s or secs	seconds
yr	year

References

1. *Anderson, G.:* The development of artificial potatoes using radio telemetry to identify potentially damaging regions in potato harvesters and handling machinery. Papers for BSRAE Association Members Day on Potatoes, Scottish Institute of Agricultural Engineering, Penicuik, 1981
2. *Bell, R.L.:* Backing a winner – the engineer's contribution to U.K. agriculture. Sixty-seventh Thomas Hawksley Lecture. Proc. Instn. Mech. Engrs. *195*, 111–125 (1981)
3. *Burgess, A.D.:* Control, data recording and retrieval-techniques in the mechanization and automation of cattle production. Brit. Soc. Animal Production Occasional Publication No. 2. Reading, 1980
4. *Carlow, C.A.:* A web speed to forward speed ratio meter for potato harvesters. Departmental Note SIN/305. Unpublished. Scottish Institute of Agricultural Engineering, Penicuik, 1981
5. *Carpenter, G.A., Moulsley, L.J.* and *Randall, J.M.:* Ventilation investigations using a cross-section of a livestock building and airflow visualisation by bubbles. J. agric. Engng Res. *17*, 323–331 (1972)
6. *Davis, R.M.* and *Wilton, B.:* The continuous preparation of cattle diets containing ground straw. II. The proportioning controls and dispensers. J. agric. Engng Res. *21*, 297–304 (1976)
7. *Dawson, J.R.* and *Turner, M.J.B.:* A gravimetric feed dispenser for the dairy parlour. J. agric. Engng Res. *21*, 439–441 (1976)
8. *Dawson, J.R., Hooper, A.W.* and *Ambler, B.A.:* A continuous weigher for agricultural use. J. agric. Engng Res., *21*, 389–397 (1976)
9. *Gasser, J.K.R.:* The efficiency of energy used in the production of carbohydrates and lipids. Proc. 13th Colloq. Int. Potash Inst. Bern, pp. 341–352 (1977)
10. *Hooper, A.W.:* Estimation of the moisture content of grass from diffuse reflectance measurements at near infrared wavelengths. J. agric. Engng Res. *25*, 355–366 (1980)
11. *Leach, G.:* Energy and food production. IPC Science and Technology Press, Guildford, 1976
12. *Lewis, D.A.* and *Tatchell, J.A.:* Energy in U.K. agriculture. J. Sci. Fd Agric. *30*, 449–457 (1979)
13. *Matthews, J.:* The mechanical farm of 2030. Paper presented to the 150th Anniversary Meeting, British Association for the Advancement of Science. York, England, Sept. 1981
14. *McGechan, M.B.:* A comparison of some studies of damage susceptibility of different potato varieties. J. agric. Engng Res. *26*, 161–170 (1981)
15. *MacIntyre, D.* and *Pascal, J.A.:* Experimental direct drill. Biennial Report of the Scottish Institute of Agricultural Engineering April 1978 – March 1980, pp. 32 and 34. Penicuik, Scotland, 1980

16. *McRae, D.C.:* A potato harvester delivery conveyor with automatic discharge height control. Potato Res. *17*, 138–151 (1974)
17. *Randall, J.M.:* The prediction of airflow patterns in livestock buildings. J. agric. Engng Res. *20*, 199–215 (1975)
18. *Randall, J.M.* and *Battams, V.A.:* Stability criteria for airflow patterns in livestock buildings. J. agric. Engng Res. *24*, 361–374 (1979)
19. *Randall, J.M.:* Selection of piggery ventilation systems and penning layouts based on the cooling effects of air speed and temperature. J. agric. Engng Res. *25*, 169–187 (1980)
20. *Randall, J.M., Herbert, M.J.* and *Hepherd, R.Q.:* An automatic pneumatic conveying and weight dispensing system for floor-feeding pellets to pigs. J. agric. Engng Res. *21*, 233–245 (1976)
21. *Stanhill, G.:* The energy cost of protected cropping: A comparison of six systems of tomato production. J. agric. Engng Res. *25*, 145–154 (1980)
22. *Street, M.J.:* A pulse code modulation system for automatic animal identification. J. agric. Engng Res. *24*, 249–258 (1979)
23. *Turner, M.J.B.:* Performance monitoring of animals using on-line computers. Brit. Soc. Animal Production, 1980
24. *White, D.J.:* Energy in agriculture. Proceedings No. 203. The Fertiliser Society, London, 1981
25. *Wilton, B.:* Drying grain and whole crop cereals by burning straw. Report of a Conference on 'Straw as a fuel' pp. 3–4, Ministry of Agriculture, Fisheries and Food, Oxford. February 1980

Co-ordinator's Report on the 3rd Session

New Policies in Crop Utilization and Fertilizer Use

I. Arnon, Settlement Study Centre, Ramat Gan/Israel*;
Member of the Scientific Board of the International Potash Institute

Introduction

Farming systems have generally been appraised according to their efficiency in producing foods, their potential for productive employment, and their economic returns. It is only in recent years that energy supply problems have made a reappraisal of different farming systems and agricultural production methods essential in the light of their energy requirements.

One aspect of this problem is the need and justification for agriculture to produce energy in addition to food, and the possible socio-economic implications of such a change in production policy. One indication of the interest generated by the question of bioenergy production is the fact that for the first time, in more than a quarter century of symposia and congresses organized by the IPI, a full session has been devoted to this problem.

Prof. *Seifritz* in his paper 'Alternative and Renewable Sources of Energy' reviews the use of biomass as a source of energy and the ensuing potential conflict between food production and the production of 'technological calories'.

He considers the energetic balance between the main energy inputs of modern agriculture: Fertilizers, plant protection chemicals, fuel, agricultural machinery and equipment, on one hand – and food harvested on the other. He concludes that energy invested in production exceeds that harvested as food and that modern agriculture is, therefore, an endothermic process. It is, however, justified to use agriculture to transform fuel into food despite the inherent negative energy balance, because a calorie of food energy is infinitely more valuable than a calorie of primary energy. There is, however, no intrinsic difference in utility between a biomass fuel calorie and a calorie of primary fuel. In the light of the low energetic efficiencies Prof. *Seifritz* concludes that it does not make sense to produce technical energy from biomass.

A further argument is that enormous land areas would be required for the production of technical energy, which would therefore, compete with food production and would result in 'automobiles of the rich eating the bread of the poor'. Prof. *Seifritz* concludes that 'faced, as we are, with the severe problems of how to meet the food needs of the

* Prof. Dr. *I. Arnon*, 12 Hazeitim Street, Ramat Gan/Israel 52433

world, it is abundantly clear that, globally speaking, the still available agricultural areas in the world must be used for the production of food calories and should not be used for the production of technical calories. Other ways must be found.' Nuclear energy is mentioned in this context.

As to energy from agricultural wastes, 'the costs of collection, transport, storage and preparation, militate against the systematic use of these residues. In particular, the use of biogas from plant and animal wastes as tractor fuel is not yet thought to be economic.'

By contrast, Prof. *Meinhold* in his paper on 'Economic Aspects of Alternative Crop Utilization with Reference to Lower Saxony' refutes the opinion that the use of crops as a source of energy is neither economically nor energetically justified. He contends that:

- (1) The proposition that modern agriculture is an endothermic process is false. It is inadmissable to consider only protein in the energy balance, and to leave out carbohydrates, fat and the energy content of by-products such as leaves, stalks and roots, which are transformable into high-grade energy.
- (2) Regarding competition for land between energy crops and food crops, he points out that the energy requirements for producing technical calories are lower than for food calories, and that a unit of land can produce more energy calories than food calories. Already, more efficient energy crops are available than the conventional food crops. He also dismisses Prof. *Seifritz*' contention that there is no point in breeding special energy crops or varieties for ethanol production, on the contrary, 'plant breeding *can* produce more efficient varieties and this is not pure speculation.'
- (3) For the EEC as a whole – from 1985 to the end of the decade – large, heavily subsidized food surpluses will be produced, constituting an intolerable burden if present production programmes are continued. Eliminating these surpluses would free some 7–8 million ha for energy crops. The argument that as long as mankind is unable to feed the population of the world at an acceptable level, the utilization of biomass to provide fuel should be put aside, is not convincing. Undernutrition in wide areas of the world has less to do with food supply than with the lack of purchasing power, problems of distributing available surpluses, neglect of the agricultural sector in the policies of the LDCs and uncontrolled population growth.
- (4) And finally: an economic analysis comparing unsubsidized ethanol production with subsidized sugar production is not valid.

Prof. *Meinhold* concludes:

- (1) The cultivation of crops to provide raw material for ethanol production is already a practical proposition in suitable parts of Lower Saxony.
- (2) Using the best available methods of cultivation and manufacture, and the full utilization of residues, the overall energy balance is favorable, and ethanol can compete with industrial alcohol.

- (3): There is no conflict with food production, because food is already in surplus in the EEC countries. Exporting the food to LDCs is no solution because prices in the EEC are well above those on the world market.

Dr. *Gasser* in his paper 'New Dimensions in Agricultural Engineering' discusses ways in which the engineer can provide the farmer with the means to improve the ways he uses fossil energy for crop and animal production, and how to decrease losses from the system.

Some of the points made by the author:

- (1) Cereals and potatoes show a net return of energy greater than the support energy used, and therefore, the considerable energy input as fertilizer to the production of these crops is justified.

In the joint paper on 'Optimum Nutrition of Forest Trees' Prof. *Tamm* and Dr. *Aronsson* state that with adequate fertilizer application the energy output of timber under Swedish conditions is 10–15 times more than the input. If needles and branches are also harvested the benefit/cost ratio is still more favorable.

The papers by *Seifritz* and *Meinhold* both present the results of studies in depth on the justification of producing technical energy from biomass. The former is mainly concerned with data from West Germany and only marginally refers to Brazil, whilst the latter is specifically concerned with data from Lower Saxony. Both papers are almost exclusively concerned with a single energy carrier: Ethanol, and almost exclusively with a single crop grown for this purpose: Sugar beet.

Whilst a study in depth on a very restricted base is perfectly legitimate, extrapolating the results obtained to the world in general does not appear valid. The fact that the two scientists reach exactly opposite conclusions strengthens this reservation.

I, therefore, feel impelled to review the subject of energy production from biomass and crop residues on a broader basis and, in particular, to differentiate between countries with advanced agriculture and the LDCs, whose requirements of energy are not only quantitatively but also qualitatively different and whose potentials for the production of technical energy are also vastly different.

Developed countries

Among the developed countries already producing ethanol for fuel, or actively considering it, are the USA, South Africa, New Zealand and Australia, *i.e.* countries with large exportable agricultural surpluses.

The USA is accelerating efforts to encourage alcohol fuel production based on energy crops. Particular attention is given to sweet sorghum. It is also estimated that it is now economically feasible to convert 80% of the country's food processing wastes into alcohol, with a present potential of 500 million gallons of ethanol. In New Zealand, it is considered technically and economically feasible to provide all road transport fuel from crops with a saving of US $ 2 for every dollar lost as a result of displaced agricultural production.

In Australia a strong commercial interest in biofuel is beginning to emerge from the private sector and it is estimated that the country could get about 75% of its transports

fuel from crop and food residues. South Africa also has a large project to produce alcohol from crops, mainly cassava and sugarcane. A pilot project of the *Department of Technical Services for Agriculture* is studying the use of sunflower oil as a fuel substitute in diesel-powered tractors.
As regards Europe, Prof. *Meinhold* has pointed out that for the EEC countries producing large heavily subsidized food surpluses, energy crops may be an attractive alternative. This is confirmed by the example of Austria which is producing an exportable surplus of grain, totalling 200 000 to 300 000 tons a year, which is currently exported to Eastern Europe. Because this wheat is heavily subsidized, Austria is now seriously considering the conversion of the grain into fuel grade alcohol.

Developing countries

Both Prof. *Seifritz* and Prof. *Meinhold* have mentioned the potentials of energy production from biomass in the LDCs only marginally, extrapolating from their findings in Western Europe. Though their conclusions for the EEC countries were contradictory, curiously both agree as regards the LDCs, namely: That the production of energy in the LDCs is premature and that they should concentrate on producing food. Even the use of organic wastes for biomass is dismissed by Prof. *Seifritz* as 'not yet economic'.
As I have already mentioned, there are enormous differences in the potentials for producing biofuel between the majority of the developed countries and LDCs. The major characteristics of the latter, relevant to our subject, are:

- (1) They are mostly situated in the tropics and subtropics and enjoy year-round warmth and sunlight; radiant energy for plant growth is 60–90% higher than in the temperate zones.
- (2) They have a far greater choice of energy producing crops of high efficiency.
- (3) Bio-energy production is labor intensive. Not only is labor cheap and abundant in the LDCs, but the provision of productive employment is one of the major development objectives, equal in importance to the provision of food.

Whilst it is true, as Prof. *Meinhold* stated, that the production of food crops has been largely neglected in the LDCs, one cannot accept his proposal that a greater concentration on food crops should be at the expense of areas devoted to export-oriented plantation agriculture. Prof. *Meinhold* has stated correctly that a major cause for undernutrition in wide areas in the world is lack of purchasing power. Yet, he suggests to curtail the production of crops of which tropical countries have a monopoly, such as coffee, cocoa, rubber, bananas, tea, canesugar, and palm products, and which account for more than three quarters of the total value of their exports. Without this income the LDCs would ve unable to purchase yield-increasing inputs, such as fertilizers, crop protection chemicals, etc.
The main characteristics of energy use in the developing countries are:

(1) Very little commercial energy is used either as fuel or in the form of yield-increasing inputs.

(2) Commercial energy is very expensive, frequently several times higher than in the USA or in Europe.

(3) Energy is mainly derived from traditional sources: wood, charcoal, dung, crop residues. These are mainly used for cooking.

(4) Energy is used with very low efficiencies and high ecological costs.

The basic problems of the developing countries are twofold, because *energy deprivation* exists not only for agricultural production but also for cooking, lighting, food processing and transport.

In order to make agriculture capable of meeting the food requirements of a rapidly increasing population, production must be considerably increased, mainly by applying more fertilizers, chemicals for plant protection, developing irrigation where water is a limiting factor, and the use of double-cropping; all these are energy intensive practices. Yields of food crops could be more than doubled by applying simple, known technology.
From the foregoing it is clear that apart from the greater *need* for renewable energy resources, the LDCs have a greater potential for bio-energy production by exploiting their natural and human resources, than many developed countries. For this reason the developing countries 'may even enter the solar era before most developed countries'.

There are several options open to the developing countries:

(1) Biomass from forests and fast growing tree plantations,

(2) biomass from crops with high energy production potential,

(3) use of agricultural and other residues,

(4) aquatic biomass systems.

Biomass from forest and tree plantations

For about half the world population, energy problems take the form of a daily search for wood with which to cook food. The amounts of wood, dung, and crop residues burned daily in the LDCs are equivalent to about 5 million barrels of oil.
The growing scarcity of traditional fuels is *the* energy crisis in much of the developing world.
Woodfuel is in principle a renewable resource; in practice, uncontrolled cutting has in general resulted in the complete destruction of former sources in the parkland savanna areas and in the humid tropical forests.
Around some of the Sahelian capitals deforestation is virtually complete to a radius of 100 km. As a result, in some places the cost of fuel to cook a meal costs more than the food itself.
Large tracts of former tropical forests in Africa and Latin America have been completely denuded of vegetation. The rate of destruction of the humid tropical forests has been estimated to be as high as 1.5–2% per year which would signify the complete disappearance of all humid forests within 50 years.

Deforestation has led to soil erosion, desertification and flooding – sometimes on an epic scale. Deforestation in the highlands also has adverse effects on the lowlands: Siltation of reservoirs, devasting floods, reduced underground water resources. The large scale destruction of the forests is also expected to have global environmental effects.

Reforestation is the only practical means to prevent the irreversible loss of huge areas of land, especially on the slopes on which a large proportion of shifting cultivation was practised before the system broke down under population pressure, and can no longer serve for food production. Under these circumstances reforestation does *not* compete with food production.

To meet likely fuelwood demand in the LDCs, without further damage to forests, would require an estimated 20–25 million ha of forest to be planted during the next 20 years. At present rates of planting only 10% of this target will be met. Large and succesful self-help schemes have been initiated in China, India, and the Republic of Korea. Reforestation mainly involves land, labor, and time. The major drawback is that planting can do little to satisfy immediate need in the drier parts of the tropics and subtropics. The *Club of Sahel* considers the production of fuelwood as a national priority equal to food self-sufficiency. They even recommend that a reasonable proportion of fertile land should be reserved for reforestation. Much planting could be done on small plots around the villages, along roads, as windbreaks, along irrigation channels, etc. If modern methods of food production replace the present traditional methods, yields can be more than doubled, releasing land for bio-energy production. There are a number of options for reforestation: Fast growing trees, hydrocarbon trees, combined tree and food production.

Leucaena leucocephala

can be repeatedly cut at 3–6 year intervals in the Philippines. It is estimated that a 9000 ha plantation of *Leucaena* could produce enough wood to fuel a 75 megawatt electricity generating plant making possible net savings of foreign exchange of US $ 146 million in the first 10 years of operation.

Hydrocarbon trees

Certain trees can produce hydrocarbons, instead of the usual carbohydrates. These hydrocarbons can serve directly as fuel and are superior to crude oil as they are practically free of contaminations. For dry areas *Euphorbia* spp. could be suitable. It is estimated that one ha of *Euphorbia* could produce between 25–125 barrels of oil per year.

Combined tree and food production

Agri-sylviculture is a land use system, whereby areas being reforested are also used for crop production during the first years of the establishment of the forest. A US-aid sponsored research project in Ghana has shown that a 40 000 ha plantation of fast-growing trees can produce the energy equivalent of 500 000 metric tons of coal per year. In addition, food crops interplanted among the trees produce around 60 000 tons of peanuts and 54 000 tons of maize.

Energy crops

Three main categories of crops can serve for the production of ethanol:

- Sugar crops: Sugarcane, sugarbeet, sweet sorghum
- Root crops: Mainly cassava
- Cereals: Mainly maize
- Certainly others: Oil palm, sunflower.

In a study undertaken for the *US Department of Energy* by the *Battelle Institute*, which analyzed the potential for alcohol fuel of sugar crops, it was concluded that 'sugarcane is most promising in the near term, sweet sorghum will gain promise in the future (if a modest investment in research is made to upgrade it). It also has wider adaptability. Sugarbeet is so unpromising as to warrant dropping it from the fuel-from-biomass program.'

Cassava has a promising long-term potential as an energy crop, adapted to a great variety of soils and to semi-arid conditions. It can produce fair yields even without modern inputs, and can be grown by small landholders. It can be cultivated and harvested during the entire year, making possible year-round processing.

Among the cereals there is little variation in the rate of conversion of alcohol, so that alcohol yield is subject to the same considerable variations as grain yield. Yields of alcohol are far lower than for sugarcane but costs of production are also much lower. With present petroleum fired distilleries, the ethanol produced requires an investment of an approximately equal amount of fossil fuel. New distilleries, specifically designed to produce fuel grade alcohol, may be able to increase this ratio fourfold.

Interest in alcohol fuel production is already evident in a number of developing countries, in particular oil-hungry countries which have sugar surpluses, sugar prices being unreliable whilst oil imports costs have increased steeply.

The *leading country* in producing fuel from crops in Brazil, replacing approximately 20% of its gasoline requirements by ethanol from sugar cane. Brazil believes that by relying on sugarcane and cassava to produce all its bioenergy requirements, it will need to reserve for this purpose only 2% of its land surface and thereby replace all imported petroleum.

There are a number of developing countries that are actively promoting agricultural fuel production:

- Kenya and Sudan are building an alcohol industry that will use the molasses by-products of their sugar mills.
- Thailand is considering agricultural fuel production in order to make use of any seasonal surpluses that might arise in the production of cassava, rice, maize, sugarcane or molasses. In this case the major objective of fuel production would be supply and price stabilization of the major agricultural commodities produced.

Plant wastes and other residues

The net oil potential from one ton of organic wastes is estimated at 1.4 barrels of oil However, the economics of using crop residues directly to raise steam are not very favorable, except in cases in which the residues are concentrated in any case in the production plant, and their disposal is essential, as in the case of the use of bagasse in the Hawaiian sugar industry.
Bio-conversion is, however, a promising alternative by generating methane from animal, human, and agricultural wastes.
Methane plants are most efficient at relatively high ambient temperatures, and are relatively labor-intensive. They are, therefore, particularly suited to the conditions prevailing in many LDCs. Therefore, the conclusion mentioned by Prof. *Seifritz* regarding biogas do not apply to the LDCs. Methods have been developed that are suitable for rural conditions, for individual households, and for village communities, and tens of thousands of plants have been built in India, Taiwan, China, Thailand, etc.

The use of rural wastes for methane production has the following advantages:

- It produces an energy source that can be stored and used efficiently.
- The remaining sludge retains the fertilizer value of the original material.
- It provides a sanitary way to dispose of human and animal wastes and reduces the public health hazards of fecal pathogens. In China this is considered the major advantage of the process.
- It reduces the time spent on collecting fuel and cooking.

Aquatic biomass systems

A number of water plants could produce biomass energy, such as certain algae, freshwater weeds (water hyacinth), marine species such as seaweeds and giant kelp.

In conclusion

As to the developing countries there is certainly no question of their devoting 'large areas to the production of biomass energy to provide the fuel needs of the industrialized countries under the slogan 'spirit for the world' as mentioned by Prof. *Seifritz*. For them the major objectives of biofuel production are:

(1) To replace the rapidly dwindling supplies of fuel for domestic purposes, which mainly involves land not suitable for crop production, incidently saving it from total destruction, and,

(2) the efficient transformation of agricultural and other residues into fuel.

In those cases, in which there is an inevitable conflict for land between food and fuel requirements, the solution must be sought in increasing the productivity of native agriculture by the use of modern inputs.

Dependence on imported fossil fuel will exert considerable political pressure to produce liquid fuels domestically, even in those countries that do not have large agricultural surpluses. However, for these countries, the economic production of biomass for energy will depend considerably on technical innovation.

For those countries that do have large amounts of exportable agricultural produce, especially when production is subsidized, diversion of agricultural resources to the production of fuel crops is particularly attractive. This is bound to reduce the amounts of grain available to the food-deficit countries and to push up prices. Therefore, the national self-interest of the food-surplus countries may conflict with the needs of the food-deficit countries and may exacerbate the problems of food supply to the poor in general, and to the countries unable to feed adequately their populations in particular.

12th Congress of the International Potash Institute
June 1982 at Goslar/Fed. Rep. of Germany

4th Session

Economic Aspects of Optimization of Yields

Co-ordinator *L. Gachon*, Head, Dept. of Agronomy, I.N.R.A., Clermont-Ferrand/France; member of the Scientific Board of the International Potash Institute

Fertilizer Use and the Common Agricultural Policy of the EEC

E. Guth, EEC Commission, Brussels/Belgium* and
D. Guth, Federal Food Office, Frankfurt am Main/Federal Republic of Germany

Summary

Under the Common Agricultural Policy, differences between Common Market countries in the scale of fertilizer use are now much less wide than in the past. The political and economic conditions surrounding agriculture (and fertilizer use) are very different from those obtaining at the setting up of the EEC. In considering future fertilizer policy the environmental effects and raw material policy must be given greater weight, though at the present time it is difficult to foresee how these will develop. For the individual farmer, now as before, the best way to increase crop production is to make full use of biological and technical progress, including the use of fertilizers. However, what is best for the individual farmer is not necessarily right for the economy as a whole. Looked at from this angle, fertilizer use, encouraged by the high farm prices, is excessive, but this is the fault neither of the individual farmer nor of the fertilizer industry, it is rather the fault of the given political framework. Recent EEC policy proposals seek to correct earlier mistakes.

1. Introduction

The use of mineral fertilizers, combined with advances in the biological field and in farm mechanisation has enabled farmers to achieve an almost unimaginable increase in crop yield. The technical value of fertilizers has therefore never been questioned from the time of their discovery. However, the context of agricultural policy has changed. Whereas in 1951 experts recommended to the German *Federal Ministry of Agriculture* that it encourage the use of fertilizer to improve the performance of agriculture, much is now heard about the link between fertilizer use and the accumulation of agricultural surpluses and its budgetary cost, while its effects on the environment and its significance for energy policy are also sometimes questioned *[4, 18, 19, 20, 21]*.

We shall here consider how far this change in attitude may be justified and how far it results from the great changes which have taken place in the economy as a whole and in the agricultural sector. Comparison of fertilizer use and crop yield between the countries of the EEC forms a statistical basis for the analysis *[9]*. Several recent developments in EEC agricultural policy will be described in this connection and we shall then attempt to find answers to the following questions:

- is there a limit to the increase in crop yield?
- would the restriction of fertilizer use be the right way to slow down production increases?

* Dr. *E. Guth*, EEC Commission, Rue de la Loi 200, Brussels/Belgium

- do environmental considerations impose limits on fertilizer use?
- how far do overall economic considerations affect fertilizer use?

2. The history of fertilizer use and crop yield in the EEC [9]

Fertilizer use per ha has increased since 1955/56 in all nine countries of the EEC (Table 1), but there have been two distinct periods, with markedly different growth rates. In the first phase (average 1955/56–1969/70 compared with 1965/66–1969/70) fertilizer use increased rapidly, by 63%. In the second phase (1965/66–1969/70 to 1975/76–1979/80) it increased by only 39%. This latter phase was affected by the oil crisis in 1974/75, which resulted in a decrease of 9%. Trends in the individual member countries have been similar, though there were great differences between them in level of use at the start of the period as there were in nutrient ratios and in growth rates. The countries can be placed in three groups according to use at the start: high, medium and low users. The highest fertilizer users at the outset were the Benelux countries, and here fertilizer use over the whole period increased by 55 and 47% respectively. In the Netherlands the increase rate in the second half of the period was only 19% and use has been virtually stagnant since the early seventies. In Belgium there was no increase over the second half of the period and, in fact, fertilizer use has declined slightly since the mid-seventies. That use still went up in the Netherlands despite the high average rates of application is due to the extension of market gardening and the intensification of grassland husbandry.
The Federal Republic of Germany and Denmark, two countries which started at the middle level, increased fertilizer use over the whole period by 78 and 92%. The rate of increase virtually halved over the second half of the period. Whereas Denmark,

Table 1. Percentage increase in fertilizer use in the EEC-9, in %

	Average 1975/76–1979/80 against 1955/56–1959/60	Average 1965/66–1969/70 against 1955/56–1959/60	Average 1975/76–1979/80 against 1965/66–1969/70
EEC-9	+127	+ 63	+ 39
F.R. Germany	+ 78	+ 45	+ 24
France	+211	+111	+ 47
Italy	+243	+ 59	+115
Netherlands	+ 55	+ 30	+ 19
Benelux	+ 47	+ 47	± 0
United Kingdom	+ 91	+ 57	+ 22
Ireland	+317	+135	+ 78[1]
Denmark	+ 92	+ 48	+ 29

[1] Average 1975/76–1978/79 against 1965/66–1969/70

Sources: FAO, Statistical Yearbook, various years
SOEC, Soil utilization and production 1955–1979, Luxemburg, 1980

with a high livestock rate (generally similar to the Netherlands) was able to reduce somewhat its application of phosphate and potash, in Germany, the large root-crop area prevented any sharper reduction in use of phosphate and potash. The increase in nitrogen use in the Federal Republic was mainly caused by the shift from fodder crops to cereals.

Those countries which had the lowest use at the beginning (Italy, France, Ireland, United Kingdom) showed the highest rate of increase up to the end of the seventies, as might be expected. Growth in the United Kingdom was only at the rate of the countries which started in the middle group, that is below the average for the EEC as a whole. In these countries also the increase was mainly due to increased nitrogen use. It can be concluded that the effect of the common agricultural policy has been to reduce differences between the member countries in fertilizer consumption. It seems likely that further integration in the Community will bring with it further levelling up to the rates which apply in the Benelux countries. Nevertheless there are still wide differences between the member countries *[3, 21]*.

The fall-off in fertilizer use which followed the drastic price increase of 1973/74 indicates that fertilizer price markedly influences use, but it is difficult to quantify this accurately. Investigation of the interdependence of price and use leads to the conclusion that the price of nitrogen is a significant factor and that the price elasticity of demand for NPK is less than that for individual straight and compound fertilizers *[9, 10]*. It seems that countries with high fertilizer use have a higher price elasticity (with the exception of the Netherlands) than the others. This suggests that countries with high use have approached more closely to optimum use levels, reacting fairly promptly to changes in economic conditions.

Table 3 shows that as fertilizer applications have increased, yields have also risen in all member countries. Some of the negative deviations in individual years can be explained by the effects of weather. The sharpest yield increases were recorded by the countries with the greatest increases in fertilizer consumption (France, Italy, Ireland), but the yield increase lags behind the fertilizer increase. Countries which were high or medium fertilizer users at the beginning also show yield increases, but there is no definite correlation between yield and increase in fertilizer use. This indicates that from a certain level of production the interaction of a large number of factors is of greater importance than when the general yield level is low. It also suggests, however, that there are natural limitations to yield increases. A noteworthy point is that differences in fertilizer consumption are not reflected in differences in yield as between the member countries. Apart from Italy, yields in all the member states are roughly similar, indicating that fertilizer use on cereals and sugar beet is less variable than usage per ha of total agricultural land. The overall statistics lump together widely differing kinds of land-use, different types and sizes of enterprise *(e.g.* a large proportion of grassland in the U.K., extensive farming in the south of Italy). The decreasing rate of increase in fertilizer use on intensive tillage crops indicates that in this sector we are approaching the technological and economic optima. Thus, in the future, a further increase in yields and in fertilizer use will depend less on individual countries catching up on the average than on further technical and biological progress and on the extension of intensive arable farming. The decrease in the rate of yield increase could be an indication that yields are approaching a biological limit. In any case, the effect of current changes in the economic environment have much influence too.

Table 2. Fertilizer use in individual countries (Netherlands = 100)

	Average 1955/56–1969/70	Average 1975/76–1979/80
EEC-9	35	51
F.R. Germany	73	84
France	27	53
Italy	19	41
Netherlands	100	100
Benelux	97	92
United Kingdom	28	35
Ireland	12	31
Denmark	60	74

[1] Average 1975/76–1978/79 against 1965/66–1969/70

Sources: FAO, Statistical Yearbook, various years
SOEC, Soil utilization and production 1955–1979, Luxemburg, 1980

Table 3. Percentage increase in yield per hectare for grain and sugar beet in the EEC-9, %

	Average 1975/76–1979/80 against 1955/56–1969/60		Average 1965/66–1969/70 against 1955/56–1959/60		Average 1975/76–1979/80 against 1965/66–1969/70	
	Cereals	Sugar	Cereals	Sugar	Cereals	Sugar
EEC-9	+63	+28	+34	+22	+22	+ 4
F.R. Germany	+51	+24	+24	+21	+22	+ 2
France	+87	+47	+52	+42	+23	+ 3
Italy	+64	+35	+24	+ 9	+32	+24
Netherlands	+54	+ 9	+18	+12	+30	− 3
Benelux	+29	+19	+ 5	+21	+22	− 1
United Kingdom	+44	+ 5	+25	+22	+15	−14
Ireland	+57	+47	+29	+26	+22	+16
Denmark	+18	+ 5	+19	+10	− 1	− 4

Source: SOEC, Soil utilization, cited, and SOEC, Crop production

3. The context of agricultural policy and the general economy

The increase in yields in all member countries has largely satisfied one of the four main goals of agricultural policy – to increase agricultural productivity by making use of technical progress, to rationalize farms, and to optimize the use of production factors, particularly labour. Through this the food needs of the population were largely assured. Thanks to the long-term prosperity of the non-agricultural sector of the economy, many farm workers were able to find alternative employment. This, with the price support given to all the main agricultural products under EEC regulations, made it possible for the farming community to enjoy a share of the general prosperity. In the context of the generally rising standard of living and, with that, the decreasing proportion of spending on food, food prices were not a key political issue. The assumption was that consumer food prices were reasonable. But the Community faced serious problems in the market-place. The difficulties could be coped with, or glossed over as long as the structural market imbalances led 'only' to an increase in self-sufficiency and a decrease in imports from third countries and/or financial resources were sufficient to use the surpluses for export or consumer subsidy.

However, agricultural and economic conditions have recently altered considerably. The demand for food is increasing only slightly and we are now appreciably more than 100% self-sufficient in almost all agricultural products so that any increase in production is more and more oriented to exports. Export support has increased from 20% of the agricultural budget at the beginning of the seventies to about 50% today. But the effects of negative trade policies and the exhaustion of the financial resources of the market do not allow us to look to exports as a convenient safety-valve for our unsolved internal problems. The use of agricultural surpluses for food aid is often regarded as a way out, as a general solution; however, considerable political and financial difficulties stand in the way of this solution.

In this situation, the control of supply growth is increasingly recognized as the main problem in agricultural policy formulation. Remedies suggested by scientists and agricultural policy-makers range from purely marketing measures through placing more responsibility on the producer and the introduction of quotas to the curtailment of technical progress, including a reduction in fertilizer use *[5, 13, 14, 20, 21]*. At the same time as the agricultural economic environment has changed, general economic conditions have also changed much recently. Two calamitous increases in the price of oil have created a need for structural change in the economies. Obvious signs of the changed economic conditions are high unemployment and high rates of inflation in the member countries of the Community. Both of these have an important effect upon agriculture. In the first place the drift from the land has been largely halted, so there is no longer the means to increase per capita production by this route. Secondly price rises for farm inputs such as machinery, fertilizer and plant protection materials have eaten into farm incomes.

Against this background of rising energy costs and rising prices of farm inputs and because fossil energy is a limited resource, some scientists have pointed out the opportunity that may exist for agriculture as a producer of renewable energy. The intensification which has accompanied the increase in agricultural productivity, including fertilizers, is surely going to lead to more and more concern for the environment. The conflict between increasing productivity with the help of fertilizers and spray-chemicals on the one hand and concern for maintaining the quality of the environment, soil and water, and of crop produce itself, on the other, is an apparent conflict in which economic advantages and disadvantages must be weighed carefully *[4]*.

4. Fertilizer use – the individual farmer and agriculture as a whole

The economics of fertilizer use are determined by the production function relating crop yield to fertilizer rate and the shape of this curve is subject to the law of diminishing returns. The optimum point on this curve is that where marginal earnings = factor costs, in other words where marginal yield increase × price of crop product matches the incremental input cost. Thus fertilizer use is to a great extent determined by the relationship between crop prices and input prices. Since crop and input prices are largely beyond his control, the key to improved crop production, and hence income, for the farmer, is the proper exploitation of biological and technical progress. In most of the member countries, real crop prices have risen only slightly and, indeed, in some have actually declined, while fertilizer prices have risen steadily, so that the profitability of the increased use of fertilizers in the past is essentially accounted for by the farmers' intensive exploitation of technical progress (plant breeding, plant protection and cultivation techniques). The contribution of the various factors to yield increases differs between crops; thus *Schuster [16]* credits plant breeding with 38% of the increase in yield of winter wheat but only 15% for sugar beet. The remainder of the increase is due to progress in mechanisation and to improved fertilizing. Certainly, improved farmer education has played an important role. Technical progress is the reason why (as in other sectors of the economy) agricultural output has increased despite a fall in real product prices. Unhappily, there is often the tendency to ascribe this phenomenon which can be easily explained in economic and scientific terms to a quite different consideration – namely the inverse reaction of farmers. The theorem of the inverse reaction likes to make believe that in order to maintain their income in an environment of declining prices it is inevitable that farmers must increase total production *[1]*.

Under present agricultural conditions, the question arises as to how the farmers will react in fertilizer use to changes in product and factor prices and what will be the overall effect on total production. Investigation of individual farms and of production statistics shows that when the price changes are moderate there is no great tendency to reduce fertilizer use *[8]*. This means that under the given conditions it pays the farmer to strive for maximum yield. If this is so the problem of the surpluses has to be solved by economic manipulation of the market. However this type of farmer reaction may not hold good for all farms and if the price changes are greater. There is always a number of marginal producers who are forced to react even to a relatively slight worsening of the economy by closing down one part of the enterprise or by going out of business altogether. If the land thus freed is not taken up by other farms total production will fall. However, since as a rule only marginal farms or marginally fertile soils are affected, the effect on total production is relatively small. These considerations hold for relatively small price changes.

If, as in the two oil crises, the fertilizer price changes are large, they can, in concert with other factors, result in drastic change. This was shown very clearly in France where, following 1974, nitrogen use was greatly reduced *[3]*, but the reason for this was not just a decrease in the profit margin, but a worsening liquidity situation which the farmers countered by saving on fertilizers *[11]*. Other countries of the EEC reacted differently to the price increases and worsening liquidity by reducing application of P and K fertilizers. Recent signs of recession in fertilizer use are to be ascribed to a combination of the effects of poor liquidity, steep increase in fertilizer cost and a fall in real crop prices. Whether this will result in a fall-off in the rate of increase of production depends upon how far the efficiency of fertilizer use can be improved. In this connection, the use of the N-min method for accurate forecasting of N requirement in the spring and of quick tissue tests to determine N status of the growing crop *[6]* are worthy of attention.

Clearly, fertilizer use has only been slightly affected by the rise in fertilizer prices. On the other hand, lowering of crop prices would have a more marked effect. A policy of restricting fertilizer use by the imposition of a tax or by introducing quotas would clearly be a blunt instrument with which to attack the surpluses. But the most recent proposals of the EEC Commission gradually to reduce cereals prices to a level corresponding to that of our competitors would be a different matter *[5, 21]*. It must also be remembered that such an adjustment of crop prices would have very much more serious effects on farm income than would control of fertilizer use. This is because fertilizer cost is a relatively small part of total outgoings.

5. Fertilizer use in the context of the overall economy

The economically optimum use of fertilizer on the individual farm does not necessarily result in optimum use for the economy taken as a whole. The optimum may differ between the individual holding and the interests of the economy as a whole because:

a) Crop and input prices for the farmer do not accurately reflect opportunity costs *(e.g.* distortion through administratively fixed prices, monopoly prices),

b) There are some advantages and disadvantages in the use of fertilizers which do not affect the individual farmer (so-called external effects such as pollution, danger to health, landscape conservation).

In view of the strong market position of some fertilizer producers and, to some extent, because fertilizer prices vary considerably between the member states, it may be inferred that the prices charged do not reflect a situation of free competition in the market and are, in fact, somewhat higher. Nevertheless, the price differences cannot be too great within the free-trade area, otherwise offers from neighbouring countries would be too attractive to resist. As, moreover, the optimum intensity of fertilizer use is only slightly affected by small fertilizer price changes, this kind of price distortion can only have slight effects on the optimum allocation of factors of production. From the point of view of agricultural policy, however, price differences on the input side, which increase the differences in income between member states, must be regarded as a negative aspect.
Changes in crop prices are more effective on account of the higher elasticity of fertilizer use as a function of crop price. The key question here is how far the fixed farm prices reflect true economic prices. There is no exact quantitative answer to this political and economic question. From the overall economic point of view, prices should be applied which would assure self-sufficiency in the main products of agriculture within the Community and this would not be fully achieved at present-day world prices. On the other hand the present EEC crop prices have resulted in levels of production which can only be utilised by export support or consumer subsidies. From the point of view of the economy as a whole, agriculture is using too many production factors. This appears tolerable with factors for which no alternative uses are available in the short term, such as labour.

The over-use in agriculture of inputs, for which alternative uses *are* available, like fertilizers and plant protection chemicals, is a mis-allocation of resources and represents an economic loss. These considerations are not merely theoretical, as is shown by the most recent proposals of the EEC Commission for the adjustment of cereals prices *[5, 7]*. Since the EEC, originally a net importer of cereals, has now become a net exporter, the Commission has proposed that the European cereals price should be adjusted over a 5-year period to correspond more closely to the USA price. The main point from the viewpoint of agricultural policy is that EEC produced grain should become more competitive with cheaper alternatives. Such a policy would have some effect in reducing fertilizer use intensity but the main effects would be reduced cultivation and the abandonment of marginal land.

The proposals of the EEC Commission for cereals policy are guided by considerations which are sound in overall economic terms. The solution to the problem will not be found in the imposition of quotas or by deliberately restricting technical progress *[21]*. To limit the use of technical advances would mean only that a given level of production would be achieved with a higher level of inputs than would otherwise be needed. Such a policy would limit the improvement of welfare while it would do little to eliminate any undesirable side-effects, *e.g.* on the environment. Various proposals to introduce production quotas have for long been discussed in the Commission. These have been rejected mainly because of the difficulty of deciding on the size of the quotas and the way in which they would be distributed among the member states and because of the high administrative costs. The decisive economic argument that any quota would make it impossible – or at least very difficult – to achieve optimum adjustment of the production factors to the altered economic conditions and that the result would be a reduction in welfare standards was given little consideration in the policy discussions. The effects of a quota on intensity would vary greatly according to the type and extent of the quota *[15]*. Only if the whole of agriculture were subject to a quota would the level of use of inputs such as fertilizer be affected to the same extent as it would be by a reduction in prices. In practice, however, quotas have been used only for individual products when their pricing has been taken right out of the whole agricultural price structure *(e.g.* sugar). This has resulted in distortions of the intensity of production and of the inner structure of the agricultural economy.

These considerations demonstrate that the 'extensivization' of farm production associated with a comprehensive quota system, though to a certain extent a desirable goal in agricultural policy terms and general economic policy terms, cannot in practice be achieved with this instrument. On such grounds rest proposals to strive for a less intensive agriculture through price adjustments and to compensate for the resulting loss in income by direct income subsidies. Even so, significant changes in intensity would only be expected on marginal holdings and in marginal conditions so long as the price adjustments were politically realistic. The instrument of producer co-responsibility, more and more widely used in EEC agricultural policy in recent years, has much the same effects on production intensity as a reduction of prices, or a decrease in price support. There is always the danger, however, that with growing differentiation the co-responsibility levy will gradually become an instrument similar to a quota, so that it has the same effect as imposition of a quota *[5]* with the above-mentioned disadvantages.

These considerations show that an increase in agricultural production is not the consequence of some inevitable natural law but that market forces can affect this supply component just as much as any other. For the EEC, which has changed from being a cereals importer to an exporter, this does not mean that in the future every increase in production must be limited. It means rather that production must be achieved at a price which allows the product to compete on the world market.

6. Fertilizers and renewable sources of energy

The present problems of EEC agricultural policy invite consideration as to whether agriculture could make a contribution to the solution of the energy problem. It is possible, at least in theory, that one of the chief problems, that of over-production and the lack of production and employment alternatives could be overcome. Rural depopulation, which is a great problem in many member countries, could be countered. Some of the cultural difficulties of over-specialization could be averted by broadening the range of crops grown, to include those grown to provide raw material for energy production. The move away from specialization would also be desirable from the environmental point of view, while it would increase the scope for growing crops which are really suited to the environmental conditions *[2]*. The medium- and long-term possibilities for growing energy crops will be decided by the interplay of a wide range of cultural, economic and political factors, and at the present time future trends are difficult to foresee, so that it is scarcely possible to make firm forecasts as to the future of biomass cropping. Exaggerated expectations in this field were largely based on considerable under-estimation of adjustments in the market which have led to change in demand for motor fuel and crude oil, changes which a few years ago would have been thought unrealistic. There is little reason to expect any significant change in the economics of biomass production for energy provision in the short term. The middle- and long-term future depends upon how well raw materials from agriculture and forestry are able to compete with fossil energy. Agriculture has the means to grow large yields of these crops and, in this field, the aim for maximum possible yield does not need to be constrained in any way by considerations of quality or palatibility as in the growing of food crops. Thus, plant breeding and plant nutrition are faced with a new challenge. Because the cost of fertilizer depends mainly on the price of energy, economy in fertilizer use, especially in the case of nitrogen, would play an important part in determining the competitive ability of energy crops. The capability of the plant breeder to increase the gross production of biomass should be utilised to the full and it would be important to keep the use of fertilizers with a high energy cost to a minimum and to look for the optimum combination of fertilizers and organic manures.
The slogan 'raw material from agriculture' can only make sense if development in this direction could be sustained in the long term, and we lack the data needed to make firm forecasts *[12]*. There is need for further research in both the technical and economic fields.

7. Fertilizers and the environment

In traditional agriculture the aims of farming and of conserving nature and landscape were completely compatible, but the increased use of plant protection chemicals and of fertilizers has introduced changes to the extent that this may no longer be the case. A typical controversy is that touching battery hens. Though there may be little scientific evidence for the sufferings of animals, the protests of the conservationists have led to the introduction of standards which have reduced the profitability of such enterprises. It is possible that similar problems may arise regarding fertilizers. The influence of the environmental lobby is growing – though to differing extents in the individual countries of the Community – and it is gaining political power. Some farmers are becoming uncertain about the possible undesirable effects of fertilizers on our flora and fauna and the quality of our food *[17]*.

Several investigations have shown that N fertilizers can have undesirable effects and the following may be mentioned:

- deterioration of crop quality,
- pollution of surface waters (eutrophication),
- pollution of ground water *[18]*.

Should these negative effects become so large that they can be shown definitely to be a danger to health or to threaten the water supplies, they will have to be taken into account in formulating agricultural policy. The prevention or avoidance of these side-effects can be achieved in different ways. In the first place, by farmer education concerning the possible negative effects of fertilizers on crop, water and soil quality as well as the rising cost of fertilizer and by the use of new methods to determine the actual fertilizer need *(e.g.* the N-min method) which may lead the farmers to be more economical in their use of fertilizers. There are signs that this is happening already.
If the farmers do not come up with their own answer, the objective could be realized by administrative means (fertilizer quotas, maximum permissible N dressings). But, so long as a rate of fertilizer use which appears to be damaging to the environment is still profitable to the individual farmer, control would require the setting up of a large scale bureaucracy. A better method would therefore appear to be one that changed the economics of fertilizer use *(e.g.* a tax on fertilizer) *[18]*. The basis of this measure would be to introduce the factor of high fertilizer cost into the decision-making process on the individual farm (internalization). Such measures, because of their effects on competition and income development, would have to be applied on a Community basis. The differing attitudes to the environment and the varying degree to which the side effects of fertilizers are apparent in the different countries mean that this kind of regulation could only be contemplated if the environmental aspects of fertilizer use were to become of greater public and political importance than is now the case. Therefore it is in the interests of farming and of agricultural science to pay more attention to the undesirable side effects of fertilizers.

8. Conclusion

From the point of view of agricultural policy, the significance of fertilizer use is still to be found predominantly as a means of increasing crop yield, even when due attention is paid to environmental aspects and in connection with energy cropping. Even though the problem of the agricultural surpluses looms so large in discussion about farming policy in the EEC, one cannot do otherwise than advise the individual farmer to exploit the yield potential of his crops to the full. It is clear, however, that the support prices, which are primarily dictated by incomes policy, are over-generously stimulating fertilizer use and, thereby, entailing losses to the overall economy. The responsibility for this problem cannot be attributed to the individual farmer or the fertilizer industry but depends upon the policy which sets the context within which these operators work.

9. References

1. *Altmann, A.* and *Guth, E.:* Wie reagiert die Landwirtschaft auf Preissenkungen? Wirtschaftsdienst No. 8, pp. 381–385 (1979)
2. *Damroth, M.:* Nutzungsmöglichkeit nachwachsender Rohstoffe als Chemiegrundstoffe und Energiesubstitute in der Bundesrepublik Deutschland. Agra-Europe No. 46, Dokumentation pp. 9–23 (1981)
3. *de Beaucorps, G.:* Evolution de la fertilisation en France et perspectives d'avenir. Document présenté au Conseil de surveillance E.M.C., 1978
4. de *Haen, H.:* The Impact of Nitrogen Fertilizer Application on the Nitrate Concentration of Groundwater – A Cost-Benefit-Analysis Concept. Paper presented at the International Institute for Applied Systems Analysis, Luxembourg, 1981
5. *EC-Commission:* Leitlinien für die Europäische Agrarpolitik, KOM (81) 608 endg., Brussels, 1981
6. *Hanus, A.:* Rückläufige Einnahmen – weniger Stickstoff düngen? DLG-Mitteilungen No. 2, pp. 60–62 (1982)
7. *Koester, U.* and *Tangermann:* Alternativen der Agrarpolitik. Landwirtschaft – Angewandte Wissenschaft No. 182, Münster 1976
8. *Langbehn, C.:* Einfluss veränderter Preis-Kosten-Verhältnisse auf Betriebsorganisation und Einkommen in Ackerbaubetrieben. Lecture presented at the 22nd Annual Meeting of GEWISOLA, Hohenheim (1981)
9. *Leithmann, G.* and *von Berg, U.:* Entwicklung und Prognose des Mineraldüngereinsatzes in der EG (9) und den beitrittswilligen Ländern. Agrarwirtschaft *29*, No. 5, pp. 141–151, Hannover (1980)
10. *Lyons, D.C.* and *Thompson, R.L.:* The Effect of Distortions in Relative Prices on Corn Productivity and Exports: A Cross-Country Study. Journal of Rural Development, pp. 83–102 (June 1981)
11. *Popken, H.:* Mineraldüngernachfrage 1980 – Bestimmungsgründe und Elastizitäten. Hamburg, Berlin, 1973
12. *Rohr, H.J.:* Politische Ausgangssituation. Nachwachsende Rohstoffe – eine agrarpolitische Perspektive? Agra-Europe No. 46, Dokumentation pp. 1–8 (1981)
13. *Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung:* Unter Anpassungszwang, Jahresgutachten 1980/81, pp. 176–199, Stuttgart und Mainz, 1980
14. *Scheper, W.:* Inwieweit ist eine neue Agrarpolitik in Europa nötig und möglich? Diskussionsbeiträge No. 37, University of Kiel, 1980
15. *Schmitt, G.:* Angebotskontingentierung: Ein Instrument zur Lösung des Agrarproblems? Agrarwirtschaft *19*, pp. 10–22 (1970)
16. *Schuster, W. et al.:* Über die Ertragssteigerung bei einigen Kulturpflanzen in den letzten 24 Jahren in der Bundesrepublik Deutschland. Acker- und Pflanzenbau *145*, pp. 119–141 (1977)
17. *Steffen, G.:* Die Rentabilität des Handelsdünger- und Pflanzenschutzmitteleinsatzes in landwirtschaftlichen Unternehmen bei steigenden Preisen für Betriebsmittel und sinkenden Erzeugerpreisen. Berichte über Landwirtschaft *59* (4), pp. 584–606 (1981)
18. *Stemmler, S.:* Kosten und Nutzen alternativer Massnahmen zur Beeinflussung des Stickstoffeinsatzes in der Landwirtschaft aus ökonomischer und ökologischer Sicht. Unveröffentlichtes Manuskript, Göttingen, 1982
19. *Wissenschaftlicher Beirat beim Bundesministerium für Ernährung, Landwirtschaft und Forsten:* Gutachten zur Frage des steuerbegünstigten Düngens (1951), Sammelband der Gutachten 1949 bis 1974, pp. 117–119, Hiltrup, 1975
20. *Weinschenck, G.:* Was von Bonn und Brüssel zu erwarten ist. Möglichkeiten und Grenzen einer Neuorientierung der Agrarpolitik. Archiv DLG *66*, pp. 49–76 (1980)
21. *Weinschenck, G.:* Lässt sich die spezielle Intensität der Bodenbewirtschaftung reduzieren? Unpublished report; Betriebswirtschaftliche Gesellschaft, Hannover, 1981

The Optimization of Fertilizer Use in Agricultural Systems

G. Steffen, Agricultural Economics Institute, University of Bonn/Federal Republic of Germany*

Summary

The farmer has at his disposal a range of decision and control tools provided by science and the advisory organizations, which assist him in making decisions about the conduct of his business.
Changing price relationships are compelling him to pay more attention to maximization of profit per hectare rather than simply to maximize yield. If the price of fertilizer increases more rapidly than crop prices, this does not cause a fall off in demand for fertilizer by the more fertile farms, mainly because the economics of nitrogen usage are still good. But the less fertile farms are more sensitive and on these quite a modest increase in factor price can cause a decline in fertilizer usage. On the more fertile farms the effect of increasing fertilizer price can be counteracted by increasing yields.
This paper adopts profit per hectare as the criterion. That there is already a fall off in fertilizer demand, though the price increase has been relatively slight, can be ascribed to the effect of various decision criteria.

1. Introduction

Making use of all the possibilities offered by biological and technical advances to improve the yield and quality of crops, farmers have been able to increase their incomes and, because the ratio between factor price and produce price has been favourable, fertilizer usage has increased. From time to time it is necessary to forecast future usage from a study of past development and, in this, an interruption in the steady train of events can be of particular significance. A congress like the present one offers an excellent opportunity for crystal-gazing of this kind.
The core of this paper is a consideration of the pattern of fertilizer usage upon which plans for future optimization must be based and, in this context, optimization is to be understood as maximization of profit under a given set of circumstances.
The individual farmer has to adjust his policies to meet changes in his economic and other circumstances among which the following are likely to affect fertilizer demand:

1. A persistent worsening of the ratio between produce price and factor price and any limitation of the rate of technical progress which in turn would limit the rate of increase in profit obtainable from yield-increasing inputs.

* Prof. Dr. *G. Steffen*, Institut für landwirtschaftliche Betriebslehre, Meckenheimer Allee 174, D-53 Bonn/Federal Republic of Germany

2. Falling incomes can result in a cash shortage, and cash is needed to buy fertilizer. It is possible that there would then be a temporary fall in demand for P and K fertilizers and, though the resulting imbalance entails a risk – especially on the less fertile farms – this is not so great as the risk of yield loss through cutting down on nitrogen the effect of which on crop yield is more obvious, and this might also be thought preferable to a reduction in consumer spending.
3. So long as the availability of land is limited, a need to increase farm income will demand further intensification within the farm, notably an increase in livestock. The result will be an increase in farm manures which could also lead to a reduction in demand for N, P and K.
4. Farmers will tend to a more controlled use of inputs if the technical advice available will enable them to do so. Further, the State may be compelled to introduce legislation to control the use of fertilizers and plant protection materials by a growing environmental conscience.

The aim of this paper is to consider a number of examples of how changing conditions may affect fertilizer demand of various farming systems, this without being too specific, and thus to obtain some idea as to how fertilizer usage may develop in the future.

2. Fertilizer advice

Various methods have been devised, some of which are still in the experimental stages, to assist farmers to rationalize their fertilizer usage and further developments may be expected. The present state of affairs in this field will be briefly reviewed in this section and consideration will be given to how procedures may be further developed.

2.1 Methods for the determination of nitrogen rates

Various methods have been devised to forecast the nitrogen requirement of grain crops, including timing of application. The N-min method *(Wehrmann et al. [12])* or methods based on crop behaviour *(Heyland [5])* may be mentioned.
One expects from such methods to reach an increase of gross margin per hectare. This does not mean just saving of fertilizer, it means rather evaluating as nearly as possible the nitrogen supply of the soil in comparison with the needs of the crop. The difference between these values at any time as related to the expected yield determines the fertilizer N requirement.
The decision as to nitrogen application has to be made in relation to the expected yield. When the aim is to achieve maximum yield per hectare, imprecision in the determination of soil N supply may lead to any of the following situations:

- If much nitrate is released from the soil the result may be over-fertilization;
- if the prediction is correct there will be sufficient N to achieve maximum yield;
- if liberation of N is less than expected then maximum yield will not be obtained.

Similar situations can apply if the farmer is using N-rates only for an average yield. The only distinction between the alternative strategies, of maximum or average yield is the yield level aimed for. The decision as to which strategy to adopt rests on estimating the loss which may be expected in a particular year if one or other is chosen. *Hanus [3]* advises the Schleswig-Holstein farmer to aim for maximum yield, saying that in this way maximum profit will be the result in the average year. This high-yield strategy is similar to the policy of an insurance company which bases the probability of future loss on historical performance. The experimental evidence available so far applies only to *one* location. Similar experiments should be conducted on other sites and over a period to check the rationality of basing N fertilization on maximum yield. Further improvement could be obtained by studying the scatter of profit per hectare resulting from the adoption of maximum yield or average yield strategies. Such data would provide the foundation for risk evaluation at different probability levels.

Advice that the rate of N fertilizer should be based on maximum yield is restricted by:

- the shape of the response function,
- the shape of the cost function for fertilization.

If the response function in the part with maximum yield is flat, and particularly when the cost of fertilizer is high, the difference in yield between maximum obtainable and that at a lower rate of N will be relatively small and unimportant. It is particularly important to avoid over-manuring when the curve takes an overturning form; this involves loss in the washing out of surplus nitrogen.

2.2 Requirement for phosphate and potash

Phosphate and potash applications should be equilibrated with nitrogen usage and the type of fertilizer chosen accordingly. P and K requirements can be based on the following:

- the results of soil analysis and plant analysis which indicate whether soil contents are increasing, remaining steady or decreasing.
- calculation of the amounts of nutrient supplied in farm manures for which allowance should be made.
- the crop's nutrient requirement throughout growth to support the production of organic matter.

Balancing the plant's requirements against supplies available from the soil and from organic matter gives the fertilizer need. These calculations can nowadays be done by computer *(Hesselbach [4])*.
This simple-sounding procedure is not without problems, for the farmer still has to decide what yield plateau he is aiming for and what is the appropriate soil nutrient level; his decision will be affected both by his aims and the economic conditions prevailing on his farm.

- What, in economic terms, are the factors limiting the gross margin obtainable?

- What soil nutrient content should be aimed for in order to maintain soil fertility in the long term? While a temporary economy in fertilizer may have little effect, downward adjustment in the long term may be dangerous.
- How much risk is involved in making a wrong decision which may result in over- or under-manuring?

In the light of these uncertainties, and especially uncertainty about the effect of weather conditions, fertilizer recommendations have to vary between regions and between farms. However, for reasons of economy in time, these recommendations are normally based on averages and suffer because it is not possible to lay down universally applicable norms for individual nutrient levels.

At present, P and K recommendations aim to achieve optimum soil levels which will support maximum yields *(Finck [2])*. For instance, optimum K supply is based on a figure appropriate to the soil type and is maintained by applying fertilizer to restore to the soil the amounts of K removed in harvested crops *(Rodewyk [9])*.

Some reduction of this level is considered permissible if soil moisture conditions are favourable. However practical advice opposes any reduction because of uncertainty about weather conditions *(Rodewyk [9])*. This is justified as an insurance cover to ensure maximum yield, though the cost of such cover is not fully evaluated. Such advice is based on premises which require checking especially in the light of the changed crop/fertilizer price ratio; maximum yield is not necessarily the same as maximum profit.

A better assessment of optimum P and K fertilization, based on profit per hectare, can be made when the following are also taken into consideration:

- As in the case of nitrogen it has to be determined whether, from the point of view of the individual farm, maximum yield as an aim results in optimum economic use of inputs and advice has to be made specific to the site. Otherwise, advice might as well be based on average yields.
- Long-term experiments should not merely record yields but also a full evaluation of profit per hectare for the alternative strategies, and in this it is necessary to take account of changing fertilizer costs.

The experiment should also include a treatment with a temporary reduction of P and K supply such as might be brought about by a cash shortage. In this connection it is not only of interest to know the yields obtained but also what increase in yield variance might be expected to result from temporary under-supply.

Such a long-term experiment would allow us to follow the dynamic processes for which not only the present conditions but also the future development of P and K supply should be taken into account. In such a way the long-term nutrient situation could be assessed and judgements made. Unhappily there is, so far, a lack of such experiments.

2.3 Checking P and K usage

Thereby it is assumed that farmers aim for a decrease in fertilizer costs, while other factors as, *e.g.* the risk influencing farmers' attitude, are not considered.

The control consists of a comparison of a value envisaged based on the recommendations of the *Agricultural Investigation and Research Institute (LUFA)* with the actual values obtained on farms. The worsening of the price/cost ratio has made it ever more necessary to take account of PK manuring in arriving at measures to rationalize the use of farm inputs. A requirement for such an approach is a standardized system of farm reporting.

Preliminary results are now available for Lower Saxony. LUFA recommendations which took account of the nutrients supplied by crop residues and farm manures were compared with the rates of P and K fertilizers actually used *(Wehrmann [12])*.

Amounts of potash were being applied regardless of the nutrient status of the soils. The result was that soils well supplied with nutrients (classes D and E) were being over-fertilized while fertilizing of poorer soils (classes A and B) agreed more closely with the recommendations, taking into account crop residues and farm manures. Similar results were obtained for phosphate, though the difference between good and poor soils was not so marked as with potash – even the poorer soils tended to be too generously treated with phosphate fertilizer – but again the extent of over-fertilization was most marked on the better soils.

On the average of all the holdings investigated it appeared that 220 kg/ha K_2O and 116 kg/ha P_2O_5, more than the actual requirements, were applied in the course of a three year rotation at an annual cost of about 90 DM per ha. Obviously, very considerable economy could be achieved through farmers adopting a fertilizer policy more in line with the recommendations.

As well as improving the use of the available information on which to base fertilizer recommendations for N, P and K it is necessary to evolve models for computer based advice. These models could utilize fully the information available from individual farms which would be compared with the standard model to result in individual recommendations. There is no doubt that if advice were more specific to the individual holding, there would be a considerable improvement in economic performance.

The necessary data processing can be done in different ways, either using computer terminals through existing television installations or by using microprocessors on individual holdings or in the advisory office *(Kuhlmann [7])*. Here is a challenge both for science and for private and public institutions – the means are available.

The degree to which an economy in expenditure on fertilizer might be achieved has been indicated in a dissertation of the University of Kiel. Test runs of a cost minimization model showed that on both stockless and heavily stocked farms, cost saving could be of the order of 110 DM/ha *(Sundermeier [11])*.

1. Standard fertilizer recommendations are inadequate because they take no account of site to site and year to year variations, nor do they cater for the specific needs of individual farmers. They may not cover economic and ecological requirements.

2. Experiments to provide a basis for advice should be flexible so that it is possible to adjust the advice to suit the individual farm.

3. Variation in weather from year to year introduces an element of uncertainty for which allowance may have to be made in the recommendations.

4. For this purpose, where possible, the recommendations should allow for adjustment during the growing season based on observation of crop development.

3. Adaptation to changing circumstances

Circumstances compel the farmer constantly to check his fertilizer management to meet changing conditions. Each individual farm is subject to certain constraints. Important limitations are imposed by the area of land available, the availability of labour and financial resources and farm policy is largely dictated by these.
In the following we shall deal mainly with the limits imposed by land and finance which may lead to a limited supply, seen physiologically. Labour availability is less important; though labour need can be reduced through fertilizers, the gain is often counteracted by an increase in expenditure on feeding stuffs.

3.1 Fertilizer use on small farms

Land shortage is an important limiting factor on family farms where there may be little opportunity to expand by buying or renting more land. Moreover, land requirements have to be seen for animal production, differentiating between agricultural and commercial enterprises and the necessary disposal of manures.

3.1.1 Effect of fertilizer price on demand

Under these conditions the product/factor price ratio greatly influences fertilizer usage. The farmer tries to meet changing circumstances by making adjustments.
Consideration starts with a discussion of fertilizer usage on individual crops and this leads on to discussion of the whole farming system as it is affected by the changing competitiveness of the various crops and changing price ratio.

3.1.1.1 Relationships between yield and fertilizer rate

Optimum fertilizer rates can be deduced from the fertilizer response curves which so far are available only for a few sites and crops and do not yet take full account of fertilizer interactions. The effect of rising prices on fertilizer demand can therefore be only partly elucidated.
Yield curves have been based on data published by *Boguslawski [1]* in 1961–1964 and summarized for the main crops by *Müller [8]*. Figure 1 shows production functions for winter wheat and sugar beet. The curves for each nutrient show the response to increasing applications of that nutrient in the presence of generous amounts of the other two nutrients.
The response of both crops to nitrogen is almost linear, maximum yield of wheat being reached at a lower level of N than that of sugar beet. The response to phosphate is relatively steep so that maximum yield is reached when only modest amounts of P are applied. The optimum rates for the two crops are not very different. The response to potash shows more curvature. The high K requirement of the root-crop is demonstrated by the fact that maximum yield is only achieved by applying a high rate of K. Further consideration of the yield curves shows that very high rates of fertilizer do not necessarily give the highest yields. Above certain levels the response to increasing fertilizer may be negative.

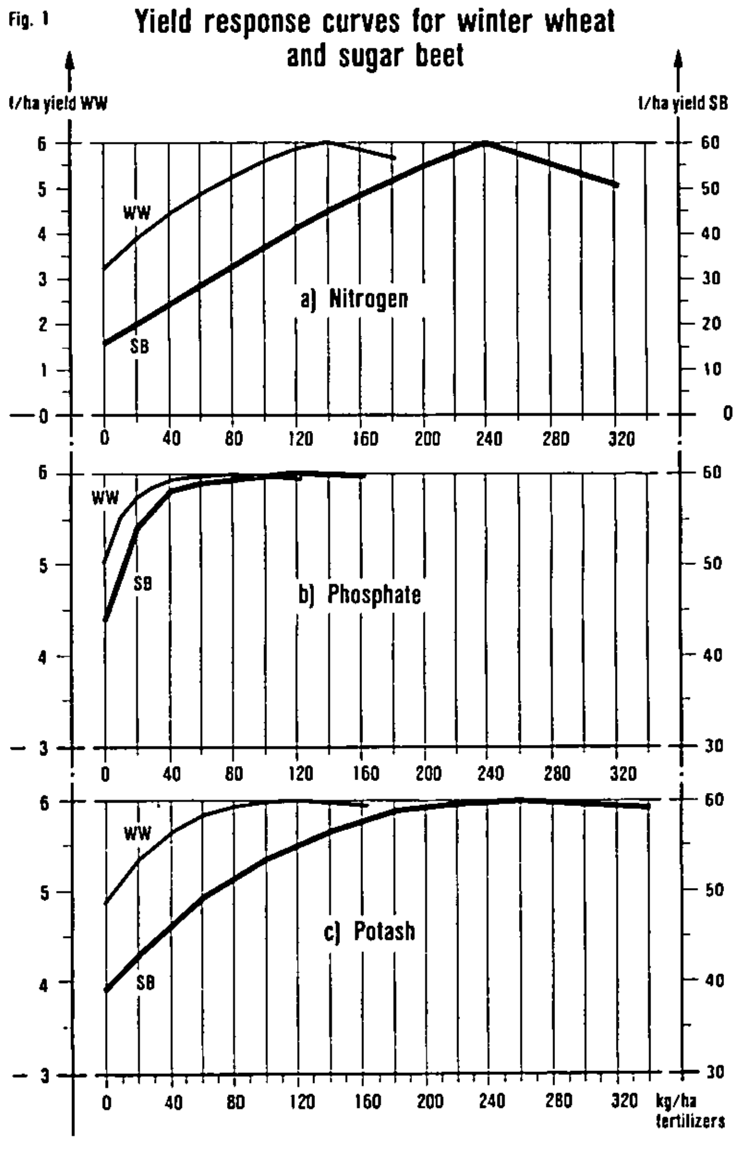

Fig. 1. Response curves for winter wheat and sugar beet.

Kick [6] drew similar conclusions from his experiments. In one 20 year experiment significant response by wheat to potash was only recorded on 2 crops out of 7. For oats and sugar-beet, the maximum yield was never obtained from the highest rate of fertilizer applied.

For a proper economic evaluation of the results for the various nutrients it is necessary to judge how far the yield may fall below the aimed-for maximum yield if somewhat less fertilizer is applied. In this example, the effect of reducing P application would be quite small. Applying 20 kg/ha less P_2O_5 than that needed for maximum yield would reduce the yield of wheat by only 0.01 t/ha and putting on 40 kg less P_2O_5 would reduce the beet yield by only 0.15 t/ha. Similarly for potash: reducing K_2O by 20 kg/ha lowers wheat yield by 0.02 t/ha and reducing it by 40 kg/ha for sugar beet reduced the yield by 0.31 t/ha. Both crops are much more sensitive to nitrogen. Reducing by 20 kg N/ha reduces wheat yield by around 0.18 t/ha; applying 40 kg less N to beet reduces the yield by 5 t/ha below the maximum. In the region of maximum yield, nitrogen is more productive than the other nutrients.

Because of the uncertainty of crop growth and fertilizer response, some degree of over-fertilization may be justified as an insurance policy, but we should be aware of the costs of such a policy. For example, to exceed the optimum potash dressing by a modest amount of 20–40 kg/ha K_2O costs 14 to 28 DM/ha which is covered by an increase in wheat yield of only 0.05 t/ha which would not be detectable in a field experiment. Against this we have to weigh the crop loss which may be occasioned by reducing the application below the optimum for the sake of a small saving in fertilizer cost. These considerations will, of course, be affected by change in the cost/price ratio.

3.1.1.1.2 Economic evaluation of increasing fertilizer applications

The fertilizer response curves can be translated into terms of gross margin which take into account both product and factor prices and this allows for the proper economic evaluation of fertilizer response.

Table 1 gives the gross margins obtained by applying increasing rates of nitrogen, phosphate and potash to winter wheat. Data are based on production functions from literature *(Boguslawski [1])*. The variable costs include expenditure on all fertilizers and plant protection materials with the costs of labour and machinery. The return as expressed in gross margin increases as more nutrients are applied. In this particular example the optimum rate of nitrogen has not been reached, the margin increases between the two top rates applied. However the picture is different for phosphate and potash and at present prices the optima are 60 kg/ha for phosphate and about 100 kg/ha for potash.

In practice there is some difficulty in deciding on the optimum rates to apply because there is a lack of certainty about interactions between the individual nutrients. The result could be a failure to achieve maximum yield. As well as the chance that increasing application of a nutrient will increase profit per hectare there is a danger that over-generosity may reduce profit/ha. This has particular significance if the risk of a loss which arises from a fertilizer policy which pays little regard to the actual needs for P and K can be quantified.

Table 1. The effect of increasing rates of nitrogen, phosphate and potash on returns from winter wheat

		Phosphate				Potash					Nitrogen					
		80	60	40	20	120	100	80	60	40	140	120	100	80	60	40
Gross return	DM/ha	3000	2995	2965	2860	3000	2990	2965	2915	2825	3000	2910	2775	2615	2420	2195
Yield	t/ha	0.01	0.07	0.28		0.02	0.07	0.17	0.35		0.18	0.45	0.77	1.16	1.61	
Variable costs	DM/ha	1450	1425	1398	1363	1450	1437	1422	1404	1382	1450	1409	1350	1305	1244	1195
Gross margin	DM/ha	1550	1570	1567	1497	1550	1553	1543	1511	1443	1550	1501	1425	1310	1176	1000
Gross margin difference	DM/ha	−20	+3	+70		−3	+10	+32	+68		+49	+76	+115	+134	+176	

3.1.1.2 Optimizing fertilizer use on the farm as a whole

So far we have considered only individual crops and the consideration now needs to be extended to embrace the whole farming system. When the nutrients, so far dealt with in isolation, are combined it has to be born in mind that the increased yields grown with more nitrogen raise the needs for P and K fertilizers.

The data applied will not be the same as those used up to now which were derived from mutually independent experiments. There has been no exact testing of maximum fertilizer dressings and maximum yields and many other factors such as fungicide treatment which affect fertilizer response are not precisely known. For this reason the relations between price and demand for the various nutrients shown in the following figures show a stepwise pattern. These illustrate the effects of increasing fertilizer prices on the consumption of N, P and K on two different sized farms following two different systems and on different sites, but with the same cultivation methods and the same crop utilization.

Figure 2 shows the effect of increasing nitrogen price on the nitrogen and fungicide requirements of a 100 ha cash crop farm with ⅓ of the area devoted to the growing of each sugar beet, winter wheat and winter barley and carrying no livestock.

Until the nitrogen price rises to 3 or 3.5 DM per kg N the rates of application to all three crops at present crop prices will remain the same. Because the response to N is linear, the price elasticity is relatively low. Only when the N price exceeds 3.5 DM/kg will the farmer have to reduce the rates of application, to sugar beet by 40 kg/ha and to winter wheat by 25 kg/ha. The value of the increment in yield is then exceeded by the cost of the extra fertilizer required to produce it. Total N usage for the 100 ha farm would reduce by 4.7 t, or 27%.

The requirement for P and K is, apart from price, governed by the yield obtained which is largely determined by the rate of N applied. Usage of these nutrients would also remain unchanged up to a nitrogen price of 3.5 DM/kg with correspondingly increased prices for P and K. But, above this level phosphate usage on the farm would decrease by about 0.4 t or 4% while potash would need to be reduced by 0.6 t or 3%.

The increase in fertilizer price would reduce the return per family labour unit. As compared with the situation at low price levels (1.5 DM, 0.75 DM and 0.5 DM per kg for N, P_2O_5 and K_2O, respectively) the financial return would reduce by as much as 33% when the price of N increased to 2.5 DM and the other fertilizer prices correspondingly. With a price of over 3.50 DM per kg N and simultaneous increases for other inputs, unless there were some radical change in the farming system, the farm income would be reduced catastrophically which is explained by decreases of income and increases of prices.

The effects would be different for the 30 ha farm with a low yield level on which winter wheat, winter barley, rye and grass-clover are grown with some of the land in permanent grass (Figure 3). The rather flat response to N means that the farmer would have to reduce his application of N to grassland if the price exceeded 2.50 DM/kg N. A reduction by 60 kg/ha N would be called for. The same, or similar, applies to wheat and barley.

Because of this higher price sensitivity, the farm demand for nitrogen would be reduced by 0.6 t, or 19% when the N price reached 2.50 DM/kg. In sympathy with the reduced yield, the demand for P and K would also fall.

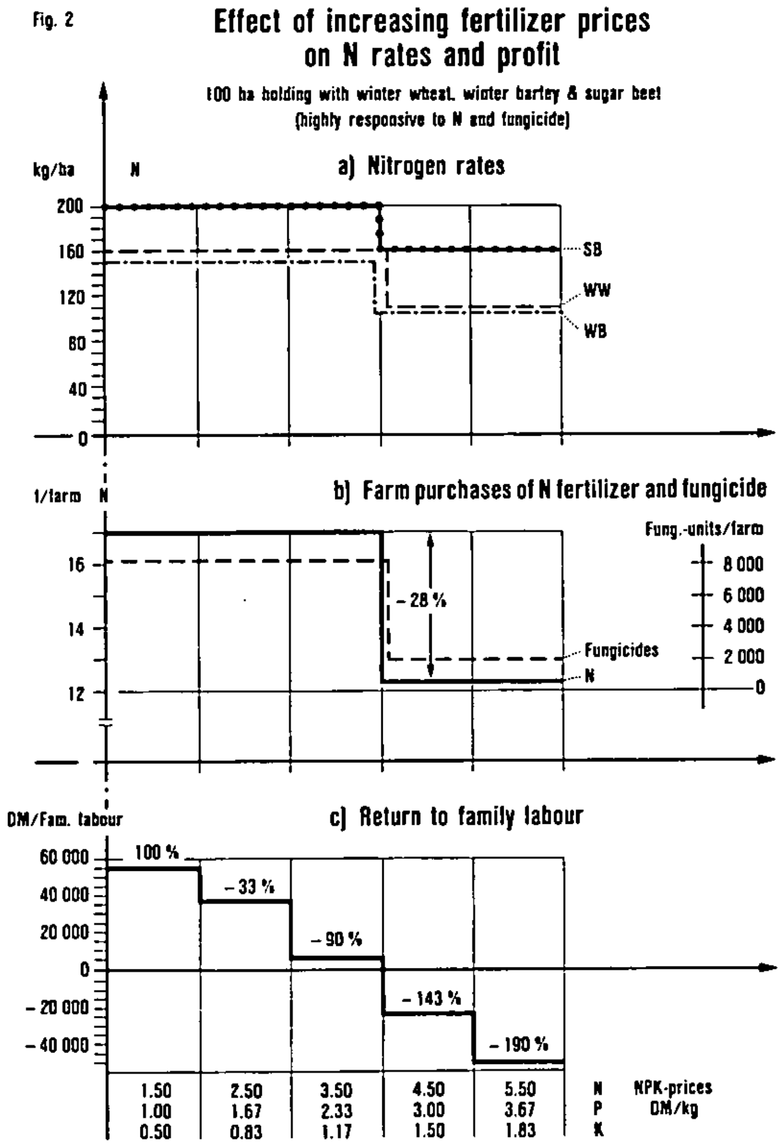

Fig. 2. Effect of increasing fertilizer prices on N rates and profit.

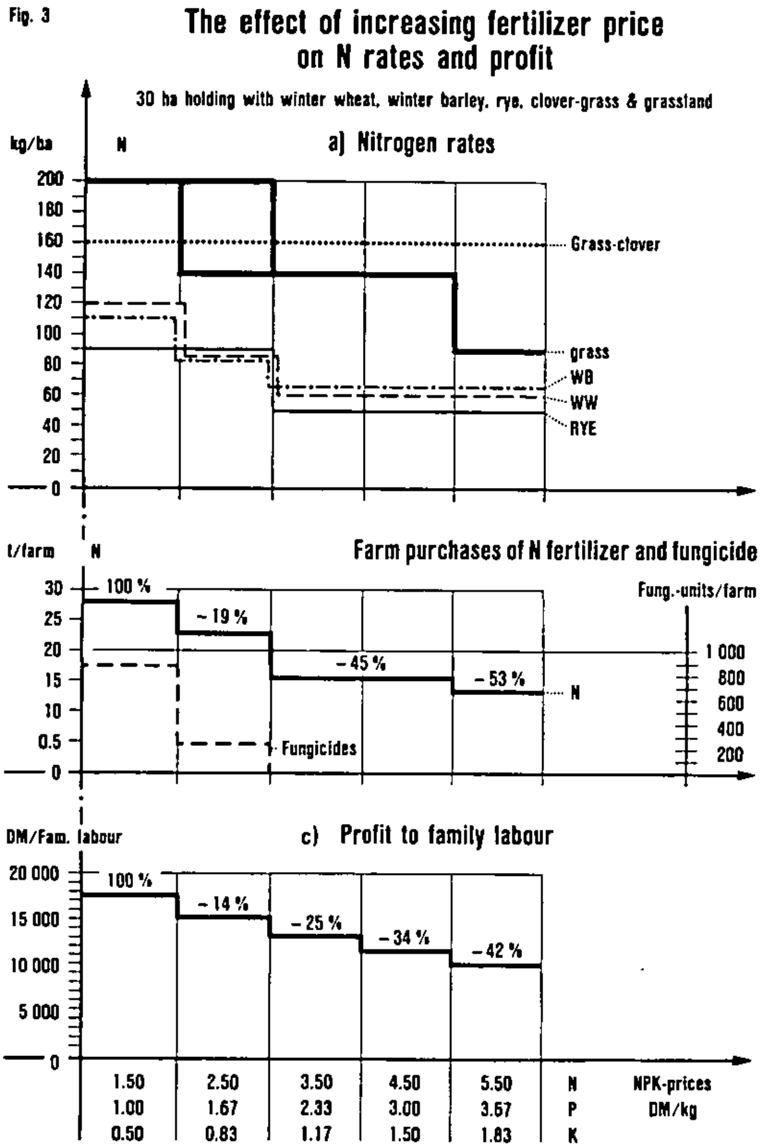

Fig. 3. The effect of increasing fertilizer price on N rates and profit.

The price increase would also have a significant effect on the return to family labour. The already relatively low return would be reduced by some 15% by the increase in price of nitrogen and other fertilizers. Even so, the relative fall in income is less than it is on the more intensive farm. A more complete picture could be obtained of future demand for fertilizer by allowing for yield increases which may still be expected. Rising yields in the past have resulted in a rising demand for N and other fertilizers. The question remains as to what extent further possible increase in crop yield might affect fertilizer usage. Model calculations have been done to investigate the effect of further technical progress on fertilizer usage in a climate of increasing input costs *(Steffen [10])*.

It was shown that on *high yielding farms* it is possible that fertilizer usage will still increase if there is a modest increase in fertilizer price, *e.g.* of 6%. It is not possible, however, to forecast the possible yield increase if crop yields continue to rise in the same way as they have done up to now and with a larger increase in fertilizer price over the long term, say of 12–18%.

Rising input prices would have a much greater effect on *low yielding farms* where there is less scope for technical progress. Even if the price rise is only moderate the possibilities offered by technical progress can no longer be realized.

The possibility of exploiting technical advances alone to maintain the level of profit should not be overestimated. In many cases it would be necessary to make radical changes in the farming system, *e.g.* a change in labour management and a switch to alternative enterprises in order only to maintain the present standard of living of the farmer and his family.

3.1.2 The intensification of animal production and fertilizer requirement

On mixed farms, the stocking rate affects fertilizer consumption independently of fertilizer price through increasing the recycling of nutrients on the farm. More stock means more manure which in turn reduces the need for P and K fertilizers. The effect is particularly large on the small family farm with limited land.

One effect of a rise in fertilizer prices is to place a higher value on animal manures, whose value was not fully appreciated in the past. There have also been improvements in techniques for applying these manures. On the other hand there are difficulties in making the best use of animal manures which are not suitable for late application to the growing crop. The nutrient content of these manures may not be known precisely and the rates of mineralization and release of nutrients may be erratic. There are thus some limits to the value of these residues as a replacement for fertilizers.

Should crops be processed in decentralized units, there would be further possibilities for economy in fertilizer by recycling plant nutrients. The byproducts of biogas production are useful sources of nutrients.

On pig farms, a high stocking rate will enable the whole need for P to be covered with slurry. Increased stocking rates of cattle will make a large contribution to the requirements for N and K.

Rising fertilizer prices pose special problems in connection with the growing of fodder crops. The question here is whether falling milk prices accompanied by increasing fertilizer prices will result in less intensive exploitation of grassland. Just as in the case of grain growing the answer will depend on individual farm circumstances.

Calculation shows that with simultaneous reduction of the milk price and increase of

fertilizer price the less intensive farms could no longer justify high nitrogen usage of the order of 300–350 kg/ha on grassland while such dressings would still be profitable on higher yielding soils *(Steffen [10])*.
Account must also be taken of the relationship between the costs of forage (or grazing) and of concentrate feeds. An increase in the fertilizer price raises the cost of producing grass and it remains to be seen whether grass will be able to maintain its competitive ability with concentrates. It can be shown that if fertilizer prices rise more steeply than feed prices the intensive production of grass with high rates of N fertilizer will become less attractive, but the veracity of this forecast has to be further tested using a range of forage and concentrate prices applied to particular farming situations *(Steffen [10])*.
The increased use of organic manure will influence the fertilizer system. The irregular and often unknown nutrient content will require the increased application of straight fertilizers; this is another reason for the expected decrease in the usage of compound fertilizers. Moreover, the benefit of decreased work requirement will lose in importance when farm profits decline.

3.2 Farmers aims and fertilizer requirement

So far our considerations have been based on the premise that the farmer's aim is to maximize profit per hectare. However the fall in fertilizer demand which has already occurred though the fertilizer price has increased only slightly shows that other factors must be at work. The situation will alter should some other criterion be substituted for maximum profit per hectare or should the farmer lower his sights. Because our knowledge of the behaviour of demand in response to altered input prices is incomplete it is possible only to generalize.
It is conceivable that the demand for fertilizer could fall off even when the price increase is only slight if the economy in time offered by some measure is valued more highly at a high than at a low fertilizer price. A change in management could cause a reduction in fertilizer rates. It is also possible that the conventional aim (being not always close to reality), to purely maximize profits, will be modified by additional criteria resulting in a reduction in fertilizer rates. Thus the desirability of reducing yield variance by generous fertilization decreases as the cost of such an insurance policy rises.
The reaction will be similar in the case of the farmer who has up to now used suboptimal fertilizer dressings. Rising input costs can lead him to adopt a different attitude which could result in his either increasing or decreasing his fertilizer usage.
Finally it is possible that there will be a reduction in fertilizer demand if the aim for maximum profit per hectare is replaced by the optimum profit in relation to limited availability of capital. Under these conditions there could be a reduction in demand for certain fertilizers in the face of an increase in demand for other inputs or for consumer products.

3.3 Measures to meet financial stringency

Deteriorating price ratios have led to the situation that cash flow is becoming a limiting factor. It is possible that there will be limited scope for credit. Psychological

Table 2. The effects of limited finance on fertilizer use on winter wheat

Soil status	Nitrogen	Phosphate	Potash	Concentrate feeds
	P* = 1.80 DM/kg	P = 1.20 DM/kg	P = 0.60 DM/kg	P = 60 DM/t
Good	120→140 kg/ha = +2.36 GM**/DM	40→60 kg/ha +1.13 GM/DM	80→100 kg/ha +1.83 GM/DM	5000–5500 kg/cow +2.0 GM/DM
Rank	1	4	3	2
Poor		20→40 kg +3.92 GM/DM	60→80 kg +3.67 GM/DM	
Rank	3	1	2	4

* P = price
** GM = gross margin/ha

and other considerations which cannot be given an actual cash value may cause a laying aside of the simple aim to maximize profit. The first policy restriction is then imposed by the need to restrict production to a level that is consonant with the available finance and this can, of course, affect the demand for fertilizer.

When money is in short supply for the purchase of inputs the increase in gross margin obtainable by making some change must be related to the cost. Table 2 shows the possibilities offered by change in the level of various inputs in a situation of tight money supply for their purchase; this includes purchased concentrates for a dairy herd in addition to fertilizers. The table shows the increase in gross margin which can be expected by increasing one or other of the inputs under given conditions for winter wheat and sugar beet.

When P and K are being applied in adequate amounts, the best return on money used for purchase is given by nitrogen, followed by potash and phosphate. Money spent on extra phosphate gives a particularly poor return. It is otherwise when P and K are applied at low rates. Here phosphate gives the best return followed by potash and then nitrogen.

On a dairy holding, the need to purchase feed may compete for the available money. Calculation shows that using the available cash to purchase concentrate feeds to increase milk production gives a better return than spending it on phosphate and potash in the case where adequate forage is available from the farm (generous P and K manuring). It is not surprising that in such a case concentrate feed would be given priority over fertilizer. In the case of sugar beet on a farm well manured with P and K the return from increasing nitrogen application is also higher than that from increasing P or K but the difference is not so great as with wheat.

Hanus [3] recommends that when available finance imposes limits, P and K applications should be based on crop removals, while on soils of high nutrient status P and K applications may, temporarily be reduced or even omitted. Of course in such circumstances occasional heavy dressings to build up fertility will not be required and P and K fertilizers should be applied each year in accordance with requirements.

4. References

1. *Boguslawski, E.V.* and *Schneider, B.:* Die dritte Annährung des Ertragsgesetzes, Zeitschrift für Acker- und Pflanzenbau. 1st communication: *114*, No. 3, pp. 221–236 (1961/62); 2nd communication: *116*, No. 2, pp. 113–128 (1963); 3rd communication: *119*, No. 1, pp. 1–28 (1964)
2. *Finck, A.:* Der Nährstoffgehalt der Pflanzen bei Höchsterträgen und einigen Hinweisen zur Düngung. Lectures held on occasion of the 33rd Meeting of the Faculty of Agriculture, Bonn University, Münster, p. 179 (1979)
3. *Hanus, H.:* Möglichkeiten zur Kosteneinsparung im Getreidebau aus pflanzenbaulicher Sicht. Betriebswirtschaftliche Mitteilungen, Landwirtschaftskammer Schleswig-Holstein, No. 322, p. 3
4. *Hesselbach, J.:* Optimierung der mineralischen Grunddüngung – ökonomische Folgerungen aus der EDV-Beratung. Lectures held on occasion of the 31st Meeting of the Faculty of Agriculture, Bonn University, Münster, p. 187 (1979).
5. *Heyland, K.U.:* Schema eines Anbauverfahrens zur Saat, Düngung und Pflege des Winterweizens. *In:* Landwirtschaftliche Zeitschrift Rheinland, Bonn, p. 586 (1978)
6. *Kick, H.:* Nicht veröffentlichte Ergebnisse eines Versuches auf dem Versuchsfeld Meckenheim, Manuskript des Institutes für Agrikulturchemie der Universität Bonn
7. *Kuhlmann, F.:* Moderne Betriebskalkulation und ihr Nutzen. *In:* Landwirtschaftliches Unternehmerseminar, Seminar Gut Schlüterhof, No. 4, p. 241 (1980)
8. *Müller, H.:* Unternehmensspiel ULB 2, Ausbau eines Unternehmensspiels als Ausbildungsmethode in der Landwirtschaft. Giessener Dissertation, p. 234, 1981
9. *Rodewyk, A.* and *Orlovius, K.:* Bei der Kali Düngung sparen? Einfluss unterschiedlicher Kali-Gehalte des Bodens auf den Ertrag. DLG-Mitteilungen *97*, H. 6, pp. 331–333 (1982)
10. *Steffen, G.:* Die Rentabilität des Handesldünger- und Pflanzenschutzmitteleinsatzes in landwirtschaftlichen Unternehmen bei steigenden Preisen für Betriebsmittel und sinkenden Erzeugerpreisen. Berichte über Landwirtschaft, *59*, No. 4, pp. 584–606, Hamburg – Berlin (1981)
11. *Sundermeier, H.H.:* Düngungskostenminimierung. Kieler Dissertation, 1980
12. *Wehrmann, J.*, *Wollring, J.*, *Scharpf, H.C.* und *Molitor, H.D.:* Praktische Erfahrungen und neue Ergebnisse mit der N-min-Methode. *In:* DLG-Mitteilungen, p. 67, Frankfurt (1979)
13. *Wehrmann, J.:* Landwirte düngen oftmals mehr, als die LUFAS empfehlen. Top Agrar, No. 2, p. 54 (1982)

The Use of Computers for Farm Management and Fertilizer Advice

J. M. Attonaty, Laboratory of Rural Economy, I. N. A., Grignon/France*

Summary

Structural problems prevent the use of computers for individual farms but they are useful for farmer organisations for collecting and processing information and the technique is widely used in French agriculture. An example is the system for the control of soil fertility developed in the Aisne Departement which has improved the effectiveness and lowered the cost of advice, reduced delays and improved interpretation: it has also made possible rapid reassessments in times of crisis. Farmer, analytical laboratory and computer centre are linked. Information is assembled on physical description of soil, farming system, etc., and the computer calculates indices of behaviour relative to friability, plasticity and compaction, nutrient balance and determines maintenance and corrective fertilizer dressings. The farmer is sent a calculation of nutrient balance with fertilizer recommendations. The system has some limitations.
An experimental scheme using television (telematics) in agriculture is described.
Mini-computers have been used in dairy advice to forecast milk production, receipts from milk sales, to plan breeding and feeding and to forecast approximate cash-flow and management.
New techniques using mini-computers and telematics will become valuable tools for agricultural extension but a number of problems have yet to be solved. They can be valuable aids in disseminating knowledge.

1. Development of computerised advice in agriculture

Computers came into use at the end of the fifties and in the early sixties and the needs at that time were envisaged as:

- to undertake regular and repetitive work (for questions of amortisation),
- design of basic programmes (to avoid the need for changing programmes),
- investigation of the possibilities of widening the scope of the technique (to make maximum use of computer capacity).

The work involved the use of an expensive computer which required a team of specialists.
In general it can be said that in 1972 the system was used mainly for paysheets, invoicing, accounting methods and the keeping of accounts. The computer was making a contribution by reducing office time and achieving economy in costs.

* Dr. *J.M. Attonaty*, Laboratoire d'Economie rurale, INA, F-78850 Thiverval-Grignon/ France

The structural problems of agriculture prevented the use of these techniques at the individual farm level, but they were useful at the level of farmer organisations where they were used to collect and process information. This work had the same characteristics of repetition and wide scope as in other kinds of activity. There is practically no field of French agriculture in which the technique has not been used and we shall give here an example from the field of the control of soil fertility.

1.1 Use of computers for the control of soil fertility

The system described was developed in the Département de l'Aisne/France. Though the demand for soil analysis was much increased by the oil crisis of 1973 and, further, by the second oil crisis, it is still a matter of fact that farmers demand soil analysis only occasionally: 72% of farmers only call for 1 to 4 analyses at a time. Again, specialist advisers consider that there should be 1 soil analysis per 50 ha per year, which would mean a total of 10 000 samples per year in the Département, but in practice the number of samples sent in is only a quarter of this.
The analysis distinguishes between stable parameters (determined once and for all) and variable parameters which call for periodic adjustment (*e.g.* pH or K content every 5 years).

1.1.1 Objectives

There were several reasons for introducing this service:

- A desire to improve the effectiveness and to lower the costs of advice. It takes an agronomist at least ten minutes to interpret a soil analysis whereas a computer, even of small capacity can make a more complete assessment in seconds, and at the same time frees the agronomist to do less repetitive work and to devote himself to more important problems or to do research, or to interpret problems more deeply than the computer can; it is no substitute for the human brain.

- A desire to improve service to the farmer by cutting out delays. The farmer is none too happy with a service that takes 3 months to reply to his enquiry; using the computer means that advice is with the farmer within 15 days of taking the sample.

- A desire to improve interpretation. This is made possible by the accumulation of information and easy recall from the information bank. This was just as desirable before the advent of the computer but difficult to achieve.

- The need to make rapid reassessments in times of crisis. For instance when the price of phosphate fertilizer rose steeply, the knowledge of soil fertility conditions in the Aisne-Département already accumulated made it possible to economise to the tune of 25 million francs ($4.5 mio) without undesirable consequences for soil fertility. Similarly the building up of information on soil magnesium status made it possible to identify the areas of need and to direct the efforts of distributors to these areas.

1.2 The system in practice

The system is based on the exchange of information between: the farmer – the adviser – the analytical laboratory – the computer centre. This is indicated in Figure 1.

1.2.1 Data collection

Having identified the farm and field by coordinates, information is assembled about:

- Physical description of the soil; facilitated by reference to the soil map.
- Description of farming system: as well as previous cropping this takes into account future cropping and resulting balances, taking account of the rotation practised.

1.2.2 Data processing

The results of soil analysis are sent to the computer centre which calculates:

- indices of behaviour relative to friability, plasticity and compaction,
- diagnostic features obtained by comparison with standards,
- nutrient balance (organic matter, Ca, N, P_2O_5, K_2O, B...) from which are determined maintenance and corrective dressings.

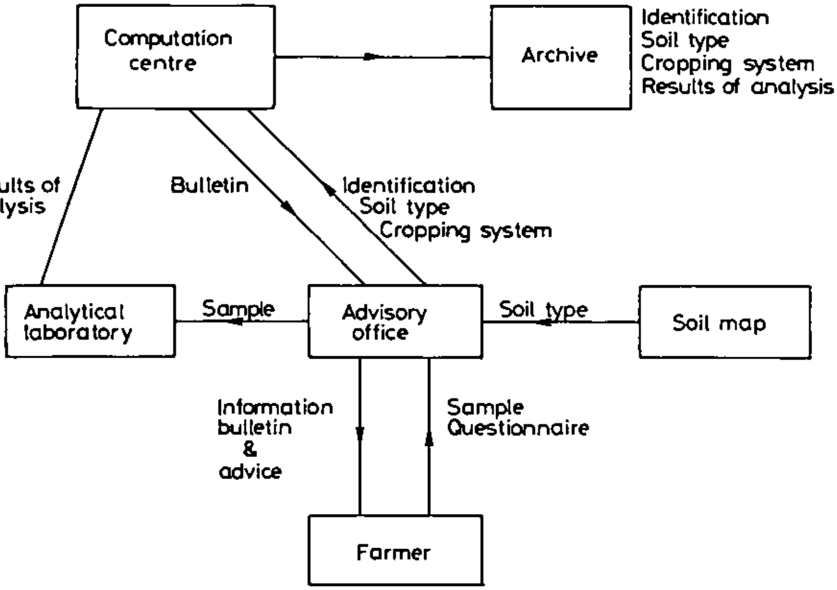

Fig. 1. Exchange of information beetwen the farmer — the adviser — the analytical laboratory — the computer centre.

1.2.3 Feed-back

Finally, the farmer is sent an information bulletin comprising:

- qualitative and quantitative soil description,
- diagnostic conclusions,
- calculations of balances
- fertilizer recommendations (maintenance and corrective dressings),

with a recapitulation relating to his own farm giving characteristics of its fields, diagnosis of problems and fertilizer recommendations (Figure 1).

1.3 Limitations of the system

The system has already dealt with more than 25 000 analyses and experience shows that farmers welcome the service and the extent to which they are able to profit from it. Among other things, they have become progressively more demanding of their advisers' services, itself an indication of progress.

Similar systems are found in other sectors of agriculture; the oldest is without doubt the collection and processing of genetic data. This is a rather more complex system than that we have described. In practice there are different levels of operation using inputs differing as to weight and capacity.

However, though many practical systems have been developed and are in use they have certain weaknesses. They are generally expensive and take a long time to put into use and are mainly confined to special fields: soil analysis, genetic improvement, accounting. As they are designed for routine, repetitive work which needs a large and constant input in order to be economical, they are not of great help with isolated requirements which are not regular and which may be unforeseen. The transfer of information between farmer, computer and data processing office usually takes time. The reliance on manually prepared notes imposes delay, and opens up possibilities of error, correction of which imposes further delay. They are ill-adapted to meet specific demands for rapid advice which may involve modifications to the programme. Assisting the farmer in decision-making poses a whole range of problems which show up the limitations of the method as applied to the farmer and these we have ourselves investigated.

We tested a number of programmes designed to help the farmer in making technical and economic decisions. Programmes concerning modification of the farming system aimed to demonstrate the economic and cultural consequences of possible decisions and to provide dated, quantified forecasts. While some of these programmes, notably the financial one, are still used widely, they can only be used on a confidential basis, and for this there are two explanations:

The first is essentially material, touching the accessibility of data to advisers in the field. While these programmes are easily used by a laboratory which disposes of a computer and a source of information and can obtain results quickly, the same does not apply to most development organisations. They must usually sub- contract their source of information while simple operations like the modification of a value entail time-consuming coming and going between the levels of data collection and processing which means that much time passes between collecting the data from the farmer and returning the advice to him. Finally the rather small but relatively frequent demands on computer services designed for long-term repetitive work such as computing the needs of dairy herds or interpreting soil analysis, and subject to financial constraints, do not fit well into the programme.

The second explanation is connected with the planning of programmes which is imposed by the type of information used. All involve batch-processing with feeding in of much data at the same time and the output of results in one batch. Making one correction involves putting the whole lot through again. Again, this rigidity leads to the design of complex programmes in which one tries to foresee all needs and the establishment of standard rules for decision which may not suit the individual case well, and often lack subtlety.

In view of these difficulties, we have established that certain conditions should be satisfied in data processing if we are to be able to help the farmer in decision making:

- The interpretation must be made on the farm in the presence of the farmer.
- The result should become available within a reasonable time. Truly, farm management does not compare with the control of a rocket and 'real time' has not the same significance for agriculture as it has for traditional applications of informatics..
- The system must allow for direct operating by the farmer and if necessary, to return and to make adjustments. For instance if requirements are covered to the extent of 95%, is it really necessary to re-do the calculations or is the result tolerable? Considering the relatively imprecise nature of the data, one must often be satisfied with an approximation. In a word, the machine can do the most fastidious calculations but it is still up to the farmer and his adviser to reflect.

The development of information technology offers us new means, opposing but also complementary, to answer these demands. At a same capacity level, computers are now much smaller. The machine which ten years ago took up a whole air-conditioned room can now be replaced by a desk-top machine which can be carried in the boot of a car: thanks to processors one disposes now of micro-computers. Alternatively, the resources of the greatest capacity can be made accessible directly to the final user. The connection may be:

- by radio, a non-conversational system, in which the user through his television screen and decoder has access to a constantly up-dated information store, using the titles which interest him, as in the *ANTIOPE* system,
- alternatively the connection may be by telephone line which allows two-way communication and allows the user full access to both information storage and computation. He can both store his own information and take advantage of the general information store. This is the case with *TELETEL*.

These possibilities are already beyond the feasibility study stage and various agricultural projects are now in use or in the experimental stage. For our purposes we have decided to try out the possibilities offered by the micro-computer but we cannot yet decide on the advantages offered by the alternative systems proposed. Before dealing with this work, we shall discuss some applications which are being developed based on telematics.

2. Telematics

2.1

2.1. ANTIOPE was the name given to the first experimental agricultural scheme using television.

2.1.1 Principles

This is based on a televised text giving information on markets, road conditions, general farming news etc., which is directed to subscribers who may be private individuals or groups operating a receiver in a public place. It is estimated that these programmes are seen by 250 000 to 300 000 subscribers every morning. The information is contained in pages of 800 characters in coded form either as a supplement to the programme or in place of the normal picture. The subscriber is provided with a decoder; he calls up the information store with a key and the display appears on his screen. The system is non-conversational, that is the subscriber cannot enter into dialogue with the programme. The decoder will cost 500–600 francs in 2 or 3 years, and the user will have a magnetic subscription card giving access to his choice of programme. The promoters of the scheme estimate that 300 000 sets will be in use by 1985 and 3 million by 1990.

2.1.2 Agricultural application (TELECHAMPS)

This is centred at Pau. Information is supplied by the *Chamber of Agriculture*, Crop Protection, Agricultural Bank, *DDA* (Agricultural Direction of the Département), Artificial Insemination Centre, Regional Education Department and is contained in a store of 100 pages covering weather forecasts, market information, plant protection advice, bulls standing at the Artificial Insemination Centre. In the early stages 10 sets of equipment were installed for public use and at the beginning live commentary was needed. Later 10 individual farmers tried it out and their reactions were analysed.

2.1.3 Reaction of the farmers

Two information headings were immediately popular; weather forecast and market information. Weather forecasts were put to immediate use for timing cultivations and harvesting forage crops. The cost of this new service was considered by farmers to be

worthwhile. The popularity of the weather service caused some problems for the Met. Office from whom the farmers demanded reliable forecasts which took account of their own micro-climate and which needed to be updated several times a day, especially in stormy weather.
The agricultural advisory services also had pressure put upon them by the new service. Where irrigation is widely used the farmer wants immediate useful information on evapotranspiration and on the amount of water to apply to his various crops. The rapid publication of market intelligence gave the farmer a strategic advantage in timing marketing of his produce. As in the case of the weather the farmer has become demanding of more and better market information, and now Orep uses a number of correspondents in all mayoralties to supplement their information. The farmers wished to have quotations from professionals.

2.2 Telematics and their use by the general public *(TELETEL)*

This system uses the telephone lines. The subscriber has a computer terminal and television screen with which he can make calculations and through which he has access to the information store. Unlike the previous scheme, this is a two-way system allowing the user to introduce his own data and give instructions to the computer. The system has a quadruple function: information, data processing, carrying out transactions, despatch of goods.
In practice, the user can at any time contact the computer of his choice through his telephone and a decoder. He calls up the service centre using the appropriate code and this gives him access to information the cost of which is automatically invoiced. The information can be displayed either on a special screen or on his television set.
Right from the start it was decided to experiment in the agricultural field, a first choice of the management of the telecommunications system. There were both *vertical* projects testing a series of services on a confined subject of interest to farmers and *horizontal* projects for testing out procedures and methods needed to ensure an adequate service over a whole region. The tests were carried out with the cooperation of about 50 users.

- A vertical programme has now been proposed by the agricultural managment centres for the farmers of Loire-Atlantique and of Aveyron. It includes an accounting service and gives information on general agricultural matters, prices and characteristics of agricultural equipment, etc. It is constantly being expanded.

- Several other similar projects are being carried out with the cooperatives. Thus, one cooperative in the West serves its members by telematic with technical, economic and commercial information: choice of inputs, ordering, invoicing and even electronic payment.

A horizontal project is established in Picardy. In addition to the services described above this offers various official services as its centre is connected with computers of agricultural organisations. There is a similar scheme in Meurthe et Moselle.

2.3 An example which combines both systems *(Figure 2)*

The crop protection service is now developing a new approach to advice on crop disease control based on using both *ANTIOPE* and *TELETEL*. Each farmer, through *ANTIOPE* has access to a special information store, updated every day which gives him the essential advice for each of his crops. Using *TELETEL* he can search the information store for control techniques and can select the plant protection materials suited for any particular disease and crop. He has access to results obtained in his own region and with the crop varieties he grows. But he can also feed in his own information and receive immediately advice appropriate to his own particular case.

The method of deciding fungicide treatment of wheat used by the District Poitou-Charentes and now used on an experimental scale can be taken as an example of the combined use of the two approaches.

The principle is to evaluate the risks of crop loss in relation to three criteria:

- the crop potential,
- disease symptoms,
- forecasts of epidemics.

By combining these criteria, decisions can be made as to treatments and choice of chemicals appropriate to each case. At the outset, the farmer indicates the cultural conditions of his field (drilling date, variety, cropping history, nitrogen usage) and each week, according to the diseases and pests identified, can be advised whether or not to take control measures. The system allows the use of local information at minimum cost to the farmer.

However, such a system, giving up-to-date information can only be as effective as the supply of information is well organised. The metereological section of the crop protection service, which complements the national weather service, intends to install more automatic weather stations which send information daily direct to the computer. In the future collection of biological and phenological data uses the post less and less and relies more on automatic tele-transmission.

The system is based fundamentally on simulation models which are capable of forecasting the development of pest and disease attack over an area, while information collected by observers and advisers serves to check the models.

The Midi-Pyrénées District has worked on this subject for several years in cooperation with the *CEMAGREF** computing centre. Various models have been used, in the early stages mainly for fruit and vines, but later for farm crops, mainly cereals. Some of these have been used on the large scale by agricultural advisory centres (*e.g.* 'Tordeuse' for codling moth of apple and grape moth).

3. The use of mini-computers

The large scale telematic systems require an appreciable infra-structure and, at the present stage, are experimental as regards both technical execution and the creation of data bases. At the same time, the reactions of farmers are under examination.

* Centre d'Etudes du Machinisme Agricole, du Génie rural et des Eaux et Forêts

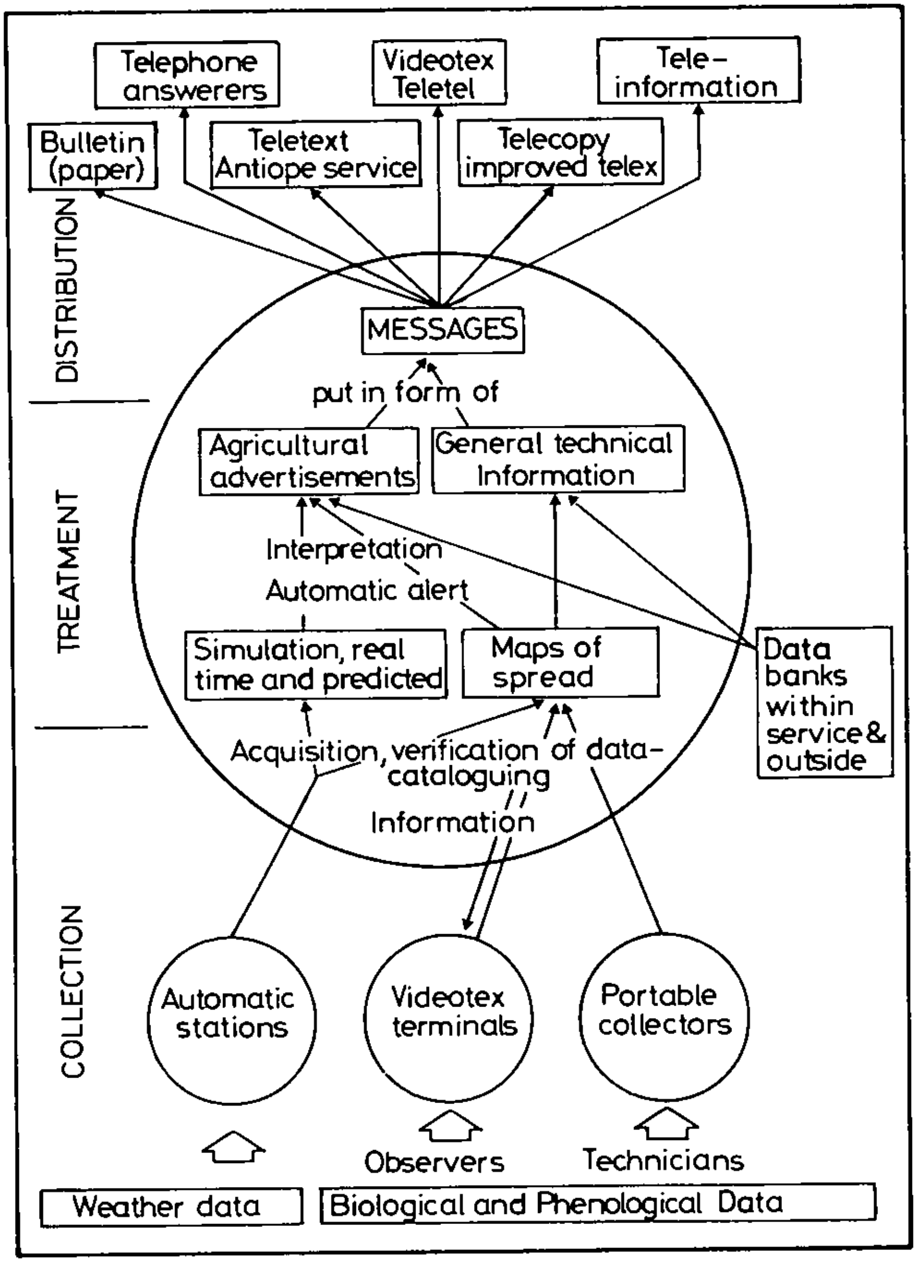
Telephone answerers
Videotex Teletel
Tele-information
Bulletin (paper)
Teletext Antiope service
Telecopy improved telex
DISTRIBUTION
MESSAGES
put in form of
Agricultural advertisements
General technical Information
TREATMENT
Interpretation
Automatic alert
Simulation, real time and predicted
Maps of spread
Data banks within service & outside
Acquisition, verification of data-cataloguing
Information
COLLECTION
Automatic stations
Videotex terminals
Portable collectors
Observers
Technicians
Weather data
Biological and Phenological Data

Fig. 2.

The mini-computer offers an alternative which may be easier to bring into use: computers and programme languages are still being modified and improved but, even at this stage, the possibilities they offer for the storage of data and their treatment are sufficiently large as to indicate that they can make an important contribution. The cost of the equipment, of the order of 6000–8000 dollars for a complete system with storage and printout, means that they can be available to most advisory centres and even to the larger farms.

At the farm level an obvious use of the equipment is for accounting for which there are already a number of suitable programmes. It is only necessary to experiment to find out the possibilities and costs of accounting by this method and to show up possible difficulties. In livestock enterprises the mini-computer can be of immense assistance in herd management, checking service dates and computing rations. In some cases the computer may be connected to information captors giving information on milk production and on rationing.

However, the initial cost of the equipment and programmes limits the use of the mini-computer to a few large farms and we have been more concerned with its use as an advisory tool, our wish being to render it less elitist and of real use to a large number of farmers. With this aim we have established a number of short-term programmes (12–15 months) to aid decision-making in both the economic and financial sphere as well as the technical (see Figure 3). Assuming that we are not concerned with re-organisation of the whole farming system, we concentrate on day-to-day management. Eventually, we shall move on to organisational problems which will call for longer-term programmes. The objective is to provide a detailed monthly forecast of cash flow, accounts and a balance-sheet.

3.1 Forecasting milk production and the sale of cows

Starting with the number of cows in milk, dates of last calving, or insemination and individual milk yield the programme provides a forecast of milk production week by week and month by month. Essentially, this is a well established programme modified for use by the mini-computer. The results of this first calculation can be used directly to show up milk production problems and control of calving using simple step-by-step procedures.

3.2 Forecasting receipts from milk

From the milk production forecast, monthly receipts are calculated by simple multiplication. Finally, we can take account of the method of disposal farm/dairy, and different methods of selling, for example, direct retailing.

3.3 Planning breeding

A necessary annual decision is the choice of bull. Two programmes have been used for this. The first is simple and consists essentially of using the computer to search for the characteristics of bulls standing at the A.I. centres and select those which meet

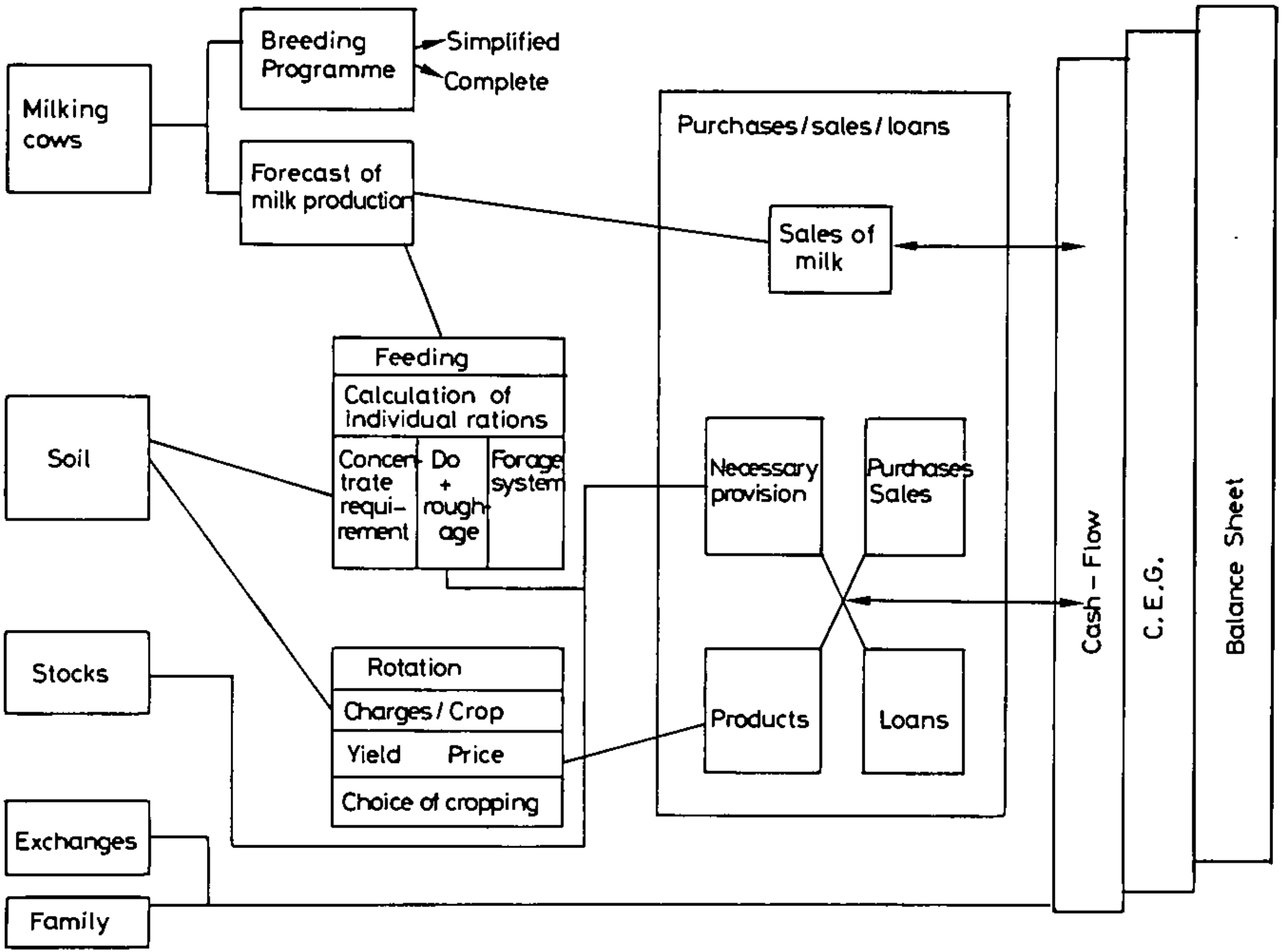
Milking cows
Breeding Programme
Simplified
Complete
Forecast of milk production
Purchases / sales / loans
Sales of milk
Feeding
Calculation of individual rations
Concentrate requirement
Do + roughage
Forage system
Soil
Stocks
Rotation
Charges / Crop
Yield Price
Choice of cropping
Necessary provision
Purchases Sales
Products
Loans
Exchanges
Family
Cash – Flow
C. E. G.
Balance Sheet

Fig. 3

the minimum requirements of the farmer. From these he can make his final selection. Usually the process requires two or three stages, each requiring several minutes. In the first stage one looks for the 'miracle' bulls, those with a very good milk index and which improve conformation. After finding out that such a bull does not exist, the second passage will throw up a veritable plethora of bulls – having been too demanding in the first case, we have not been sufficiently circumspect in the second and a third step is necessary to give usable results.
Another programme is rather more refined as it aims to offer a choice of bull for each cow, rejecting those which have similar faults to those of the cow. The disadvantage is that it takes much time – two or three hours for a herd of sixty.

3.4 Feeding of the dairy herd

Once having made the milk production forecast one knows the effective number of cows to be fed month by month and their production levels and from this the food needs can be calculated. This is done in two ways:

- Individual basis. The programme calates the milk yield possible from a ration proposed by the farmer without supplementation and proposes a supplementation plan based on the concentrates available and the farmer's practice.
- Herd basis. The problem can be approached in three ways:

a) First of all, a simple version takes no account of forages. The programme calculates the concentrate needs for the coming months, taking account of the basic programme suggested by the farmer.

b) A more complete version, starting from a plan given by the farmer, calculates the total maintenance requirement and production ration.

c) The final, more refined, system takes account of the whole forage system and calculates at the same time food requirements, utilisation of pasture, silage and hay.

3.5 Forecasting inputs and production

The farmer lists the inputs for each crop; type, amount, date of application and the yields envisaged. Then the gross margins for the whole rotation are calculated. It is possible to include several variations in rotation and different assumptions as to yield, price etc. before making a choice. From these the detailed monthly needs can be calculated with the quantities of produce for sale. A programme is now under study to provide detailed manurial requirements field by field.

3.6 Calculation of approximate cash-flow

This is based on crop forecasts, forecast milk production and sales on animals, requirements for bought-in food for the herd and input requirements for crops. The forecast takes into account the due dates for farm bills and the expenses of the family from which is obtained a global picture of all the receipts and expenses of the enterprise for each month. This first approximation of forecast cash-flow shows up the difficult months and may suggest reconsideration of the suggested management or reconsideration of the management of sales and purchases.

3.7 Management of purchases and sales

Provided there are no doubts about the production system, we are concerned simply with improvement of commercial practices. For the main inputs, forecast prices, months of purchase, time allowed for settlement, percentage margins are all important and for the products, marketing periods and settlement time. The first approximation of the cash-flow ignored the seasonal variation in prices but, now, monthly variation and variation according to method of disposal are included. We thus obtain a closer approximation which makes possible comparison of several commercial alternatives: purchase of fertilizer during the off-season, for example, or negotiation of financing arrangements with the bank.

The kind of programmes we have described are now in the experimental stage and are used by the advisory organisations.

Conclusion

From now on these new techniques using the mini-computer and telematics will become more important and more valuable tools for agricultural extension but they may cause some confusion and give rise to numerous problems. They will not be immediately accessible to all farmers and, without doubt, may be a further cause of disparities in agriculture. The mini-computer is only available to a few, on account of its cost. Telematics can obviously be of great benefit but require specific training of farmers if they are to be of use outside the relatively small circle of the initiated, who have the necessary technical competence.

Among other things there has to be some change in the relationship between the farmer and his adviser who will require knowledge of the whole farm business and not just of some technical aspects. With its capacity for calculation and for storage of information, the computer can substitute for part of the job of the adviser but it cannot take account of the imponderables, or of subjective considerations; first-hand knowledge of the farm and of the farmer. For these the adviser is irreplaceable.

The computer is a challenge to advisory organisations; it can view the farm business as a whole but it is not as well adapted as the present advisory organisations which are usually specialised.

Finally these techniques demand attention as a new way of disseminating knowledge; most of the proposed models supply both data and methods of interpretation. Their commercial impact is obvious and consequently questions may arise as to the quality of the basic data and their independence of commercial pressures.

It seems certain that these new methods will develop further. It is necessary, however, that this development should be preceded by efforts on the part of the users, farmers and their advisers, so that they remain in command of the situation, giving critical assessments of the data and proposed methods so that they may even be a counterpoise to the promoters of these new systems.

References

Attonaty, J.M.: Micro-informatique et aide à la décision des exploitations agricoles. C.R. Académie d'Agriculture, pp. 1018–1036 (1980)

Blumenthal, M.: La Direction Générale des Télécommunications et le développement de la télématique (unpublished)

Pelzer P. and *Deveaux, P.:* Dossier Informatique, Télématique. Cultivar, pp. 154–179 (1982)

Projetti, F.: Lutte intégrée et informatique. Les avertissements agricoles de demain. Phytoma n° 336, pp. 8–10 (1982)

Rémy, J.C.: L'ordonateur et le contrôle de fertilité des terres. I.N.R.A. Station d'Agronomie de Laon (unpublished)

Rémy, J.C. and *Marin-Laflèche, A.:* L'analyse de terre: réalisation d'un programme d'interprétation automatique. Ann. Agron. *25*, (4), pp. 607–632 (1974)

Co-ordinator's Report on the 4th Session

Economic Aspects of Optimization of Yields

L. Gachon, Agronomy Dept., I.N.R.A., Clermont-Ferrand/France*;
Member of the Scientific Board of the International Potash Institute

I would like to open my report on the 4th Session by thanking the speakers for three contributions of outstanding quality.

It was interesting to learn from Dr. *Guth*'s opening lecture that during the course of the past 20 years in the EEC there is no general relationship between the increase in fertilizer usage and the increase in farm yields. This is partly because the individual countries started out at different levels, as was pointed out in the discussion, but also because of the number and complexity of the interactions between the various factors concerned in crop production, which are the more important the higher the yield. Fertilizer usage is only one among many production factors. Dr. *Guth* treated us to a discussion of many other interesting facts and concepts concerning the agricultural policy of the EEC, and I will return to these at the end of my comments.

Professor *Steffen* uncovered for us the means which the farmer has at his disposal for maximizing profit per hectare and for combatting as far as is possible the deterioration in the relationship between product prices and production costs. These include: more accurate and more reliable estimation of soil nutrient supplies, particularly of nitrogen; improved knowledge of the physiological requirements of growing crops; adjustment of the level of inputs to suit crop demand, based on the economic interpretation of response curves; adjustment of fertilizer policy to suit the farming system. This is the classic approach which is particularly relevant to the optimization of nitrogen usage but not so helpful in the case of P and K for which the response curves are rather flat when soils are well provided with these elements and it is only necessary to apply restitution dressings.

Dr. *Attonaty* described the various ways in which the computer can be used in helping the farmer with his day to day decisions and speculated on future developments in this field. I have the impression that the use of such methods has fundamentally affected the relationship between the farmer and his advisor. Whereas in the first place it may have appeared to farmers as a competitor of the extension officers, the development of computer usage has made it apparent that it is in fact an additional tool which aids the advisor by reducing his work load and increasing the objectivity of the advice he offers; it is however no substitute for on-the-farm advice and man-to-man discussion.

* Dr. *L. Gachon*, Head, Agronomy Dept., I.N.R.A., 12 Avenue du Brézet, F-63100 Clermont-Ferrand/France

This is but a very brief review of the lectures you have heard but I must now pass on to consider some of the fundamental issues raised by Dr. *Guth* so far as they concern the future of agriculture, notably in Western Europe.

Following the Second World War agriculture made great progress in these countries and production increased by 3–5% per year on the average. Now there are signs of a kind of exhaustion and the rate of increase has considerably slackened. Furthermore, farmers' incomes have stagnated or even fallen, particularly since the first oil crisis which adversely affected cost-price relationships in farming.

Will this deterioration in price relationships continue? This is not altogether certain. There has been a tendency in recent years for energy costs to settle down and it cannot be excluded that there may be some modification in the ratio between prices for agricultural and industrial products.

On the other hand, there appears now to be some *conflict between the interests of the farmer and those of the community, but is this a real conflict and will it always be so?* While, on the one hand, it is true that there has been an increase in the budgetary cost of disposing of EEC agricultural surpluses, there have at the same time been indications of reconciliation between the world and European prices in relation to movements in supply and demand on the world market. Such has been the case for sugar beet and cereals. Such readjustments can only be favourable in the long term for the disposal of the EEC surpluses of commodities of which there is a world deficit. Continuing surpluses of dairy products and cereals, for example, could be advantageous in reaching long term export agreements (for example with the Arab countries of the southern Mediterranean). If such arguments hold water there is fundamentally no conflict between the general laws of the market economy and the interests of the farmer who wishes to take advantage of technical progress.

Increasing inputs to a crop does not necessarily result in maximizing profit per labour unit. There is potential scope for economy in inputs in very intensive cropping systems depending on progress in the following areas:

- tillage methods
- crop and animal breeding (development of more productive cultivars and/or especially improving of resistance to disease)
- crop protection (optimization of treatments, biological control, combined systems)
- in the field of fertilizer usage (improved adjustment of N fertilization to potential yield and in relation to weather and soil conditions and attention to the maintenance of P and K levels in the medium and long term).

The agriculture of the future will make full use of computer-based models which will draw on more and more information (information banks) of greater reliability (weather forecasting) to aid management decisions and to make more economical use of all the factors of production; it will pay greater attention to the quality of produce and to the conservation of the environment.

Any intensification will inevitably tend to accentuate disparities between farm types, between the various sectors of agriculture and between regions. This economic 'law' has already resulted in agricultural and rural 'desertification'. *Do we have to expect* *the freezing of whole areas with poor soils and unfavourable climate or are there other possible ways of exploiting our natural resources?* There are a number of avenues for exploration by research workers and by the people themselves:

- systems which give priority to larger farms with reduced use of intermediate factors (livestock and sheep for example)
- making use of 'marginal' products to exploit temporarily available labour and premises (soft fruit, honey, small animals, mushrooms, medicinal plants etc.)
- harvesting secondary products of forest and heathland (mushrooms, bilberries etc.)
- above all better combination of the activities of and a better quality of life for all members of the family living permanently or temporarily on the farm, which is favoured by:
  - mechanization of farm work
  - reduction in working hours for those members of the family working off the farm
  - generalization of pension shemes for the retired, whose expectation of life will grow
  - tourism on the farm.

Finally it must be said that the development of the farming economy and the whole future of agriculture itself depends on the *investment of 'grey matter'*: investments in agricultural research, certainly, but also investment in the farmers themselves in their daily work of growing our primary products. Nor must we forget the ancillary workers active in the agricultural advisory services. After all, it is in such fields that the technologically advanced countries can make such a large contribution to aid the developing countries.

12th Congress of the International Potash Institute
June 1982 at Goslar/Fed. Rep. of Germany

Panel Discussion

Increasing Population — Can Agriculture Meet this Challenge?

Chairman of the Panel	**Dr. N. Celio**, Former President of the Confederation of Switzerland; President of the International Potash Institute, Bern/Switzerland
Panel members	**Prof. Dr. I. Arnon**, Settlement Study Centre, Ramat Gan/Israel; member of the Scientific Board of the International Potash Institute
	Dr. G. W. Cooke, Honorary Scientist, Rothamsted Experimental Station, Harpenden, Herts./United Kingdom; member of the Scientific Board of the International Potash Institute
	Dr. R. Dudal, Director, Land and Water Development Division, FAO, Rome/Italy
	Dr. L. Gachon, Head, Dept. of Agronomy, I.N.R.A., Clermont-Ferrand/France; member of the Scentific Board of the International Potash Institute
	Dr. J. S. Kanwar, Director of Research, Int. Crops Research Institute for the Semi-Arid Tropics, I.C.R.I.S.A.T., Andhra Pradesh/India
	Dr. B. N. Okigbo, Deputy Director, International Institute of Tropical Agriculture, I.I.T.A., Ibadan/Nigeria
	Prof. Dr. h.c. E. Pestel, Member of the Board of the 'Club of Rome', Hannover/Fed. Rep. of Germany

Land Resources and Production Potential for a Growing World Population

R. Dudal, FAO, Rome*

Future populations

According to U.N. projections *(Salas [1981])*, world population could reach a stable level of 10.5 billion by 2110, compared with 4.4 billion at present and 6.2 billion projected for the year 2000. The bulk of the increase is projected to take place by the middle of the 21st century, with world population reaching 9.25 billion in the year 2055.

The significance of these projections for future requirements of food and other agricultural commodities is that world demand could increase by 50% in the next 20 years and would more than double again in the first half of the next century. Requirements will actually grow faster than world population since almost all the population increases – 95% – will take place in the developing countries which, at present and on average, have low per capita consumption levels. Hence, by the time the world was getting reasonably close to population stability, demand for food and agricultural products could be three times its present level *(FAO [1981])*.

The most striking feature of projected population growth is that the share of world population living in developing countries will increase from the present 72% to 87% in the year 2110, that is 9.1 billion out of the total of 10.5 billion. Within the developing world, differences in fertility levels and in decline of birth rates will entail a marked regional demographic diversity. The stable population of various regions will be reached in different years, ranging from 2030 for Europe to 2110 for Africa. Table 1 shows years of stabilization and the populations projected to live in different parts of the world. Proportionally the largest increases are expected in Africa – fivefold – and in South Asia – threefold –, in the latter case, however, from a much larger 1980 base. Africa and South Asia together, with 6.3 billion people, will account for over 60% of the world's total population at the time of stabilization *(Salas[1981])*.

Agriculture: Toward 2000

The FAO study 'Agriculture: Toward 2000' *(FAO [1981])* examines world agricultural perspectives and policy issues up to the year 2000 for 90 developing countries. Three major scenarios are analyzed: a continuation of existing trends, a modest

* Dr. *R. Dudal*, Director, Land and Water Development Division, FAO,
Via delle Terme di Caracalla, I-00100 Rome/Italy

Table 1. Projected stable populations in different regions

Years of stabilization	Regions	1980 population (millions)	Stable population (millions)
2110	World	4434	10 529
2080	More developed regions	1092	1 390
2110	Less developed regions	2975	9 139
2110	Africa	470	2 193
2100	Latin America	364	1 187
2060	Northern America	248	318
2090	East Asia	1059	1 725
2100	South Asia	1405	4 145
2030	Europe	484	540
2070	Oceania	23	41
2100	U.S.S.R.	265	379

Source: *Salas [1981]*

improvement over trends since the early 1960's, and a more ambitious but still feasible rate of growth. No attempt is made to forecast what will actually happen up to the end of the century; rather the purpose is to unfold and analyze the implications for agriculture of the different scenarios.

Past and existing trends in food and agriculture have led to a situation which, despite notable achievements, is fundamentally unsatisfactory with 450 million people seriously undernourished. A continuation of current food consumption trends and income distribution would raise this figure to some 650 million people seriously undernourished in the year 2000, according to conservative estimates. For the developing countries, the outcome would not only be unsatisfactory but alarming. The great majority of developing countries with nutritional problems in the mid-1970's were in that situation precisely because past trends in per capita supplies, whether domestically produced or imported, were unfavourable: they declined, remained stagnant or, at best, increased only slightly. If these trends were to continue to 2000, no fewer than 34 countries, accounting for half of the 90-country population, would have per capita calorie supplies under 100% of national average requirements. The lesson is clear: past trends must be changed. More hopeful alternative paths of growth have to be considered.

In Scenario A, a much improved agricultural production performance by the developing countries matches demand. An approximate equality of increase in demand and production is also achieved in Scenario B, but at a distinctly lower level. The heart of Scenario A is a doubling of agricultural production in the developing countries between 1980 and 2000. The less ambitious Scenario B is built around an 80% rise in output.

These hopeful outcomes depend on achieving an ambitious transformation in the agriculture of the developing countries – almost an agricultural revolution, involving widespread modernization in technology and techniques. The overall development strategy relies heavily on rapid increases in current inputs, backed by a steady expansion of relatively high-cost investment with longer gestation periods, and pursued with an increased awareness of the need to conserve the environment and avoid undesirable social consequences. The production growth rates envisaged require a sustained and substantial expansion not only in the land and water base but in the modernization of the production process itself. For the 90 developing countries crops account for about four-fifths and livestock about one-fifth of additions to production during 1980–2000. Expansion of arable land provides 26% of the additional crop production, increased cropping intensity (the number of times that a hectare of land is cropped each year) 14% and higher yields 60%.

Table 2. Contribution to increases in production (90 developing countries – 1975 to 2000)

Region	Contribution to output growth (percent)		
	Arable land growth	Changes in cropping intensity	Yields
90 countries	26	14	60
Africa	27	22	51
Far East	10	14	76
Latin America	55	14	31
Near East	6	25	69

Source: *FAO [1981]*

Table 2 shows marked differences between regions with regard to the contributions to output growth. Table 3 provides a breakdown of projected increases in inputs to production.

Table 3. Inputs to production (90 developing countries)

Inputs	Year 2000		Growth rates 1980–2000	
	A	B	A	B
	(Index: 1980 = 100)		(percent per year)	
Arable area	120	115	0.90	0.71
Irrigated area (arable)	141	129	1.72	1.27
Irrigated area (harvested)	162	146	2.43	1.91
Tractors	553	417	8.92	7.40
Fertilizer	514	412	8.53	7.33
Pesticides	240	207	4.47	3.70
Commercial energy (in oil equivalent)	494	383	8.32	6.94
Improved seed	317	280	5.93	5.29
Cereal feed	304	258	5.71	4.85
Labour requirements (man-days)	146	137	1.91	1.60

Source: *FAO [1981]*

The use of commercial energy, in the form of machinery, fuel, irrigation, fertilizer and pesticides, is between four and five times as high in 2000 as in 1980. The differences between the 2 scenarios reflect only differences in the extent of increases in inputs, not in the modernization of the production process. In addition to this rising volume of

current inputs, substantial increases in capital expenditure will be required. Mechanization and livestock, including increases in herds, are the largest items, followed by irrigation. In the Far East, however, irrigation is the largest single investment item. Irrigated land at present accounts for about one third of the total developing-country crop output, but by 2000 its share should be over 40%.
It is clear that the future availability of agricultural land and the agricultural labour situation will strongly influence the specific country pattern of input use. In countries with little new land to bring into cultivation, almost all increases in crop production will need to come from raising yields and cropping intensity. By contrast, land-abundant countries follow a development path of more equal shares between expansion of arable area and intensification of its use.

Is there enough land?

The question arises, more pressingly now than ever before, is there enough land to feed the populations of the future. The results of the recently completed FAO/Unesco Soil Map of the World *(FAO [1971–1981])* provide a global answer: if the people of the world were to live in harmony, if resources were shared, if all cultivable land were used in an optimal way, and if there were unrestricted movement of produce, there would be food for all for many years to come. The reality, however, is different: land resources are unevenly distributed between and within regions, technological inputs are in limited supply in developing countries, the gap between rich and poor is steadily widening, and the movement of food from surplus to deficit areas is hampered by difficult communications and unfavourable balances of payment.
In the early fifties, imports of cereals by developing countries were limited to a few million tons. By 1981 imports were near to a burdensome 100 million tons, half of the world's trade in cereals. It is not enough for the world as a whole to have the capability of feeding itself, it is necessary to produce more food where it is needed. Since developing countries need to strive at greater self-reliance, the question – is there enough land – has to be raised again, region by region, country by country. Assessments of the production potentials have to be based on the evaluation of land attributes which reflect the interaction between soil, water, climate, plants, animals and human influences, and which determine the suitability for different types of land use in agriculture, grazing and forestry *(FAO [1976])*.
Planning for optimum land use, and for increased food production requires answers to many questions, such as:

- is there sufficient land to meet future needs
- where are the arable areas and what are their extent
- for which types of land use are they suitable and what is the range of their potential
- which level of technology is required
- what is the risk of land degradation and what control measures are required
- what level of investment is needed

- where and for which crops can maximum returns from increased inputs be obtained
- what are the limitations to production increases
- where should research efforts be concentrated.

In order to obtain answers to such questions, FAO is conducting a study of the rainfed production potential in developing countries by agro-ecological zones *(FAO [1978–1981])*. The determination of this potential is made by matching soil and climatic inventories with the soil and climatic requirements of 11 major crops at 2 levels of inputs *(Higgins* and *Kassam [1981])*.
The climatic inventory used in the study takes into account both temperature (major climates) and moisture conditions (lengths of growing periods). The soil resources data for the study is obtained from the 1 : 5 000 000 FAO/Unesco Soil Map of the World *(FAO [1971–1981])*. Overlay of the climatic data on the soil map allows creation of unique land units within which soil and climatic conditions are known and quantified.
The low level of inputs is characterized by subsistence production, low capital intensity, manual labour, local cultivars, little or no fertilization or pest control, small holdings. The high level of inputs assumes commercial production, moderate to high capital inputs, mechanized labour, improved cultivars, optimum fertilization and pest control, medium to large holdings and accessibility to markets.
The suitability assessment for each crop is defined in terms of a percentage range of the maximum attainable yield without constraints. Land areas capable of yielding 80% or more of the maximum yield attainable are classified as very suitable (VS); areas yielding less than 80 to 40% are suitable (S); areas yielding less than 40 to 20% are marginally suitable (MS) and areas yielding less than 20% are classified as not suitable (N).
Table 4 reflects the distribution of the world's lands and their population. The world's potentially cultivable land (VS, S and MS) is estimated at 3 031 million hectares, or

Table 4. Land use and population (areas in million ha)

	Developing countries	Developed countries	Total world
Land area	7619	5773	13 392
% of world's total	(57)	(43)	
Population (1979, millions)	3117	1218	4 335
% of world's total	(72)	(28)	
Potentially cultivable	2154	877	3 031
% of land area	(28)	(15)	(22)
% of world's potential	(71)	(29)	(100)
Presently cultivated	784	677	1 461
% of potential	(36)	(77)	(48)
% of world's total	(54)	(46)	(100)
Persons per ha presently cultivated	4.0	1.8	3.0

Source: *Dudal, Higgins* and *Kassam [1982]*

Table 5. Land use and population in developing countries (areas in million ha)

	Africa	S.W. Asia	S.E. Asia	Central Asia	South America	Central America
Land area	2886	677	897	1116	1770	272
% of world's total	(21)	(5)	(6)	(8)	(13)	(2)
Population (1979, millions)	427	153	1232	947	239	119
% of world's total	(10)	(3)	(28)	(22)	(6)	(3)
Potentially cultivable	789	48	297	127	819	75
% of land area	(27)	(7)	(33)	(11)	(46)	(27)
% of world's total	(26)	(2)	(10)	(4)	(27)	(3)
Presently cultivated	168	69	274	113	124	36
% of potential	(21)	(144)	(92)	(89)	(15)	(49)
% irrigated	(4)	(16)	(24)	(44)	(6)	(18)
Persons per ha presently cultivated	2.5	2.2	4.5	8.4	1.9	3.3

Source: *Dudal, Higgins* and *Kassam [1982]*

22% of the total land area, of which nearly half is presently in use. The distribution of the world's potentially cultivable lands between developing and developed countries is 71 and 29% respectively, practically in the same proportion as their share of the world's population. However, the actual agricultural land is very unevenly distributed. The developed countries have 46% of the total land which is presently cultivated, that is far more than their 28% share of the world population. Thus population pressure on the land is more than twice as great in the developing countries. Differences between regions are shown in Table 5.

Most of the land reserves are located in the developing countries, especially in Africa and South America, where only 21 and 15% respectively of the potential agricultural land is presently used. In South East Asia on the contrary, 92% of the potential is already utilized. In South West Asia, more land is being used than the extent which is considered to be suitable for rainfed cultivation. The number of persons per hectare of cultivated land is highest in Central and South East Asia, regions which also have the highest share of irrigated agriculture.

Land suitable for adding to cultivated area inevitably becomes more scarce. For the 90 countries as a whole, 40% of the total arable land potentially available was already under the plough by the mid-1970's. Almost half of the 90-country population was in 17 countries which were already using more than 90% of their potential arable area. Expanding production inputs, by 5.8% annually in Scenario A and by 4.7% in Scenario B, should raise yields and cropping intensity, especially in countries with more limited land availabilities.

For the countries with high land-scarcity and the land-abundant countries, year 2000 yields in Scenario A are 85 and 31% respectively, above those of 1975. Cropping intensity, already high in the land-scarce countries, is raised by an average of 14% in Scenario B.

Population supporting capacity

If developing countries are to reach a greater degree of self-sufficiency in their food production, it will be necessary to match available land resources with the needs of present and future populations. Only when land potential is quantified, in terms of population supporting capacity, can the attainable degree of self-sufficiency be realistically assessed. The previously described land inventory has been used by an FAO/UNFPA study, for calculating calorie-protein production potentials, and hence potential population supporting capacities, under various input, crop-mix and conservation assumptions *(FAO [1980])*. Deductions were made for land required for non-agricultural use, for irrigation and for rest period (fallow) requirements. Limitations imposed by degradation hazards and presently grown mixtures of crops according to levels of inputs, are also taken into account.

The study estimates that the lands of the developing world could produce sufficient food, at a low level of inputs, to provide for more than double the 1975 population. With intermediate level of inputs, production could be increased to feed four times that population. Comparison of these estimates with projection of populations envisaged by the year 2000, reveal that population supporting capacities of the lands of the developing world are also in excess of future population densities. However, these potential population supporting capacity estimates assume the use of all cultivable land, incentives to produce and unrestricted movement of food and labour within regions and countries. Since these requirements can hardly be expected to be met, it is necessary to analyse the potential for food self-sufficiency by geographic regions, economic communities, individual countries, in accordance with the various physical environments that make up these territories.

Estimates at the country level make it possible to identify national and sub-national situations where the land resources are insufficient to meet the food needs of the people living or projected to be living from them. For Africa, for instance, though the overall future situation for the continent as a whole could be satisfactory, the variation in land resources endowment between countries results in very wide differences. Table 6 shows the number of 'critical countries' where potential population supporting capacity is less than year 1975 and year 2000 populations, at each of 3 levels of inputs.

Table 6. Critical countries in Africa

Levels of inputs	Number of countries	
	1975	*2000*
High	2	3
Intermediate	9	12
Low	22	28

Source: *Higgins et al. [1981]*

These assessments include the production from land presently irrigated, and planned to be irrigated by the year 2000. The contribution of irrigation to population supporting capacity varies greatly between regions. In South East Asia, for instance, the contribution of irrigation development planned by the year 2000 is estimated at 79% of the total production potential at low levels of inputs. For Africa planned irrigation development is far below existing potentials.

Land degradation

Limits to agricultural production are set by soil and climatic conditions and by the use and management of the land. In the long term any 'mining' of the land beyond these limits results in decreased productivity. Hence, land resources and their production potentials are not static. The productive capacity of land can be impaired and even entirely lost through various forms of degradation. For a number of developing and developed countries alike, land degradation has emerged as one of the major constraints to the further expansion of agriculture, both across the land surface as well as in terms of higher yields per unit area. Projections of production potentials and land reserves would be very deceiving if the effects of degradation were ignored. Therefore soil conservation practices have been included in the intermediate and high levels of inputs assumptions. Though attention is focussed here on potentials for food production, requirements for other types of land use, such as forestry and grazing, have been taken into account and due regard has been paid to the conservation of the land.

While the forms of land degradation are well known, especially erosion and salinization, there are only very general estimates of the areas which are affected, of the rate of degradation and of the losses of productivity which occur. In order to improve knowledge of land degradation *FAO*, *UNEP* and *UNESCO* initiated a global assessment of soil degradation. In a first phase the study covered Africa north of the equator and the Near East *(FAO [1979])*. The main objective of the project was to develop a methodology which can be applied both at the regional and country level to assess the vulnerability of the land to degradation on account of its physical constituents and of human interference. With the low level of inputs, where soil conservation measures are assumed absent, it is estimated that by the end of the century, developing countries may loose up to 20% of the productive capacity of their land resources.

Soil conservation is usually denied priority because immediate economic returns are often not apparent. It is imperative, however, that conservation be incorporated in all land development in order to avoid the risk that more land be lost than can be gained by the expansion of agricultural areas. The loss of land and of productivity increases a country's food dependency and threatens its autonomy.

Conscious of this situation, the 21st Session of the *FAO Conference*, in November 1981, adopted the *World Soil Charter*. The Charter establishes a set of principles for the optimum use of the world's land resources, for the improvement of their productivity, and for their conservation for future generations *(FAO [1981b])*.

The *World Soil Charter* calls for a commitment on the part of governments, international organizations, and land users in general, to manage the land for long-term advantage rather than for short-term expediency. Special attention is called to the need for land use policies which create the incentives for people to participate in soil conservation work, taking into account both the technical and socio-economic elements of effective land use.

Energy for agriculture

Agricultural production is only a modest consumer of energy, in comparison with transport or industry. It accounts for only 4.5% of total commercial energy use in the developing countries and 3.5% in the developed countries, excluding food processing, storage and transport. The use of commercial energy in the developing countries (excluding China) in agricultural production is only about one quarter of the amount used in farming in the developed countries.

The comparitively limited use of commercial energy in developing country agriculture holds down the productivity of land and of labour. If farm yields and earnings are to rise, there must be a steep increase in the use of commercial energy. Scenario A estimates total commercial energy consumption in agriculture in the 90 countries to rise from 36 million tons of oil equivalent in 1980 to five times as much, or 178 million tons, in 2000. Even the much less ambitious increase in production in Scenario B requires an annual growth of 6.9% in the oil equivalent of commercial energy although this is well below the 8.3% of Scenario A.

Fertilizer accounts for practically 60% of the total increase in energy in both scenarios, mostly in the Far East, where land scarcity enforces dependence on raising yields (Table 7). The next largest increase comes in machinery, particularly in the more land-abundant areas of Latin America.

Table 7. Commercial energy use in agriculture (90 developing countries)

	A					B
	Total million tons (oil equivalent)	Fertilizer	Machinery	Irrigation	Pesticides	Total million tons (oil equivalent)
			(percent)			
90 countries						
1980	36	54	31	12	3	36
2000	178	56	38	4	2	138
Low-income						
1980	14	59	16	22	3	14
2000	91	69	24	6	1	69
Middle-income						
1980	22	51	40	6	3	22
2000	86	44	52	2	2	68

Source: *FAO [1981]*

The intensification of developing-country agriculture through an increased input of commercial energy may seem a paradox in an age of energy shortages and high prices. It is, however, essential if agricultural production is to increase adequately, and in view of agriculture's very modest share in total energy consumption, it is also a very reasonable increase. If it should come to a choice of priorities in allocating scarce energy supplies, agriculture must be assured of its supplies at equitable prices. Its assured availability and the maintenance of satisfactory price relationships between energy costs and the price of farm products should be key objectives in agricultural policies. At the same time, it must be stressed that commercial energy in agriculture should be used with maximum efficiency and that full use should be made of new and renewable sources of energy such as sun, wind, biogas, organic recycling, animal power and various means of biological fixation of nitrogen. In addition, it should be realized that in 1980, 2 billion people, *i.e.* three-quarters of the population in developing countries depended on fuelwood and other local fuels for their daily domestic energy. A FAO survey *(FAO [1981c])* shows that fuelwood deficits are very widespread, especially in Africa and Asia, and presently affect over 1 billion people. Critical areas where minimum needs are met at the cost of further depleting existing resources, urgently require remedial action. Hence land requirements for renewable sources of energy need to be taken into account when planning horizontal expansion of agricultural production.

Development and access

Growth in production as envisaged in the progressive scenarios will, in addition to technical inputs, require a transformation in institutions and social relations. It will mean an effort to create an effective framework of policies and services encouraging and ensuring growth in production with equity in the distribution of income, wealth and services.

Annual investment in primary agriculture as a proportion of the agricultural GDP in developing countries must rise as production processes come to make use of more productive technologies, so that by the year 2000 the share rises to 21% in Scenario A but only to 17% in Scenario B. To bring about such increases in agricultural investment, especially in the poorer countries, will not be easy. Quite apart from the acute shortage of capital, it will be necessary to overcome a prevalent conviction that agriculture is not very capital-demanding.

An essential problem which must be tackled along with production, is one of distribution, or redistribution, of existing productive assets and of those that can be brought into existence. Hungry populations, urban and rural alike, must have access to food or to the means of growing it; to gain access to food, they must have access to the income necessary to buy it; to earn money, they must have access to work, and to the education and training that they need if they are to find employment.

At the same time, if small farmers and landless labourers are to contribute substantially to increased agricultural production to meet their own needs and those of coming generations, they must have greater access to suitable land and water with which to grow their crops, to all the other inputs without which the crops will not grow or yield sufficiently, to the services without which they cannot obtain these inputs and to a distribution system that will give them a fair return on their own labour and at the same time ensure that the food reaches those who need it most.

Technological changes never take place in a social vacuum: if they are to be adopted on a wide enough scale, social and institutional structures will have to be built up at the same time to make that adoption possible. Institutions have a key role to play in every sector of agriculture: to organize land improvement, deliver inputs, teach new methods, provide credit and marketing facilities, and back all these activities up with research and training; and all the institutional aspects of food and agricultural development are closely linked to the distribution problem.

Combined with even a moderate rate of economic growth, redistribution can have more impact on poverty, especially in the short to medium term, than rapid economic growth without it.

An overview

The world, as a whole, has enough land to produce food for present and future populations. However, with the uneven distribution of land resources, populations and agricultural inputs, food production falls short of requirements in a great number of countries. In order to avoid dependency on external supplies, these countries will need to increase their domestic food production.

When planning for a higher degree of self-sufficiency, it is essential that differences in land resource endowment and in crop production potentials, be fully appreciated. In some countries, land reserves are such that cultivation can be expanded to meet national requirements, and even beyond. In other areas the limits of cultivable land have already been, or are about to be, reached and most of the increased production will have to come from the intensification of agriculture on land already cultivated. Certain countries with unfavourable soil and climatic conditions, may not have means to meet the food requirements of their populations, even if the level of inputs were to be optimized. Furthermore, other needs also have to be met such as fibre for clothing, raw materials for housing and industry, lumber and fuelwood, environmental conservation, and possibly export crops. Therefore a balance should be established within each country, matching needs with the suitability of the land base for various types of use.

The precarious food situation in a number of developing countries indicates that the mere availability of land is not sufficient to fill the gap between demand and supplies. Incentives need to be created for the farmers to remain on the land and to make it produce. Priority has to be given to rural development in terms of investment, pricing policies, energy allocation, access to inputs, technology transfer, transport and credit, training and research. This intensification of agriculture is crucial in many developing countries where land resources are insufficient, at a low level of inputs, to meet the food needs of their present or future population.

The solution to the world food problem is, in the first instance self-reliance of every nation in accordance with its production potential. With the identification of critical areas in various parts of the world, it clearly appears that food security will also have to rely on international cooperation and on a complementarity of production between areas of different suitability. In 1980 the community of nations adopted this 'one world' concept in the form of an international development strategy reflecting their recognition of essential and comprehensive interdependence among nations.

References

Dudal, R., Higgins, G.M. and *Kassam, A.H.:* Land Resources for the World's Food Production. Proceedings 12th International Congress of Soil Science, New Delhi (1982)

Food and Agriculture Organization of the United Nations: FAO/Unesco Soil Map of the World, 1 :5 000 000, Vol. 1–10, Unesco, Paris, 1971–1981

Food and Agriculture Organization of the United Nations: A Framework for Land Evaluation. Soils Bulletin, 32, FAO, Rome (1976)

Food and Agriculture Organization of the United Nations: Reports of the Agro-ecological Zones Project. Vol. *48*/1, Africa; Vol. *48*/2, South West Asia; Vol. *48*/3, South and Central America; Vol. *48*/4, South East Asia. FAO, Rome (1978–1981)

Food and Agriculture Organization of the United Nations: FAO/UNEP/Unesco Provisional Methodology for Soil Degradation Assessment. FAO, Rome, 1979

Food and Agriculture Organization of the United Nations: Report of the Second FAO/UNFPA Expert Consultation on Land Resources for Populations of the Future, FAO, Rome, 1980

Food and Agriculture Organization of the United Nations: Agriculture: Toward 2000, FAO, Rome, 1981

Food and Agriculture Organization of the United Nations: World Soil Charter. Report 21st Session of the FAO Conference, FAO, Rome, 1981b

Food and Agriculture Organization of the United Nations: Map of the Fuelwood situation in the Developing Countries, scale 1 :25 000 000, FAO, Rome, 1981c

Higgins, G.M., Kassam, A.H., Naiken, L. and *Shah, M.M.:* Africa's Agricultural Potential. Pages 13–21. *In:* Ceres *14*/5, No. 83, FAO, Rome (1981)

Higgins, G.M. and *Kassam, A.H.:* Regional Assessments of Land Potential: A Follow-up to the FAO/Unesco Soil Map of the World. Pages 11–23. *In:* Nature and Resources *XVII*, No. 4, Unesco, Paris (1981)

Salas, R.M.: The State of the World Population 1980. United Nations Fund for Population Activities, New York, 1981

Report of the Panel Discussion: Increasing Population – Can Agriculture Meet the Challenge?

G. W. Cooke, Rothamstead Experimental Station, Harpenden, Herts./United Kingdom; Member of the Scientific Board of the International Potash Institute.*

The President of IPI, Dr. N. **Celio,** welcomed those attending this final Session; they included agriculturists of this region of Germany and industrialists who support the work of the Institute. The Session was planned to put the theme of the Congress – 'Optimizing Yields – the Role of Fertilizers', into the context of the world's food problem.

Three-quarters of the world's population live in developing countries and these populations are increasing rapidly. A large proportion of people in developing countries are engaged in agriculture, but the yields they harvest are small and fertilizers are a great help in increasing them.

Difficulties are caused by the serious increase in the costs of energy which have taken place during the last ten years. These problems of energy costs and of low yields, have a great influence on the direction of the scientific work needed to increase food production in developing countries.

The **President** then introduced the members of the Panel some of whom would present the topics for discussion; they were:

Prof. Dr. *I.Arnon*, Settlement Study Centre, Ramat Gan/Israel; member of the Scientific Board of the International Potash Institute

Dr. *G.W. Cooke*, Honorary Scientist, Rothamsted Experimental Station, Harpenden, Herts./United Kingdom; member of the Scientific Board of the International Potash Institute

Dr. *R. Dudal*, Director, Land and Water Development Division, FAO, Rome/Italy

Dr. *L. Gachon*, Head of the Département d'Agronomie, I.N.R.A., Clermont-Ferrand, France; member of the Scientific Board of the International Potash Institute. (Dr. *Gachon* took the place of Dr. *G. Février*, Commission of the European Communities, Brussels/Belgium, who could not attend the Congress.)

Dr. *J.S.Kanwar*, Director of Research, Int. Crops Research Institute for the Semi-Arid Tropics, ICRISAT, Andhra Pradesh/India

Dr. *B.N. Okigbo*, Deputy Director, International Institute of Tropical Agriculture, IITA, Ibadan/Nigeria

Prof. Dr. h.c. *E. Pestel*, Member of the Board of the 'Club of Rome', Hannover/Fed. Rep. of Germany

Dr. **Dudal** initiated the Session by presenting his paper *Land Resources and Production Potential for a Growing World Population*, (pages 277–288.)

* Dr. *G. W. Cooke*, Honorary Scientist, Rothmsted Erperimental Station, Harpenden, Herts. AL5 2JQ/United Kingdom

Professor **Pestel** opened the discussion, saying that he shared Dr. *Dudal's* view of the likely increase in world population during the next 20–50 years; he said that 650 million people would still be seriously under-nourished in the year 2000. He agreed with the estimates of the land available; the area under arable crops should be expanded where possible and Professor Pestel stressed the need to maintain the fertility of this land and protect it from erosion. The extra food needed should be produced **where** it was needed.

To achieve extra production the developing countries needed massive inputs into their agricultural systems; soil conservation practices, energy, fertilizers and pesticides were all required, as well as the capital to establish irrigation and to purchase machinery, and improved seeds and livestock. Without these inputs, nutritional standards in the poorest countries would diminish further. There were serious monetary problems. On the national scale farmers needed incentives to produce more. The cost of imports was a serious obstacle to developing countries which tried to increase production. Much progress will be made by attacking immediate problems; for example stable systems to replace shifting cultivation must be developed. But there was a tendency for longer-term problems such as soil conservation to be neglected. In the longer term continued growth will require, besides technical inputs, institutional changes in the developing countries and changes in relations between sectors of the community. Professor **Pestel** then commented on the scenarios for development during the next 20 years envisaged in FAO's *Agriculture: Towards 2000;* he considered that these were unrealistic. While he thought that the goals for extra production could be reached, this would not be possible in the remaining 18 years of this century. He considered that the problems of food production would not be overcome in the next 20 years because the population in the poorest developing countries is now doubling every 20 to 30 years. By 2000 AD the developing countries will have 1½ billion more people than they now have. The age structure of the population also creates problems. In the developing countries 55 percent of the people are less than 18 years old; if to these are added the old, and those who are ill, then two-thirds of the population is not available for regular employment. A critical factor which affects the possiblities for development is the number of employed people per thousand of the population; in this respect Africa has serious problems because, although the continent has plenty of land to develop, the the proportion of the population employed is the least. Difficulties are just as serious when too many of the people are too young for work as when too many are too old. Development is then very difficult to initiate with a high level of population growth. Some countries have an effective birth control policy. China, for example, has brought the rate down from 40–45/1000 to 18/1000 and this will enable the country to overcome food deficits. But in India the birth-rate is still 30–35/1000; it is even higher in countries of Asia, Africa and Latin America, these high rates will inhibit development. A rapid growth in population inevitably leads to unemployment and consequently to hunger. About 300 million, mostly young people, are unemployed at present in the developing countries and the numbers are rising. To alleviate these problems ½ billion new jobs will have to be created in the developing countries in less than 20 years. If the investment needed is as little as $5000 per job the total capital cost of creating these jobs will be about $3000 billion during the next 20 years and much of this investment will have to be imported – this seems an almost impossible task.

It is imperative to move development policies away from urban industry and to create new jobs in the agricultural areas where greater productivity can result from smaller investment than in the cities. Decentralization and investment that improve services to the villages, such as supplies of electricity, improved education, hospital services, and entertainment facilities, were desirable to check the drift to the cities. In addition plans must be made to establish and/or extend research and development services for the food and agriculture industries. All this development would be costly. However, would governments in the developing countries have the courage to increase benefits to the rural areas at the expense of the urban population, which has more political power, and a greater capacity for creating disturbances?

Professor **Pestel** concluded by making two suggestions: His first suggestion was that small neighbouring nations should join together, giving up much of their individual sovereignty to create larger communities of which there would be 10 to 15 in the whole world. In each community there would be free exchange of goods, other resources, and labour. This would lead to regional plans for population control, for the production and distribution of food, and for the reduction of military expenditure. The *Club of Rome* had proposed this to the United Nations in New York two years ago, but the suggestion had not been popular with the UN bureaucracy.

The second suggestion was to send increasing numbers of young people from the developed countries to the developing countries to aid development. President*Kennedy* had initiated this scheme and other countries had followed the example, for instance there was an organization in Germany. The scheme should be expanded to secure more local participation; a particular county in a developed country should agree to aid a nominated county in a developing country. Volunteers should be properly trained and should remain in the host country for long enough to be effective – at least a year or two. They would bring back to their own country a reliable account of conditions in the developing country and would be able to indicate what kind of aid was needed. In this way the population of the country which sent the volunteers would become more aware of needs in the developing country and would become more sympathetic to providing aid, even at the cost of personal sacrifices.

Dr. **Kanwar** continued the discussion; he agreed with the assessment of the world food situation as presented in FAO's *Agriculture: Towards 2000*. He emphasized points that must be considered in planning for development:

1. Countries should optimize the kinds of production for which they were most suited by using technology appropriate to their conditions which did not damage the environment.

2. Farmers must be given the incentives to produce more.

3. Research and development organizations were often the key to higher production, where none existed they must be set up, most existing organizations needed to be strengthened.

4. Food programmes must have priority and all must strive to optimize production. A world policy for food storage and distribution was needed which did not make food a political weapon and which provided a defence against famine.

The fact that food should be produced where it was needed could create difficulties where resources were limited. Whereas the developed countries have 45% of the world's best cultivated land, but only 28% of the world's population, the developing countries have 72% of the world's population but only 55% of the world's cultivated land, and some of this land is of poor quality. There was little scope for bringing new land into cultivation in Asia. There was much more scope for cultivating new areas in Africa and South America. But in some areas with suitable land there were not enough people to cultivate it. During the last 30 years 73% of the increase in production in developing countries, and 92% of the increase in developed countries, had come from increased yields. These increases had come from government policies to increase the use of improved varieties, fertilizers, pesticides and irrigation, and to encourage better agronomic practices. While the use of high-yielding varieties (HYV) had been a vital factor, it must be emphasized that the increased yields resulted from the interaction of these varieties with other inputs, all backed up by problem-oriented research and development work and by better farming practices. In this connection the International Centers for Agricultural Research (such as *IRRI*, *CIMMYT* and *ICRISAT*) have had a vital role in furthering the 'Green Revolution'; their work will become even more important.

Dr. **Kanwar** then outlined the progress in increased food production that had been achieved in India. In the period from 1950 to 1980 the production of food grains had been increased from 60 million tonnes to 135 million tonnes. Production in the Punjab had increased remarkably and 8 times as much wheat, and 30 times as much rice, was now produced as was grown 15 years ago. Average yields had risen from less than 1 t/ha to 3 t/ha. A fifth of the farmers now harvested over 5 t/ha of rice and wheat and many farmers were getting over 10 t/ha annually by growing two crops (rice followed by wheat) in a year. The Punjab alone has the capacity to increase the production of cereal grains from the present 12 million tonnes up to 30 million tonnes.

In this period from 1950 to 1980 the consumption of fertilizers had increased in India from 0.06 to 5.6 million tonnes of nutrients. An interesting contrast was between the Punjab and the Federal Republic of Germany; both had increased their wheat yield by 2.2 t/ha in the last 30 years (of course, they started from different bases). In the Punjab less than 1 kg/ha of nutrients was used in 1950/51, whereas Germany used 102 kg/ha; the increased yields had resulted from using 106 kg/ha more nutrients in the Punjab, and 172 kg/ha more nutrients in Germany. Other Indian States had achievements similar to those of the Punjab; but some States lagged far behind, though they were changing now.

The great achievements in India had resulted from political determination to give high priority to agriculture. Dr. *Kanwar* also stressed that the research and development done in India under the *Indian Council of Agricultural Research* had been a very important factor in the success of their 'Green Revolution'. This had been made possible by setting up 22 agricultural universities which had trained the scientists who now contribute so much to Indian agriculture. About 2000 agricultural scientists are now trained each year to MSc or PhD level. About 30 agricultural research institutes have been established and India now has probably the third largest manpower devoted to agricultural research and education in the world.

Other important factors have been support prices for wheat, rice and other products, the high priorities given to irrigation, fertilizers and high-yielding varieties, and the emphasis on the transfer of technology, and particularly that involving cooperation with the International Agricultural Centers. These measures have been successful, even in spite of the variable monsoons that Indian agriculture experiences. 1979 brought the worst drought on record and in that year, if the programme had not been successful, 20 million tonnes of grain would have had to be imported. It is true that there are shortages of oil-seeds and pulses, but work is being done to try to correct this situation.

While efforts are being made to control the expansion of the population of India, plans are being made to increase agricultural production further, mainly by increasing yields as there is little scope for increasing the area under crops. The immediate measures proposed are to increase the use of high-yielding varieties, to double the use of fertilizer in the next 5 years, to increase double cropping, and to increase the land that is irrigated by 3 million hectares annually; by the end of the century the irrigated area will have been increased from the present 40 million hectares to 77.5 million hectares. Research will have to be further intensified; it is not sufficient to *create* greater potentials, *these potentials must be realized in practice*. The keys to securing the increases planned will be to increase the efficiency of water and fertilizers and to establish prices which provide satisfactory incentives to farmers. Increasing energy costs will constitute a serious obstacle, particularly to the increased use of nitrogen fertilizers; research to improve the efficiency of nitrogen must have the highest priority. Other problems of intensification are emerging; for example micronutrient deficiencies are increasing.

Dr. **Kanwar** considered that India can meet its needs for food to the end of this century and the huge potential for irrigation could make the country an exporter of grain. But India needed the support and goodwill of the international community to help with investment in agriculture and in trade of both industrial and agricultural products. In general terms the problems now facing the country will be solved by the correct use of both improved technology and of capital.

Dr. **Okigbo** discussed the problems of food production in African countries, particularly those south of the Sahara. The annual rate of population increase was 3 percent and increase in food production did not keep pace so most African countries were net importers of food, furthermore the amount of food available per head of the population was tending to decrease. Nigeria, for example, must plan to increase production of food crops by 6% annually, livestock production by 11%, and cash crops such as cocoa by 7%, in order to become self-sufficient in food and in balance in foreign trade. With the resources now available this was an almost impossible task.

There was an urgent need to replace shifting cultivation by stable agricultural systems. This was a long-standing and difficult problem which had not been solved in colonial times and even now, when the tropical countries concerned were independent, it was as intractable as ever. Shifting cultivation relies on recycling nutrients and this process is no longer adequate for the production levels required. Problems in the development of new systems are accentuated by the wide range of crops grown on small areas for this makes mechanization difficult. Pressure on land had led to shortened rotations which had caused increased soil erosion, particularly from ridged land. The techniques used for cultivation needed further investigation so that they could be fitted to soil, climate and farming system and to ensure that they conserved both soil and water.

Serious problems were caused by shortage of labour in most African agriculture; for example the weeding of some crops accounted for 70% of the effort needed to produce the crop. It was necessary to lessen the drudgery in African farming and the development of new technologies had to take account of the abilities both of the present generation of farmers, and of the younger people who would be the farmers of the future. Government schemes for tractor-hiring had not been very successful and further efforts were needed to make suitable machines available. This raised the question, which had not been solved, – of the extent to which agricultural development should be sponsored through government projects, and how much by the participation of the private sector.
The importance of crop breeding in agricultural development must be stressed as it could be of great help to farmers working on a small scale who could not afford costly inputs. Breeding for disease and pest resistance was very important and it could help in lessening post-harvest losses, particularly of the root and tuber crops that were so important in the humid tropics. For example potato varieties that were resistant to weevil attack did not deteriorate in store; yams were selected for the sizes and shapes of tubers that were least liable to damage by bruising during mechanical harvesting and therefore suffered least losses during storage in the post-harvest period.
Dr. **Okigbo** discussed the *post-harvest losses of food* in some detail, for these were a serious matter; if such losses could be prevented the food deficits of the developing countries would be eliminated. Losses were very variable; they could be very serious with cereals, and could range up to 50% for the edible roots, fruit and vegetables. The *National Academy of Sciences* (USA) had reviewed the question of food losses, particularly in Africa. In 1976 it was estimated that the total post-harvest losses in the world amounted to 10% of the food grains (legumes and cereals), and to 25% of the perishable crops. The food grain loss totalled 45 million tonnes, worth $7½ billion. The overall amount of food lost in 1976 was estimated as 107 million tonnes, equivalent to the food needed by 168 million people. It was calculated that if losses on a world-scale could be halved, there would be enough extra food to supply the present deficits in developing countries. The forecasts that have been made indicate that by 1985 the post-harvest losses in developing countries alone would be worth $11 billion.
Food losses started in the field with physical loss, and then occurred at all stages in threshing or other handling, and in transport, storage and distribution. They included losses in viability of seeds due to weather and then infestation by insects, rodents and other pests, and by microorganisms. Therefore many kinds of expertise were necessary to prevent losses and international cooperation to this end was essential. Programmes to prevent post-harvest losses should be regarded as essential components both of the general economy and of agricultural development. Planning and policy decisions would have to be made to establish research programmes, and the necessary advisory work and training, and to take account of local socio-economic conditions. The magnitude of losses at various stages in food chains must be assessed carefully so that priorities and strategies in research programmes can be formulated. This information must also be used to convince the policy-makers that it is essential to support these activities by providing adequate resources. Finally, information should be made available in forms that small-scale farmers can use readily.
Transfers of food from areas in a country, or in a region, with surpluses to areas where there were deficits was essential; suitable monetary arrangements and subsidies would

be needed. International arrangements were required to provide food as aid where natural catastrophies (such as severe drought) greatly diminished local production. Not *all* countries need be self-sufficient in food production; but if they are not self-sufficient they must grow crops for export markets, and/or have other industries to provide exports; food can then be bought with the foreign exchange earned. However, all developing countries should acquire the modern technologies needed for food production as a part of their agricultural and general economic development. Attention must be given to the training of adequate reserves of man-power, and to the development of good infra-structures, not only in urban areas, but particularly in rural areas.

The role of the developed countries in overcoming shortages of food is very important. They can help to develop appropriate infra-structures, but, even more important is the work that they can do in giving suitable training and in initiating research of the kinds that are needed. The help given by young volunteers, mentioned by Professor *Pestel*, is much appreciated and it was a very good idea; but it must be pointed out that the great need is for people with more experience than most of these workers have if they have only recently graduated. Furthermore the mature people who are required must be prepared to work with the farmers, as the local scientists do, so that they can really understand and assess the farmers' problems. Research strategies should be directed to solving the problems raised in applying the methods needed to increase production. Universities in developed countries could help greatly by planning both training programmes and research projects to suit the needs of developing countries.

Intensification of farming in Africa is causing problems of soil degradation and erosion, and consequent environmental pollution. More work is needed on the maintenance of soil organic matter – which is vital in the tropics. Most important is the help needed to ensure that supplies of fertilizers are available, and to improve their efficiency and so minimize pollution. Fertilizers will have to be used to an increasing extent to stabilize production systems in the developing countries. Extra nitrogen is needed everywhere, but it is very expensive and, with the methods now used to apply it, it is often not very efficient. The maximum use must be made of systems for the biological fixation of nitrogen.

All of these problems now being experienced in Africa, which were discussed by Dr. **Okigbo**, require more cooperation and collaboration between developing and developed countries. It must be realized that effective relationships between the two groups of countries will depend on a full understanding in the developed countries of the nature of local conditions in agriculture and of social attitudes and problems in the developing countries which are being assisted. It is difficult to accept the advice from people in Europe that African countries should give up their territorial integrity, and possibly their independence, to form larger groupings of peoples. (Some European countries are much smaller than countries in Africa.) Human nature is much the same the world over; countries act to serve their national interests, and people to serve self-interest, caring little about inequalities that may exist in their own country, or in other countries. People in developed countries should not have one set of standards for use in their own countries, and then use quite different standards in behaviour, or in trading, when they go to a developing country. These problems must be overcome by education of the right type to develop a balanced outlook on world problems; but this will take time.

Finally, no real progress will be made in solving food deficits and related problems unless we have the political commitment that secures policies and decisions that ensure stable and adequate allocations of the resources needed for the general development of agriculture, and of the rural areas, which will result in increased food production. Policy-makers in developing countries must accept these commitments and coordinate work within their government departments to ensure that research, extension, education and training meet the needs of the plan for development.

The Transfer of Food

The President, Dr. **Celio**, thanked the four speakers for their contributions which had laid the framework for the general discussion which would follow. He said that the first need was to discuss how to alleviate the present hunger of so many of the world's population. The situation was that there was over-production of some commodities in some areas, for example within the *European Economic Community*, while in other parts of the world many people were suffering from hunger and some were dying from prolonged malnutrition. Was the solution to transfer food from areas with surpluses to areas that were in need?

In a perfect world, where all resources were equally shared, it would not be necessary to discuss this question. But the world is not perfect and such distribution can never provide adequately for all people. In the first place surpluses of food will not be produced in developed countries for export unless the prices offered provide sufficient incentives. In the second place the developing countries lack the financial means to contemplate having imports of food as a permanent solution. When natural disasters, such as drought or serious attacks on crops by pests or diseases occur, then food aid *is* justified to save human health and life. But, under ordinary circumstances, continued large gifts of food had a bad effect because they encouraged governments to ignore the need to develop production in their own country.

The only sound long-term solution was to produce the extra food needed in the region where it was required. This would involve most farmers in the developing countries in the transformation of their traditional systems to more intensive agriculture. In making these changes aid from the developed countries was essential, but this would not be effective unless it was fully supported by the attitudes of the authorities in the developing countries concerned, who must give leadership to the rural population in their development.

With these generally accepted conclusions as a basis the *President* invited discussion on the technologies needed to achieve this aim of producing the food where it is needed, and on the social, political and institutional problems that would be involved. The report which follows reflects statements by individual members of the Panel, and by other participants in this Session of the congress. There was insufficient time for the full discussion of all topics which would have been necessary to secure the unanimous agreement of all who were present with the conclusions. Nevertheless these conclusions appeared to represent the views of the majority of those who took part in the discussion.

Increasing the Production of Food in the Developing Countries

Targets for Production

There was a need to consider the production and consumption of food on a world scale. This must lead to 1) assessments of present and future needs for food, and 2) production targets. The targets for production must be agreed nationally and internationally, so that production can be regulated to avoid deficits in a region as a whole. These objectives would be assisted by nations agreeing to collaborate in planning for the benefit of the whole community of a region. While nations would negotiate from a position of strength, more liberal and forward-thinking attitudes should be developed to encourage feelings of wider responsibility on the part of governments. Subsidies cannot be justified on a long-term basis. The agreed targets would have to take account of the types of food which a particular country could produce most efficiently and economically. There was also a need to make plans for exports of food from one region to another; usually this will be justified where, for climatic reasons, a particular food or industrial crop cannot be grown. International agreement on trade tariffs will be needed. Where crops are particularly suited to a region, for example oil palm in the humid tropics, their production should be encouraged provided that markets are adequate; the amounts produced should fit both regional and world-wide targets.

National Attitudes

Solving the world's food problems will require changes in some national attitudes. In the first place officials of all countries must give good leadership to encourage the determination of all people that food deficits would no longer be allowed to imperil the welfare of large sections of the population of some regions. Examples of the need for regional rather than national considerations will occur when large-scale schemes for development, such as irrigation, should logically cross national boundaries.

Policies for future population need discussion and agreement. Unlimited population growth would be disastrous in the long-term as it would destroy the quality of life. Stabilization of the world's population must be discussed internationally. Population forecasts by the *United Nations* took family planning into account. While family planning was a very important subject, it was often difficult for politicians to discuss it objectively because people may not welcome statements on limitation of population. Nevertheless some countries (India and China, for example) were making real efforts to control population.

The rural population is, of course, responsible for all food production – a point that is often ignored by the urban population of developed countries. There is a world-wide need to improve the status of the basic producers of food, to recognize their vital role, and to give them not only the conditions under which they can secure a satisfactory living, but also have the facilities and services (electricity and water supplies for example) that have already improved the quality of life for urban people. National leaders must be prepared to develop policies that benefit the rural population, because their role in food production is so important. If a consensus of opinion can be developed on the role of food producers in the national life, many problems of rural neglect will vanish.

Enterprise systems for food production must be appropriate to both the needs and philosophies of people and the facilities that they have. Further consideration must be given to the roles of both private enterprise, and the publically-funded and controlled sectors, in both production and distribution. If the main responsibility remains with free enterprise there must be general agreement that this system is best, and a nation-wide determination to make it work. Careful attention should be given to marketing arrangements and, from the farm gate onwards, business management must be at a high level.

Incentives to Farmers

Farmers cannot be expected to produce food for sale to the population unless the payment received covers the costs of the inputs they have to purchase and gives some return for their work. In simple terms the profitability of increased production is determined by the ratios between costs of inputs and prices of crops.

This subject is very important. The ratios between crop prices and fertilizer costs, which determine profitability, have a great effect on the speed with which fertilizers are adopted in developing countries where farmers' resources to purchase inputs are very limited. The publications of the *International Potash Institute* have provided many examples of how prices of fertilizers have affected the amounts that are used. The table below gives figures that have recently become available. They show the great variability in the price of paddy rice and the cost of NPK fertilizers in four Asian countries.

	Price ratio	*Fertilizer use*	*National average yield of paddy*
	kg of rice needed to buy 1 kg of NPK fertilizer	NPK used on arable and permanent crops in 1979 (kg/ha of $N+P_2O_5$ $+K_2O$)	average for 1979–81 (t/ha)
Nepal	4.13	8	1.8
India	3.04	27	1.9
Indonesia	1.60	39	3.3
Republic of Korea	0.35	395	5.5

Sources of these data:

FAO: Production Yearbook for 1981
FAO: Monthly Bulletin of Statistics 5, 3 (1982)
Fertiliser News *24*, 12, Special Supplement, 23 p. (1979)
Uddin, S.: High-yielding varieties of rice and fertilizer supply in Bangladesh (1980)
The Association for Potash Research, Seoul

The ratio between the price given for rice and the cost of fertilizer is least favourable to the farmer in Nepal and most favourable in the Republic of Korea. The table also gives the average rate of NPK fertilizer (expressed as kg/ha of $N + P_2O_5 + K_2O$) used on all crops in these countries; the amounts used increase as the price ratio becomes more favourable. The average yields of paddy for three recent years (from *FAO*'s Production Yearbook for 1981) are also stated and it is not surprising that the Korean Republic tops this list of yields; in fact this country has grown national average yields of paddy that are the highest in the world in some recent years.

A consideration of these figures shows how important it is for national authorities to establish favourable price ratios to encourage fertilizer use when they desire that food production should be increased.

Subsidies. Many countries subsidize food production either by direct subsidies on food, or by subsidies to the costs of inputs such as fertilizers. There is much argument, and no general agreement on the roles of subsidies. But it is clear that where food prices are maintained at low levels, and therefore that farmers' incomes are also low, that subsidies on fertilizers are justified.

Other financial aids to induce farmers to produce more have been suggested. One is to increase the facilities for securing *loans* on advantageous terms. Schemes for *crop risk insurance* may help in combatting some of the risks in farming. There is, however, little doubt that the best way of securing increased production, by persuading farmers to grow more, is to set *guaranteed prices* at levels which give a good return on the effort and investment involved.

Labour Problems

A striking feature of agricultural development in this century has been the rapid fall in the percentage of the total working population in developed countries which is engaged in food production. In many of these countries less than 10 percent of the work-force produce not only enough food for their nation, but in some countries also provide a surplus for export. By contrast many developing countries have over half of the working population in agriculture, and yet they produce too little food for their national population.

It is important to maintain full rural employment. Policies which subsidize inputs which displace labour, such as mechanization, are wrong unless there is a place for extra labour in other industries which are themselves productive. To establish new jobs in industry requires capital; it was also pointed out that in some developing countries the increased urban population produces little in the way of goods and services as they are largely engaged in the distribution of goods and services already existing.

Intensification of agriculture does often lead to some increase in employment in farming. For example, the great improvements in productivity in the Punjab in India have required great increases in labour – which has come from other States. The large rural populations in developing countries should not be regarded as a liability. Intensification of production must require increased effort, and the large labour force is an asset that is waiting to be used. Many tasks in improved farming, such as weeding, special methods of cultivating and sowing seeds, placement of fertilizers, and spraying of agrochemicals, were originally done by hand in the developed countries; the high wages now paid in these countries make such hand-work uneconomic and the tasks are mechanized. But in the developing countries there is a reserve of workers who could initiate such modern technologies by human effort and get them established into farm practice. When the improved systems are functioning smoothly, and the new practices have proved their worth in terms of increased yields, mechanization can be considered against the background of economics and of alternative work for the people who may be displaced from the farms by machinery.

Where labour does become surplus to the needs of agriculture rural industries might be established, particularly those that benefit farming. (Thus it may become possible to establish small local fertilizer factories if present research on nitrogen fixation processes and on the use of local mineral resources, is successful). Such industries strengthen the rural community.

Some rural workers have moved temporarily to developed countries. The benefits of the earnings that they remit to their families and of the knowledge and skills that they acquire abroad are very real. But the numbers of people who can work in this way are limited to a small fraction of the surplus rural population. The possibilities for work in other countries are influenced by growing unemployment in developed countries and by the problems of integrating foreign and domestic supplies of labour.

Modernization of Agriculture

The change from traditional to modern and more intensive methods in agriculture in developing countries will involve political decisions to make progress and when implemented, the programmes will involve considerable social and technical changes. It should not be forgotten that during the first half of this century the agriculture in most countries now regarded as 'developed' also changed from traditional to 'modern' patterns. The lessons that were learned during modernization in developed countries should be studied so that the mistakes that were made may be avoided during the corresponding changes in the developing countries. Developed countries have, however, a wider responsibility to assist in producing more food where it is needed and their assistance will be required with many aspects of the development and organization of the new agricultural systems. There will be special needs to arrange for training at different levels, ranging from the laboratories to the farmers' fields, and to help with establishing suitable infra-structures in the developing countries.

The Role of International Organizations

Excellent work has been done by *FAO* to assist the modernization of agriculture in the developing countries by establishing and supervising good development programmes. A notable example is the *Freedom-from-Hunger Campaign* for which industry has supplied both money and fertilizers to establish a very large network of fertilizer trials which have established the benefits to be obtained from fertilizers in the developing countries. Such work must continue and be expanded.

There is no doubt that the network of *International Agricultural Research Centers (IARCs)*, now supervized by the *Consultative Group for International Agricultural Research (CGIAR)* is of the greatest importance for the future development of agriculture in the developing countries. The sucess of the changes, often known as the 'Green Revolution', which have transformed production levels in many countries, has depended greatly on the new high-yielding varieties developed by the Centers, and the new systems in which these varieties are grown; the total effect of this research and development has been to raise the whole potential of agriculture. The Centers do research that is beyond the resources of most national organizations. Examples are the large plant-breeding programmes of *CIMMYT* and *IRRI* and the intensive work on farming systems done by *IITA* and other Centers. They also collaborate closely with national research and development organizations, giving these national institutions much help with plant material and other specialized inputs. The example they set of 'mission-oriented research' is vital to the development of local research in the countries of the regions which the Centers serve. It is absolutely essential to the objective of producing more food where it is needed that the work of the Centers should be increased and that there should be no restriction on the funding by industrialized countries for this vital work.

The information acquired by research and development at international and national institutions has no practical value until it has been transmitted to local advisory workers, and ultimately to farmers. The IARCs and other international organizations have a very important part to play in this essential work of 'transfer of technology' by arranging courses and other forms of training. They must work to overcome the problems that may occur through ignorance of local conditions on the part of those whose duty is to transfer information, and sometimes because of the inadequate education of the recipients of the information. Both international and national organizations should give very serious consideration to the problems of communication and understanding that are involved. The processes in communicating the results of research must be examined from the farmer's point of view so that there is no gap in applying the results of costly investigations. The selection of advisers of high quality is vital; they must be good scientists, but they must also have a good understanding of agriculture, and be aware of, and fully sympathetic to, the social and economic problems involved in agricultural improvement.

Pathways for Development

As often happens with a scientific development that is vital to human welfare, there has been questioning and criticism of modern intensive agriculture, even by well-meaning people. Although it is the only way to secure more efficient use of resources in plant and animal production, and is essential in providing the adequate food which the majority of the world's people enjoy, intensive production involving the use of fertilizers and other agrochemicals has been criticized. The criticisms have included the fuel energy used in modern agriculture, the possibilities of environmental pollution and of damage to soils from intensive systems, and the risk that food quality may be impaired. Some have proposed a return to the traditional farming systems of the times before fertilizers were widely used. It is generally agreed that the scientific objective of securing 100 percent efficiency in the use of plant nutrients supplied by fertilizers and manures is exactly the same as the objective of those concerned about environmental pollution. Neither party can condone any escape of nutrients from agricultural systems into natural waters or the air, these escapes do pollute the environment, but they also represent a financial loss to the farmer.

Against this background it has even been asked whether the 'Green Revolution' was a failure. The Panel gave very clear answers that far from having been a failure, it had been a great success. For example, if it had not been successful India would have had to have imported vast amounts of food in recent years. The successes of the Green Revolution had been mainly with rice, maize and wheat. The need was now to consolidate what had been achieved with the new high-yielding varieties and to develop cropping systems which exploited their potential to the full. At the same time research to develop even more productive cereals must continue; with the new techniques of genetic engineering now available, the prospects for even greater advances are good. At the same time these techniques in research and development must be applied increasingly to the pulses which provide so much of the protein needed by people in developing countries. Little improvement in the potentials of these crops has been achieved up to now and greater investment in research is needed.

It must be recognized that the world's increasing needs for food, produced where it is needed, will be largely met by increasing yields on areas now cultivated and to a lesser extent by increasing the areas under cultivation. Consequently we have no option but to intensify farming by scientific methods. We must plan our work so that the intensification that produces more food does not result in damage to soil, or erosion, or any pollution of the environment. The quality of the food produced by the new systems will be improved, and any social and economic problems resulting from intensification will be overcome. There can be no turning back to the old traditional methods in agriculture; that pathway cannot lead to a solution of the world's food problem.

The Role of Fertilizers in Food Production

Fertilizers have had an essential role in the increases in production of food that have been achieved in recent years. Without the increased use of fertilizers yields would have been very much less. Figures published by *FAO* show that 112 million tonnes of nutrients ($N+P_2O_5+K_2O$) were used in 1980 by the world's farmers and this amount is four times greater than was used 20 years earlier. It is estimated that 262 million tonnes of nutrients will be needed by the year 2000 A.D. This increase in fertilizer use alone should produce an extra 1600 million tonnes of food grains – enough to feed an extra 8 billion people if they live mainly on cereal products. If this great increase in use is to be achieved policies will be required to produce much of the fertilizer locally, and the cost must not be excessive. Dr. Kanwar had described to the Session the great increase in the use of fertilizers that had been achieved in India; this is an example which many other developing countries will have to copy if they are to produce the extra food they need.

Through the foreseeable future fertilizers will be essential in developing countries to raise the low fertility of the soils to levels which can provide for satisfactory crops.

Even when the soils have been improved fertilizer use must continue to maintain the higher levels of productivity by replacing the nutrients removed in the yields that are sold from the farms. There is no competition between the use of manures made from plant and animal wastes, and fertilizers. Manures contain plant nutrients that have already been used to produce the crops that provided these wastes; these nutrients should be recycled efficiently, but even when all the nutrients in a crop are returned to the soil they can do no more than maintain yields. Fertilizers introduce extra supplies of nutrients and they are the only means we have of increasing, at will, the stock of plant nutrients in production systems, and therefore of raising yield levels.

It is clear that the amounts of fertilizers used in the developing countries will have to be increased greatly in the next twenty years. The obstacles will be the high costs of these inputs and their limited availability in some areas. High costs are a world-wide problem and they will affect nitrogen fertilizers even more seriously as the costs of the fossil fuels needed to make them increase – which they are certain to do. This means that the highest priority must be given to all research on fertilizer efficiency, and particularly to the efficiency of nitrogen.

The maximum use must be made of systems which permit the biological fixation of nitrogen, by the legumes we now grow, and by new systems for fixation by micro-organisms living in association with plant roots on which research is now being done. In this context we are looking for new possibilities to be opened up by genetic engineering. While much attention will have to be paid to nitrogen we must not neglect the other nutrients. Much phosphate will be needed to raise the fertility of poor soils. Large amounts of potassium will be needed to support more intensive production systems on the soils where the natural low fertility was only just sufficient to support traditional farming. Lime will be needed in many parts of the humid tropics, and magnesium too. Sulphur fertilizers will be required in many areas; micronutrient deficiencies will also have to be corrected by fertilizers supplying these elements to soils where organic manures are not used. Research on soil organic matter (which is so essential to the fertility of tropical soils), and on soil conservation to prevent erosion, will be needed to support the new farming systems.

The majority of farmers in most developing countries use little or no fertilizer and they will have to be introduced to these inputs which will be essential in achieving the higher levels of productivity that will be required. Much will have to be done to ensure that the fertilizers the farmers receive can be used efficiently by them. Formulations and manufacturing methods must result in products that are fitted to the local constraints set by crop, soil and climate, and by the farmer's ability and knowledge and the equipment that he has. It is important to recognize that the fertilizers commonly used in temperate agriculture may not be equally suitable for use in the tropics. In order to secure high efficiency it may be necessary to build 'know-how' into fertilizers by modifying both physical form and chemical composition so that they suit soils and climate and method of application, and release nutrients at rates which match uptake by the crop. This aspect of the 'transfer of technology' will have to be solved by the soil scientist and the chemical engineer working together.

An important aspect which must receive attention is the availability of fertilizers where they are needed. Here the developed countries should be prepared and willing to give much assistance. Initially, they may help by granting fertilizers to developing countries or by subsidizing the prices to levels which the developing countries and their farmers can afford. Longer-term assistance will be needed with the construction of fertilizer factories for production in the areas where the fertilizers are needed, using local raw materials wherever possible, and with simple technology that can be operated by the engineers who are available. Again it is essential that this aid should be provided at minimum cost, with maximum technical efficiency, and it must take full account of local social and economic conditions. It will also be found that aid with fertilizer production will usually have to be supported by help to develop packaging, transport and distribution systems to ensure that farmers receive their fertilizers in good condition at the time when they need them. Finally, it will often be necessary for developed countries to help in establishing services that can analyze the farmer's soils and advise him on the fertilizers he should use, and when and how they should be applied.

Concluding Remarks

Modern agriculture is a science-based industry operating in an ecological environment. Success in fulfilling targets for increased food production will depend on our success in providing information on the working materials of cropping systems – plant, soil, water, nutrients, air and solar radiation. This will demand research on soils and crops, and on the fertilizers that are essential to increase soil fertility, done in both controlled and natural environments. The information on crop nutrition that is obtained must be used to guide both the advice on using fertilizers in cropping systems that is given to farmers, and also the advice that is given to fertilizer manufacturers on the materials that farmers require. The high efficiency which is so essential to repay the cost of inputs will come from the right fertilizers, applied in the right place and at the right time. One of the most important duties, which at present we tend to neglect, will be to examine lines of communication to ensure that all the information needed to make the use of fertilizers fully efficient is transferred smoothly and promptly from workers in the research and development services to advisers, and then to farmers.

While it is essential to have a sound scientific basis to improve production by the efficient use of inputs of fertilizers, irrigation, crop protection chemicals, and improved methods of growing more productive varieties of crops, it is even more important that the social and economic background should support the farmers' efforts. In the first place there must be a political determination to give the highest priority to agriculture. This means that there must be adequate allocations of resources for agricultural and rural development and that these must be maintained at stable levels. Policy-makers must accept this responsibility and coordinate the work of their ministries to make sure that programmes of research, extension, education and training are sufficient to support the plans for development. The vital role of those who produce the food must be recognized and their status in society must be improved. The rural areas must be given the facilities and services that have improved life for the city-dwellers; outstanding needs are for the provision of electricity and water supplies, and adequate health services.

The economic background of food production must also be set so that farmers receive a sufficient income to cover the cost of inputs they must purchase and to give some return for their labour. They cannot be expected to produce food for sale to the urban population unless these conditions are met. It is very important that governments should give careful attention to the ratios between costs of inputs and prices of crops. Authorities who are responsible for planning must realize that these ratios determine whether the increased production that is needed will be profitable and they must establish favourable price ratios to encourage the use of fertilizers and other inputs where extra food is needed. The returns from agriculture cannot be assessed on a short-term basis; farmers must be able to see that extra expense and effort will be rewarded in the future. Therefore the best way of increasing production by persuading farmers to grow more, is to establish a system of guaranteed prices which will give a good return on work and on investment.

The governments of industrialized developed countries also have a responsibility and an essential role in aiding the improvement of agriculture in the less-developed countries. This they will do by supporting the *International Agricultural Research Centers* and other international organizations for research and development; they will also establish courses and other arrangements for training that fit the needs of developing countries. They can assist greatly with the supply of fertilizers, without which all other work for development will be ineffective. Because fertilizers produce many times their own weight of food the provision of fertilizers is one of the most effective forms of aid. In the longer-term the developed countries will, of course, assist with the establishment of factories for the production of fertilizers where they are needed, particularly by processes which make the fullest use of local raw materials

In Summary: The Panel was asked whether agriculture can meet the challenge of feeding the world's increasing population. They considered that agriculture will certainly meet this challenge, and will produce the extra food needed, *provided* that the economic, socio-economic and political conditions, and the facilities for education, research and industrial production that are established are adequate to support the scientific expansion of farming.