Potassium in Relation to Grassland Production

Proceedings of the first Regional Conference
of the International Potash Institute

Wexford (Ireland) 1963

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Introduction

During the first ten years of its activity, the International Potash Institute has organised, at regular intervals, seven International Potash Congresses. These meetings have allowed a review, at a general and universal level, of our scientific knowledge on the nature of potash in the soil, its implication as regards the utilization of water and its role in the nutrition of plant and animal organisms. At the last Congress, in Spring 1962 in Greece, these basic scientific datas have been examined in their specific application to Mediterranean Regions.

Thereupon, it has been considered that, in spite of the high interest raised by such international conferences, it might be easier and even more fruitful to discuss scientific problems within small groups of specialists. The Scientific Board of the International Potash Institute has, then, proposed to hold these international congresses at longer intervals and to organize, in the meantime, study meetings dealing with scientific subjects restricted either by their local application or by their high level of specialisation. In the first case those meetings would be attended by regional technicians specialised in the study involved and in the second case by a small group of international experts carrying out researches on the same basic scientific problem. Among such a reduced number of participants it would be possible to examine the chosen subject in details and to discuss it, taking the bearings of what is known or still to be found.

One of the most acute problems which the experts are facing, owing to the increasing needs in animal origine proteines of a steadily growing World population, is high productivity in intensive grassland production. Grassland production is widely depending on ecological factors and human managements. In the Northern European countries, pastures cover large areas and cattle breeding represents an important part of agricultural production. Among those countries, Ireland stays in first line; its soil and humid climate are very favourable to grass growing; cattle breeding is by far its main activity and animal products one of its main export items. Therefore, to deal with "Potassium in relation to Grassland Production", Eyre was chosen as the proper place for the First Regional Conference of the International Potash Institute. This conference was held at Wexford, from July 2nd to 4th 1963, under the patronage of H. E. the Minister of Agriculture of Ireland.

During two days, eminent lecturers submitted to the participants the last datas regarding the availability of potassium in grassland soils, its mode of action in the plant and its influence on the botanical and chemical composition of pasture plants. Specialists of the Northern European countries presented a series of short papers summarising research work on potassium in relation to grassland management systems carried out in their own country, and on the influence of potassium supply on the composition and quality of sward. For a last working session, the seventy participants, divided into four syndicates, discussed different aspects of potassium in relation to grassland production. They prepared recommendations and conclusions on their findings in relation to the present state of knowledge, to be submitted to the closing session for further investigation.

Furthermore, the participants have had the opportunity to see field and laboratory investigations being undertaken by the Agricultural Institute at Johnstown Castle.

The Board of the International Potash Institute sincerely hopes that the work accomplished by its First Regional Conference will contribute to forward our knowledge about the influence of potash fertilizers on the production, composition and quality of herbage. We would like to seize this opportunity of thanking the speakers for their kind and valuable co-operation and for making the results of their sterling work available for the common weal.

A special word of gratitude is due to His Excellency the Minister of Agriculture of Ireland, Mr. P. Smith, for his kindness in assuming the patronage of this Regional Conference.

We are also especially indebted to Dr. T. Walsh, Director of An Foras Talúntais (Agricultural Institute), for accepting the heavy responsibility of presiding over the activities and discussions of the Conference, after dedicating a good part of his time to preparing, with his staff of the Agricultural Institute, the successful proceeding of this meeting.

We would also like to thank Mr. J. C. Litton, Chairman of the Council, and all his colleagues of Johnstown Castle Experimental Station, for their kind and warm hospitality.

The Management of the International Potash Institute

Welcoming Addresses

Mr. Minister, ladies and gentlemen,

When the Advisory Council of the International Potash Institute decided to institute a new programme of regional conferences, Ireland was selected as the venue for the first meeting.

To open this conference today we are honoured by having the Minister for Agriculture and I would now ask the Minister to formally open the conference.

Dr. T. Walsh, Director

Ladies and gentlemen,

I am interested in the purpose of your conference as a layman because, as well as being Minister for Agriculture, I am a farmer and I am always anxious to obtain new knowledge to help me to be a better farmer.

I come from a part of the country where the land is not too fertile, and I have a limited knowledge of the extent to which improvements are possible. I hope that this conference will help towards improving these areas.

There is a growing awareness in this county of the subject which you will be discussing during the next couple of days.

When I was a young man I remember the attitude of farmers towards the application of any form of fertilizer. I have seen the slow growth and development of the public mind towards the application of fertilizers, their effects on land and the beneficial results that accrue.

The proper economic use of fertilizers is very important especially here on this small island where so many of our people are dependent on agriculture for a living and where it plays such a tremendous part in determining our standard of living.

Thus, to me this work in which you will be engaged during the days ahead and in fact during your whole lives, is of tremendous interest both as Minister for Agriculture and as a farmer. I am sure that your conference will prove both interesting and beneficial.

Mr. P. Smith, Minister for Agriculture

Mr. Minister, ladies and gentlemen,

It is my privilege to welcome, on behalf of the Council of An Foras Talúntais, the delegates to this conference. We feel very honoured that it has been decided to hold this conference in Ireland and we are only too pleased to place what facilities we have here at Johnstown Castle, the headquarter of the Soils Division of our Institute, at your disposal.

We are well aware of the excellent work which the International Potash Institute has been doing for the past eleven years and very much appreciate the important contribution which it has made to world agriculture during that period and the active part which it is playing in the Freedom from Hunger Campaign. I may say that my Council takes no small pride in the fact that our Director, Dr. T. Walsh, is a member of your scientific advisory committee.

Owing to the preponderent position occupied by grasslands in our agriculture the theme of your conference is of special interest to us.

Approximately 85 % of our farming land is under grass. If we take into account mountain grazing and so forth the percentage can be regarded as even higher.

As regards the 15 % which is under tillage crops I might mention that practically all the tillage in Ireland is based on a ley farming system, that is the rotation comprises temporary grass of two, three or more years duration. From the husbandry point of view this system has much to commend it but its profitability, and here I am speaking from my personal experience over a period of 30 years, its profitability depends on the rapid establishment of a high yield sward. In particular the clover is important and the use of properly balanced fertilizer essential.

The high percentage of our land under grass is of course mainly due to the fact that our mild, moist climate is very suitable to the growing of grass. Grass is a crop which grows "naturally" in Ireland.

But it is one thing for grass to grow "naturally"; it is quite another thing for a farmer to grow grass profitably especially in these days of relatively high costs of production at low prices for agricultural produce.

I am afraid the scientist can do very little to secure higher prices for the farmer but he does look to you to provide him with even better tools, methods and products to increase his efficiency.

To show the farmer's appreciation of what you have to offer him I might appropriately draw your attention to the very rapid, even spectacular increase in the consumption of potassic fertilizers in Ireland.

As you are probably aware some 50 per cent of our soils are inherently deficient in potassium. During the war years this position was further aggravated by the almost total cessation of imports and a food production programme, which, while essential, still further depleted our soils. After the war supplies again became available and in 1947 our consumption, in terms of potassium was 6000 tons. In 1962 it was 60 000 tons. That is a tenfold increase in a period of 15 years, and consumption is steadily rising.

I think it is impossible to overestimate the benefits to be derived from conferences such as this, where there is not only an exchange of views and of knowledge but also very valuable personal contacts are made between scientific workers.

While wishing your deliberations every success may I say, in rather a selfish spirit perhaps, that when this conference is over you will take away with you some idea of the problems we have in this country and bear them in mind in your future work.

Mr. J. C. Litton, Chairman of the Council

Mr. Minister, ladies and gentlemen,

On your behalf I would like to say a word of thanks to the Minister for Agriculture, Mr. Smith, for coming here this morning and opening our conference. I know his presence will be a stimulation to us for the next few days.

I would also like to thank our Chairman, Mr. Litton, for talking to us and outlining the vital role of grassland in the Irish economy.

There is possibly no country in Europe where the rational use of fertilizers is as essentiel as in Ireland. 35 per cent of our people are employed on the land. Agriculture looms larger in our economy than in any other country in Europe.

In our meetings over the next three days it is very important that the problems be discussed fully. The International Potash Institute are looking to you to give them a clear expression of your views on what we know, and do not know, regarding these problems.

Dr. T. Walsh

Potassium in partially weathered soils

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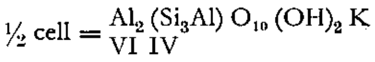
Although most temperate soils contain an abundant reserve of total potassium, its usefulness to plants varies greatly. Practically all reserve K is in micas, micaceous clays and potash feldspars which occur in varying proportions, in different particle sizes and at various stages of weathering. It is, therefore, not surprising that there is no easy approach to a detailed understanding of the behaviour of soil K. Even when the bulk of the reserve K is inert, the problem of defining K status is seldom concerned solely with the labile or, readily-exchangeable and water-soluble K. Plants obtain their K through dilute soil solution from an often comparatively large reservoir which is in exchange equilibrium with the soil solution, however, as K is removed so there can be a slow release from initially non-labile sources. The generally accepted concept is that of a slowly attained equilibrium of the type:

$$\begin{array}{l}\text{Solution and readily}\\ \text{exchangeable K}\end{array} \rightleftharpoons \begin{array}{l}\text{some lattice}\\ \text{K}\end{array}$$

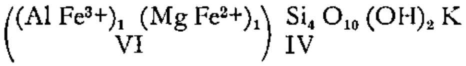
but, in addition, some release from unstable crystals is almost bound to occur by irreversible weathering in many different soils.

Most workers are agreed that mica lattices play a dominant role in determining the K status of many temperate soils, particularly as sources of useful reserve K. Well-crystalline micas fall into two broad groups; the dioctahedral type in which only about two-thirds of the total octahedral holes are filled and the trioctahedral type in which all, or nearly all, such holes are filled. It is impossible to summarise the information on the constitution of well defined micas in a short space, but the following points are relevant. In the dioctahedral micas *(10)*, few, if any, of which possess the composition of idealised muscovite



$$\tfrac{1}{2}\text{ cell} = \underset{\text{VI}}{Al_2}\,\underset{\text{IV}}{(Si_3Al)}\,O_{10}\,(OH)_2\,K$$

calculated formulas range from those in which the ratio of tetrahedrally co-ordinated Si:Al is < 3.0 to formulas in which practically all the negative charge arises from substitution in the octahedral layer. In the former, more than enough negative charge arises from Al proxying for Si, and substitutions in the octahedral layer are such as to produce a positive charge in order to preserve a composite layer charge of 1.0; in the latter, represented by minerals like celadonite



$$\underset{\text{VI}}{\left((Al\,Fe^{3+})_1\;(Mg\,Fe^{2+})_1\right)}\;\underset{\text{IV}}{Si_4}\,O_{10}\,(OH)_2\,K$$

and the not dissimilar glauconite, there may be almost no tetrahedral substitution.

In trioctahedral micas *(11)*, typified by the idealised formula for phlogopite

$Mg_3\,(Si_3\,Al)\,O_{10}\,(OH)_2\,K$
VI IV

the proxying by other bivalent cations (Fe^{2+}) in octahedral positions will not affect the layer charge but trivalent cations will give a positive octahedral layer charge which means that the Si:Al ratio in the tetrahedral must be < 3.0. Monovalent ions in octahedral sites lead to negative charge on these layers and thus Si:Al in the tetrahedral layers must be > 3.0 to give a composite layer charge of 1.0. In most trioctahedral micas, the total layer charge is usually made of positive octahedral and negative tetrahedral contributions. In view of the complexity of mica structures it is difficult to decide whether all trioctahedral members are true to type with complete octahedral occupancy. The best evidence suggests that although some octahedral sites may be vacant, with the lattice tending towards the dioctahedral form, there is not a continuous series between trioctahedral and dioctahedral types; lattices are either predominantly of one or the other type.

Almost all past work has shown that the K in trioctahedral micas, such as phlogopite and biotite, is more readily released on weathering than the K in dioctahedral micas. Any suggestions that the stabilities are little different probably arise because the K in such minerals as biotite becomes progressively more difficult to remove after more than half the K has been lost, provided it weathers slowly. It is, however, well established that much of the K in biotite is useful to plants *(17)* and that the mineral is, in fact, quite a good fertilizer *(7, 24)*. As a rule only highly weathered trioctahedral micas are likely to be found in partially weathered soils. It is usual to find that for a given lattice structure, the larger the ferrous iron content, the more easily does the mineral weather. However, it is clear that, despite a high ferrous iron content, dioctahedral lattices, like glauconite, do possess considerable stability; this mineral can be found in an apparently unweathered condition in certain surface soils of high K status in England. The underlying reason why dioctahedral micas are more stable than trioctahedral types seems to be associated with differences in the orientation of hydroxyl ions. Following the work by *Serratosa and Bradley (23)*, *Bassett (4)* concluded that if all the hydroxyl ions in a mica are inclined to its cleavage plane, as in muscovite, alteration by ion exchange does not take place at all easily unless the K content is exceptionally low. If some hydroxyls are perpendicular to the cleavage, as in trioctahedral micas like biotite, weathering is much easier.

The first stage in the weathering of micas is their partial conversion to hydromica by the replacement of some interlayer K ions by hydronium ions. Further changes. undergone by micaceous lattices on weathering have been reviewed by *Arnold (1)*. Studies, mainly on a profile basis, have greatly increased our knowledge of weathering sequences but the precise nature of the processes concerned in the important layer-charge reduction are still poorly understood. Weathered products from dioctahedral minerals usually contain more silica and water but less aluminium than the parent lattices. Depending on the conditions, layer charge may be so reduced that freely expanding lattices of the montmorillonite type are obtained or, when the charge reduction is less, vermiculite type lattices result; whereas neutral and alkaline conditions favour the formation of the former product, acid conditions favour the latter. The ability of the weathered products to fix K depends on both the magnitude of the layer charge, which may not be uniform within crystallites, and on the location of the charge as discussed by *Weaver (26)*. Briefly, high layer-charge, particularly if tetrahedral in origin, favours fixation but K induced collapse to about 10 Å, may be inhibited by highly polymerised interlayer aluminia. In most mica-containing soils some mica may be present as largely unweathered crystals together with illitic material which invariably consists of the 10 Å component interstratified with some expanded > 10 Å layers. It seems likely that where substantial K release does take place it occurs mainly from those layers which, having already lost some K, are nearing the stage of expansion to 12 Å or more; a general lowering of K ion activity in soil may, therefore, cause releases of "packages" of K from certain interlayer planes as they expand.

As discussed by *White (28)*, most successful attempts to characterise micaceous lattices have come from X-ray diffraction studies. Work on the effects of charge reduction in dioctahedral micas by introducing the small lithium ion into vacant octahedral sites (27) has added greatly to the understanding of layer expansion and K release. For example, it will be very unlikely for any 10 Å mica layers having less than one-half a full complement of K to be found under natural conditions. Detailed studies by *Hensel and White (14)* on the coarse clay (0.2–2.0μ) from superficial Wisconsin till showed that soils on the older Tazewell substage were significantly more highly weathered than those on Cary substage. About 6400 years of extra weathering (carbon dating) caused a cumulative additional loss of about 0.1 per cent K_2O per 1000 years in the coarse clay, showing that even after 13 000 years, differences between the tills had not been obliterated. Supplies of available K were smaller in the more highly weathered soils both near the surface and at depth; it seems that in X-ray spectrograms of the illite in the clay, the 001/002 intensity ratios increased as the estimated weathering period increased, and the intensity ratios were inversely related to the availability of soil K.

Potash feldspars are, from a geochemical standpoint, unstable in soils compared with several tapes of mica which are recognised as being much more stable. At first sight this is difficult to reconcile with that, invariably, K-feldspars have been found to be very poor sources of K for plants *(21, 24)*. Of apparent relevance to soil studies, it has long been known that freshly broken K feldspar surfaces release K ions to pure water *(25)*. Experiments have shown that the affinity of the feldspar lattice for H+ ist exceedingly great; the activity ratio K+/H+ in solution must be $> 10^8$ before the K-feldspar $\rightarrow$ H-feldspar trend is halted which is consistent with the absence of orthoclase in primary sediments *(12)*. Although the first step in the hydrolysis is

$$\text{K-feldspar} + H_2O = \text{H-feldspar} + OH^- + K^+,$$

other changes take place because the amount of K+ released exceeds the accumulation of OH−. As established by *Correns* and *Von Engelhardt (6)* the surface H-feldspar or H-alumino-silicate is unstable and breaks down releasing some of its ions to leave a thin but stable residue on the mineral.

From studies *(12)* of the common association of K-mica and K-feldspar in rocks, the hydrolysis of K-feldspar ist not simply

$$\underset{\text{K-feldspar}}{2\,K\,Al\,Si_3\,O_8} + 3\,H_2O = \underset{\text{kaolinite}}{H_4\,Al_2\,Si_2\,O_4} + 4\,SiO_2 + 2\,K^+ + 2\,OH^-$$

but an alteration suite which is probably more complex than

$$\underset{\text{K-feldspar}}{3\,\mathrm{K\,Al\,Si_3\,O_8} + 2\,\mathrm{H_2O}} = \underset{\text{K-mica}}{\mathrm{K\,Al_3\,Si_3\,O_{10}\,(OH)_2}} + 6\,\mathrm{SiO_2} + 2\,\mathrm{K^+} + 2\,\mathrm{OH^-}$$

$$\text{and } \underset{\text{K-mica}}{2\,\mathrm{K\,Al_2\,Si_3\,O_{10}\,(CH)_2}} + 5\,\mathrm{H_2O} = \underset{\text{kaolinite}}{3\,\mathrm{H_4Al_2\,Si_2O_4}} + 2\,\mathrm{K^+} + 2\,\mathrm{OH^-}$$

in which K-mica has a stability field. The transformations of K-feldspar → K-mica → kaolinite have been considered in terms of superficial lattice rearrangements by *DeVore (9),* but despite quite strong theoretical support, experimental evidence on the nature of both the intermediate and final surface product is still lacking *(5).* At present we cannot do better than accept the picture described by *Nash* and *Marshall (19),* in which K release from weathering feldspar is slow because of the stable thin superficial layer of unknown constitution, merging first into H-feldspar and then into unaltered mineral.

Clearly, in soils containing both micas and K-feldspars, it becomes extremely difficult to assess the role of each in the long-term K economy. In temperate soils K-feldspars are comparatively rare in the $< 2\mu$ soil separates and it is believed that once the particles are reduced to small size, they weather to completion quite rapidly. On this basis it is conceivable that soils rich in small sized K-feldspar particles may be of good long-term K-supplying power, but I know of no positive support for this conjecture. Apart from the work of *de Leenheer (8)* in Belgium and several reports from the USA *(13, 20, 22)* there is little evidence to suggest that K-feldspars play a significant role in K-releasing power of soils in temperate climates. At present there seems to be no special case for attempting to recognise small differences in the stabilities of different K-feldspars under soil conditions. If hot strong acids *(15)* fail to extract appreciable amounts of K from feldspars, then it is unlikely that the natural weathering processes on feldspar surfaces under soil conditions will help the K economy of productive agricultural soils.

In attempting to understand why soils differ so markedly in their long-term K supplying power, several procedures have been used. *Rouse* and *Bertramson (22),* working on soils from Indiana, related the intensity of 10 Å peaks on X-ray spectrograms (illite contents) to K supplying power assessed by chemical means. Using a non-specific approach with little nor no attention given to the nature of the minerals concerned, *Arnold* and *Close (2)* correlated the total K content and the amount of fine clay (both < 0.1 and 0.1–$0.3\,\mu$) with the long-term K releasing power of a variety of British soils which were cropped continuously in the greenhouse. Where soil contained accumulated K fertiliser residues or unusual mineralogical composition (glauconite) no such correlation was found. It was also concluded that information on the coarse clay (0.3–$2.0\,\mu$) was not necessarily related to K release ability, and therefore, X-ray data on soil separates which include the coarse clay are unlikely to be related to the K release from soils of varied origin.

Because of the properties of the K ion and the nature of soil surfaces, both external and internal, there is no clear demarcation between labile and non-labile K. *Mortland (18)* has outlined the dynamic character of K release and fixation and stressed that because plant roots neither explore nor remove K uniformly from soil, a relatively small amount of soil may have to supply the crop with its K requirement. Following K depletion in small volumes, releases of non-labile K may occur even though the K status of the bulk of the soil is not lowered. It is now generally recognised that much of our apparent lack of understanding of soil-plant relationships may stem from the lack of knowledge of what happens on a micro-scale in the vicinity of the plant root.

Within the framework of existing knowledge it seems we need, for the study of soil K status, both

I quantitative information on the effects of additions and removals of K, considered in relation to time (because equilibrium is usually approached slowly)

and II a mineralogical and physico-chemical understanding of the soil system.

As discussed by *Arnold (3),* in defining the effects of additions and removals of K to soil, too close an adherence to the concept of exchangeable K may restrict the logical development of our treatment of nutrient status problems, there being no reason why different soils should hold a given amount of K with the same intensity or bonding energy. The use of equilibrium techniques like that used by *Matthews* and *Beckett (16)* for studying the release and fixation of K ions in soil seems to offer the best hope for overcoming the disadvantages inherent in so many of the more traditional techniques. Because previous cropping and manurial history greatly influence the amount and behaviour of the relatively more labile K supplies in soils, few fine differences between soils are likely to be established mineralogical investigations. Mineralogical studies should, in the first place, be designed to establish the broader differences between soils. In conclusion, it would be particularly advantageous to know more about the mechanism and extent of layer-charge reduction which occurs during the weathering of micas; the importance of weathered products in determining the K economy of most temperate soils suggest that such fundamental studies will continue to be among the most rewarding.

Summary

Potassium in partially weathered soils

Most of the potassium in partially weathered soils is in micas, micaceous clays and potash-feldspars. The release of potassium from these groups of minerals is briefly discussed. X-ray reflection and infrared absorption studies have added greatly to the understanding of both weathering sequences and the factors determining the stability of micaceous lattices. However, mineralogical studies are likely to explain only the broader differences between soils of varied nature and origin, particularly because previous cropping and manurial histories greatly influence the more labile potassium contents of soil. The chemistry of partially weathered potash-feldspar surfaces and the layer-charge reduction processes in micas both remain rewarding subjects for further detailed study.

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Factors governing the availability of potassium in the soil

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The literature on the factors governing the availability of potassium is extremely abundant and reviewing even a specialised part of it could hardly be achieved in the time allowed.

Excellent summaries of the experimental results have been given and there would not be much point or interest in trying to duplicate them or bring them up to date. We could, however, start the study of the subject matter from first principles along lines which are common to all nutrient elements when their availability in the soil system is studied. An actively growing plant exhausts the nutrient content of the soil at a rate which is related to the nutrient concentration in the immediate vicinity of the absorption sites. Depletion of nutrients near these sites leads to a diffusion process in the soil solution or on soil colloidal surfaces in order to restore the equality of the electrochemical potential of the nutrient ion everywhere in the soil system. This diffusion process leads in turn to a shift of the equilibria between the solid phase and the surface and solution phase which are restored by other processes such as diffusion in the solid phase.

If no equilibrium can exist between the solid phase and the soil solution due to, for instance, the metabolic transformation of organic matter into mineral nitrogen, the rate at which this process occurs plays the same role as that at which equilibria between solid and solution phases are restored.

If we want to specialise this general outline for the case of potassium ions, we must obviously specify the various equilibria and rate processes which are likely to play a part in determining the potassium nutrition of plants.

It might be said that this is nothing but a more elaborate statement of the problem. Although this is quite true, there are several advantages in stressing the fact that the potassium nutrition of plants is above all a rate process and in undertaking to delineate the successive processes some of which may be so slow as to be rate limiting for the whole process of nutrient absorption.

We may, however, more conveniently divide the study of equilibria and rate processes which determine potassium uptake into those which are governed by the properties of the soil system and those which are related to the colloid chemical properties of the root system.

The two aspects of the soil factors which are to be considered are the exchange equilibria between the soil solution and the surface phases and various processes such as diffusion in the soil solution, surface diffusion on soil colloids or in the interplanar space of the lattice of clay minerals. Further, the rate at which under different conditions, potassium ions become included in the clay lattice, the so-called potassium fixation must be considered.

The contrast between the very large amount of well documented information on potassium fixation and the relatively meagre data on ions exchange equilibria in which potassium is involved is striking.

This is not meant to imply that numerous experiments on potassium exchange have not been done since the work of way more than one hundred years ago. There are, however, relatively few experiments on ion exchange in soil or soil clays in which the conditions for further generalisation were met, namely accurate description of the experimental conditions and the proper evaluation of thermodynamic exchange constants.

The problems of fall-out and radioactive waste disposal have caused renewed interest in the accurate evaluation of ion exchange data in soils and clays.

A typical example of the values which may be expected for the thermodynamic functions is shown in Table 1.

Table 1 *Exchange of K^+ by other monovalent ions*
Free energy ΔF_0 and enthalpy (ΔH_0), in kcal / equivalent

	ΔF_0	ΔH_0
Na by K	—0.83	—1.08
K by NH_4	—0.20	—0.20
Cs by K	+1.74	+2.54

It is seen, and this corroborates other experimental evidence, that the free energy of exchange between potassium ions and the monovalent ions which are likely to be found in the soil is fairly low. This is especially true for ammonium. It may be said that in the case of the clay studied the ratio of adsorbed K to solution K is to all practical purposes equal to the ratio of adsorbed NH^+_4. In view of the important role which is played by ammonium ions in the K fixation process, it might be interesting to know to what extent this remains true for different clays and soil colloids. The accurate determination of exchange isotherm and the calculation involved are quite lengthy especially if the difference of adsorption affinites is never likely to be as great as in the case of K^+ and NH^+_4. Fortunately the exchange entropy is practically negligible and the free energy of exchange can be very well approximated by the exchange enthalpy. It has been shown that direct calorimetric determination of the heat of exchange is feasible and involves much less time than the adsorption isotherm.

Further, soils which fix potassium even in the wet state might be detected by an abnormally high heat of reaction when a potassium salt is added to the clay suspension.

This brings us to the problem of the potassium fixation.

It is well known that in some soils the amount of exchangeable potassium may decrease to an extent which is larger than the loss which may be accounted for by crop removal or leaching.

This may be interpreted as a practically irreversible immobilisation of potassium ions in the clay lattice. Experimental evidence on the correctness of this interpretation is very abundant. It has also been proved that potassium fixation is most marked when 2–1 clay lattices are present. Since the negative charge of those lattices is due to isomorphic substitution in the tetrahedral or octahedral layers, there will be a tendency for positive ions to get as close to the seat of the negative charge as possible. The diameter of K ions being within a few hundredths of an Å unit the same as the hexagonal hole in the tetrahedral oxygen layer, one could expect that entry of K ions into those cavities would result into a very stable structure. All clays which are found to be able to fix K^+ ions always belong to the group of the swelling clay minerals with an interplanar distance which is determined by the water content.

Numerous studies have been made on the influence of alternatively wetting and drying soils or clays on the fixation of potassium. The practical importance of such studies is obvious, and an understanding of the mechanisms which play a role should lead to easier generalisation of K fixation studies.

This is why we have thought that it might be worthwhile to present here some new results which might throw some light on the mechanisms involved in different clay minerals.

Starting from a montmorillonite which in the wet state does not fix potassium, we observe that after 50 cycles of wetting and drying the base exchange capacity has decreased to 40 per cent of the original value. If on the other hand the clay is dried only once down to a water content so that only one water layer is present, it is then possible to interpret quantitatively the measured interplanar distances on the basis of a 10–12.5 Å interstratification. Under these conditions it is observed that the amount of fixed K varies linearly with the percentage of 10 Å interplanar distances. It is thus well established that drying a clay promotes the dehydration of K ions and that the energy of binding of water molecules is now found as energy of binding of those ions to the clay lattices. It should thus be possible to investigate this transfer of binding energy according to the well known methods of infra red spectroscopy.

Two types of modification can be observed, namely, those pertaining to the Si–O bonds of the tetrahedral layers and to the OH bonds of the constitution hydroxyls. Modifications of the length of the Si–O bond are difficult to study but the examination of the vibration of the OH group has brought some new facts to light. In a montmorillonite, the oxygen of the constitution hydroxyl has a free sp^3 orbital since among the four orbitals resulting from the hybridisation two are occupied by Al–O bond and one by the OH bond. As shown by other authors working on micas, the orientation of one cleavage plane with respect to the infra red beam has the consequence that the O–H bond is also oriented and that the absorption of incident light is decreased according to whether the O–H direction is parallel or perpendicular to the direction of the electrical vector of the incident radiation.

Similar experiments made on oriented clay films show indeed a variation of the intensity absorbed in the two possible directions for the vibration of the O–H bond according to the amount of potassium which has been fixed.

It can thus be concluded that potassium fixation on a diodaedric clay material goes with a modification of the proton occupancy of the sp^3 orbital of the constitution OH oxygen. If the influence of wetting and drying on K fixation is studied using a triodaedric mineral such as hectorite, it is found that no K fixation occurs no matter how high the number of drying cycles. In the light of what has been found this may be explained by the fact that all four sp^3 orbitals of the oxygen of the OH group are occupied: three by the O–Mg bonds and one by the O–H bond. It seems thus well established that there is a narrow relationship between the possibility of irreversible K fixation and the di– or triodaedric nature of the clay mineral which determines the likelihood of new orientations of the vibration of the O–H bond.

One could of course raise immediately the question of the applicability of what has been said to the case of illite where the seat of charge is in the tetrahedral layer. An interesting observation in that respect is the following: studies on the rate of non-exchangeable K release have shown that when the octahedral layer has been practically removed by HCl dissolution a noticeable amount of K remains bound to the silicic acid residue, the latter being still partly structured. In this case the kinetics of K release are practically parallel to those silic solubilisation which implies a strong relationship between the clay lattice, no matter how far disintegrated, and the compensating cations. The reverse process of K fixation or the release of potassium from potassium bearing minerals is still little understood as far as the fundamental mechanism is concerned.

But no matter how high this potential release may be, if the diffusion rate of potassium ions towards the plant root is not such that diffusion effects do not control K uptake by the plant, there would be little interest in solubilisation studies of K bearing minerals in the soil.

There is very great interest at the present in the question of knowing whether this diffusion process might control the rate of nutrient uptake by the plant.

Before using the values which have been and will be obtained on the rate of movement of K ions in the soil system, there remains to be known at what rate the plant can absorb K ions when no film diffusion process is rate limiting. When this is known it will become possible to decide whether either one or none of these rate processes is rate limiting.

Although it may seem a simple matter to determine at what rate a whole plant in culture solution absorbs potassium, there is a serious problem of so doing while completely eliminating diffusion effects or calculating the limiting rate which could be obtained if diffusion was not limiting.

In an entirely symmetrical fashion to what we have seen for the soil, not only rate processes but also equilibria may be considered for the plant system in so far as they aid an understanding of nutrition.

The rate process of K uptake by the plant is already beyond the frontier of soil science in the realm of plant physiology. The ion exchange equilibria which may be considered to exist at the surfaces of the root system are undoubtedly of great importance.

Especially when two different species such as a legume and a grass have to compete for a limited amount of available K as in a pasture, knowledge of the distribution of K ions between the three colloidal systems may bring us a long way towards a better understanding of the K nutrition of plant communities.

There has been a fair – and I am tempted to say – misleading amount of success in interpreting the compatibility of different species in terms of the base exchange properties of their root system. This success may be misleading to the extent that what is obviously a rate process is interpreted solely in terms of equilibrium data, and further that the theoretical foundation of the application of the Donnan equilibria to the systems considered is not very firm.

There is, however, little doubt that a proper understanding of the potassium manuring of pastures will be obtained by a combination of the methods of approach outlined above and which may be summarised as an integrated study of, on the one hand, the rate processes concerning movement, fixation and release of K in the soil and uptake of K by the plant and, on the other hand, of the ionic equilibrium distribution between the soil-plant colloidal systems and the soil solution.

The role of potassium in plant nutrition

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As a plant nutrient potassium is the Cinderella of the elements; to it has been attributed the highest and the humblest functions in the plant organism. Although, as its name implies ("pot-ash") it was one of the first of the mineral elements to be recognised in plants it is only in recent years that some understanding has been obtained of its functions. Our knowledge, however, is far from complete.

This review will consider potassium under three main headings for convenience, (1) what will be called "Development", which will attempt to cover all processes such as absorption and growth, (2) carbohydrate metabolism, and (3) nitrogen metabolism.

1. Development: Potassium Absorption

As pointed out by *Pirson et al. (1)* the explanation of the function of an element which is not incorporated into the living substance of the cell is very difficult. It may attach itself to the plasma as a free ion, as seems to be the case with potassium, in a non-stoichiometric manner, and its action can only be explained by experiments with model colloids. This is particulary true, say *Pirson et al.,* for both potassium and calcium to which usually the function of antagonism is ascribed for the total cell functions, assuring optimal plasma conditions. The physiological role of K and Ca can only then be interpreted by their adsorptive and descriptive actions and must include an understanding of the problems of the ionic action of these two elements. This is obviously a task for biophysics.

Isotope studies with K^{42} have revealed no potassium organic compounds *(2)* but K^{42} has a half life of only a few hours and work has tended to be confined to algae studies. As will be seen later, postulates of potassium compounds with cell constituents have been made and some experimental work would appear to support this conclusion. *Stout and Hoagland (3)* have shown that passage of K^{42} into a plant results in an equal distribution in both xylem and phloem and the direction of movement is from the xylem to the phloem and thence into cells. For phosphorus, the rate of transport is proportional to growth rate; it may also be so for potassium. *Jenny et al. (4)* supplied radioactive K to seedlings and then transfered them to non-radioactive solutions. By so doing they were able to show that the non-radioactive solutions later became radioactive indicating that potassium excretion was taking place from the plant. The process appeared linked also to the calcium ion concentration. Potassium excretion has also been reported by *Müller (5)* for wheat in which in the last 3–4 weeks before harvest, during the drying off of the leaves and stems, the potash returns to the soil. A possible mechanism for this has been suggested by *Olsen (6)* who points out that as much as 30 per cent of total K is adsorbed in the plasma of the leaves of higher plants; the remainder is in the cell sap. At harvest the stems of wheat are free of plasma and the potassium has thereby been released. In potassium deficiency *Löhr (7)* has shown that the main shoot of wheat dies and more side shoots develop in which K passes from the main shoot; there is no loss to the soil. Excretion of potassium may even take place through the leaves of *Ricinus (8)* and the cuticle has been suggested as a medium. After eighteen days the loss was three times greater than the original potassium content of the leaves.

There seems very little doubt, therefore, that potassium is a highly mobile element in the plant and internal redistribution readily occurs and is continuous during the life of the plant. Potassium is transported from older to younger organs *(9)* and the most active growth is associated with the highest potassium contents; thus meristematic tissues, buds, young leaves and root tips are especially rich in K which is low in seeds and mature tissues. The high K content in cells compared with the surrounding medium and its comparatively constant level inside, has caused plant physiologists to postulate chemical binding of the element without, however, much experimental evipence *(10, 11)*. Although *Simonnet (12)* considers that organic combinations of K are numerous in the animal organism, glucose-1-phosphate, glucose-6-phosphate, fructose 1, 6 diphosphate, ATP, polyphosphates, nucleic acids, hyaluronic acid, heparin and myosin, all being quoted, phosphate esters bind K and Na equally well, and it is definite that potassium cannot be replaced by sodium except to a limited extent, as will be discussed below. Moreover, other authors *(13, 14)* are of the opinion that the cell contents do not contain substances which will bind potassium. *Hill et al. (15)* have pointed out that the osmotic pressure of cells can only be accounted for if K ions are free and *Hodgkin et al. (16)* and *Harris (17)*, using labelled K in nerve and muscle cells respectively, point out that this element has so large a mobility in an electric field that it seems incompatible with complex binding of the ion. Potassium ion distribution in striated muscle is what would be expected from the Donnan equilibrium *(18)* and although in plant cells, the potential difference between the cell interior and the surroundings is almost unknown, where the potential difference has been measured the K concentration is also what would be expected from the Donnan equilibrium *(19, 20)*. The exchange of potassium in the yeast cell, at least, appears to depend upon the respiration rate, however, as was shown by *Hevesy et al. (21)* in which the rate of exchange between radioactive and non-radioactive K was measured. Illumination and temperature increase also raised the exchange rate *(22)*.

Although the negative potential of most cells would allow of incraesed potassium concentration, this concentration is much higher than can be accounted for by the membrane potential alone. For example, the cells of *Valonia macrophysa* show a concentration of potassium over forty times higher than the surrounding seawater *(23)*. It appears that an "active" transport is involved. In the animal it has been shown *(24)* that the influx of K into the cell is inhibited by dinitro-phenol, cyanide and acids and also by low temperature (1°C), but the same agents do not influence potassium efflux or even potassium influx from K-rich solutions (52μM). Hence, potassium can enter the cell by two pathways, only one of which is metabolically controlled. Twenty per cent to 40 per cent of the potassium of the cell may be in a different phase from the remainder, according to *Ponder (25)*. The nature of this active transport mechanism is unknown but it is thought that some cyclic process may be involved in which potassium is bound to a "carrier" at one membrane boundary and released at the other, after which the carrier returns empty to the first side, or possibly charged with sodium ions. Potassium binding is therefore only a very short lived process. Some evidence is available for the "potassium-sodium pump" as it has been called, for the same metabolic inhibitors which prevent potassium uptake also prevent sodium extrusion to an equal extent, and in K deficiency, sodium extrusion is reduced to about one third of its former value. Working with *E. Coli, Cowie et al. (26,27)* using Na^{24} and K^{42} showed that the cells were permeable to sodium ions, which were, however, easily washed from the cells and therefore presumably not bound. With K^{42} the cells were also permeable to these ions which were, however, markedly concentrated. The freely diffusible K was in equilibrium with the medium and the cells were highly permeable to the ions. Without metabolism, the potassium compounds disintegrated slowly and ionic K was released. Following glucose addition, a large uptake of K took place which was limited either by the potassium or glucose available. Attempts to isolate these postulated potassium compounds were unsuccessful as they were very unstable. Carbohydrate derivatives, such as glucose-1-phosphate, gave an uptake of potassium greater than with glucose, but with sodium no effect was observed, and with rubidium there was a competition with potassium. The hypothesis is, therefore, that after diffusion into the cell, K is fixed on a compound formed by hexose with some compound already in the plant cell. Approximately two atoms K are bound for each molecule of glucose. The hexoses are regarded as producing salts with potassium after phosphorylation by ATP. Possibly glucose-6-phosphate or fructose-6-phosphate may be involved but no success has attended efforts to show these reactions in higher plants. The linkage of this process with carbohydrate metabolism is interesting, however, as will be seen later. Further work in this field must depend upon a study of the metal chelate compounds and on sub-cell morphology to explain accumulation mechanisms.

Water relations

Some authors have stressed the necessity of potassium for maintaining the colloidal condition of living matter *(28)* and the balance of hydration in the plant, due possibly to lipoid solubility and the control of fluid exchange. Potassium deficiency leads to rapid ageing of root cells and the normal osmotic gradient and permeability or viscosity gradient is lessened *(29)*. There is an antagonistic action of calcium and potassium ions on plasmolysis *(30, 31)*. *Neeb (32)* has shown that whereas in nitrogen deficiency there is an increase in the osmotic pressure of cells, in potassium deficiency there is a decrease and in each case this is related to the cell sap concentration. In practice this is observed in a relation of succulence of the plant to high potash nutrition, but succulence can also be observed in barley in cases of potash deficiency as shown by *Richards (33)*. In these cases, barley accumulates sodium, giving rise to a succulence in the plant with high water content but low photosynthetic rates; this is, however, exceptional and *Gregory* and *Baptiste (34)* pointed out that potash deficient plants are usually "hard" with lower water content, darker green than normal, having increased carbohydrate and ratio of root to top. The high sodium type of deficiency alone produces increased succulence. In the tomato, *Nightingale et al. (35)* have shown that plants in the early stages have a reduced water content and the leaves are dark green, but later succulence is increased and exceeds that of the high potash plants. All these results are interpretable by the effects of potassium deficiency on carbohydrate metabolism and will be discussed in that connection.

Growth

Studies of potassium deficiency in plants have shown a clear effect of this element on growth. In algae, *Neeb (32)* studied growth in relation to phosphorus, nitrogen and potassium fertilizers; the greatest growth inhibition came with K deficiency and the least with phosphorus. *Burns (36)* in a histological investigation of potash deficient tobacco plants showed that there was a decrease in cell division if the potassium content fell below 0.5 per cent of the dry matter and there was a decrease also in cell size. *Cooil (37)* conversely showed with *Avena* coleoptiles, that potassium additions caused an increase in cell size. In potassium deficient leaves, *Neeb (1c)* pointed out that the chromatophores are greener than normal, because although there is less chlorophyll, it is contained in a smaller cell. There is thus more chlorophyll per unit volume of cell, because decrease in cell size exceeds decrease in chlorophyll concentration. Later, however, there is chlorosis and death. The effects of potassium on growth are explicable from its as an essential element in the production of high molecular weight compounds, in particular structural carbohydrates, from monosaccharides (q.v,). Unless it is extreme, *Richards (33)* considers that potash deficiency has little adverse effect on meristematic activity in barley. The leaves grow large and the plant tillers nearly as rapidly as with a full potassium supply. Finally, there are more tillers than normal, because the plant continues to grow later than a high potash plant. If sodium is present, there is rapid top growth with diminished photosynthesis, giving carbohydrate shortage which is reflected in thinner cell walls and a reduced ratio of root to top. There is also more succulence. In tomato in the early phase of deficiency no new growing points are observed *(35)* as distinct from barley.

pH regulation in plant cell

Work with algae has shown *(38)* that the hydrogen ion concentration in the nutrient medium, in the light, is higher than in darkness, but in darkness the potassium ion concentration is higher than in light. Hence in assimilation K^+ is taken up and H^+ excreted. Potassium therefore appears to neutralize acids produced in assimilation by the hydrogenation of carbon dioxide. *Simonis (39)* showed that acid concentration in the cell is proportional to the rate of photosynthesis, so that by absorption and excretion of potassium with varying intensities of acid formation, the hydrogen ion concentration is maintained almost constant in the living cell.

Transport

The possibility that potassium may be involved in the transport of reserve materials in the plant has been considered by some workers such as *Alten (39, 40)* but appears to be rather hypothetical. Since 1940 very little more work appears to have been done in this field. Some earlier ideas are due to *Eckstein (41)*.

Interaction of K with other mineral elements

The most obvious elements which might replace potassium in its functions in the plant are the other alkali metals. Sodium in particular has already been mentioned. Although consensus of opinion favours the idea that potassium cannot be replaced by any other atom entirely, *Lehr (42)* has reported that in spinach, both sodium and rubidium can replace potassium, and *Coleman* and *Richards (43)* have shown that sodium and rubidium will remove putrescine, although more slowly than K, from the leaves of barley suffering from potassium deficiency. *Pratt (44)* has shown with *Chlorella* that photosynthesis is accelerated with potassium bicarbonate solutions but inhibited by sodium bicarbonate. The effect of sodium in replacing potassium on the development of the barley plant has been discussed under "Water relations" above. In general, it has been found that while potassium accelerates enzyme activity, sodium inhibits it, but one interesting reaction is reported in which this is not true and which may offer some explanation of the energy requirements of the "Sodium-potassium pump" described earlier. *Skon (45)* has shown that the enzyme responsible for the degradation of adenosine triphosphate (ATP) to adenosine diphosphate with release of energy, requires Mg^{++} which is not, however, sufficient for activity. Na^{+} also is necessary and K^{+} further accelerates the reactions in nerve tissue. Extrusion of sodium and accumulation of potassium only takes place if ATP is present to supply the necessary energy *(46)*. It would seem that much the same reasoning applies to plants. Possibly, however, hydrogen replaces sodium in this reaction.

According to workers at Long Ashton *(47,48)* potassium is an essential element to maintain limited supplies of iron, necessary for chlorophyll formation in the plant. *Pirson (49)* had shown that carbonodioxide assimilation in chlorotic cells, deficient in K, could be rectified by addition of this element, and that the effect was a direct one, because immediately after addition a renewed formation of chlorophyll and cell material took place. In young potato leaves deficient in iron, potash deficiency causes acute chlorosis which can be remedied by potash addition, which makes it appear that the utilisation of limited iron supply is more efficient with potash. Reciprocally, high iron causes temporary retention of K in older leaves, when normally it would be translocated to younger parts of the plant.

2. *Carbohydrate Metabolism*

It is generally agreed that potassium plays its major rôle as a plant nutrient in carbohydrate metabolism, where it appears to influence every stage of the process. The respiration of tissues, which have been washed for some time in water, can be increased by the addition of salt and in carrot tissue, for example, the rate of oxygen uptake increases by 70–100 per cent after addition of 0.01 M, KCl. This increased respiration was originally called anion respiration by *Lundegårdh* and *Burström (50)* but is more appropriately described as "salt respiration". Conditions which vary the rate of this salt respiration, vary equally the rate of accumulation, and inhibitors such as cyanide, which arrest salt respiration without at the same time inhibiting the basal respiration, completely inhibit the accumulation. As salt respiration is inhibited by carbon monoxide in the dark but not by CO in light, this indicates that it is catalysed by cytochrome oxidase. Earlier work by *Gregory* and *Sen (51)* on the relation of total respiration rate to nitrogen and carbohydrate metabolism in barley, showed that in potash deficiency respiration rate was proportional to the amino-acid content and the products of glycolysis were not respired unless they had first been drawn into the cycle of protein synthesis and degradation. Although as will be shown later, potassium deficiency exercises a profound effect on nitrogen metabolism, it appears very probable that potassium also has a direct effect on carbohydrate metabolism in a number of ways. Firstly, as has been shown by *Richards (33)*, in severe potash starvation in barley leaves the rate of photosynthesis is proportional to the potassium content of the leaf, an effect which disappears at higher potassium content. The work of *Neeb (32)* indicates that this may be due to a lowered chlorophyll content. *Buslova (53)* working with barley, rice and corn, stated that potassium did not participate in the synthesis of primary carbohydrates in these plants but promoted their assimilation. Calcium, however, did have this function and potassium was related more closely to protein metabolism, promoting the intake of nitrogen and sulphur. *Steinberg (54)* reports only slight change in the total carbohydrate in potash deficiency with an increase in reducing sugars. The divergencies in these views may be explained by the two stages of deficiency symptoms, the first in which carbohydrate increases derive from protein breakdown, the second in which these increases are finally utilized and disappear. *Cooil (55)* has reported a higher citric acid content in guayule with a high potash content and it has been reported that potassium acts directly on the formation of organic acids in plants *(28)*. *Pirson (49)* had shown the direct participation of K in carbon dioxide assimilation.

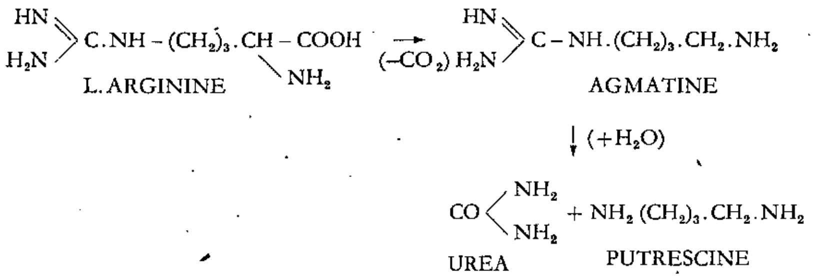
Among the least controversial aspects of the role of potassium in plant nutrition is its function in the production of polysaccharides from simple sugars, and here there is a fairly substantial body of evidence in support. Yeast cells in aerobiosis take up potassium ions from solution if glucose is present and one atom of K is absorbed for every four molecules of glucose in the formation of glycoden *(Verzar, 56)*. In sugar beet it is claimed *(40)* that three molecules of sucrose are produced for every atom of K present. In tung plants, *Lunstalot et al. (57)* have shown that potash deficiency induces the formation of reducing sugars at the expense of non-reducing sugars, arguing a role for potassium in the transition from hexoses to disaccharides. *Gregory* and *Baptiste (34)* also showed in barley that the ratio of reducing sugars to sucrose was higher in potash deficient plants and as this was equally characteristic of phosphorus deficient plants, K might be concerned in phosphorylation reactions relating to sugar formation. *Buchner (58)* claimed that the hexose to total carbohydrate ratio was equal to the ratio of potassium to chlorine in the plant. *Muntz (59)* claims that the production of hexose diphosphate from hexose monophosphate in yeast is activated by potassium ions which are, however, replaceable by NH_4+. The uptake of potassium which is greater with glucose-1-phosphate than with glucose itself in *E. coli* as mentioned earlier and the possibility of compound formation of potassium with phosphorylated derivatives would imply a close connection with carbohydrate metabolism. Further evidence for the function of potassium in polysaccharide formation is derived from enzyme studies in which it has been shown that potassium deficiency induces increased amylase and invertase activity *(60)*. *Schulz (52)* has summarized these views by pointing out that the energy for polymer formation derives from the phosphoric esters whose formation depends upon the presence of potassium ions. Hence in potassium deficiency, accumulation of monosaccharides and amino-acids takes place. That potassium is involved in the polymerisation process even up to the stage of cellulose formation itself is shown in the smaller cells *(36, 37)* with thinner cell walls *(52)* produced by potassium deficiency in plants. The length and thickness of cellulose fibre in the cell wall depend upon potassium according to *Antoniani (28)* and its presence consolidates the structure and turgor of pectin in fruit.

3. Protein metabolism

Although possibly the greatest emphasis has been placed on potassium in relation to carbohydrate metabolism, the most interesting work in recent years is in its relation to protein and amino-acid metabolism.

The work of *Gregory et al. (51)* on barley had early established that there was a higher content of free amino-acids in potassium deficient plants. This, according to *Richards* and *Templeman (61)* was not due to decreased synthesis of proteins in the young growing parts, but to breakdown of protein in prematurely dying parts. The amides glutamine and asparagine are produced in excess in K deficiency and their formation is at the expense of the corresponding acids which are less *(62)*. Mulder has reported higher tyrosine contents in potassium deficient potato tubers *(63)* but the quantitative protein composition is unaffected by differences in potassium status *(64)*. Many mineral deficiencies in the plant can lead to amino-acid accumulation, however, as shown by *Steinberg et al. (65)* for the tobacco plant. The accumulation of certain compounds can produce characteristic symptoms, as in the accumulation of an isoleucine isomer producing symptoms of "frenching" in tobacco. This and other visual symptoms, especially chloroses, are held to be due to an accumulation of amino-acids.

The differences between nitrate and ammonium nutrition in relation to potassium deficiency are of interest with regard to the function of potassium and have been described by *Wall (66)* and *Tiedjens (67)*. In potassium deficient plants supplied with nitrogen only as ammonium serious injury and death of the plant follows; when nitrate is supplied, little injury results. This was regarded as evidence that the toxicity was due to ammonia but the matter is not quite so simple. Although there is increase of ammonium salts in deficient plants there is also an increase in the amide fraction, as noted above, but in addition other more basic components of soluble organic compounds accumulate and in barley the diamine putrescine is especially evident *(68)* and has been shown to be the agent producing deficiency symptoms. In flax, arginine and not putrescine accumulates *(69)*. The expected precurser of putrescine by decarboxylation would be ornithine but *Smith* and *Richards (70)* have shown that although ornithine and arginine increase putrescine formation in K deficient barley, the increase is slight compared with feeding agmatine (1-amino. 4 guanidino butane). Arginine feeding increased agmatine production. Both agmatine and putrescine were present in potassium deficient red clover plants, but the latter is known to contain diamine-oxidase which can attack putrescine *(71)*. The suggested pathway of putrescine production is therefore as follows:



As potassium deficiency increased agmatine and putrescine production without changing the arginine level, the effect is not apparently due to the result of mass action with increased arginine. Bryant and Richards found that uniformly labelled L (C^{14}) arginine produced labelled putrescine more rapidly in K deficient barley shoots than in those grown with optimum K supply, indicating activation in at least one of the enzymes concerned. More recently *Smith (72)* has shown an increase of arginine decarboxylase activity at potassium deficiency levels in barley. This therefore appears to be a direct effect of K deficiency on an enzyme reaction.

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The influence of potassium levels in soils on the growth of various pasture species

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It would probably be of minor interest to try within a very short time to express a certain number of general ideas, or to give some detailed values taken everywhere in the literature dealing with the subject: the influence of potassium levels in soils on the growth of various pasture species. Many agronomists have published on this matter, either referring to general aspects of this problem or tackling a very particular point.

Assuming that we know on which kind of soil a given experiment was laid down or a definite fodder crop is growing, and that available or exchangeable potassium in this soil, estimated following a common method of analysis, reaches a normal level, it would be interesting to try to understand the behaviour of the crop, during a growing season and the following ones, because forage crops are usually established for more than one year. In addition, it could be of interest to know how far we can expect that a more or less complex mixture of species used under different systems of management will keep its initial components, or shift towards another composition which could be less productive or produce a less valuable forage.

Finally, from analytical data to which some "linking" ideas could be added, it would be worth while to draw some general rules, or programmes, the aims of which could be the definition of a manuring policy, or of comprehensive schemes for further experiments. In other words, is it possible to change our "statistical opinion" on the question of potassium manuring into a comprehensive one?

As a geneticist, working on different species of grasses and legumes, the main components of any forage crop, I am more or less ready to consider at first that these species do not have either the same root system, or the same type of growth. It is important to refer to this problem the uptake of any mineral nutrient resulting partly from a probability, for a functional root to meet an exchangeable ion.

The roots of the grasses and the stolons of white clover are somewhat similar, and belong to the advantitious type. They are of small diameter, fibrous and extend only in the upper region of the soil. Their extension can be limited by some soil properties, systems of management including manuring, age of the crop: the older, the more limited and restricted to the surface layers.

We can expect that the K content of these surface layers is of primary importance owing to the relatively limited possibility of migration of this element from one level to another; the humus content of the surface layers generally increases with the age of the crop in grassland soils so that K can probably be exchangeable at a higher rate than in arable soils. Another characteristic of these grassland soils already cited by numerous workers is the great variability of their K content *(Schuffelen et al., Hemingway, Ferrari* and *Vermeulen, Van der Paauw)*. This is partly due to the fact that the grazing animals behave as additional factors for increasing variability: *Doak* calculated that 80 per cent of the ingested K was excreted in the urine of grazing animals and *Barker* and *Steyn* estimated that, under a strip-grazing system of management, with an average carrying capacity of 0.75 cow per acre, maintained for 10 years, the different parts of the surface receive an additional manuring due to urine patches:

8%	without any patch
20%	one application
25%	2 applications
22%	3 applications
14%	4 applications
7%	5 applications
3%	6 applications
1%	7 or more applications

Excluding such events, we were able to get relative estimates of this variability, thanks to a control of dry matter production of small plots of a cocksfoot-white clover association (2 sq meter/plot), and of the K content of the forage produced on each plot. Results are given in the following table: they are expressed by the significance of the F tests, used to compare "between blocks" and residual variances, calculated in each design, from the data collected for dry matter production, K uptake on one side, and by the comparison of "between blocks variation" for K and N uptakes.

1960 Harvest	Significance of the "between blocks" variation		Comparison of the "between blocks" variation for K and N uptakes	
	Dry matter production	K uptake	Value of F for $n = 5$ and $n' = 5$	Significance of K/N var.
1st cut 4.5.60	N–S	$P<0.01$	22.80	$P<0.01$
2nd cut 5.6.60	N–S	$P<0.01$	8.62	$0.05>P>0.01$
3rd cut 7.8.60	N–S	$0.05>P>0.01$	6.56	$0.05>P>0.01$
4th cut 8.9.60	N–S	N–S	2.60	N–S
5th cut 9.10.60	N–S	$P<0.01$	7.42	$0.05>P>0.01$
Total	$0.05>P>0.01$	$P<0.01$	13.15	$P<0.01$
1961 Harvest	Variation coefficient	Variation coefficient		
1st cut	$P<0.01$ 2.67%	$P<0.05$ 13.0%	0.695	N–S
2nd cut	N–S 3.96	$P<0.01$ 12.8	2.97	N–S
3rd cut	$P<0.01$ 4.8	$P<0.01$ 11.9	101.8	$P<0.01$
4th cut	N–S 8.5	$P<0.01$ 12.7	1.78	N–S
Total	$P<0.01$ 5.1	$P<0.01$ 9.7	6.36	$0.05<P$ 0.01

The chemical analysis of the forage was made by the laboratory of S.C.P.A. Mulhouse

1960 was a very wet season and growth started early; 1961 was dry and growth was two weeks later compared to a normal season. In addition, the location of the trials was different, especially as far as exchangeable K_2O is concerned: in 1960, at the beginning of the season, the values for the different blocks were:

	A	B	C	D	E	F
0–4 inches	0.18‰	0.19‰	0.22‰	0.22‰	0.23‰	0.27‰
4 inches	0.21‰	0.20‰	0.23‰	0.23‰	0.27‰	0.27‰

in 1961, the corresponding figures were as follows

	A	B	C	D	E	F
0–4 inches	0.12‰	0.11‰	0.10‰	0.11‰	0.16‰	0.14‰
4 inches	0.12‰	0.11‰	0.10‰	0.13‰	0.13‰	0.13‰

From this first table, many conclusions can be drawn: the growing conditions in the spring are of major importance on K absorption: this is expressed in the following table in which are recorded for the replications A/1960 (exchangeable

1960 Replication A

Dates	Stage of growth	Dry matter harvested	K uptake kg/ha	K content
30 March	Stem 1.02 cm	0.77	15.4	2.00
9 April	Stem 3.5 cm	0.65	12.4	1.90
13 May	50% heading	2.33	32.6	1.40
16 May	100% heading	3.95	37.9	0.96
18 May	1% flowering	6.27	76.0	1.21
30 May	25% flowering	6.20	50.2	0.81

1961 Replication E

Dates	Stage of growth	Dry matter harvested	K uptake kg/ha	K content
13 April	Stem 1.6 cm	0.39	10.8	2.77
19 April	Stem 3 cm	0.37	0.5	2.31
8 May	63% heading	1.47	26.2	1.78
12 May	100% heading	2.96	49.7	1.68
3 July	1% flowering	6.00	70.8	1.18
6 July	25% flowering	4.75	66.97	1.41

$K_2O = 0.18$ per thousand) and E/1961 (exchangeable $K_2O = 0.16$ per thousand), at identical stages of growth of the cocksfoot, dry matter production in T/ha, quantity of K exported by this dry matter and, finally, K content (in per cent of the dry matter harvested at these stages of growth).

As already pointed out by *Garaudeaux*, a high K content is an index of youth, not only from a developmental point of view, but mainly correlated with the quickness of growth of the total plant. 1961 data are always higher, for the same biological stage than 1960 results, but on one occasion: beginning of flowering. In fact, there are two days only between 100 per cent heading and 1 per cent flowering in 1960, against more than a fortnight in 1961.

If we consider the general trend of K absorption during the first growing period of the grass, we can detect that any period of rapid growth is preceded by a more or less important decrease of K content of the grass. A high quantity of available K is the preliminary to normal growth, and, of course, this is particularly true in the spring for the grasses. It appears from figure 1 that there is a succession of equilibrium between K content of the dry matter produced, and the total consumption of K uptake expressed in kg/ha, but that the variations in K content of the grass are limited, at least at the beginning of the growing period, when the exchangeable K is at a higher rate in the soil. At the end, K uptake is higher, when the available K in the soil is higher. For the levels 0.10–0.16 per thousand (1961) and 0.18–0.27 per thousand (1960), there is from another point of view, no relation

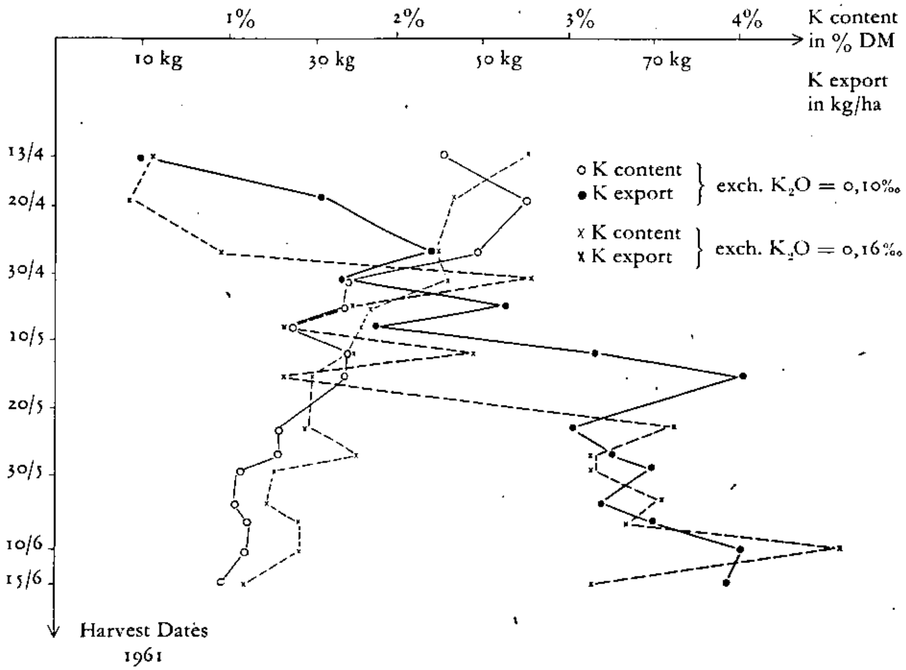

Figure 1

between dry matter production and K availability, even during a critical phase of growth such as a rapid growing period.

The same conclusions can be drawn from the data obtained on the following cuts, for the two years. (The cuts were taken every 6th week after the previous one, on the same plot.) The only general observation which could be done was that the K content of the grass harvested, and the K uptake expressed in kg/ha were always higher in the plots which had, at the beginning of the season, the higher level of exchangeable K. In addition, it seems reasonable to assume that the total consumption reached respectively in 1960, 263 and 348 kg/of K ha, and in 1961, 102 and 141 kg/of K ha, quantities which are correlated to dry matter production, mainly influenced by the climatic conditions of the two years on one side and the management system on the other. (The earlier the first cut the greater the total annual export if the other cuts were taken at similar intervals.)

Until now, we only took into consideration the total dry matter production irrespective of the botanical components; in fact, the cocksfoot, for these two years eliminated completely its "companion crop", the white clover. This could frequently be the case in any intensive pasture, and one of the first reasons is probably that the grasses generally have a very rapid spring growth, consequently a high need for K early in the season, whereas the white clover starts growth later, when a high quantity of available K has been exported. This is to add to the normal effect of competition, studied in detail by *Y. Coic* and *J. Bosquet (4)* in a pot experiment. But, under field conditions, and owing to the fact that cocksfoot, like *Poa pratensis* keeps an important part of its root-system effective after flowering, when the clover needs are at their maximum, the true effect of competition is maintained, even increased, if the climatic conditions in summer, and the type of management applied previously are favourable to the grass.

In 1960, the summer was wet, and we noticed that during the 5th growing period (July–August) following a spring cut after which the fertile tillers were eliminated early in the season, the average uptake of K, for a 6 week regrowth increased suddenly from 40–50 kg of K/ha to 80–90. Of course, this was very harmful to the remaining clover which is at a disadvantage, even in the absence of this supplementary stress of grass need (see the graph).

This observation was not available in 1961, when the summer was dry, but as complementary irrigation is extending now in every country, it seems that such a fact should lead to a revision of our actual conception about the need for splitting potash applications, as far as manurial treatments are able to induce an immediate increase of available K in the soil. In fact, from experimental data, *Barbier* concluded that this did not happen, at least at a satisfactory rate.

In conclusion, it seems that the best policy concerning K manuring of grassland is to supply a sufficient quantity of K, so that the exchangeable part of this element would not reach a critical level (determined for different soil types and different species by *K. J. Mac Naught (17)*, taking into account the high possibility of consumption from grasses, especially under pasture conditions.

Returns are probably important, but so irregularly distributed that the only way to prevent a shortage at any period of need in any part of a pasture is to supply a sufficient quantity of mineral manure on the total surface.

I should add that from a nutritional point of view, which was discussed by many people, if a normal supply of K is available for every grass species during the first

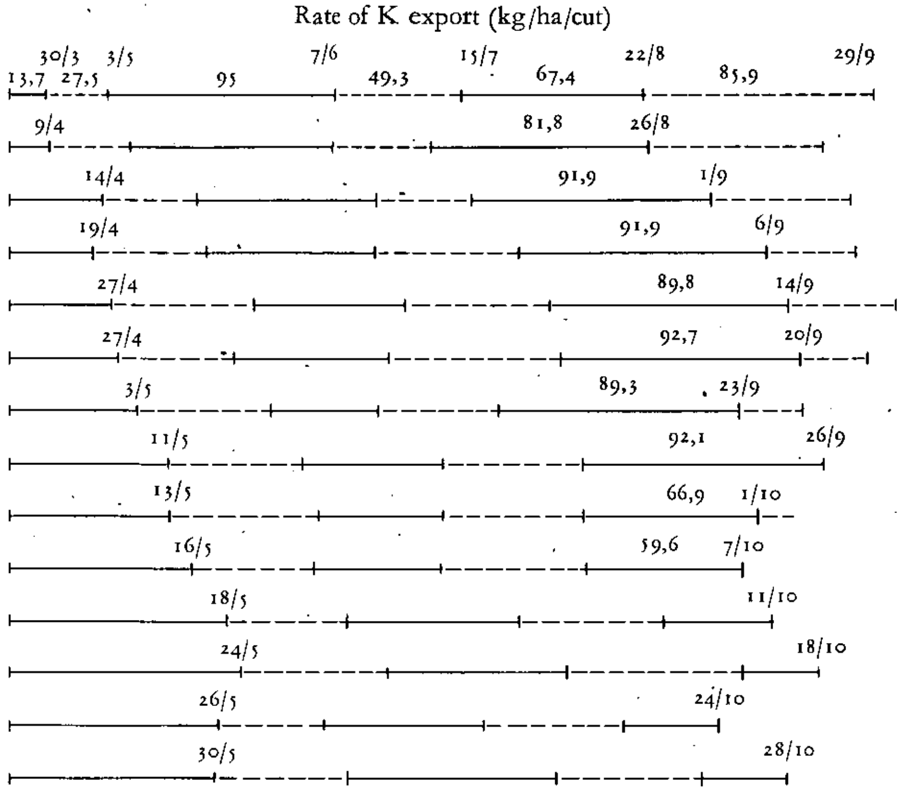

Figure 2 Cocksfoot - Var. Floréal.

Harvest 1960 - le Pin. au. Haras.

period of growth in the spring, the K content of the harvested grass decreases with the physiological age of this grass. It is always possible to prevent nutritional disorders of the grazing animal by managing the grass properly.

In addition, it could be interesting for the plant breeder to pay attention to the fact that significant differences in cation exchange capacity can be found within the same grass species, as pointed out by *Drouineau* and *D. Blanc (1)*. Taking into account this additional characteristic in their breeding programme, they would probably find some grass strains which could be a better companion crop for the clover, and/or white clover varieties which could support a strong nutritional competition from the grasses.

At the beginning of this report, I mentioned that this aspect of nutritional competition between the components of a grass-legume mixture could depend on the species themselves: I had in mind that lucerne for instance, a short time after its establishment in prospecting soil layers which are out of reach for grass roots. Of course the problem of available K for it is different in this case because, in addition, the two-thirds of the annual production of this species is harvested between June and the end of the season.

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The balance of uptake, utilization and accumulation of the major elements in grass

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Introductory

Extensive use has been made of analysis on mineral constituents in grass for the purpose of attaining more definiteness on their effect upon growth and quality for the grazing cattle. For this branch of grassland research that involves questions as to the uptake and utilization of soil elements by grass and their distribution over different plant species, a programme of greenhouse experiments was started with the idea of strengthening the approach to field problems by furnishing the fundamentals for generalizations in a more rapid and less expensive manner than could be attained by means of field experiments.

It is the purpose of the present paper to review the main results with regard to the uptake, utilization and accumulation of ions of the major elements and to arrange these data in a manner consistent with the electrochemical and biochemical aspects of ion translocation into and ion utilization by the growing plant. Much use is made of a domain of plant physiology concerning the role of organic acid synthesis and breakdown in response to ion accumulation that can be traced back to the days of Pfeffer and has been reinstated by the work of *Pucher (26)*, *Ulrich (31)*, *Burström (6)*, *Chouteau (8)*, *Dijkshoorn (16)* and others. It will be shown that balance obtained is useful to further considerations on the particular role of potassium when account is taken of the relative rates of uptake and redistribution of the cations by grass and other plant species.

A simplified balance of uptake, utilization and accumulation of potassium nitrate

Merely as an introduction to the more complex balance of uptake, utilization and accumulation of the different elements involved in normal growth, consider the comparatively simple case of a plant growing on a solution of the neutral salt potassium nitrate. Let the amount of available salt be 10 equivalents and let the nitrate be absorbed to complete exhaustion. The plant therefore contains 10 equivalents NO^{-}_{3}. It is known that NO^{-}_{3} is absorbed by grass in excess over K^{+}. When the uptake has established, let the amount of absorbed K^{+} be 5 equivalents, so that the plant contains 10 equivalents of NO^{-}_{3} and 5 equivalents of K^{+}.

Since the prerequisite for movement and uptake of ions is electroneutrality, the uptake of 10 equivalents nitrate and 5 equivalents potassium is associated with an uptake of 5 equivalents H^{+} ions. This uptake of H^{+} ions together with the salt ions means that the exhaustion of the solution also concerns H^+ supplied by the water. Its counter ion OH^- remains behind in the solution in association with the excess K^+ over NO^-_3.

Therefore, the residual salt in the solution contains 5 equivalents of titratable alkali and this is the physiological alkaline effect, associated with excess salt anion uptake over salt cation uptake and typical for nitrate nutrition of Gramineous and many other plants. Its presence is indicated by an increased pH of the sufficiently exhausted solution. In the presence of the soil system the increase of pH is far less pronounced because the residual OH^- becomes neutralized by H^+ desorbed by the adsorption of the excess salt cations over salt anions remaining in the soil solution *(Walker, 36)*.

The balance of uptake concerns 5 equivalents K^+, 5 equivalents H^+ (= the acidity of the uptake = the external alkaline effect) and 10 equivalents NO^-_3.

Assume that 8 equivalents of the nitrate absorbed are used up in the formation of organic N. This means a reduction of NO^-_3 to the reduction stage of ammonia and the ionic equation:

$$(N^{5+}O_3)^- + 8\,H^+ + 8\,e \rightarrow (N^{3-}H_3) + 2\,H_2O + OH^-$$

shows that in the metabolic reduction of nitrate its equivalent is transformed into a strongly basic OH^- ion. This means, here, that the utilization of nitrate liberates 8 equivalents of internal alkali.

The balance of uptake showed that the acidity of the uptake was 5 equivalents H^+. It is clear that this acidity neutralizes 5 equivalents of the internal alkali under the formation of water.

Thus, the balance of uptake and utilization indicates that what remains in the plant is 5 equivalents K^+, 3 equivalents OH^- and 2 equivalents NO^-_3. Instead of internal acidification by the acidic uptake, utilization of the nitrate in excess of the acidity absorbed tends to render the plant tissue more alkaline.

The following step is to convert the strongly basic OH^- anion into a less basic anion. The formation of HCO^-_3 by CO_2 addition reduces the alkalinity considerably, but the bicarbonate anion is still too basic to allow a common degree of accumulation without affecting the pH of the tissue too much. A second transformation into an anion which is less basic than bicarbonate is required and this is accomplished by metabolic carboxylation of bicarbonate leading to its transformation into an only slightly basic carboxyl function of one of the common organic anions, in grass mainly malate and citrate.

The result is that the internal alkali produced in nitrate utilization in excess of the acidity of the uptake is rendered harmless to the plant by its conversion into the practically neutral salts of the organic acids.

The final balance of ion accumulation shows the presence of 5 equivalents K^+, 2 equivalents NO^-_3 and 3 equivalents organic anions. This means that in ion accumulation the excess of salt cations over unchanged inorganic salt anions equals the amount of organic anions formed. In the present example, the amount of organic anions can be found by plant analysis on K and on NO_3 and subtracting the NO_3 equivalents from the K equivalents.

The balance of uptake

Plant analysis has shown that the major proportion of the total uptake by grass concerns the elements K, Na, Mg, Ca, Cl, P, S, N and Si. With a single exception, these elements are absorbed in the ionic state and for balance studies it is necessary to express the quantities involved as electrochemical equivalents.

Some difficulty may arise in choosing the correct valence for P and Si. However, this can be simply solved by taking into account the pH of the plant tissues. For *Gramineae* this is slightly on the acid side (pH 5 to 6) and therefore P should be expressed as $H_2PO^-_4$. Although on a weight basis there is considerable Si in grass, Si must be omitted from the balance, because silicic acid is a very weak acid with pK values of 10 and 12 so that silicate anions only occur in a medium more alkaline than pH about 9*. Apparently, Si passes into the plant in the non-ionic state, probably as a polyacid, which might be connected with its typical location in the peripheric tissues of the plant body.

The balance of uptake can therefore be made by conversion of plant analytical data on the cations, Cl, total N, total P and total S into the equivalents of their common ionic state at pH 5 to 6: K^+, NA^+, Mg^{++}, Ca^{++}, Cl^-, NO^-_3, $H_2PO^-_4$, $SO^=_4$, if the balance concerns the more common case of nitrate as the only source of nitrogen. Plant analysis has shown that, apart from artefacts, this balance covers 97 per cent of the total uptake of salt ions.

The next step is the addition of the equivalents of K, Na, Mg and Ca and considering the sum obtained as a single salt cation. Herewith, we have agreed to neglect the specific value of each of the cation species K, Na, etc. and have appreciated them all by one single property of being a salt cation. In the more simple case of potassium nitrate uptake it was pointed out that the deficit of K in the uptake is occupied by H^+ absorption. The common function of the above cations in the balance of uptake is also to prevent excessive H^+ uptake (compare also *Wadleigh, 35*). In this respect they are comparable because they form practically neutral salts with the inorganic and organic anions resulting from uptake and utilization.

To obtain the total of anion equivalents absorbed it is sufficient to add the equivalents of the anions mentioned above as representative for the ionic forms of uptake of Cl, N, P and S. Their common property is that they are the anions of neutral salts at the given conditions of uptake.

To show graphically the aspects of the ionic balance of uptake by *Lolium perenne* during its growth at two nitrate levels of supply consider figure 1. As the age increases, total nitrogen (N) becomes lower in both treatments in a similar fashion. In short, the line thus defined is the line of the effect of age on the utilization of nitrogen in growth and is independent of the treatment. It is not until the 28th day of growth that nitrate exhaustion is reached in the lower treatment (a) as evident from the sudden onset of a decline of NO_3 in the herbage. From there on total N declines at a more rapid rate because at exhaustion the uptake ceases and the amount absorbed is thenceforth diluted by further growth.

The proportion of salt cations (C) over salt anions (A+N) absorbed is shown in the lower graphs. It is seen that when the relative proportion of nitrate in the total

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* Its inclusion by *Bear (4)* and others rests upon a misconception of the properties of silicic acid and silicates. *Pucher et al. (26)* correctly omitted Si in the balance of ion accumulation.

uptake declines at the advance of age (log N declines more steeply than log C and log A) the proportion of salt cations relative to salt anions absorbed increases, which indicates that the acidity of the uptake becomes gradually lower. When nitrate uptake ceases, the further uptake exhibits a slight excess of salt cations over salt anions (log C declines less rapidly than log A) and their proportion increases more rapidly in the herbage.

It is seen, however, that the total uptake remains acid during the entire period and its acidity is given by the difference between absorbed anions (A+N) and absorbed salt cations (C). During early growth the balance shows an H+ uptake of about 2100 mEq/kg dry weight and its lowest value of about 600 mEq/kg dry weight is found at the latest date of harvesting with exhaustion of nitrate (fig. 1a). At the standard time of 28 days, used for re-growth in most of our experiments, N corresponds to 2700 mEq/kg and the H+ uptake to 1400 mEq/kg dry matter, in the absence of nitrate exhaustion and at moderate Cl supply.

The balance of utilization

In terms of the balance-sheet, utilization should be regarded as the conversion of a salt ion into some form of chemical combination which is non-ionic.

A portion of the cations absorbed is subject to complex formation (e.g. Mg in chlorophyll), adsorption by structural configurations (Ca in phosphatides, pectates, etc.) or formation of insoluble salts (e.g. Ca oxalate). This binding may concern their specific physiological functions for growth, but the plants' use of the cations is not associated with a change of their ionic valance. Therefore, there is no utilization of salt cations in the present sense. There is, however, utilization of the H+ ions because they loose their ionic state during neutralization by the internal alkali production.

Among the anions, phosphate becomes involved in the metabolism by partial esterification. Although at normal phosphate levels there is an appreciable proportion present as free orthophosphate in the herbage, at low levels more than 50 per cent is involved in organic linkage (fig. 2). However, this form of combination does not affect its ionic state, because the first acidic function of phosphoric acid determines the ionic state of phosphate at the pH of the tissues and this is not involved in the esterification, when the small change in pK^1 is neglected. Therefore, there is no utilization of phosphate.

Utilization in the present sense occurs only with nitrate and sulphate. As long as growth proceeds, a considerable portion of these anions is reduced by the metabolism to organic N and organic S, and they cease to exist as anions. Electroneutrality requires that this process liberates their equivalents as other anions and the ionic equations of their reduction:

$$(N^{5+}O_3)^- + 8\,H \rightarrow (N^{3-}H_3) + 2\,H_2O + OH^- \text{ and}$$

$$(S^{6+}O_4)^= + 8\,H \rightarrow (S^{2-}H_2) + 2\,H_2O + 2OH^-$$

show that their utilization in the metabolism liberates the equivalent amount of the strongly basic OH− anion *(Dijkshoorn, 13)*.

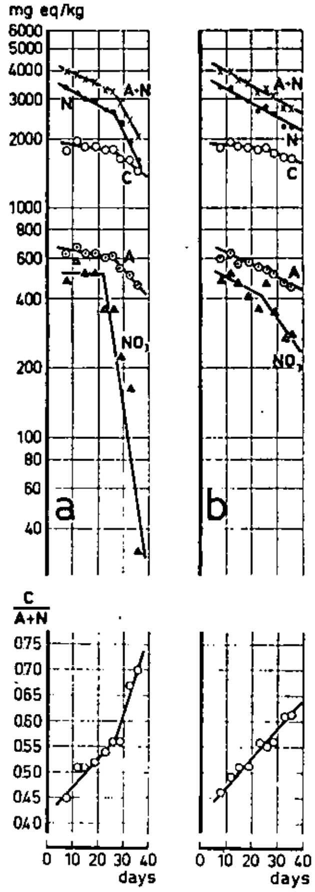

Figure 1

Figure 1 Salt cations (C = K + Na + Mg + Ca), elements absorbed as anions (A = Cl + P + S, and N and A + N) and of accumulated NO^{-3}, in me. per kg dry matter produced, plotted against the time in days of re-growth at lower (a) and at higher (b) nitrate supply. Pot experiment with *Lolium perenne (Dijkshoorn, 10)*

Figure 2 Total phosphorus (P_t), TCA-soluble phosphorus (P_s), TCA- insoluble phosphorus (P_p) and free inorganic orthophosphate (P_i) in microgramatoms P per gram dry matter of herbage of *Lolium perenne,* grown at varying P levels *(Dijkshoorn* and *Lampe, 15)*

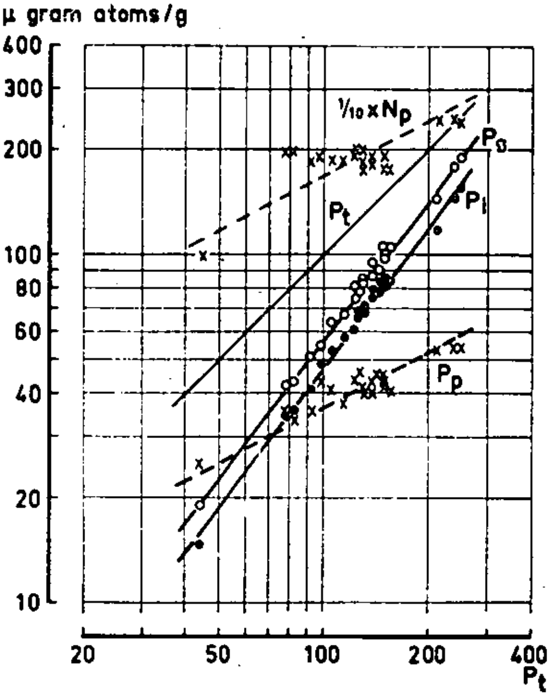

Figure 2

This means that the internal alkali produced equals organic N + organic S expressed as their equivalents of NO^-_3 and $SO^=_4$

For assessing the balance of utilization we have investigated the utilization of nitrate and sulphate, by growing *Lolium perenne* on solutions of various equivalent proportions of nitrate and sulphate and otherwise constant ionic composition. Analysis of the protein fraction showed that proteinization of sulphate and nitrate occurs in a constant proportion of 0.027 moles S per mole N. Herbage analysis showed that the same proportion holds for total organic S and total organic N (fig. 3 and 4).

The conversion of this relationship to equivalents gives that organic S is found by multiplying organic N by 0.054. The excess of total sulphur over organic sulphur, as found by herbage analysis on total S, is unchanged inorganic sulphate. Its absence indicates sulphur shortage.

Other investigations have shown that the non-protein N is made up of NO^-_3 and of organic nitrogenous compounds. Only when nitrate exhaustion occurred at some stage of previous growth, NO^-_3 is low or absent.

For balance work the ion utilizaton and internal alkali production is computed from data on total Kjeldahl N, obtained by the use of a method which includes all nitrate nitrogen, and on nitrate. Organic N is found by difference and organic S by the use of the proportionality factor* and the values are added to calculate the internal alkali production.

Hitherto, uptake and utilization have been regarded as discrete steps. Actually, of course, there is a ceaseless interplay between the acidity of the uptake and the alkaline utilization and it can be assumed that the latter is a condition to the progress of acid uptake with excess salt anions over salt cations. In the absence of utilization the acidic uptake cannot proceed without excessive internal acidification or breakdown of carboxylates. It is of interest to note in this connection that the acidity of the uptake declines when at the advance of age less N is utilized per each kg of dry matter produced. Also it was found that after nitrate exhaustion uptake continues with an excess of salt cations over salt anions (fig. 1) which means that the uptake has become alkaline and the external effect reversed from alkaline to acid (compare e.g. *Wander* and *Sites, 37*).

The balance of accumulation

A complete balance for herbage of 4 weeks re-growth is given in figure 5.

It is very similar to the balance found after 28 days in the time of re-growth series of figure 1, made under comparable conditions of season (summer in greenhouse) and nutrition (adequate at low Cl). It is seen that salt cations and salt anions were absorbed with an acidity of the uptake of 1.4 equivalents H^+ per kg dry matter, while anion utilization indicates the liberation of 2.5 equivalents internal alkali. Accordingly, the excess internal alkali was 1.1 equivalents per kg dry matter.

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* Errors due to lack of precision of this factor 0,054 are small relative to the errors involved in the balance. Its use is preferable to neglecting S-assimilation (*Pierce* and *Appleman,* 25) or to the arbitrary assumption that 0,7 of total S remains unutilized (*Pucher et al., 26*).

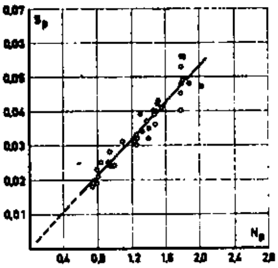

Figure 3 Protein-sulphur and protein-nitrogen in gramatoms per kg dry weight of herbage of *Lolium perenne,* grown at varying sulphate and nitrate supply *(Dijkshoorn et al., 17)*

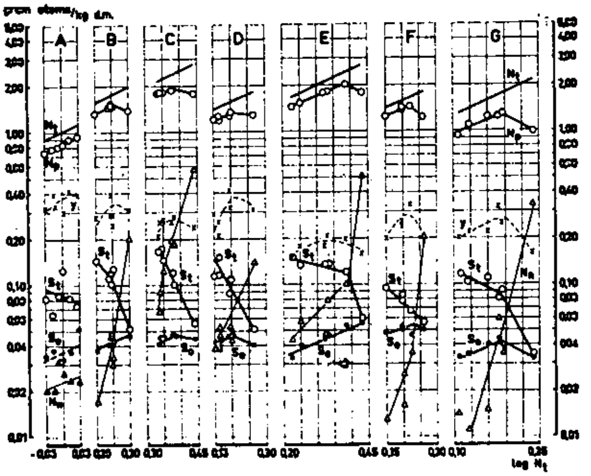

Figure 4 Total nitrogen (N_t), protein-nitrogen (N_p), nitrate-nitrogen (N_n), total sulphur (S_t) and organic sulphur (S_0) in gramatoms N or S per kg dry weight of herbage of *Lolium perenne* grown on solutions of varying nitrate-sulphate proportions and otherwise constant ionic supply *(Dijkshoorn et al., 17)*

The final balance of accumulation is 1.8 equivalents salt cations, 3.2—2.5 = 0.7 salt anions (Cl^- + total P as $H_2PO^-_4$ or $RHPO^-_4$ + inorganic $SO^=_4$ + inorganic NO^-_3) and the difference 1.8—0.7 = 1.1 equivalents of organic anions per kg dry matter.

This implies the complete neutralization of the excess internal alkalinity by its transformation into organic anions, either by carboxylation reactions or by its complete neutralization by organic acid molecules formed in the metabolism. Neutralization is here used in the loose sense that each equivalent of the excess internal alkalinity is destroyed by an equivalent H^+ resulting from the synthesis of an equivalent of organic acid molecules. This concept is more simple than that of carboxylation reactions (direct transformation of HCO^-_3 into $RCOO^-$) and the numerical result for the balance is the same. For the present purpose, the choice between these mechanisms is what suits the convenience.

At this point it is advisable to review briefly the evidence for considering this complete neutralization as a condition to normal growth.

From experiments of *Martin (22,23)*, *Leuthart (21)*, *Hurd-Karrer (18)* and others it can be inferred that the buffer capacity (equivalents of H^+ or OH^- required to change the pH by one unit) is only 0.02 per litre of sap which is less than 0.2 equivalents per kg dry matter. It is only in the more acid range of pH 3 to 5 that the buffer capacity increases considerably due to the presence of organic acids capable of buffering in this region *(Böning* and *Böning-Seubert, 2; Rombeck, 28)*. It was found that the actual pH of the plant sap is little dependent on the treatment *(Arnon, 1)*.

Also the buffer capacity in the region pH 5 to 7 is unaffected by the treatment, but in the more acid range there is a large effect of treatment on the buffer capacity *(Böning* and *Böning-Seubert, 2)*, showing alterations which agree with changes in the organic anions to be expected from the shifts of the balance of accumulation. This, and much other evidence, shows that the organic anions do act as a regulatory unit in a way better defined as neutralization than as buffering. They serve to the neutralization of in the order of 1 equivalent excess internal alkali at a buffer capacity of only about 0.2 equivalents per kg dry material.

Hurd-Karrer (18) found that proteins play little or no part in the buffer system. Compare also *Chibnall* and *Grover (7)*. This can be expected, because their density of ionic charge is low and, with the acidic formulation of ionization, pK's are about 2.4 and 9.

According to *Martin (22, 23)* the buffer capacity in the range pH 5 to 7 is mainly due to the phosphates. As an illustration figure 6 shows titration curves of the ash of grass grown at ample P supply. This result shows that the buffer capacity due to phosphate is only 0.02 equivalents per kg dry matter between pH 5 and 6, and 0.08 between 6 and 7.

As shown above, there must be practically complete transformation of the excess internal alkalinity into the salts of organic anions, to prevent any excessive rise of the internal pH. The number of equivalents of organic anions formed follows directly from the balance of accumulation, if the internal pH remains unchanged. There is often little point in attempts to apply a separate determination of the organic acids, because difficulties are sometimes involved in their complete

Balance-sheet of uptake and utilization by Lolium perenne L, eq./kg d.m.	
uptake	
cations K+Na+Mg+Ca	1.8
anions NO_3+Cl+H_2PO_4+SO_4	3.2
H^+	1.4
utilization	
cations K+Na+Mg+Ca	0
anions nitrate	2.4
sulphate	0.1
chloride	0.
phosphate	0
final state	
metabolic alkali HCO_3^-	2.5
acidity uptake H^+	1.4
excess internal alkalinity	1.1
organic anions (malate etc.)	1.1
cations - inorganic anions	1.1 $= C^+ - A^-$

Figure 5 Balance sheet of herbage of *Lolium perenne* of 4 weeks re-growth at adequate nutrition low Cl level in the soil, natural light under greenhouse conditions in the summer, as a closed crop in pots *(Dijkshoorn, 13)*

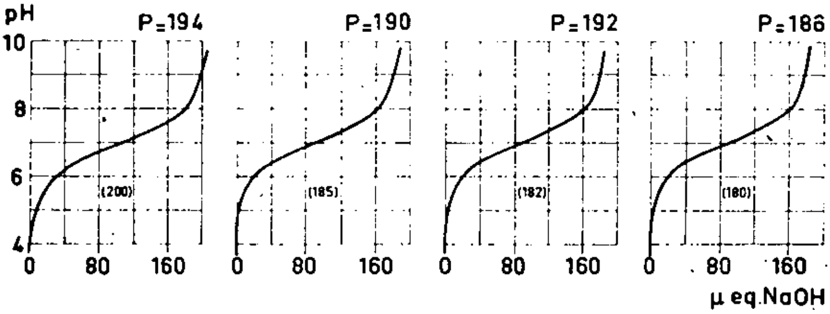

Figure 6 Titration curves of the ash of 1 gram dry matter of *Lolium perenne* grown at ample phosphorus supply *(Dijkshoorn* and *Lampe, 15)*

recovery by extraction. For *Lolium perenne* we were able to recover the complete fraction as the water-soluble, non-volatile organic acids and to achieve their separation by partition chromatography on silica gel (fig. 7). *Pierce* and *Appleman (25)* were able to recover the acids from a number of plant species by ether extraction of the acidified material in amounts very near to the quantities predicted by the balance of ion accumulation.

The above examples on the balance of *Lolium perenne* all yielded an organic anion content very near to 1 equivalent per kg dry material, independent of age (fig. 1) or treatment (fig. 8). A further examination of the results indicated that the nutrition was always adequate with the only exception that nitrogen was somewhat short at the lower fertilization levels.

Thus, in spite of a larger variation in the acidity of the uptake and in utilization of nitrate and sulphate (internal alkali production) the plants appeared to maintain their organic anion content at the same level.

From this we have acquired a certain affection for considering this value as essential to normal, optimal growth. It was found that lower values occurred only when there was more severe N shortage or K shortage, when the plants accumulated excessive amounts of Cl or when NH_4 was utilized instead of nitrate, all conditions leading to less vigorous growth. Before continuing on this line we have to consider briefly the selectivity of the plant in ion uptake.

The effect of ion selectivity of the plant

The balance of accumulation indicates the presence of inorganic cations $K^+ + Na^+ + Mg^{++} + Ca^{++} = C^+$ and of inorganic anions $Cl^- + H_2PO^-_4 + SO^=_4 + NO_3^- = A^-$ and the difference $C^+ — A^- =$ organic anions. They were only considered as the ions of neutral salts, which can accumulate without affecting the internal pH. Further, experience has shown a tendency to maintain the organic anion value approximately constant under varying conditions of supply and age when nutrition remains adequate.

Given a certain anion uptake and accumulation and varying proportions of cation supply there must be a tendency toward a constant total salt cation content which reminds of the older theorem of "cation constancy" of *Van Itallie (33)*. Further, at varying anion uptake and accumulation, there must be a variation of total salt cations in a similar sense, which recalls Bear's postulate on "constancy of the cation-anion ratio" *(Kretschmer et al., 19)*.

The ability of the plant to substitute K for Na, Mg, Ca or Mg for K, Na, Ca, etc., if each of these cations is replaced by another cation in the supply, for their common function to reduce the acidity of the uptake is seen in figure 8, which shows that at the increase of nitrate uptake and accumulation, total cations C increases in a similar fashion independent of the varying proportions in which the individual cations are absorbed.

It is seen that application of the nitrates of K and Na makes those cations increase in the herbage in proportion to the extra demand for total cations. However, when Mg or Ca is supplied, there is also an increase in Na and in the divalent cation not supplied of which both are available in constant amount. Apparently the divalents

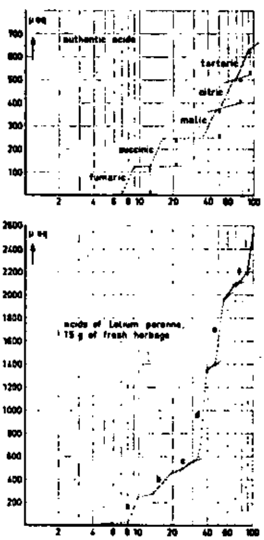

Figure 7 Partition chromatogram of the water-soluble, non-volatile organic acids of *Lolium perenne*, after previous isolation and separation from ozalic acid on exchange columns *(Dijkshoorn* and *Lampe 16)*

Figure 8 Pot experiment with *Lolium perenne* and *Dactylis glomerata*, conducted under the conditions of figure 5. The nitrates of K, Na, Mg and Ca were applied to the soil at rates from nil to 40 mEq per pot *(abscissae)*, nitrogen fully adequate at the highest rate of application (compare fig. 1). For explanation of symbols see figure 1 *(Said 29)*

Figure 7

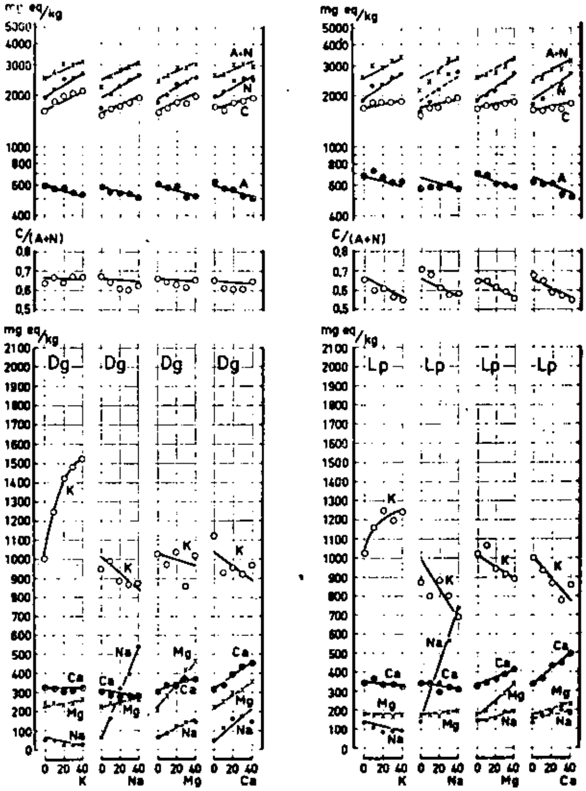

Figure 8

supplied are not absorbed at a sufficient rate relative to growth and the increase of the cation demand so that more of the other cations of constant supply are taken up to prevent an increase of the deficit in salt cation relative to salt anion accumulation. This reflects the selectivity of the grasses in cation uptake.

For both grass species and for *Plantago lanceolata* the selectivity for the cations was examined by re-growth on solutions of varying proportions of two cations and otherwise constant ionic supply (fig. 9). It is seen that replacement in the solution leads to substitution in the herbage, but its degree of completeness depends on the plant species and on the two cations compared. In the dicotylodenous herb *Plantago lanceolata* there is practically complete substitution and, within the experimental error, it is concluded that this species does not discriminate between the four cations studied, there is no selectivity. The grasses show a pronounced preference for the monovalent cations as apparent from the much steeper gradients and within the monovalents *Lolium perenne* is not selective while *Dactylis glomerata* absorbs Na with more difficulty than K. Also for the divalent cations the latter species shows selectivity while *Lolium perenne* absorbs Mg and Ca at a comparable rate. This is also reflected in the cationic composition of the two species when grown side by side in one experiment. *Dactylis* is lower in Ca and Na but higher in Mg and mostly it is higher in K because Ca and Na are absorbed with relatively more difficulty and, therefore, the cation demand is completed by the uptake of more K which is the most easily absorbed.

In the foregoing sections the salt cations were considered as operative in a similar way: the prevention of excessive H+ uptake and the formation of neutral salts with the inorganic and organic anions resulting from uptake and utilization.

Here, plant selectivity comes to the fore making the plants discriminate between the cations according to their relative rate of uptake. The prevention of H+ uptake required that uptake and translocation of the salt cations proceed at a rate sufficiently large to keep up with the growth and requirements for H+ exclusion.

The selectivity of the grasses indicates that K is mostly superior in this respect, because it is absorbed more rapidly than Na and the divalents.

If sufficient K is replaced by a less mobile cation, e.g. Ca, in the supply, salt cation uptake may fall short, excessive H+ uptake may result and, when the balance of utilization and accumulation of anions remains unchanged, the organic anion content may become depressed. This condition prevails in the experiment of figure 10 which shows reduced growth, increased H+ uptake and (as calculated from the balance of accumulation) reduced organic anion contents when K is replaced by Ca in the fertilizer. It is seen that K drops to lower values when Ca-nitrate is supplied (which is due to dilution by the increased growth), but K remains above the level of specific K shortage associated with ill-conditioned plants, which is 200 mEq K per kg dry weight. There was reduced growth but the appearance remained healthy.

This is a common aspect of the effect of increasing the K supply beyond the specific requirements for growth. Although at moderate K supply the plant is able to substitute other cations for K, sufficient exclusion of H+ uptake for optimal growth may be attained and the plants, although healthy in appearance, show a further response in growth when additional K supply relieves the stress on the balance of accumulation by a further exclusion of excessive H+ uptake and raising the organic anion content to a more normal level for optimal growth.

Figure 9 Effect of equivalent replacement of cations in the nutrient solution on their equivalent substitution in the herbage of *Lolium perenne* (L$_p$), *Dactylis glomerata* (D$_g$) and *Plantago Lanceolata* (L$_p$). *Abscissae:* subdivision in mEq per litre, increase of supply indicated by arrows *(Said 29)*

Figure 10 Effect of nitrates of *K* and of Ca (*abscissae:* mEq per pot of 5 kg soil) on per cent d.m. in fresh material (% d.m.), yield (g dm per pot) and composition of herbage of *Dactylis glomerata*, re-growth at initially low K level *(Said 29)*

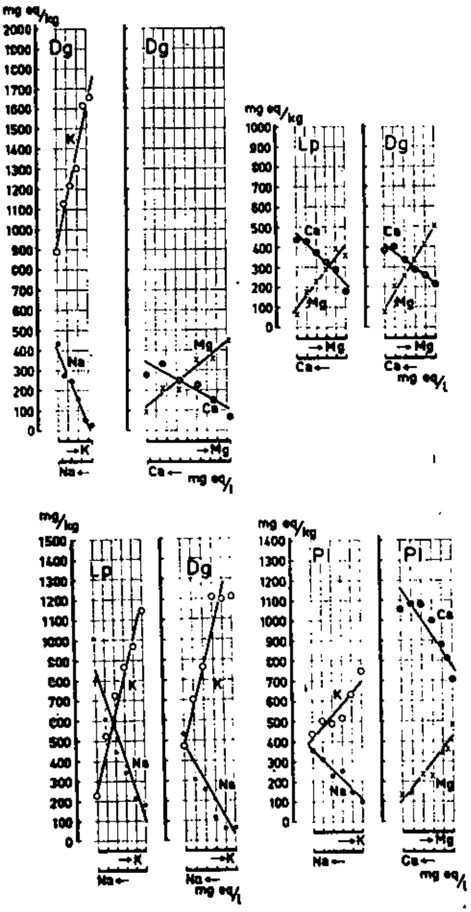

Figure 9

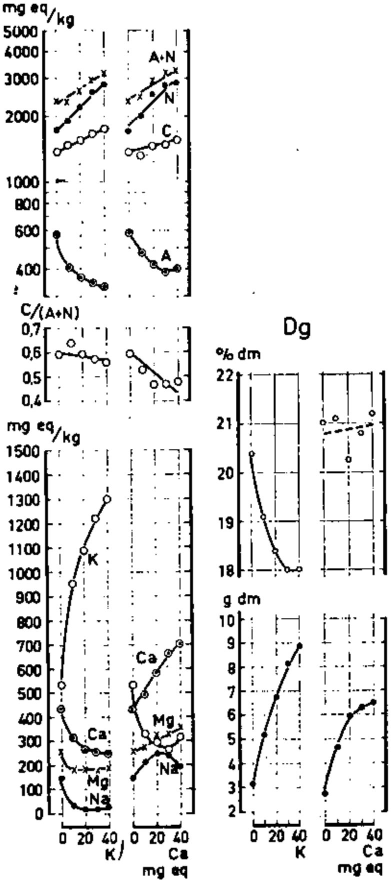

Figure 10

Substituting other cations for K

It has been shown before that, when K is moderately reduced in the supply, the plant can maintain its balance by increasing the uptake of other cations of constant supply. At low K, *Dactylis glomerata* was apparently unable to substitute Ca for K at a sufficient rate and the uptake became more acid at reduced growth and low organic anions content. The question remains, what happens if K is replaced by a cation with the same rate of uptake, that is, complete equivalent substitution in the herbage, as e.g. Na in *Lolium perenne* or any other cation in *Plantago lanceolata*. We might expect that in this case H^+ uptake and organic anion content remains unaffected, even when K falls to lower levels in the plant.

Actually, it is found that in this case the balance of accumulation is often shifted to an increased salt cation content relative to inorganic anions and the organic anion content is apparently increased to above the normal value with a reduction of the growth.

This aspect came also to our attention through the work of *Böning* and *Böning-Seubert (2), Vladirimov (34), Chouteau (8)* and others, who invariably found that K shortage induces a higher organic anion content in tobacco. The data of *Chouteau* make it clear that Ca substitutes for K in excess so that at K shortage the salt cations are relatively increased. A similar effect for barley of substituting Na for K is shown in figure 11, the data are from *Lehr* and *Wybenga (20)*. Here the situation is very similar.to our finding on the effect of Na for K substitution at low K levels in *Lolium perenne*. It should be stressed that in these cases the yield was always markedly reduced by replacing K in the supply, although its substitution in the herbage by the other cation occurred in excess.

Apparently, these cases refer to conditions where the selectivity of the plant allows a complete internal substitution, but there results a congestion of alkalinity or organic anions in the tops, because the downward translocation of excess alkalinity or organic salts cannot proceed at an adequate rate, probably because the cation used for substituting K, although sufficiently translocated upward, cannot be transported downward at an adequate rate for accompanying excess alkalinity produced in the shoots and removed by subsequent downward transport through the phloem, back to roots. At present it seems that the interpretation of these effects and the particular role of K for regulation of the balance of accumulation involves the possible rate of internal circulation in the plant. Although Ca in tobacco and Na in barley may substitute K very effectively in the total plant material, data on their distribution over different plant parts indicate their lower mobility in translocation when compared with K.

Anion induced cation shortage

The accumulation balance relates the difference between salt cations and accumulated inorganic salt anions, including total phosphorus: $C^+ \dot{-} A^-$, to the accumulation of organic anions.

The effect of replacement of anions in the supply in *Lolium perenne* is shown in figure 12. It is seen that when Cl is replaced by H_2PO_4 in the supply, there is only partial substitution of Cl by H_2PO_4 in the herbage and if H_2PO_4 is replaced by $SO^=_4$

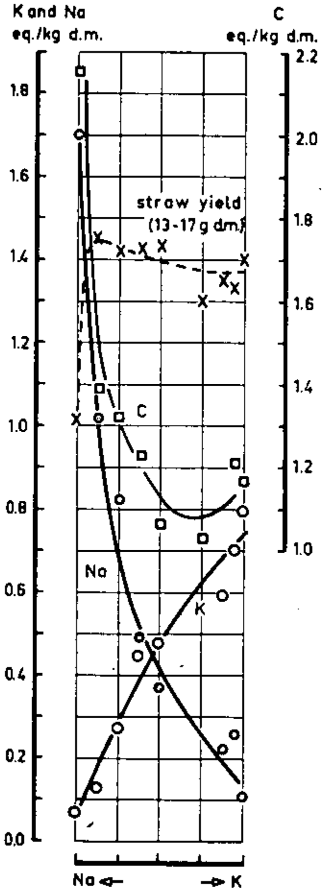

Figure 11

Figure 11 Effect of replacing K by Na in the supply on K, Na and total cations (C) in the straw of barley. Yield in 10 grams units of dry material *(Lehr* and *Wybenga 20)*

Figure 12 Effect of equivalent replacement of Cl— by H_2PO-_4 and of H_2PO-_4 by $SO=_4$ in the nutrient solution on their substitution in the herbage. *Abscissae:* mEq per litre supplied *(Dijkshoorn, 12)*

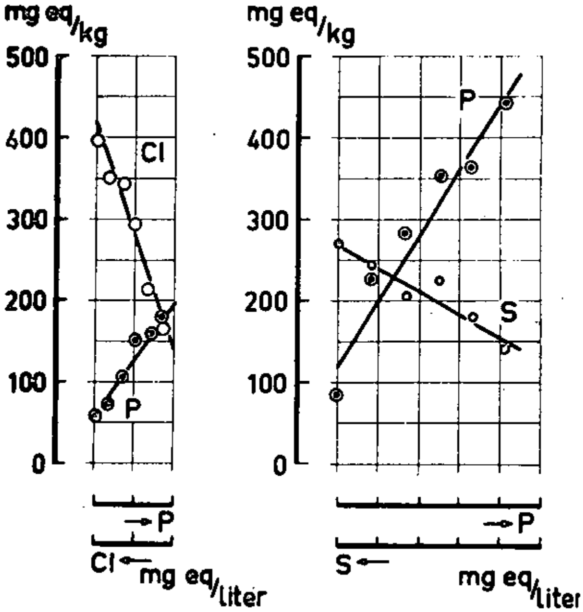

Figure 12

in the supply $SO^{=}_4$ substitutes H_2PO_4 only partially in the herbage. The order of decreasing relative rate of uptake is $Cl^- > H_2PO^-_4 > SO^{=}_4$. Further, it is known that NO^-_3 may accumulate to about 0.5 equivalents (fig. 1) prior to exhaustion and Cl may increase to about 1 equivalent per kg dry material when supplied in pot experiments without leaching.

Therefore, the greatest increase in A^- occurs when Cl is supplied in the fertilizer or when nitrate-exhausted plants are made to accumulate NO^-_3 subsequent application of nitrate.

A typical example of nitrate-induced cation demand is shown in figure 13. The experiment was made in connection with observations on an increased grass tetany frequency in grazing cattle following a rise of temperature in the spring. It is seen that transference of the plants during the re-growth from 10 to 20° C induced at first a rapid decline of nitrate in the herbage due to increased utilization. There is, however, a gradual building up of the nitrate accumulation level during the next ten days and this covers 0.3 equivalents of accumulated nitrate. Associated with this increase total salt cations C also increases by 0.3 equivalents per kg dry herbage. An examination of the data showed that the organic anions (C^+—A^-) remained unchanged for all temperature treatments and times of re-growth, at about 1 equivalent, that is the normal value. Here, the response to the increase of accumulated anions is a corresponding increase in cations at constant organic anion content. Due to plant selectivity the absolute increase was greatest for K which was high in the supply, and the herbage became higher in K relative to the other cations when compared with the constant temperature treatments or with the treatment with transfer to the lower temperature. *(Dijkshoorn* and *'t Hart, 14.)*

Generally the application of Cl in the fertilizer tends to increase the level of accumulated anions and this is mostly associated with an increased cation content *(Dijkshoorn* and *'t Hart, 14; Dijkshoorn, 11, 12)*. However, the balance of accumulation showed that increased Cl was not completely compensated by the increase in cations, so that the organic anions (C^+—A^-) declined more or less to below the normal value. Hitherto, we were unable to directly relate these findings with reduced growth, probably because the total yield of herbage is not so sensitive to more moderate changes in the actual rate of growth following unbalanced nutrition as indicated by sampling at the date of harvesting.

The lowering of organic anions in intact plants by Cl supply has been demonstrated by *Ratner* and *Akimochkina (27)* with sugar beets fed with either a K-clay or with KCl. The effect was also observed in tobacco by *Böning* and *Böning-Seubert (2)*.

An increased demand for K has been found to be associated with higher Cl levels. *Boresch (3)* mentioned that the chlorine toxicity symptoms in strawberry are difficult to distinguish from K deficiency and that its occurence depends on K relative to Cl rather than on the absolute K content. Very similar conditions were reported for citrus by *Cooper* and *Gorton (9)* and for beans by *Buchner (5)*. *Buchner* also mentions increased internal acidity due to high Cl in potato and states that the inability to neutralize organic acids inhibits starch breakdown in the leaves and the translocation of the intermediates to the tubers.

Of course, internal acidification is not a condition sine qua non for excessive anion accumulation. The pathway of synthesis of organic acids by carboxylation in the presence of excess internal alkalinity becomes reversed by excess internal acidity resulting from accumulation of excess unutilized salt anions over salt

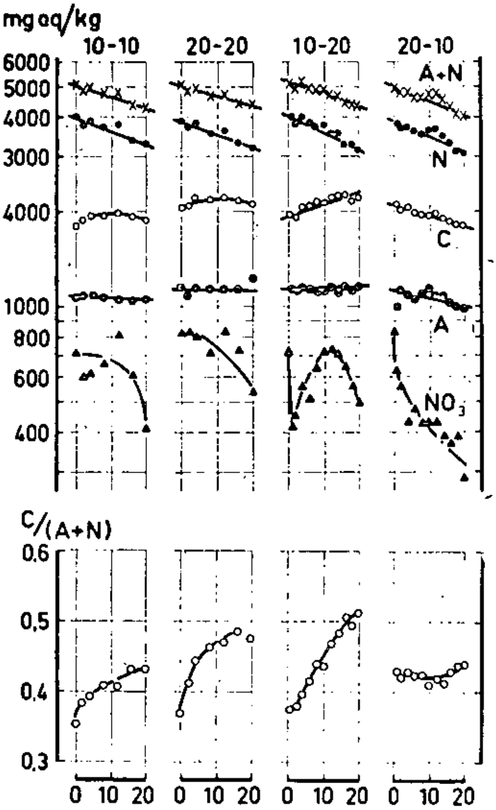

Figure 13 Composition of *Lolium perenne* grown at 10° C, at 20° C, after transference from 10 to 20° C and after transference from 20 to 10° C. *Abscissae:* time in days after transference. Periodic harvesting, first harvest occurred 11 days after the beginning of re-growth and is indicated as zero time of age. Records are given of total cations (C = K + Na + Mg + Ca), total nitrogen (N), non-nitrogenous anions (A = Cl + P + S), total anions (A + N), nitrate (NO_3) and the ratio of salt cations to salt anions in the uptake – C/(A + N) – in mEq per kg of dry herbage of the ionic forms supplied *(Said 29)*

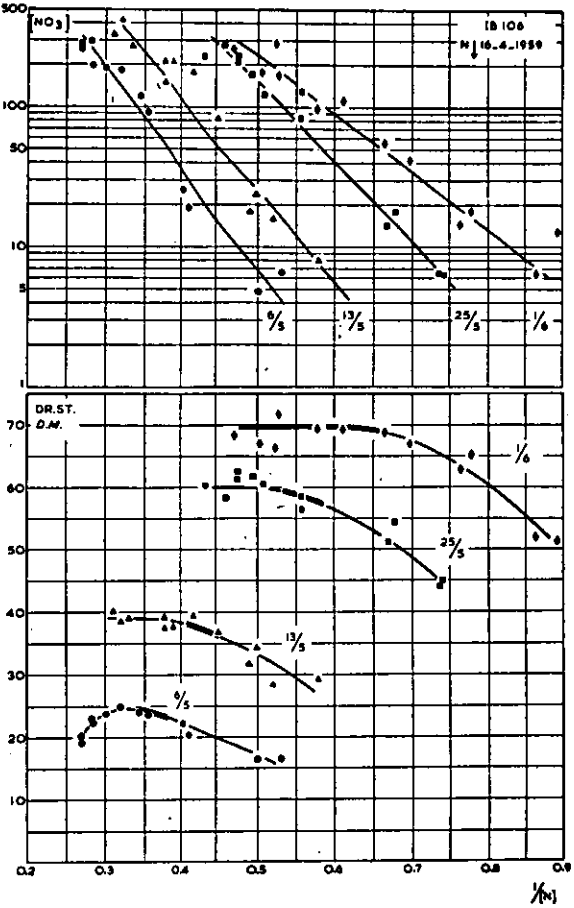

Figure 14 Upper graph: relation between mEq NO_3 per kg of dry herbage (ordinates) and kg dry herbage produced per gramatom of N absorbed (*abscissae,* reciprocals of N content in gramatoms of N per kg dry matter) in grass of different cutting dates grown after the application of varying rates of N on April 16. Lower graph: the corresponding yields in units of 100 kg dry matter per ha.

For each cutting date 1/N decreases and NO_3 in the herbage increases as a result of increasing the rate of N application (direction of the lines). Cutting at a later date shifts the line to higher 1/N levels and to higher yields (position of the lines), because at more advanced age less N is utilized per kg dry matter and growth has continued over a longer period. The highest yields occur if NO_3 is present beyond a level of about 50 mEq per kg dry herbage, indicating adequate supply up to the date of cutting.

Field experiment of the Institute for Soil Fertility, Groningen, the Netherlands *(Van Burg 32).*

cations, and the decarboxylation liberates alkalinity in the form of HCO^{-}_3 that neutralizes the internal acidity. When this neutralization proceeds to completion, the internal pH remains the same, the only effect is that organic anions are used up for the production of sufficient internal alkali (compare also *Ulrich, 31* and *Burström, 6*).

Unbalanced salt ion accumulation with reduced organic anion contents may also be expected at higher internal levels of unutilized nitrate at ample nitrate supply, because in the accumulated state nitrate and chloride must act in a similar way. The only difference is that nitrate exhaustion, when reached in a further stage of growth, leads to complete metabolic consumption so that nitrate disappears rapidly and the stress on the organic anion content is relieved. In the case of chloride exhaustion there is only dilution by growth and the stress on the balance of accumulation disappears less rapidly.

In pot experiments with grass we failed to detect growth inhibition at high internal nitrate levels. Improved growth was always obtained through the effect of better nitrate supply associated with this condition. To this comes the fact that sufficient utilization of nitrate favours the synthesis of organic anions by the metabolism *(Böning* and *Böning-Seubert, 2; Chouteau, 8; Dijkshoorn, 16,* and *others).* However, the pot experiments of *Sorensen* (1959) with oats show that reduced growth occurred at the highest N level applied while this effect disappeared in a later stage of growth when nitrate had declined from 0.5 to 0.04 equivalents per kg dry material.

The predominance of the improving effect of nitrate utilization over the inhibiting effect of nitrate accumulation due to unbalance of ion accumulation in grass is also shown by the results of *Van Burg (32)* on the effect on time of growth at different N levels in the field. Figure 14 shows that growth reduction due to excessive N application only occured in the youngest cut, but this effect may have originated from fertilizer salt damage to the sward.

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Mineral elements in pasture plants

Changes in content with advancing maturity with special reference to potassium

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Introduction

The mineral element content of herbage at different stages of maturity is a subject of obvious importance and has been dealt with by many workers including *Thomas et al. (7)*, *Oyenuga (6)*, *Gueguen* and *Fauconneau (4)*, *Van Riper* and *Smith (8)* and *Featherstone et al. (3)*. In this country, work in this direction has been undertaken on mixed swards, but the data on pure species are as yet somewhat limited. In an effort to obtain further information in this sphere an experiment was undertaken on four common grasses and two clovers. The results of the experiment are presented in this paper.

Experimental

Soil description

The soil is a grey brown podzolic, well drained, with a sandy loam to loam texture down to 13". Below this the texture is that of a clay loam. The structure is weak, subangular, blocky in the surface, but tending to prismatic in the subsurface. Parent material is boulder clay of predominantly limestone composition. General analytical data for the top 13" are as follows: pH 6.2; Ca 1800; P 2 and K 43. (The nutrient figures are in ppm and extraction was by Morgan's reagent).

Experimental layout, manuring and sampling

Four grasses and two clovers were sown *singly* in plots each 1 sq perch in area, in a randomised block layout with three replications. The grasses were cocksfoot (S. 143), timothy (S. 48), perennial ryegrass (Irish commercial) and rough stalked meadow grass. The clovers sown were white (S. 100) and red (late-flowering Montgomery). Basal manuring was as follows: 4 cwt superphosphate, 2 cwt muriate of potash and 2 cwt calcium ammonium nitrate per acre. Clovers received only phosphate and potash. For the grasses, cuttings were made at five growth stages, the first out taking place when the plants were approximately 5" high and the last cut at early maturity i.e. when the seed head had formed. In the case of timothy, however, head formation was only commencing at the time of the last sampling. Cutting dates were as follows: Cut 1 11.4.1962; Cut 2 3.5.1962; Cut 3 29.5.1962; Cut 4 14.6.1962 and Cut 5 28.6.1962. At the time of "Cut 1" no clovers were taken as the plants were only barely overground. Cutting was carried out with an Allen motor mower and for each successive cutting the mower was moved across the plots one cut width (3'). It is to be emphasised that at no time was any regrowth taken. From each well-mixed swathe a sample was drawn by hand. The samples were dried in an air oven at 80° C and ground in a Christy & Norris mill.

Analyses

Ca, K and Na were determined by flamephotometer and N by the standard Kjeldahl procedure. P and Mg were determined colorimetrically using ammonium molybdate and brilliant yellow respectively. All analyses are quoted on an oven-dry basis.

Results

A covariance analysis was carried out to determine (a) if there was a significant variation of the elements K, Mg, Na, Ca, P and N with stage of growth and (b) whether the equation describing it varied with the species. The relation appeared to be curvilinear, so linear and quadratic terms were included in the regression. The data were presented to an Elliot 803 computer in the form of seven columns. These were the six elements in question and, "days from first cut". The data were subdivided into groups according to species. Analysis was done by An Foras Talúntais Computer Programme L2.

Potassium

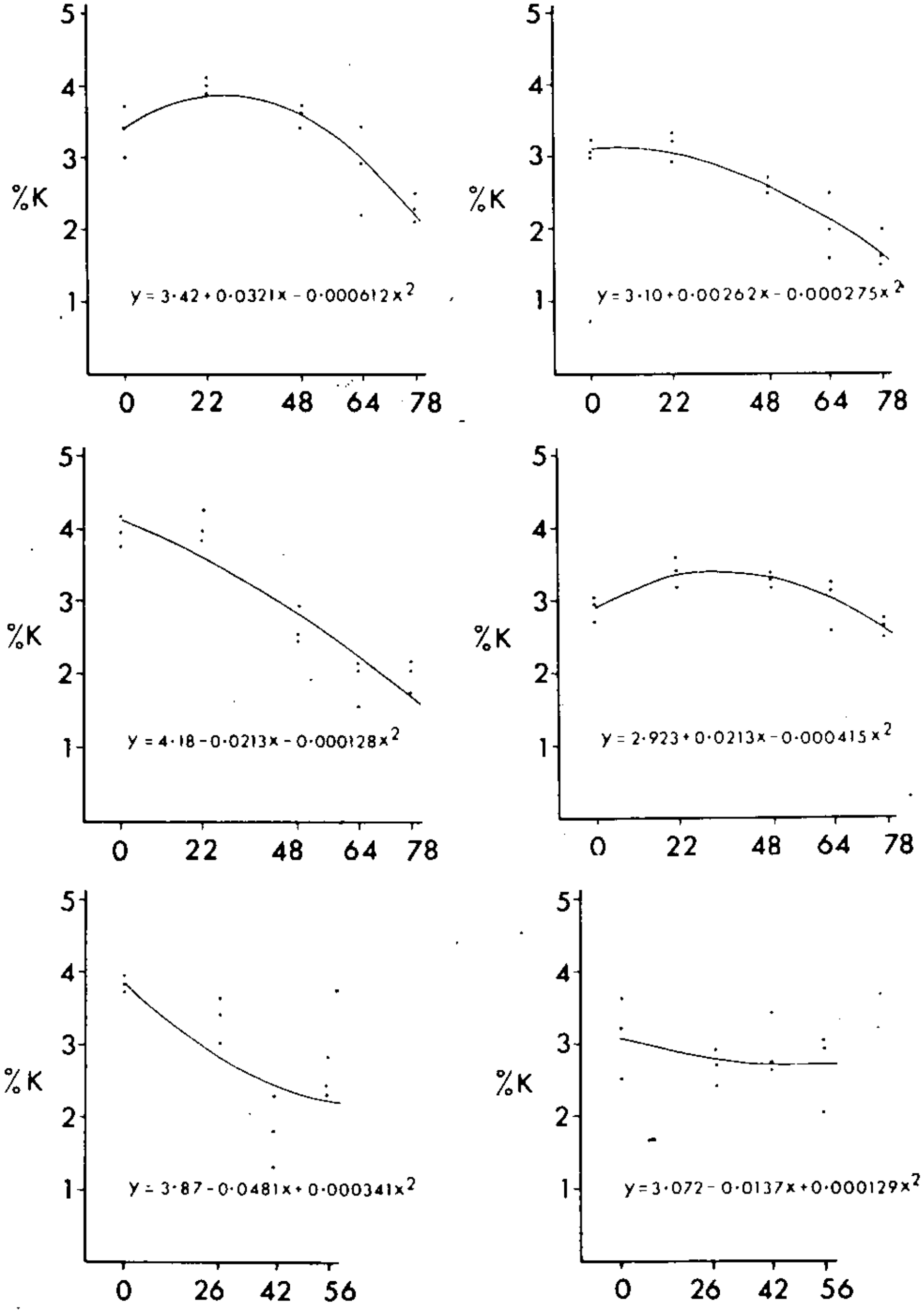
The relationship between K content and stage of growth is illustrated in figures 1–6, and was found to be significant for cocksfoot, perennial ryegrass and rough stalked meadow grass but not so for timothy or the clovers. Between the species the relationship varies significantly (P = 1 per cent) as shown by the different shapes of the regression lines.

In Table 1 are shown the potassium values found in the different species together with the seasonal average values. It is worthy of note that with one exception (perennial ryegrass) all these figures are very close at a level of approxi-

Table 1 Potassium in grasses and clovers (results as per cent on oven dry matter)

Species	Cut					Seasonal average
	1	2	3	4	5	
Cocksfoot	3.4	4.0	3.6	2.8	2.6	3.3
Perennial ryegrass	3.1	3.1	2.6	2.0	1.7	2.5
Rough stalked meadow grass	4.0	4.1	2.7	1.9	2.0	2.9
Timothy	2.9	3.4	3.3	3.0	2.7	3.1
Red clover	—	3.9	3.3	1.8	2.5	2.9
White clover	—	3.1	2.7	2.9	2.9	2.9

Potassium regression curves for individual species



mately 3 per cent. With regard to the grasses one interesting possibility suggests itself, viz. the ability of cocksfoot and rough stalked meadow grass to absorb relatively large quantities of potassium. That timothy is able to do this has been demonstrated by *Drake* and *Searseth (1)* who have pointed out that this grass is capable of absorbing up to three times as much potassium as is shown to be exchangeable by standard base exchange techniques. While it would be hazardous to suggest that because a grass can absorb relatively large amounts of potassium when in ample supply, it can do so under less favourable conditions, nevertheless the ability of cocksfoot and rough stalked meadow grass to extract non-exchangeable potassium would certainly appear to be worthy of investigation.

With regard to the clovers, it is seen that while the seasonal average values are equal, white clover retains relatively steady values with advancing maturity but red clover does not. In this respect white clover resembles timothy.

The question of luxury consumption of potassium by herbage under Irish conditions has been dealt with by *Walsh* and *co-workers (10, 11)*. Contents of 1.8 per cent K in dry matter for cocksfoot and 2.0 per cent for S. 100 white clover are put forward as luxury threshold values but it is pointed out that these values are considerably lower than those of Holland and Denmark, where a figure in the region of 2.5 per cent appears to obtain. Inspection of the potassium levels shown in the tables reveals that for cocksfoot and white clover the potassium values are higher than the luxury threshold values set by *Walsh at all stages of growth examined.* While quantitative data on other species under Irish conditions are not available it would not appear unreasonable to suppose that – with the possible exception of the June cuts for perennial ryegrass and rough stalked meadow grass – all other potassium values are above luxury threshold levels. It is obvious, however, that further work is necessary before luxury threshold values can be assigned to species not covered by *Walsh.*

Other elements

Covariance analysis was also performed on the other elements and the results are discussed below. Chemical analysis figures are shown in Tables 2 (grasses) and 3 (clovers).

Magnesium

Only cocksfoot and timothy showed significant regression and the difference between the regression equations of the six species was significant.

With the exception of the first cut, the magnesium contents of the grasses are not high. This is not unexpected, however, as the potassium contents are on the whole quite high and the antagonistic effect of this element on magnesium is well known *(9)*. Of particular interest, however, is the fact that the change in Mg content with advancing maturity was found to be significant only for cocksfoot and timothy. *Featherstone et al. (3)* in a similar study to ours but in a mixed sward recorded magnesium figures as being relatively stable over the season "deviating only slightly from an average around 0.25 per cent MgO" (0.15 per cent Mg). Seasonal stability of magnesium is also commented on by *Jacob (5)*. *Thomas et al. (7)* examined eight grass species of different stages of maturity for a variety of

Table 2 Changes in mineral content with advancing maturity – grasses (results as per cent on oven dry matter)

Species	Cut	Mg	Na	Ca	P	N
Cocksfoot *(Dactylis glomerata)*	1	.27	.20	.85	.50	4.6
	2	.16	.29	.63	.40	3.1
	3	.16	.34	.53	.32	1.8
	4	.16	.36	.59	.29	1.5
	5	.16	.34	.59	.22	1.4
	Seasonal average	.18	.30	.64	.35	2.5
Perennial ryegrass *(Lolium perenne)*	1	.27	.34	.80	.50	4.7
	2	.19	.42	.72	.37	2.9
	3	.14	.30	.50	.28	1.5
	4	.17	.30	.44	.26	1.3
	5	.15	.27	.40	.22	1.1
	Seasonal average	.18	.33	.57	.33	2.3
R. S. meadow grass *(Poa trivialis)*	1	.26	.17	.85	.53	4.6
	2	.18	.13	.70	.47	2.8
	3	.17	.11	.45	.33	1.8
	4	.16	.10	.40	.28	1.6
	5	.15	.10	.45	.27	1.4
	Seasonal average	.18	.12	.57	.38	2.4
Timothy *(Phleum pratense)*	1	.21	.10	.70	.53	4.6
	2	.15	.06	.55	.44	3.1
	3	.12	.07	.60	.36	2.1
	4	.11	.06	.50	.30	1.7
	5	.13	.06	.45	.27	1.5
	Seasonal average	.14	.07	.56	.38	2.6

Table 3 Changes in mineral content with advancing maturity – clovers (results as per cent on oven dry matter)

Species	Cut	Mg	Na	Ca	P	N
Red clover	1	—	—	—	—	—
	2	.36	.12	1.5	.45	4.7
	3	.38	.15	1.6	.36	3.4
	4	.31	.20	1.5	.27	2.7
	5	.32	.20	1.4	.26	2.6
	Seasonal average	.34	.17	1.5	.34	3.4
White clover	1	—	—	—	—	—
	2	.20	.30	1.4	.47	5.3
	3	.22	.41	1.6	.38	4.3
	4	.29	.45	1.6	.40	4.1
	5	.23	.46	1.4	.35	3.9
	Seasonal average	.24	.41	1.5	.40	4.4

elements. For magnesium, negative correlation coefficients were obtained for seven species. For four species (red fescue, tall fescue, meadow fescue and timothy) these correlation coefficients were significant at the 5 per cent level. One species (cocksfoot) showed an increase of magnesium with maturity but the positive correlation coefficient of 0.02 was not significant. These workers concluded that there was "a general tendency for magnesium decline with advancing maturity".

The magnesium seasonal averages of the clovers are greater than those of the grasses. This is not surprising, however, in view of the well known ability of dicots with their greater root cation exchange capacities to absorb divalent cations more readily than monocots *(2)*. A similar effect is noticeable with calcium. It is also noteworthy that red clover has absorbed much more magnesium than white clover at all stages of growth. Reference to the average values over the growing period shows red clover to have approximately 50 per cent more magnesium.

Sodium

Of the individual regression equations only that for rough stalked meadow grass was significant. The difference between the regression equations of the six species was also significant and this is illustrated by the seasonal trends shown in Table 2. With cocksfoot, for instance, the sodium content increases for the greater part of the growing season while with perennial ryegrass it increases at first and then appears to level out. With rough stalked meadow grass, on the other hand, an initial decline in sodium content is followed by a levelling out. With timothy the sodium values appear to stay level after the first cut. *Thomas et al. (7)* also provide sodium figures for cocksfoot, perennial ryegrass and timothy. These workers state that these grasses in general show a declining sodium content with advancing maturity.

The clovers, like cocksfoot, show an increase in sodium with age. It is to be noted, however, that the sodium values for white clover greatly exceed those for red clover. Taking average values over the season the ratio between Na values in white and red clover is approximately 2.5 to 1. This increase in sodium was also noted by *Thomas et al. (7)* for alsike, lucerne and sanfoin.

With regard to the seasonal average values for sodium it is seen that cocksfoot and perennial ryegrass are highest, rough stalked meadow grass is intermediate and timothy is lowest. These figures are interesting in the light of *Lehr's* findings *(12)*. This worker rates the capacity of the above mentioned grasses to absorb sodium as follows: perennial ryegrass "fairly good", cocksfoot and rough stalked meadow grass "fair" and timothy "poor".

Calcium and phosphorus

For calcium, only perennial ryegrass and rough stalked meadow grass showed significant regressions. For phosphorus, however, all species except white clover showed a highly significant regression. For each element the difference between the regression equations was significant.

The figures of Table 2 show cocksfoot to have the highest seasonal average for calcium while the other three grasses have lower but very similar values. Both clovers have identical seasonal averages (Table 3). In the case of phosphorus rough stalked meadow grass and timothy have the highest seasonal averages; cocksfoot comes next and perennial ryegrass is lowest. The value for white clover is considerably higher than that for red clover.

The calcium-phosphorus ratios are shown in Table 4 and it is seen that for the grasses the values with one exception fall in the relatively narrow range of 1.3 to 2.0. With the clovers the spread is larger. *Featherstone et al. (3)* also comment on this ratio and have noted that while there was a gradual decline in both elements with advancing maturity the Ca/P ratio did not change substantially.

Table 4 Calcium-phosphorus ratios

Species	Cut				
	1	2	3	4	5
Cooksfoot	1.7	1.6	1.6	2.0	2.7
Perennial grass	1.6	1.9	1.8	1.5	1.8
R. S. meadow grass	1.6	1.5	1.4	1.4	1.7
Timothy	1.3	1.3	1.7	1.7	1.7
Red clover	—	3.2	4.3	5.5	5.2
White clover	—	3.0	4.3	4.0	4.0

Nitrogen

All grasses showed very highly significant ($P = 0.1$ per cent) and clovers significant ($P = 5$ per cent) regressions. The difference between the individual regression equations was very highly significant ($P = 0.1$ per cent).

In all cases the grasses show decreasing contents of nitrogen as the season progresses.

The nitrogen contents of the clovers are quite high, white clover particularly so, while the overall decline in nitrogen content is also less apparent in these species.

Summary

1. The changes in mineral element content at different stages of maturity was determined for six pasture species during the period April to June 1962.
2. Curvilinear regression equations for the elements under study were obtained for each species. The regression equations for each species were found to be significantly different.
3. Particular attention was paid to potassium and values higher than those normally associated with luxury consumption were obtained at all stages of growth for cocksfoot and white clover.
4. For magnesium, changes in content were found to be significant only for cocksfoot and timothy.
5. The sodium content of white clover was at all times higher than that of red clover and these species together with cocksfoot showed an increase of this element with advancing maturity.
6. With the exception of red clover the calcium-phosphorus ratios fell within a relatively narrow range.
7. All species showed decreasing nitrogen contents with advance in maturity.

Acknowledgements

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General principles governing the potassium manuring of grassland

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Introduction

The amounts of potassium (K) fertilizer needed by *arable crops* are usually determined by field experiments which test the effects of increasing dressings of K on yield; from their results "optimum" dressings which return most profit are calculated, and the conclusions are extended to other areas by using soil analysis to modify them to fit local conditions. The K fertilizer needed by herbage crops that are harvested by regular cutting can be estimated in the same way. But most grass is harvested by cattle and determining fertilizer requirements is then difficult; the usual technique of clipping samples before grazing gives only an approximate measure of the true value of the yield to stock because grazing is selective and the amount that will be eaten is uncertain.

Most grazed fields grow mixtures of grasses and legumes; grazing management and manuring both affect the composition of the sward and alter the amount of N contributed directly or indirectly by clovers to the grass. Plant nutrients returned through animal excreta help to feed the herbage but the immediate value of excreta is greatly lessened by its irregular distribution, by losses of ammonia to the air, and its full effect may never be achieved because of luxury uptake.

In manuring both arable crops and conserved herbage crops, we plan to produce most yield per acre at least cost per unit of produce through optimum manuring; this is possible because we know the approximate cash value of the crop to be harvested. But grass for grazing has no value until eaten by stock. Management and manuring systems that do not achieve maximum growth of grass per acre in a year may ultimately prove more profitable if they are reliable and easier to manage; few grassland farmers achieve near maximum yields of grazed grass, most prefer to retain some flexibility in managing their pasture so that they can regulate growth to suit the needs of their stock. Producing grass of good quality that provides extra grazing at the beginning and end of the season, and in periods in summer when growth is normally poor, may be more profitable than manuring which simply raises total annual production. Grass is the cheapest feed for cattle and costs of production are least when it is used to provide *grazing* for as long as possible, both hand-feeding of conserved herbage, and purchases of concentrates, being minimised. All these facts make it impossible to plan grassland manuring in the ways that we are accustomed to do for arable crops.

Potassium used by herbage crops

Some approximate average amounts of K in a year's growth of herbage of the kinds produced in England are in Table 1. Once in the herbage the K is "at risk"; if returned through excreta to the sward it can be useful in producing more grass, but in "cut and carry" systems of conservation the K is lost to the field where the grass was grown.

Table 1 Approximate amounts of potassium in one year's growth of English herbage crops (all data are in lb/acre)

	N manuring	Common yield	Total K_2O in 1 year's growth
Grass-clover herbage for grazing			
East England	35	3000	90
West England	35	5000	140
Herbage for cutting			
Grass-clover ley	130	6500	220
Ryegrass or cocksfoot	280	9000	280
Lucerne	0	7000	180

The yield of most grassland in humid climates is governed by the N that is available to the crop. Therefore the K in herbage crops is also proportional to the N supply to the sward. This fact gives an easy way of planning the K manuring of pure stands of grass that are regularly manured with N, the crop needs about the same weight of K_2O as of N in a year if no allowance is made for K supplied by soil or returned in excreta. With grass-clover mixtures yield is still proportional to N supply even though most comes from the clover and Table 1 indicates how much K such herbage may contain. When grass is grazed it is difficult for farmers to estimate yields, but "numbers of grazing days" can be used to make a good guess of the weight of herbage produced and therefore of the K it contains.

With heavy N manuring to grass alone, or with *vigorous* grass-clover swards in the warmer and wetter parts of these islands, the 150–250 lb K_2O/acre taken up by a good crop is a severe drain on reserves of soil K. A K-rich soil may contain 15 mg of exchangeable K/100 g; a poor soil may have only 5 mg K/100 g. As the difference of 10 mg is equivalent to 200 lb of K/acre in the top 6 inches of soil, grass liberally fertilized with nitrogen can, in a single year, convert a soil rich in K into a poor one. In practice, however, most soils with much total K release some from non-exchangeable forms; "available" K which has been depleted in these soils by a season's cropping usually "recovers" to a value near to the original by the following spring.

Although grass takes up much K, it has not given worthwhile responses to K manuring in many field experiments on soils known to contain too little K for full yields of arable crops. Thus *Widdowson et al. (20)* showed that potato yields were more than doubled by K dressings which increased yields of permanent grass growing on the same soil by only 12 per cent. It seems that grass is able to make much better use of reserves of soil K than many arable crops can, and in alternate husbandry systems it is necessary to ensure that crops after grass do not suffer from K-deficiency. Where grass does not respond to K, advisors must decide whether K reserves in soil should be depleted continuously to provide for the grass, no K manuring being given, or whether fertilizer dressings should be recommended to maintain "available" soil K at constant levels.

In addition to plannning K dressings so that *crop yields are not reduced* by K-deficiency (and that soil reserves of K are not depleted if this policy is adopted), unnecessarily high dressings must be avoided. Grass that is well supplied with K takes up more than is needed to produce the yield ("luxury uptake"); this is at best wasteful as it raises the total amount of K "at risk" in the crop. High levels of K uptake by grass increase the possibility of hypomagnesaemia occurring where this disorder is a risk to stock. *Kemp (11)* has suggested that hypomagnesaemia is more likely when stock graze herbage with more than about 3.0 per cent in dry matter.

Hay crops

Until about 1950 most British experiments that measured the effects of fertilizers on yield of grassland were with hay, and some were on silage cuts. In 1954 *Boyd and Lessells (1)* summarised the older experiments on cut grass; they found that average returns from 56 lb K_2O/acre were about 280 lb of dry matter/acre. Their summary however gives no information on NK interactions or on the effect of K dressings on subsequent productivity of the sward. Recently in Welsh experiments *Jones (10)* obtained 560 lb of extra dry matter/acre by giving 112 lb K_2O/acre for hay cuts on heavy soils, the increase was 950 lb on light soils. On free-draining soils dressings given between November and April were equally good, but in high rainfall areas on soils with impeded drainage spring dressings were best.

Older recommendations for manuring hay or silage cuts advised a dressing of one or more nutrients for the particular crop. This policy is sound for inorganic N fertilizers as they are emphemeral in grassland soils and leave no residues; nitrogen fertilizers should be given when the field is closed to adjust subsequent yield to the level desired. Soil K potential is usually highest in spring and, if K is to be applied to replace that lost in the hay, there are good arguments for applying it *after* the hay is removed particularly on soils that are not very low in K. Not only will the dressing be applied *after* the serious drain on K reserves imposed by rapidly-growing herbage (which may yield 50 cwt of dry matter/acre), but fresh dressing in summer will help the clover which is usually checked by taking hay. The effect of taking hay or silage crops on the K balance in the whole cutting and grazing sequence should therefore be considered when planning the K manuring of grassland.

Herbage grown for continuous cutting

Up to dressings totalling 250-300 lb N/acre in a year yields of grasses grown alone are directly proportional to the N supplied. Many experiments show the amounts of K in the crop harvested to be roughly equal to the weight of N applied; if manuring is planned to conserve soil K at least as much as this must be supplied. Several papers (a few are discussed below) have described NK interactions in grassland manuring and have shown how much K must be used to maintain continuous cutting systems. Most of these workers used N heavily and made no special attempts to maintain clover in the herbage where it had been sown.

Scotland

Reith et al (14) worked with leys of ryegrass, timothy and clover which were cut continuously for 3 years. Response to N fertilizer depended on adequate K fertilizer and there were large NK interactions. With adequate K the return from 1 lb of N was 15 lb dry matter; without K the return was only 10 lb of dry matter. Where no more than 100 lb N/acre/year was used increases in yield from K dressings were small (about 550 lb/acre) and there were no NK interactions. With about 350 lb N/acre used in the year yield was increased by K by about 1 ton of dry matter/acre and the N response was greatly increased by K dressings. The authors suggested that where N is used heavily on grass cut continuously for conservation 1 lb of K_2O should be used for each lb of N applied.

Castle and *Holmes (3)* reported the last 6 years' results of a 12-year experiment which showed that grass dressed heavily with N, and cut continuously, only yielded well where K was supplied. Without N fertilizer the original grass-clover sward yielded 5460 lb dry matter/acre without K and, in fact, did not respond to K. When 260 lb N/acre/year was given 6410 lb of dry matter was produced without K fertilizer and the swards were of poorer grasses; this amount of N together with K fertilizer gave vigorous swards of productive species of grasses producing 8420 lb/acre. When 520 lb N/acre was used each year yield was only 6210 lb of dry matter without K, but rose to 10:180 lb with adequate K. Soils receiving 400 lb/acre of K_2O/year were "high" in soluble K at the end of the experiment; those with only 200 lb K_2O/acre were "low" in soluble K at the end but yielded as well as those receiving more K. The authors suggested that as little potash as is needed to maintain yield should be used – "applications which are less than full replacement requirements may maintain yields for a considerable period". Applying 1 lb K_2O for each 2.5 lb N used was enough to maintain yield but these dressings allowed soil K reserves to be depleted.

Hemingway (6) tested 280 lb N/acre/year applied in portions before each cut for a grass-clover sward cut continuously, the herbage became grass alone where N was used. Approximate total yields over 3 years were:

	O	K	N	NK
Dry matter, lb/acre	12000	14000	20000	24500

With this N level 135 lb K_2O/acre was not enough and there was a good response to doubling the dressing. Exchangeable K values in the soil fell seriously where no K fertilizer was given, but were nearly maintained by 270 lb K_2O/acre. *Hemingway (6)* calculated that 3.8 mg K/100 g of soil of non-exchangeable K was released when N alone was applied and 1.9 mg when NK fertilizer was used. His work also showed that equal weights of N and K_2O are needed to maintain yield and K level in soil under cut herbage.

England

Widdowson et al. (21) tested 130, 270 and 400 lb N/acre/year, divided and given to Italian ryegrass before each of 4 cuts. The experiment lasted 4 years. The best level of N was 270 lb N/acre and with this the total yield over 4 years was about 34000 lb of dry grass/acre. Significant increases in yield from K fertilizer were only obtained at the beginning of the third year when the site had been ploughed and resown; the new crop responded well, but later K dressings in the third and fourth years had little effect on yield. When 67 lb N/acre/cut was given applying 67 lb K_2O increased yield only by 1450 lb (total of 4 years); this extra dry matter had removed 280 lb more K_2O/acre and soluble K in the soil rose during the 4 years. Giving 33 lb/acre of K_2O for each cut maintained soluble soil K at the original level throughout the period. So to maintain soluble K in soil a fertilizer ratio of $N:K_2O$ of 2:1 was needed. The extra 1450 lb of dry matter/acre was not enough to pay for the potash and the only justification for K manuring was to maintain soil K reserves. When 67 lb/acre of N was given for each cut the soil provided about 230 lb K_2O/acre/year and there was no indication that rate of release fell off in the later years, although acid-soluble K became very low. This figure is much greater than the rate of release in *Hemingway's (6)* experiments.

America

In quite different conditions *Holt* and *Fisher (8)* tested up to 1600 lb N/acre/year on Coastal bermuda grass for 6 years. This subtropical grass responds to very high rates of N and produces a large bulk of forage; 800 lb N/acre produced about 10 tons of dry matter/acre. They found that fertilizers with $N:P_2O_5:K_2O$ ratios of 5:1:2 maintained uniform levels of P and K in the soil. *Jackson et al. (9)* concluded that a $N:P_2O_5:K_2O$ fertilizer ratio of 4:1:2 would maintain both output of cut grass and soil fertility in similar conditions.

Herbage grown for grazing

The amounts of fertilizer K needed by grazed grass depend on the reserves of K in the soil and on type of herbage and its management. They are more difficult to assess by field experiments than are the K needs of herbage that is cut continuously. The effects of excreta on the sward complicate both P and K manuring. The K returned through urine is *not* a uniform return of most of the K removed from the soil by the crop. Because excreta fall on patches that constitute only a small proportion of the area of a field, some parts receive far too much K, but most of the sward receives none in any one season. Urine and dung patches also make the soil irregular in soluble P and K and upset the interpretation of soil analysis.

Indifferent pastures of mixed herbage yielding about 3500 lb of dry matter a year, such as are common over much of the east, south and adjoining midland areas of England, may contain about 100 lb K_2O in a year's growth; good pastures in the better grassland districts can yield 5000 lb of dry matter/acre/year with little or no N fertilizer; the herbage may contain 140 lb K_2O/acre. With sheep, store or beef cattle grazing continuously in one field, 90 per cent or more of the K will be returned *to the field* and, on a long term view, little extra K may be needed to maintain the system. Dairy cattle that graze a pasture for part of the day only will *remove* much of the K in the feed they eat; this K may be *transferred* to night paddocks or, if stock are housed, it will be *lost* when excreta are voided indoors.

Potassium in excreta

In Scotland *Herriot et al. (7)* found that in 3 years grazing sheep returned a total of 390 lb K_2O/acre; 45 lb were in dung and 345 lb in urine.

In New Zealand *Davies et al. (4)* estimated that one cow excretes about 180 lb K_2O/year. Of the total intake of K by dairy stock (1689 grams K per cow per week), 10 per cent was lost in milk and "residual intake", 10 per cent was in faeces and 80 per cent in urine. On average 2.2 litres of urine covering 2 sq ft were produced 10 times a day. The urine contained 0.78 per cent K and the concentration in a patch was about 900 lb/acre of K_2O. Dung patches covered 0.75 sq ft and 12 were dropped in a day, 8 per cent of the pasture being covered in a year; concentration in the dung patch was 300 lb K_2O/acre. Another New Zealand estimate by *Saunders* and *Metson (16)* was that only one-quarter of the total area of a pasture receives urine in one year with stocking equivalent to 0.75 cow/acre.

In USA *Petersen et al. (13)* estimated that mature cattle produce 56 lb faeces and 20 lb urine/day containing 0.22 per cent K_2O and 1.15 per cent K_2O respectively. They estimated that single applications cover 1 sq ft with faeces and 3 sq ft with urine. Local rates within excreta patches were:

	From faeces lb/acre	From urine lb/acre
N	760	400
P_2O_5	350	11
K_2O	440	430

At the Hannah Institute in Scotland *MacLusky (12)* estimated that fold-grazed dairy cows returned nutrients in faeces and urine to affect half of the pasture after 250 days of grazing; the whole area of a pasture received a dose of excreta once in 3 years. (There will however be a longer gap between successive doses of the K-rich urine, perhaps as long as 6 years.)

After receiving a dressing of urine grasses are immediately stimulated by the N it contains. The extra grass growth depresses clovers but these may benefit later from the high K concentration in the patch when the N effect is finished.

Between the patches herbage must use K that comes from soil or fertilizer for several years and, on soils low in K, fertilizer K will have to be used at much higher rates than would be needed if the K returned through excreta were uniformly applied.

Losses of potassium in grazing

Over a period of years, with continuous grazing, theoretically only the K lost in animal products needs to be replaced. *Davies et al. (4)* estimate that for dairy cattle this amounts to 10 per cent of the K intake or 22 lb K_2O/acre/year on high-yielding pasture. Better New Zealand pastures may produce 10000 lb dry matter/acre each year and this can contain 300–350 lb K_2O. *During (5)* considered that 20–30 per cent of the total turnover of K by grazing stock may be lost in gateways, beside hedges, in milking sheds, and by leaching. He stated that responses to K in New Zealand were not limited to poor sands and pumice soils but also occurred quite extensively on some of the good soils of the famous Waikato dairying area. He estimated that 2 million acres of New Zealand now need K fertilizers but that 5 million acres are likely to need K in future. No estimates of losses of K have been made when grazing is by sheep, but they are not likely to be as severe as with dairy cattle since a greater number graze per acre, excreta patches are more numerous, and sheep are not usually removed from a field until the grass is eaten. In experiments at Rothamsted and Woburn quite small yearly dressings, about 20–30 lb K_2O/acre, have been enough to maintain soil K levels where leys were grazed by sheep *(Warren, Johnston, 17)*.

The high concentration of N and K in urine patches has many disadvantages. It upsets the balance of the sward, leads to irregular growth and to "luxury uptake" by the herbage, and it also increases the risk of the loss of K by leaching. Much of the N is also lost because urea decomposes quickly and the ammonia formed may blow away. *Davies et al. (4)* found that when urine was applied at a "naturalrate" (equivalent to about 1100 lb K_2O/acre) a quarter of the K was soon leached below 9 inches; deep-rooting grasses like paspalum (which penetrated 42 in deep) recovered much of the leached K but it was lost to shallow rooting grasses. They considered that in soils that have little cation exchange capacity (CEC), or that have no 2:1 lattice clay minerals, downward movement might be too great to be countered by uptake by herbage. Laboratory experiments showed that both total CEC and the clay minerals present influenced rate of leaching.

Advice on manuring grazed grass

Very few attempts to *measure* the K needed by grazed grassland have been made; most advice is based on guesswork and inference from the facts discussed above. As an example of this approach consider a good clover-grass pasture in a moist area providing 5000 lb dry matter/acre/year, the herbage containing 140 lb of K_2O/acre. If it is assumed that urine is dropped on only one-fifth of the field in a year, four-fifths of the grass must obtain its K from soil or fertilizer. If soil reserves are not to be depleted the full amount of K harvested in the herbage will be needed as fertilizer both in the first year, and also in several subsequent years, since it is not possible to single out areas that have received urine and avoid them when applying K. So a grazed pasture on K-deficient soil may need, for full productivity, 700 lb of K_2O as fertilizer in a 5-year period. On soils that are able to build up a reserve of K after this initial period the rate of fertilizer K may be reduced to levels that merely replace inevitable losses; for dairy cattle 50–60 lb K_2O/acre should be enough each year.

Timing of potassium fertilizers for grass

Correct timing of K dressings is important to avoid loss by leaching from light soils and also "luxury uptake" which results in waste and may damage the health of stock. On land where cattle are liable to develop hypomagnesaemia, dressings of K in late winter and spring should be avoided as these increase K contents in herbage at the critical period when percentage of Mg in grass is low.

Few field experiments on the best time for K dressings have been done and the results have been conflicting. *Reith et al. (14)* found good responses to a single dose of 174 lb K_2O given in winter, twice as much K applied in 5 equal dressings gave only slightly more grass. Working in Pennsylvania with cocksfoot *Robinson et al. (15)* found that split applications, half being given in spring, were inferior to a single summer application of potash; the summer dressing greatly lessened the trend caused by winter or spring dressings towards luxury uptake in spring and K starvation in autumn. *Burton* and *Jackson (2)* found that splitting K dressings between March and July for Coastal bermuda grass was better than single spring dressings; they gave higher yields, higher "available" K in soil, and reduced luxury uptake. *Wolton (22)* considers that as percentage of K in herbage is often high in spring, where hypomagnesaemia has occurred it is unwise to give spring dressings of K, the safest time is in June or July when herbage contents are low. If large dressings are needed, they should be divided and put on at intervals during the season, avoiding early spring.

Advice to avoid using K fertilizer in spring is also consistent with changes in the potential of soil K. As K is removed by crops during the season K potential in the soil falls and is at a minimum in autumn. During the true dormant period in winter, when there is no growth and no K is taken up, K potentials rise as release from non-exchangeable reserves replenishes exchangeable K. This suggests that the most effective time for giving extra K will be in summer when "available" K in soil has been depleted but much growth of grass has yet to be achieved; dressings of fertilizer K may be least necessary, and least efficient, when given in late winter or spring since, at that time, they merely add to the normal increase in "available" soil K.

Potassium needed by herbage crops in alternate grass-arable farming system

Preceding sections have discussed the K-manuring of grass considered as an individual crop. But in alternate farming systems the effects of each crop on those that follow must be considered when planning to use fertilizers. Grassland usually makes better use of soil K reserves than do many arable crops. A policy of depleting soil K by not replacing by fertilizer the inevitable losses caused by cutting and removing grass, may succeed for long periods of continuous grassland farming on soils where much K can be released from non-exchangeable reserves. But if the grass is ploughed the soil K status may be too little to give full yields of the arable crops that follow and the losses may not be made good simply by giving extra fertilizer K to the arable part of the rotation.

Warren and *Johnston (18)* have shown that on the Exhaustion Land at Rothamsted a soil containing adequate K reserves can give higher yields, especially of potatoes, than are possible from a soil poorer in K, but of the same type, however much fertilizer K is applied. This justifies a policy of maintaining adequate reserves of soil K. Whenever grassland experiments show that herbage does not respond to K fertilizer [e.g. those of *Widdowson et al. (21)*] the question of whether K should nevertheless be applied to maintain "available" K in the soil at a constant level arises. If the land is to be used only for grass there is no sound agricultural reason why K fertilizer should be given until field experiments, or laboratory measurements, indicate that the rate of release of K from non-exchangeable reserves has fallen to the extent that herbage yields are limited by K-deficiency. But where grass and arable crops alternate, K fertilizer may have to be used on grass to maintain soil K reserves for the benefit of following arable crops.

In "ley-arable" experiments at Rothamsted yields of potatoes were reduced where the crop followed grass that was cut continuously *(17)*; the grass did not receive enough K to maintain "available" K in the soil though there was no evidence that the grass itself needed K fertilizer. When supplementary dressings equal to the amounts of K that the grass had removed were applied potato yields were not affected by K-deficiency. *Widdowson et al. (19)* showed that yields of wheat that followed red clover were consistently greater than those of wheat after ryegrass; both clover and grass were cut and removed. The heavier the dressings of N given to the ryegrass, the less was the yield of the wheat that followed, irrespective of the amount of N given to the wheat. This was because the N-treated ryegrass removed much more K from the soil than did clover. In addition clover may have obtained K from deeper layers of the soil than did ryegrass which appears to remove the whole amount from the surface soil. By giving extra K fertilizer, and with adequate N, wheat yields after ryegrass were similar to those after clover. But the amount of K used to do this (about 270 lb K_2O/acre) is difficult to apply without damaging the wheat and it seems better to grow wheat on soil that has residues of K fertilizers given to the preceding grass. The best procedure might be to apply extra K to grass a few days before ploughing; this would avoid both loss by luxury uptake by grass and damage to the wheat. On soils that are low in K the generally recommended dressing for wheat (45 lb K_2O/acre) is far too little where this crop follows grass treated with heavy N dressings, unless the grass receives enough K to replace that lost in the crop that is removed.

Summing up of our present knowledge on the use of potassium on grassland

The amounts of K needed each year to produce herbage crops range from 90 lb K_2O/acre for indifferent grazed pastures in the drier areas to at least 300 lb K_2O needed by grass treated continuously and heavily with nitrogen fertilizer in the wetter areas. The amounts of K in the crops are roughly equal to the amounts of N used. The fertilizer K needed by grassland may range from none for low-yielding grazed swards, and also for higher yielding swards grown on soils which release much K over long periods from non-exchangeable reserves, to the full amounts contained in all crops grown on soils very low in "available" K. In addition to variations in the needs for fertilizer K imposed by kind of herbage and its yield, and by the amount and properties of K reserves in soil, the management and method of using grass, and the kind of stock carried, all influence the amounts of K needed *on a long-term basis* to maintain yield and soil productivity.

Grass for continuous cutting

The experiments discussed show that on soils very low in soluble K 1 lb of K_2O must be used for each lb of N to maintain yield and soil K level when heavy dressings of N are used. On other soils which are richer, but where the herbage still responds to fertilizer K, 0.5 lb K_2O or less per 1 lb of N may be enough. Even where the herbage response to K is so small that no fertilizer K is justified economically, an overall fertilizer ratio of $N:K_2O = 2:1$ may have to be used to maintain soil K status. Variations between the results of the few experiments described show how impossible it is to give reliable general advice. *If it is known* that soils are very low in K, for each lb of N involved in producing the grass 1 lb of K_2O should be used to maintain yield and soil fertility. On land where the size of the response of grass to K fertilizer is not known, and nothing is known of soil K status (and this unfortunately applies to the majority of our grassland), "insurance doses" of 0.5 lb K_2O per lb of N involved in producing herbage should be applied when grass is often cut for conservation or feeding elsewhere. Since it is impossible to do enough field experiments to characterise the K status of our soils, a better basis for manuring cut grass can only come from detailed chemical work on soil K in the field experiments that *are* possible, and in conjunction with soil mapping.

Grass for grazing

In planning the manuring of grazed herbage it cannot be assumed that the K returned through excreta will provide for more than a small proportion of the herbage in the first two or three years of a new pasture. Soil plus fertilizer will have to supply K to most of the herbage, and the amount of K needed by new grassland will be nearly as great as that required for a sward that would be cut continuously at the same level of output. On soils low in K about 150 lb K_2O/acre may be needed annually for the first few years where pastures yield well. The aim must be to build up poor soils by fertilizer K, and by K returned in urine, until the "pool" of "available" K in the soil is enough to prevent herbage growth being limited by K-deficiency, but is not so high that much "luxury uptake" of K occurs. When this stage is reached smaller yearly dressings will be needed to replace the losses inevitable in using grassland. On soils that were initially poor in K these maintenance dressings may be of the order of 50–100 lb K_2O/acre/year where dairy cattle graze intensively, the actual amount depending on soil and management; 20–30 lb K_2O/acre/year should be enough where the grass is used by store or fattening cattle or sheep.

Grass in rotation with arable crops

The work on alternate grass/arable husbandry systems discussed above shows that it is essential to maintain available K in the soil at satisfactory levels throughout the whole rotation. It is not sufficient to rely on the normally-recommended dressings of fertilizer K for the arable crops in the rotation to remedy the drain on K reserves in soil. Higher yields of arable crops have been obtained when these were grown on soils containing ample K reserves than were possible with fresh K dressings given to depleted soils. General guidance can be obtained by studying the "balance sheets" for K in experiments that test alternate husbandry systems.

Future progress

A better basis than we have at present for K manuring of grassland, and particularly of grazed grass must be found. This can only come from field and laboratory work designed to measure the size of the "pool" of "available" soil K that will sustain the yield of herbage crops (and also yields of the following arable crops where alternate husbandry systems are used).

The best time for applying K fertilizer dressings will be determined by the stability and size of the soil K pool. This depends on rates of fixation and release of K, methods are needed to determine both these quantities. We have no generally-satisfactory laboratory method for determining the size of the soil K pool itself.

It will always be difficult to maintain a satisfactory pool of K in both very light soils with low total CEC and in heavier soils that do not contain 2:1 layer-lattice minerals. Both kinds of soil are usually low in total K and have no mechanism for fixation and release; most of the K present may be associated with soil organic matter. Deficiency of soil K will be chronic and crops may need frequent small dressings to maintain growth without luxury uptake and also to maintain a good balance between grasses and legumes (which do not forage for K as vigorously as grasses do even though legumes may get K from lower depths than grasses).

To maintain vigorous legumes in mixed herbage it may be necessary to use more K fertilizer than would be needed for either grasses or legumes grown alone. In soils where it is very difficult to build up a satisfactory pool of available K it may prove impossible to maintain clovers in association with very competitive grasses, specialised herbage of a single species may do better and be easier to manage.

Soils with no reserves are often well supplied with K when first brought into cultivation because the K released from plant remains when forest is cleared, or ancient grass is ploughed, is sufficient to grow several crops. But after a few years of intensive grassland farming the stock of K falls and yields collapse; this series of events has become familiar in new countries like Australia and New Zealand, but it also occurs in reclaiming light soils in Europe. Soils with good content of clay, and containing 2:1 type minerals, fix K and it is usually possible to build up reserves through continued manuring and to establish a stable pool of K of satisfactory size that acts as a "buffer" both in supplying the crop, and in preventing waste of fertilizer K.

Much more field experimentation with K fertilizers on herbage crops should be done, and better methods of measuring the fertilizer responses of grazed grass must be developed. Discussion in the preceding paragraphs suggests that such work must be done jointly by agricultural chemists, agronomists, pedologists, and soil survey workers. The behaviour of soil K, and pasture response to fertilizer, must be related to permanent soil properties such as CEC and the nature and surface area of clay minerals, and to mappable soil criteria. In this way farmers may be provided with the basic information on their soils that is needed to establish a programme for using K (and P) fertilizers first to *increase* soil productivity and then to maintain it at the higher level.

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The effects of nitrogen, phosphate and potash on yields of herbage cut for conservation

P. A. GETHING

Experiments carried out at the Hannah Dairy Research Institute *(1, 2, 3)* and more recently at other centres in Scotland *(4)* showed that with grass managed intensively for silage production: (a) Large increases in yield were produced by nitrogen fertilizer; (b) Due to gross removals of potassium in cut herbage, yield and nitrogen response could only be maintained if adequate potash fertilizer was applied. Large responses to potash were recorded in almost every case after one or two seasons' continuous cutting and in all cases where potash responses were recorded there were large and positive NK interactions; (c) On the sites tested phosphate had little effect on yield or response to nitrogen. Similar experiments were laid down at four sites in England in 1957/58 to obtain information about the effects observed in Scotland over a wider field.

Description of experiments

The experiments were laid down at the Cheshire School of Agriculture, Reaseheath, the Warwickshire Farm Institute, Moreton Morrell, the Kesteven (Lincs.) Farm Institute, Caythorpe, and the Hampshire Farm Institute, Sparsholt. The first two sites are in predominantly grassland areas of the country, the latter in predominantly arable areas where ley farming is an important part of the system. Notes on sites and swards used are summarised in Table 1.

Each site accomodated one replication of 36 treatments comprising the full factorial combinations of

$$\begin{array}{ccccc} N_0 & & P_0 & & K_0 \\ N_1 & \times & P_2 & \times & K_2 \\ N_2 & & & & \\ N_3 & & P_3 & & K_3 \end{array}$$

The 36 treatment combinations were divided into three blocks, one half of the PK interaction being confounded with blocks. The design was a copy of one used by Scottish workers *(4)*.

Nitrogen treatments

0, 1, 2 and 4 cwt Nitro-Chalk (15.6 per cent N) per cut applied in early spring and immediately after each cut.

Phosphate treatments

0 and 5 cwt Superphosphate (19 per cent) applied either in one dressing in winter (P_2), or divided into five equal dressings along with the nitrogen (P_3).

Table 1

Year begin	Site	Soil	Soil analysis		Seed mixtures	
1957	Cheshire School of Agriculture Reaseheath, Nantwich	Keuper Marl overlying sand with high water table	P_2O_5 K_2O pH	moderate moderate 7.4	1956	S. 53 Meadow Fescue, S. 48 Timothy, S. 184 and S. 100 White Clover and Kersey White Clover + 1 cwt oats
1957	Kesteven Farm Institute, Caythorpe	Light Sandy Limestone overlying Oolitic Limestone	P_2O_5 K_2O pH	moderate low 8.2	1955	General purpose mixture with clover
1957	Warwickshire Farm Institute, Moreton Morrell	Keuper Marl overlying Lias clay	P_2O_5 K_2O	low satisfactory	1956	Undersown under barley S. 53 Meadow Fescue, S. 215 Meadow Fescue, S. 143 Cocksfoot, S. 184 and S. 100 White Clover, S. 48 Timothy
1958	Hampshire Farm Institute, Sparsholt	Medium Loam over Chalk	Not available		1957	Undersown under Wheat, S. 48 Timothy, S. 215 Meadow Fescue, S. 100 White Clover, S. 213 L.F. Red Clover

Potash treatments

0 and 5 cwt Muriate of potash (60%) applied in either one winter dressing (K_2), or divided into five equal dressings applied along with the nitrogen (K_3).

In 1957 at Caythorpe and Morerton Morrell the split potash dressings were first applied after the first cut, but in all other cases the split dressings were applied as described above. The aim was to take five cuts per annum on all experiments but this was not always possible. In cases where less than five cuts were taken, P_3 and K_3 treatments were made up to 5 cwt annual total by a late autumn application.

The results have been examined statistically on the basis of annual total yields of dry matter. In evaluating the responses to phosphate and potash comparisons

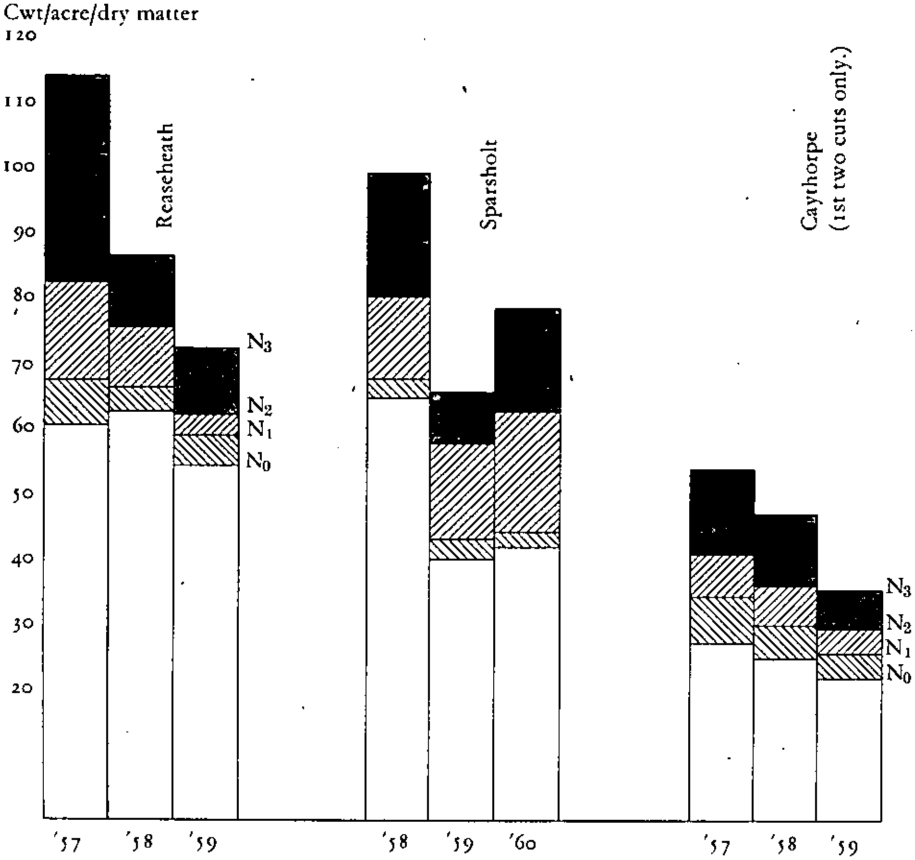

Figure 1 Yield and N response for three years. Yields as cwt dry matter/acre at the various levels of N in the presence of K

have been made between P_0 and the mean of the P_2 and P_3 treatments and between K_0 and the mean of the K_2 and K_3 treatments. NP and NK interactions have been similarly treated.

The experiment at Sparsholt, which commenced only in 1958, was modified for the final year – 1960 – by substituting for the P_2 and P_3 treatments and the K_2 and K_3 treatments a comparison of 2½ and 5 cwt of the relevant fertilizers applied in one winter dressing. This was done as there had been little indication of difference between split and single applications of either phosphate or potash.

At Reaseheath and Sparsholt complete results are available for the three years but fragmentary data only is available from Moreton Morrell and Caythorpe. At Moreton Morrell the whole of the first year's records were lost in a theft. At Caythorpe both in 1957 and 1959 the later cuts were interfered with by cattle entering the area, only two early cuts being recorded. At Moreton Morrell in 1959 two cuts only were recorded, subsequent regrowth being so poor as to be considered not worth recording.

Results

The main features of the results are shown in Tables 2 to 4 giving responses to nitrogen, phosphate and potash on total annual yields of dry matter.

Responses to nitrogen

Highly significant responses to nitrogen fertilizer were recorded in all years and in all but very few of the individual cuts.

Table 2 Mean yield without N and response to 15.6 units N per cut (averaged over all levels of phosphate and potash) (cwt dry matter per acre)

Centre	Year	No. of cut	No. yield	N response	S.E. of response
Reaseheath	1957	5	58.5	10.9	2.19
	1958	5	56.2	6.1	0.86
	1959	5	48.7	4.5	1.91
Caythorpe	1957	2	28.2	6.6	0.84
	1958	4	52.0	8.9	1.19
	1959	2	21.4	3.5	0.75
Moreton Morrell	1958	5	56.1	21.8	2.84
	1959	2	25.6	3.9	0.80
Sparsholt	1958	5	64.4	8.8	2.31
	1959	4	38.4	6.5	1.71
	1960	4	38.1	8.6	1.35

On the basis of annual total yields responses to nitrogen fertilizer were substantially linear, deviations from the linear regression being significant only at Moreton Morrell. The responses listed in Table 2 are the linear components of the response averaged over all levels of phosphate and potash. Except at Moreton Morrell these nitrogen responses are somewhat smaller than those recorded in the Scottish work. There is a general tendency for the general yield level and the response to nitrogen to fall off with the passage of time, though the Sparsholt site appears to have recovered in respect of nitrogen response in 1960. This reduction of yield and nitrogen response took place even when potash was applied at Reaseheath, Sparsholt and Caythorpe, and this apparent effect of ageing of swards appears to be quite general in this type of experiment. This tendency is illustrated in figure 1, which shows nitrogen responses in the presence of adequate potash at three of the centres.

The greater part of the response to nitrogen occured in the early cuts and in some cases nitrogen applied for the last cut or last two cuts of the season would not have produced a paying return in dry matter. A comparison of nitrogen response between sites is rendered difficult by the fact that some data are missing for the Caythorpe site and because the number of cuts taken in a season varied. For this reason the responses are listed in Table 3 on the bases of (a) response to total nitrogen applied during the year, and (b) response in the first two cuts of the season to nitrogen applied for these cuts only.

Responses to phosphate

No significant response to phosphate was recorded at Sparsholt. Responses recorded at the other sites are shown in Table 4. Very large responses to phosphate

Table 3 Linear component of N response (lb dry matter per unit N applied)

Site and year		(a) Annual response to total N applied in year	(b) Response in first two cuts to two dressings of N only
Reaseheath	1957	15.8	19.0
	1958	8.6	14.7
	1959	6.5	12.9
Caythorpe	1957	23.7	23.7
	1958	15.8	19.0
	1959	12.9	12.9
Moreton Morrell	1958	31.6	39.1
	1959	14.4	14.4
Sparsholt	1958	12.9	12.6
	1959	11.5	18.0
	1960	15.8	16.9

Table 4 Mean yield without P and response to phosphate (mean of P_2 and P_3 treatments) (averaged over all levels of nitrogen and potash) (cwt dry matter per acre)

Centre	Year	No. of cut	P_0 yield	P response	S.E. of response
Reaseheath	1957	5	75.7	3.8	2.29
	1958	5	64.8	4.2	0.90
	1959	5	52.4	5.5	2.00
Caythorpe	1957	2	39.2	1.0	0.88
	1958	4	63.7	3.9	1.25
	1959	2	26.5	1.3	0.79
Moreton Morrell	1958	5	78.7	13.9	2.97
	1959	2	25.2	6.7	0.84
Sparsholt	1958	5	75.7	3.1	2.42
	1959	4	48.5	2.3	1.79
	1960	4	52.9	0.5	1.42

were recorded on the heavy soil at Moreton Morrell and there were large nitrogen/phosphate interactions. In 1958 applying phosphate resulted in an increase in the response to nitrogen of 7.7 cwt per cwt of Nitro-Chalk applied per cut. In 1959 there was a similar large positive interaction in the first cut, but this effect was reserved in the second cut with the result that there was no nett effect on the annual total.

It is surmised that this reversal of interaction from the first to the second cut in 1959 might have been due to the very heavy yield on the high nitrogen with phosphate plots exhausting reserves of soil moisture. Phosphate responses at the various levels of nitrogen for the three experiments, where significant overall phosphate effects were observed, are listed in Table 5.

Responses to Potash

Large and significant responses to potash were recorded by the second year in all experiments except that at Moreton Morrell, which showed no response even in the third year. The lack of response on this site might well have been expected on a heavy soil which by analysis was satisfactory in available potash at the outset, although the amounts of potash removed at the highest rate of nitrogen must have been very considerable indeed – some eight to nine hundred lb K per acre.

On the basis of annual total yield there was no significant difference between the two methods of application of potash, though the split potash treatment outyielded the single application in the case of three individual cuts at Reaseheath. These responses to split potash dressings occured in the mid-season and later cuts. There would appear to be a case on such a potash-deficient soil for recommending split application of potash fertilizer.

Table 5 *Yields at various levels of N and responses to phosphate (cwt dry matter per acre)*

Centre and year	Yields at various levels of N without phosphate					Response to P_2					Response to P_3					S.E. of response
	N_0	N_1	N_2	N_3	Mean	N_0	N_1	N_2	N_3	Mean	N_0	N_1	N_2	N_3	Mean	
Reaseheath																
1957	50.3	67.3	85.0	100.1	75.7	4.8	4.8	−4.6	3.1	2.0	19.7	2.6	−1.8	2.1	5.6	5.30
1958	50.0	62.1	71.2	75.7	64.8	7.4	−1.0	−0.8	11.7	4.2	11.3	3.4	−1.6	3.1	4.0	2.08
1959	42.4	43.7	57.3	61.0	52.4	11.1	9.6	1.1	11.6	7.0	7.7	4.5	−0.6	5.2	3.9	4.61
Caythorpe																
1957	26.9	35.3	41.3	53.3	39.2	2.7	0.2	0.9	2.7	1.6	1.0	−1.0	0.2	1.1	0.3	2.04
1958	48.1	55.9	70.0	80.6	63.7	5.7	−0.3	−0.6	7.5	3.0	5.8	5.2	−1.0	9.6	4.8	2.88
1959	20.0	23.8	27.4	34.7	26.5	1.3	0.1	0.9	1.5	0.9	2.9	1.9	0.9	0.7	1.6	1.82
Moreton Morrell																
1958	54.1	61.5	81.1	118.1	78.7	1.8	0.6	13.3	30.9	11.7	4.2	8.5	16.5	34.7	16.1	6.86
1959	20.8	19.6	27.7	32.9	25.2	7.7	5.0	4.1	10.5	6.9	6.9	5.8	4.0	9.2	6.5	1.94

Table 6 Mean yield without K and response to potash (mean of K_2 and K_3 treatments) (averaged over all levels of nitrogen and phosphate) (cwt dry matter per acre)

Centre	Year	No. of cut	K_0 yield	K response	S.E. of response
Reaseheath	1957	5	74.4	5.8	2.29
	1958	5	54.3	19.9	0.90
	1959	5	41.8	21.6	2.00
Caythorpe	1957	2	39.8	0.1	0.88
	1958	4	58.0	12.5	1.25
	1959	2	24.6	4.1	0.79
Moreton Morrell	1958	5	88.1	—0.4	2.97
	1959	2	28.9	0.1	0.84
Sparsholt	1958	5	74.3	5.3	2.42
	1959	4	44.9	7.7	1.79
	1960	4	45.6	12.2	1.42

Table 7 lists the responses to potash recorded at the various levels of nitrogen in the three experiments, Reaseheath, Sparsholt and Caythorpe, where significant potash responses were recorded. In spite of the fact that large positive responses to potash were recorded and indeed, these are of the same order as those in the Scottish experiments *(4)*, there is a marked absence of interaction between the two fertilizers. The only real signs of any such interactions on the basis of annual yields are recorded in the first year at Reaseheath and the last year at Sparsholt. In both these cases the interaction of the quadratic component of the nitrogen response with potash is significant.

Discussion

In considering the results of these experiments it must be borne in mind that they are subject to limitations imposed by their rigid design and details of technique. For various reasons it was not always possible to cut the plots on the desired date and inevitable delays in cutting placed restrictions on the management of individual experiments which made it impossible to standardise management between different sites.

The most interesting feature of these results is the absence of interaction between nitrogen and potash. In the results already cited in the introduction to this paper large NK interactions have been observed in all cases where there was a response to potash, and it is therefore most surprising that in the work now reported, where potash responses were of the same order as those reported in Scotland, there should be so little of any real interaction. It seems likely that clover nitrogen has contributed more to yield in these experiments than was the case in Scotland, and this might perhaps be expected at the higher temperatures generally

Table 7 *Yields at the various levels of N and responses to potash (cwt dry matter per acre)*

Centre and year	Yields at various levels of N without potash					Response to K_2					Response to K_3					S.E. of response
	N_0	N_1	N_2	N_3	Mean	N_0	N_1	N_2	N_3	Mean	N_0	N_1	N_2	N_3	Mean	
Reaseheath	52.3	71.6	81.6	92.0	74.4	7.1	−2.3	1.3	10.6	4.2	11.4	−3.2	2.6	18.8	7.4	5.30
1957																
1958	41.6	52.3	58.0	65.2	54.3	21.5	14.9	17.5	22.2	19.0	22.5	17.0	19.8	24.0	20.8	2.08
1959	34.2	35.4	45.6	52.1	41.8	19.4	23.3	16.5	21.8	20.3	24.0	25.7	19.1	22.2	22.8	4.61
Caythorpe																
1957	29.0	35.0	41.5	54.0	39.8	−2.1	−0.7	2.3	2.1	0.5	−0.3	1.0	−1.8	−0.4	−0.3	2.04
1958	45.4	50.0	61.1	75.4	58.0	10.9	11.9	13.9	19.3	14.0	8.8	10.7	11.2	13.4	11.0	2.88
1959	20.3	21.0	24.8	32.4	24.6	0.3	3.8	4.0	4.5	3.2	3.0	6.6	5.6	4.6	5.0	1.82
Sparsholt																
1958	60.8	70.8	71.4	94.0	74.3	2.5	−1.2	11.4	9.1	5.4	8.2	−2.2	8.5	6.0	5.1	5.59
1959	34.1	40.8	48.2	56.3	44.9	5.1	2.6	12.6	10.3	7.6	7.7	4.2	9.0	10.2	7.7	3.13
											Response to K_1					
1960	32.8	42.8	49.0	57.7	45.6	9.7	2.7	15.0	21.7	12.2	7.4	2.8	9.2	20.7	10.0	3.27

Table 8 K content – percentage of herbage dry matter
mean of first two cuts 1959 averaged over all phosphate treatments

	Reaseheath		Caythorpe		Sparsholt	
	K_0	K_2	K_0	K_2	K_0	K_2
N_0	1.12	2.10	2.06	3.06	2.06	2.92
N_1	0.93	2.15	1.93	3.04	1.90	2.66
N_2	0.80	2.12	1.69	3.14	1.66	2.82
N_3	0.77	2.01	1.42	3.11	1.49	2.92

prevailing. Except at Moreton Morrell the response to potash at the N_0 and N_1 levels was very evident in the increased vigour and contribution of the clover and appreciable amounts of clover remained in the sward at Reaseheath even at the N_2 level. However, if this were the sole difference between these results and those in Scotland, one would still expect to find interaction between nitrogen and potash at the higher rates of nitrogen application. There is little evidence of this except in the first year at Reaseheath and the last year at Sparsholt. No interaction would be evident if the amounts of potash applied – 300 units per acre – were still insufficient for full production at the maximum rate of nitrogen used. This was certainly not the case either at Caythorpe or at Sparsholt. In the latter case, where in the last year of the experiment a $2^1/_2$ cwt dressing of potash was included, the additional yield obtained from the higher rate of potash over the lower is small enough to suggest that the 5 cwt application was quite sufficient. Measurements of herbage potassium content were carried out in the season 1959 and the levels recorded for the various combinations of treatments would not suggest any limitations in potash supply at either Caythorpe or Sparsholt. There is, however, a slight indication that potassium contents at the highest rate of nitrogen used at Reaseheath were somewhat depressed. Mean K contents of herbage at various levels of N for the first two cuts are quoted in Table 8.

On balance there is little evidence in favour of the suggestion that insufficient potash was applied in any of the experiments, and it can only be assumed that something other than potassium supply is in practice limiting the response to nitrogen. At Moreton Morrell there did not appear to be such other factors limiting response and hence a large NP interaction is quite evident. One factor which might have limited response at Reaseheath was the very open type of sward developed under the high-nitrogen treatments. The sward on these plots at the end of the experimental period consisted of clumps of vigorous grass separated by appreciable areas of bare or weed-covered ground.

Subsequent history of the Reaseheath experimental plots

After three years under the main experimental treatments some of the potash and phosphate treatments were reversed so that the effects could be observed of adding potash and phosphate where they had previously been omitted. Statistical treat-

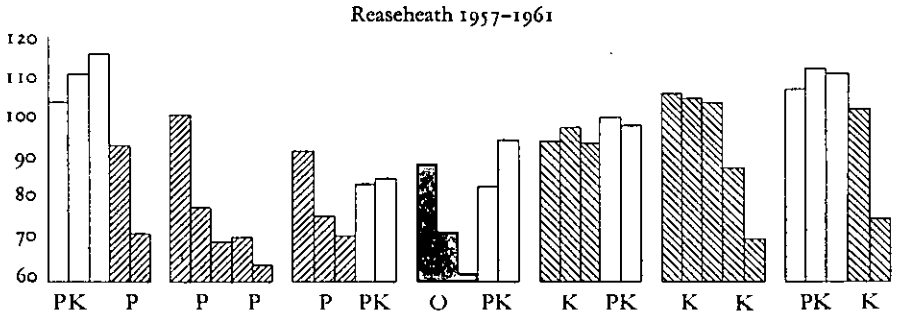

Figure 2 *Effect of change of treatment.* Mean dry matter yields of groups of four plots as percentage of yield of 8 plots receiving PK throughout

ment of the results for this phase of the experiment is not possible, though it may perhaps be assumed that the experimental error would be of the same order as previously, i.e. around 10 per cent of the mean. In any event, the trends are unmistakable and are depicted in figure 2, where the yields from selected PK treatments, averaged over all levels of nitrogen, are plotted as percentage of the yield of the eight plots which received PK throughout. Actual yields from the groups of plots are recorded in Table 9. In this table the yields from the two groups of four plots which received PK throughout are shown separately, as this may give some indication of the random variation to which the other group means are subject.

The effect of changing the potash treatments follows the expected pattern in that dropping K from the PK treatments results in an immediate sharp decline in yield. The addition of K to plot previously receiving P only results in recovery by 1961 to near the level of the plots receiving PK throughout. The result of omission of potash is in line with expectations, as soil analysis at the end of 1959 indicated that there had been no build-up of soil potash under the potash treat-

Table 9 *Effect of reversal of PK treatments at Reaseheath – yields of groups of 4 plots avaraged over all N levels (cwt dry matter per acre)*

Treatment / Year	1957	1958	1959	Treatment / Year	1960	1961
PK	82	80	71	P	75	50
P	73	55	44	PK	68	59
PK	84	80	67	K	81	52
K	74	70	57	PK	80	67
O	70	52	38	PK	67	65
K	83	75	63	K	70	48
P	80	56	43	P	57	44
PK	80	70	59	PK	78	62
PK	78	74	63	PK	85	76

ments. Recovery of plots which had previously received no potash is quite striking, as these plots at the end of 1959 were in a badly run-down condition and the rapid yield recovery is reflected also in sward composition. Similar findings are reported by *Castle* and *Holmes (5)*.

The effect of changing phosphate treatments is striking. Up to 1959 phosphate effects on yield, although appreciable, were much smaller than the corresponding potash effects. In subsequent years they are seen to be as spectacular as the potash effect. On the group of plots which received K only throughout the five years yields were fairly well maintained up to the end of 1959, but thereafter the limiting effects of phosphate shortage are clearly shown and yields decline steeply. Addition of phosphate to the other group of plots which previously received K only results in yields being maintained at a satisfactory level. Where phosphate is dropped from plots previously receiving PK the subsequent fall-off in yield is of the same magnitude as that of plots which had previously received no phosphate. This is the more surprising because soil analysis indicated that a reserve of phosphate had been built up on the plots receiving Superphosphate. Soil analysis figures for the phosphate treatments, averaged over all levels of N and K, are detailed below:

	P_0	P_2	P_3
April 1958	10	18	16
November 1959	8	13	18

Effect of treatments on soil potassium

No detailed soil analysis was conducted on the Sparsholt site but at the end of the main experimental period – autumn 1959 – soils at Reaseheath, Moreton Morrell and Caythorpe were examined plot by plot. There are interesting contrasts in the effect of mineral fertilizer treatments between these three sites.

As has been remarked above, soil analysis at Reaseheath indicated virtually no difference in available potash content between the plots which had and the plots which had not received potash during the course of the experiment. Figures for available potash (K_2O mg per cent) for the three potash treatments were as follows:

$K_0 - 4 \quad K_2 - 4 \quad K_3 - 5$

Herbage was analysed for mineral content in 1959 so that removals of potassium for this year are known and a rough estimate may be formed of the quantities removed in the previous years. It would appear that there has been a mean nett removal of potassium on the K_0 treatments of 270 lb K per acre and a mean nett accumulation on the potash-treated plots of 200 lb K per acre. It is most surprising that a difference of nearly 500 lb K per acre does not show up in the soil analysis figures. It is unlikely that leaching would be the cause of this lack of difference, as this is not a particularly free-draining site and also one would have expected leaching to be at a minimum in 1959. Even if the soil has a very high capacity to fix potassium, one would still expect some difference to appear in the soil analysis figures, especially as the plots not receiving potash fertilizer have been apparently able to release as much as 270 lb K per acre.

At Caythorpe soil analysis at the end of the experiment indicated the following levels of available potash (K_2O mg per cent) for the potash treatments averaged over all levels of N and P:

	K_0	K_2	K_3
0–3"	7	29	28
3–6"	6	12	9

One can make no accurate estimate of the amounts of potassium taken up during the course of this experiment, but the differences in soil potash recorded are certainly something of the order that one might expect if removals in cut herbage were of the same sort of order as they have been at Reaseheath. Indeed, it seems likely that the greater part of the nett accumulation of potassium under the potash treatments is accounted for in the available potash figure. Quite evidently the Moreton Morrell soil has a large capacity to fix and release potassium. Soil analysis at the end of 1959 indicated mean levels roughly as follows:

K_0	K_2	K_3
10	15	11

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Summary

1. The paper describes four experiments carried out during the years 1957 to 1960 to investigate the effect of potash and phosphate on the response of mixed grass/clover herbage to nitrogen fertilizer when cut for conservation.

2. The results are principally of interest in the manner in which they differ from those reported from Scotland *(4)*. The principal features of the Scottish results were: (a) A very marked NK interaction which was always in evidence if there

were a response to potash: (b) An almost complete absence of phosphate effect and NP interaction. The present results are characterised by an absence of NK interaction, even when there is a large response to potash; by appreciable phosphate responses; and by NP interactions which were very large in the case of one experiment.

3. The absence of NK interaction in the work now reported may be explained in part by the greater contribution of clover nitrogen to yield of grass/clover swards at the low levels of nitrogen, and in part by the apparent fact that nitrogen response at the higher levels on some sites was limited by other factors.

4. The later history of one of the experiments in which treatments were reversed after three years shows that correction of potash deficiency can result in rapid improvement of run-down swards. It also shows that after a prolonged period of continuous cutting phosphate responses become very large and that there is a noticeable lack of residual effect of phosphate applied earlier in the history of the experiment.

5. There are marked differences in the effect of potash treatments on soil potash status between the experimental sites which are connected with differences in the nature of the soils.

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Results of long-term experiments on the manuring of meadows

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The area of the Federal German Republic which is used for agricultural purposes (in all 14.2 million hectares) consists, to the extent of about 40 per cent, of permanent grassland. Of this rather more than one-third is used as pasture, almost two-thirds are mowed meadows. Regions of continuous pasture are found only in the coastal region of North-West Germany with its marshes, and in the Alpine pastures in the South. The 2-cut meadow is consequently the principal form of utilisation of our grassland. It is true that efforts are being made everywhere to turn the generally less productive meadows into pasture. However, our present agrarian structure stands in the way of these endeavours. So long as the splitting up of estates continues it will be impossible to introduce the general grazing of the grassland.

It will be understood that under these conditions it is precisely the experiments on the manuring of meadows occupying an important place in the scope of the work of our research institute from the first years of its existence and including the present time. Geheimrat Paul Wagner, who served for many years as Director of the Darmstadt Experimental Station started experiments which at first were concerned with the problems of manuring with potassium and phosphate but also later dealt with nitrogenous manuring, frequency of cutting, application of farmyard manure, etc. Even if his later successor, Professor Schmitt, still continues some of these classical experimental lay-outs, this is not only for the sake of tradition, but because many problems of manuring can only be solved by means of long-term experiments.

I would like to go into some of these long-term experiments in particular in my lecture to-day, for they have been interpreted afresh and are concerned with potash manuring.

Our oldest experiments on meadows which were laid out in 1912 and 1917, as well as younger series of the years 1931 and 1940 deal predominantly with questions of potash manuring, besides questions of the application of nitrogen and phosphates. This already manifests the great importance of potash as a factor of production from the 2-cut meadow in particular. Investigations were made on: the level of the potash dressing, different forms of potash, the change of the form of potash, the after-effect of potash, the influence on the plant stand, the nutrient and mineral contents of hay, and, finally, on the feeding value of the hay.

This comprehensive enquiry would not have been possible if precautions had not been taken in advance. Wagner laid out his experiments mostly with large plots each having an area of 100 sq m (approximately 120 sq yd). Nowadays the majority of those making use of field trials rejects these large plots. Whoever has taken care of long-term experiments knows that in the course of years fresh problems always appear which, however, can only be answered if a sub-division of the plots is possible. In plots with an area of 100 sq m a second sub-division into plots of 25 sq m is practicable without the result suffering in any way. This method of sub-division was employed on our long-term meadow-experiments.

In this connection I would like by way of introduction to point out another advantage of fertilizer trials on meadows. In long-term experiments on arable land displacements on the boundaries of the differently treated plots result from the repeated cultivations of the soil, and these necessitate the elimination of an even wider strip with increasing duration of the experiment. In experiments on meadows this mixing at the boundaries does not occur owing to the absence of soil cultivation, especially if narrow trenches are kept open between the plots. This fact renders fertilizer experiments on meadows particularly suitable for the elucidation of long-term experiment problems; also the oldest meadow fertilizer experiment still gives exact values.

If we wish to assess the production resulting from a potash treatment of the meadow, we cannot have the necessary component – the phosphate treatment – unattended. The yields of hay of our oldest fertilizer experiment on meadow show this clearly, both in the series "without potash" as well as in the series "without phosphate". This experiment is situated on an alluvium, a gravelly-sandy loam soil, in the central lower mountains. The material deposited is derived from the weathering of granite and consequently is naturally not poor in potash. Before laying out the experiment the meadow had not received an appreciable fertilizer treatment.

Table 1 Yields of hay in V.R. 1137 at Reichelsheim, Odenwald, 50 years duration of experiment

Treatment	dz hay/ha
Unmanured	50.9
Without potash (only basic slag, 96 kg P_2O_5/ha)	52.3
Without phosphate (only 40% potash salts, 120 kg K_2O/ha)	53.0
PK-treatment (96 kg P_2O_5 + 120 kg K_2O/ha)	80.2

Both nutrients were unable to increase the yield above that given by the unmanured plot when applied singly, although in the course of 50 years of the experiment in the one case 300 dz basic slag and in the other 150 dz of 40 per cent potash salts had been applied per hectare. Here the law of minimum appears in most striking fashion. Both nutrients when applied at times to the other apparently gave exactly the same increase in yield of about 28 dz/ha, which almost equals the increase given by the PK-treatment in comparison with the "unmanured". This large increase consequently is *only possible by the combined action of both nutrients.*

We found an increase in the yield of about 30 dz hay per hectare from the regular application of a potash-phosphate treatment compared with the "unmanured" in the rest of different long-term experiments, which, moreover, were carried out under quite different conditions of soil and climate.

In our oldest experiment but one, which is situated in the mild climate of the valley of the Rhine on a sandy soil (V.R. 1187) on the average of 38 years 29 dz more hay were harvested per hectare with the PK-treatment, on a high meadow of the Odenwald on a shallow, weathered sandstone (V.R. 142) actually 39 dz.

The yields of crude protein were increased relatively to a greater extent.

Table 2 Yields of crude protein (N×6.25) on various meadows

Treatment	V.R. 1137 Valley in the central lower mountains kg/ha	V.R. 1187 Valley of the Rhine kg/ha	V.R. 142 High meadow kg/ha
Unmanured	435	446	260
Without potash	433	361	260
Without phosphate	460	—	—
PK-treatment	739	728	686

The explanation for this comes from the next section: *the botanical composition of the hay*. For ten years we have determined the proportions of grasses, *Leguminosae* and herbs in the hay of the 1st cut on V.R. 1137 from the 40th to the 49th year, on V.R. 142 from the 21st to the 30th year of the experiment and arrived at the following mean values:

Table 3 Botanical composition of hay of 1st cut (means of 10 years)

Treatment	V.R. 1137			V.R. 142		
	Grasses %	Leguminosae %	Herbs %	Grasses %	Leguminosae %	Herbs %
Unmanured.....	67	6	27	66	6	28
Without potash ...	67	7	26	—	—	—
Without phosphate	59	9	32	—	—	—
PK-treatment	63	21	16	66	22	12

Compared with "unmanured" and the deficiency treatments, the PK-treatment strongly promoted the occurrence of the *Leguminosae* and this was almost exclusively at the expense of the herbs, which as undemanding but also low-yielding plants together with badly developed grasses populate the "unmanured" and deficiently manured plots. Hence, too, the particularly marked rise in the yield of protein by the PK-treatment.

There is one result which is not revealed by the figures in the 1137 experiment series, namely the particularly bad plant sward in the no potash fertilizer treatment plots.

On soils naturally poor in potash, as on V. R. 1187, it can regularly be established that the inferior swards are found on the "without potash" plots. This observation is also confirmed by the marked fall of the yield of crude protein from the "potash deficiency treatment" in comparison with the "unmanured" (see Table 2).

It is surprising to find the good agreement of the values of the botanical analyses in the two experiments, as regards the "unmanured" as well as the "PK-treated" swards. This shows that the influence of the nutrient status of the soil on the botanical composition of the meadow fodder was considerably stronger than that of the locality.

Let us now trace the course of the increase in yield due to a PK-treatment with *increasing duration of the experiment.* For this purpose the yields are divided up into sections of 9–10 years. The following Table gives the mean values of these sections from the "unmanured" in comparison with a "PK-treatment" with K_2O at 120 kg/ha.

Table 4 Yields of hay (dz/ha) with increasing duration of the experiment

Section		Unmanured	PK-treatment	Increase due to PK
V.R. 1137	1	53.0	74.0	21.0
	2	57.6	83.4	25.8
	3	57.3	84.5	27.3
	4	44.9	79.3	34.4
	5	46.9	85.5	38.6
	6 (only 3 years)	51.8	90.1	38.3
V.R. 1187	1	47.4	70.3	22.9
	2	49.3	78.6	29.3
	3	47.8	70.1	22.3
	4	51.7	84.6	32.9
	5	49.8	82.9	33.1

On V. R. 1137 the increase in yield from the PK-treatment amounted to 21.0 dz hay/ha in the first period when compared with the "unmanured". It rose in the further stages of nine years by 25.8; 27.3; 34.4; to 38.6 or 38.3 dz/ha, although the "unmanured" diminished very little in comparison with the first period.

The increases in the yield of hay on the meadow in the valley of the Rhine behaved similarly though not quite so regularly. This signifies that the productivity of the meadow soil was considerably improved by the regular PK-treatment. This is an important result for we see *that by this means the soil became progressively more productive.*

To turn now to questions of potash manuring in particular. First of all, a comparison of the *form* in which the *potash* is to be applied. Kainite, the crude potash

Table 5 Comparison of 40 per cent potash salts with Kainite (yields of hay in dz/ha)

	Light dressing (120 kg K_2O/ha)			Heavy dressing (160 kg K_2O/ha)		
	Kainite	40% salts	Increase due to 40% salts	Kainite	40% salts	Increase due to 40% salts
V.R. 1137	77.0	80.2	3.2	76.7	80.6	3.9
V.R. 1187	70.6	74.8	4.2	71.0	79.2	8.2
V.R. 142	65.8	68.0	2.2	—	—	—

salt formerly specially recommended for the treatment of meadows was compared with 40 per cent potash salts (see Table 5).

On the long-term average in all three experiments a small increase was obtained from a light dressing and a slightly larger one from a heavier dressing when the higher percentage fertilizer was applied.

This raised the question: was this so from the beginning, or did the gain begin to occur only after a certain time? To answer this the duration of the experiments is again divided into separate periods (see Table 6).

Table 6 Increase in yield of hay from 40% potash salts compared with Kainite (in dz/ha)

Decade	V.R. 1137		V.R. 1187		V.R. 142	
	Light dressing	Heavy dressing	Light dressing	Heavy dressing	Light dressing	Heavy dressing
1st	4.0	5.2	0.8	6.7	3.9	—
2nd	4.8	5.7	6.5	8.5	3.5	—
3rd	0.5	2.9	4.0	7.6	0.2	—
4th	6.2	4.5	6.2	9.5	—	—
5th	0.8	1.1	—	—	—	—

From this it follows that the 40 per cent potash salts had the advantage over Kainite from the beginning and in all decades, though it was often slight.

A comparison of 40 per cent potash salts with sulphate of potash and sulphate of potash-magnesia is possible in the experimental series V.R. 1187 and 142 (see Table 7).

The sulphate forms of potash in comparison with the chloride thus gave quite small but always regular increases of hay of 2–4 per cent.

To complete this comparison of the forms we may consider the yields of crude protein (see Table 8).

The amounts of crude protein harvested from the Kainite treatment remained only a little below those from the 40 per cent potash salts on V.R. 1137 and 142.

Table 7 Comparison of 40 per cent potash salts with sulphate of potash and sulphate of potash-magnesia. Yields of hay in dz/ha

	Light dressing (120 kg K_2O/ha)			Heavy dressing (160 kg K_2O/ha)		
	40% potash	Sulphate of potash	Sulphate of potash-magnesia	40% potash	Sulphate of potash	Sulphate of potash-magnesia
V.R. 1187	74.8	77.5	77.1	79.2	82.5	81.2
V.R. 142	68.0	69.0	70.0	—	—	—

Table 8 Comparison of the yields of crude protein from different forms of potash

	Crude protein as kg/ha			
	Kainite	40% potash	Sulphate of potash	Sulphate of potash-magnesia
Light dressings				
V.R. 1137	736	739	—	—
V.R. 142	673	686	684	703
V.R. 1187	677	728	753	758
Heavy dressings				
V.R. 1137	718	737	—	—
V.R. 1187	702	763	809	809

On the sandy soil of the valley of the Rhine, on the other hand, the latter form proved definitely superior. A further increase occurred on this soil from the application of the sulphate salts, without any difference appearing between sulphate of potash and sulphate of potash-magnesia. In the samples of the swards we were often surprised that these series of treatment were particularly rich in *Leguminosae* [chiefly common meadow vetchling *(Lathyrus pratensis)* and vetches *(Vicia)*].

The next question we have to face is that of the effect of *increasing the dressing of potash.* The experimental series No. 1137 and 1187 can give us an answer to this (see Table 9).

Whilst there was complete equality of yield on V.R. 1137 between light and heavy dressings (120 against 170 kg/ha), on V.R. 1187, there was a moderate increase in the yield of hay from all the treatments with the exception of Kainite, amounting on the average to 5 per cent. In this result we were able once more to establish the trend to a further increase of the yield with the duration of the experiment. The production from the heavy dressing rose from 2.6 dz hay/ha in the 1st decade through 2.9 and 4.5 to 6.5 dz/ha in the last.

Table 9 Yields of hay with increased dressings of potash in dz/ha

	Light dressing (about 120 kg/ha)	Heavy dressing (about 170 kg/ha)	Increase due to heavy dressing
V. R. 1137			
Kainite	77.0	76.7	—0.3
40% potash	80.2	80.6	0.4
V. R. 1187			
Kainite	70.6	71.0	0.4
40% potash	74.8	79.2	4.4
50% potash	77.6	80.0	2.4
Sulphate of potash	77.5	82.5	5.0
Sulphate of potash-magnesia	77.1	81.2	4.1

The difference in the behaviour of the two meadows to the increase in the potash dressing can be explained by a comparison of the climatic and soil conditions.

First of all the prerequisite is provided for the utilisation of the heavier application of potash on V. R. 1187 by the mild climate of the valley of the Rhine. Then the sandy soil readily gives these plants the potash which is always applied first in the spring on account of the risk of loss by leaching.

For several years we have made use of this experimental material to follow up the inquiry: *What does the soil supply from itself?* Thus, with no phosphate treatment, what phosphate is taken up by meadow plants?

We arrived at the rather surprising result that the quantity supplied to the plants in the 5th decade was exactly the same as in the first decade. If the larger fluctuations, caused by the weather of the year, be disregarded, we arrive at the statement that the removal of phosphate by the plants, in the absence of a phosphate fertilizer treatment, had remained constant for decades.

Let us put this question with regard to the *potash supplied by the soil.*

Table 10 Removal of potash when no potash fertilizer was applied

Decade	V. R. 1137 kg K_2O/ha	V. R. 1187 kg K_2O/ha
1st	64	51
2nd	70	49
3rd	62	41
4th	43	50
5th	61	—
Mean	61	48

Although the answer is not quite so clearly expressed as a result of the reduction of the potash removal in the last decade but one, one can say once more that the removal of potash in both series was just as high in the last period as in the first and also agreed to a large extent with the long-term average. The other fluctuations are similarly quite small. The deviation in the 4th decade is due firstly to the occurrence of some low yields in this period and secondly to the fact that after the destruction of our institute we were unable to carry out potash investigations for five years, so that in this case the yields of only 5 years were available for the calculation of the mean. All the other values strongly support the potash supply from the untreated soil remaining the same for many years.

On the loam soil, naturally rich in potash from the weathering of granite there were 61 kg, on the sandy soil of the valley of the Rhine 48 kg of potash which were placed at the disposal of the plants by the soil itself.

After heavy dressings of potash had been applied for 10 years on V.R. 1137, for 18 years on V.R. 1187, a sub-division of definite plots was carried out in order to examine the *after-effects of the potash treatment.* We arrived at the following results:

Table 11 Yields of hay in dz/ha with regular potash treatment and with after-effects of potash. V.R. 1137

During the years		Kainite		40% potash salts	
	Un-manured	Regular treatment	After-effect	Regular treatment	After-effect
1st–12th years of after-effect	61.1	80.6	*84.4*	86.0	*84.9*
13th–16th years	51.5	82.2	*64.7*	84.4	*66.7*
17th–29th years (1945 excepted)	45.2	75.9	*51.7*	80.0	*53.2*
30th year	33.2	65.3	*35.1*	62.2	*34.0*
31st year	51.9	83.4	*46.9*	96.8	*46.3*
31 years of after-effect	52.0	78.4	*65.3*	82.9	*66.3*

On the loam soil (V.R. 1137) the after-effect of the potash treatment persisted for 29 years and, moreover, 3 stages could be distinguished. For 12 years the yield of hay remained at about the level of that from a regular treatment with potash. Then followed 4 years in which the yield was about midway between that of the unmanured and that of the PK-treatment. During the next 13 years it slowly approached the yield of the "unmanured". It was only in the 30th year that it became the same as this and in the 31st it fell below the "unmanured". With that the investigation was concluded. During the first 10 years with an annual application of 40 per cent potash salts we obtained

a potash recovery of	42.5 per cent
during the period of the after-effect we recovered	44.8 per cent
the total utilisation consequently attained the high value of	87.3 per cent

On the sandy soil of V. R. 1187, on the other hand, no appreciable after-effect of the previous heavy dressing could be perceived after the 3rd year; Kainite alone acts for a somewhat longer period.

Here the utilisation of potash was certainly higher during the period of annual treatment, but the after-effect was so small that on the whole the high utilisation as on the loam soil was not obtained. It amounted on the whole to only 65–70 per cent (see following summary).

Table 12 Utilisation of potash treatment on V. R. 1187

Treatment in form	Continuous treatment %	After-effect %	Total %
40% potash salts	59	6	65
50% potash salts	60	7	66
Sulphate of potash............	60	11	70
Sulphate of potash-magnesia ...	58	9	68
Kainite	49	18	67

From the point of view of *quality* the *calcium content of the hay in combination with the potash treatment* is of interest, for we know of the existence of relationships between the level of the potash dressing and the calcium content of the fodder, also according to our investigations, between the form of the potash and the calcium content. See the following summary:

Table 13 Potash treatment and calcium content of meadow hay, calculated from 1st and 2nd cuts of hay with 85 per cent dry matter (mean for 6 years)

Potash treatment in form of	Calcium content (CaO)		
	V. R. 1137 %	V. R. 1187 %	V. R. 142 %
Unmanured	1.200	1.422	1.520
Without potash (only basic slag)	1.305	1.337	1.612
Light dressing (120 kg K_2O/ha)			
Kainite	0.936	0.895	1.021
40% potash salts	1.035	1.150	1.158
Sulphate of potash............	—	1.139	1.233
Sulphate of potash-magnesia ...	—	1.063	1.187
Heavy dressing (160–180 kg K_2O/ha)			
Kainite	0.908	0.831	—
40% potash salts	1.018	1.045	—
Sulphate of potash............	—	1.137	—
Sulphate of potash-magnesia ...	—	1.016	—

According to this the potash treatment led to an appreciable reduction of the calcium content of the meadow hay – certainly not to be forgotten with greatly increased yields of hay. Increasing the potash dressing produced a further small reduction except when sulphate of potash was applied. Of the different forms of potash applied Kainite gave the worst performance in this connection, sulphate of potash-magnesia mostly produced a rather lower calcium content than did sulphate of potash and 40 per cent potash salts. Apart from the case of Kainite *in no instance did the calcium level fall below 1 per cent,* which is required as the lower limiting value for a sound nutrition of cattle. This is important, for other measures which give a larger increase in yield, as for example the application of nitrogenous fertilizers to the meadow, also work in the same direction.

Finally, the last measures of the effects of a potash treatment on the production of the 2-cut meadow, are the *yield of digestible crude protein,* and of *the starch equivalents per hectare and the protein: starch equivalent ratio.* In order to determine these values the hay from areas which had received different fertilizer treatments for many years were harvested separately and used for feeding experiments with sheep at the Institute for Animal Nutrition of the Hohenheim Agricultural College, Director Professor Dr. Wöhlbier. These experiments gave – as already published in the Potash Review for 1960 – probably as the most important result, a considerable improvement of the digestibility of the substances containing nitrogen as a result of the application of potash. Since the crude protein content of the hay was also increased, there was a considerable rise in the content of digestible crude protein in comparison with a potassium deficiency treatment. With, simultaneously, a slight reduction of the starch equivalents the protein: starch equivalent ratio became narrower, and consequently the feeding value of the hay rose. The values are reproduced in the following summary:

Table 14 Feeding value of the hay

Treatment	1st cut (mean of 5 crops)			2nd cut (1953)		
	Digestible protein %	Starch equivalent	Protein: starch ratio	Digestible protein %	Starch equivalent	Protein: starch ratio
Unmanured	4.7	349	1:7.6	6.3	427	1:6.7
Without potash	4.3	354	1:8.7	5.7	408	1:7.1
PK	5.5	332	1:6.2	6.5	384	1:5.9

However, the production from the potash treatment of the meadow is not exhausted with this improvement of the feeding values. It is only by combining the increase in the quantity of hay with the improvement of the quality of the fodder, as is shown in the last Table, that the complete benefit of the potash treatment is given.

Table 15 Yields of hay, digestible protein and starch equivalents per hectare

Treatment	1st cut (mean of 5 crops)			2nd cut (1953)		
	Yield of hay dz/ha	Digestible protein kg/ha	Starch equivalent kg	Yield of hay dz/ha	Digestible protein kg/ha	Starch equivalent kg
Unmanured	34.9	163	1214	24.4	154	1039
Without potash	38.2	163	1348	19.7	112	802
PK	59.9	325	1979	38.7	252	1487
Increase due to potash	21.7	162	631	19.0	140	685

Whilst the quantity of hay on the average of five crops of the 1st cut was increased by 22 dz or almost 60 per cent by the potash treatment, the yield of digestible protein rose from 163 to 325 kg per hectare, thus it was doubled, the yield of starch equivalents was raised from 1348 to 1979 kg, and so by 47 per cent. In the 2nd cut of the year 1953 the return was still larger. Here the weight of hay was nearly doubled, the yield of digestible protein increased by 125 per cent, that of starch equivalents by 85 per cent.

These results emphasize the great importance of regular applications of potash with at the same time an adequate supply of phosphate to the meadows.

Experience derived from fertilization of clover grass in Denmark

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In the years 1958–1962 the Danish grassland area averaged 993000 ha, about one-third being permanent grass outside the rotation of crops, whereas the rest is short-period clover grass fields, included in the rotation of crops.

According to the official statistics the grass production of this area has been utilized in the following way:

Table 1 The Statistical Department (Statistik Department)

	Millions crop units	
	Total	Per cent
Direct cropping	32.4	81
Haymaking	6.7	17
Ensilage	0.8	2
Total	39.9	100

By far the greater part of the grass production is utilized as pasturage for cows, young cattle, and horses.

It is still rarely seen, that the grass fields are utilized for hay-harvest only. As a rule they are only mowed once early in summer, whereas the areas for the rest of the season are used for grazing.

For this reason a rational potash fertilization of clover when used for cropping will, in Denmark, be of the utmost importance.

In making experiments with potash fertilizer for clover grass, the fertilizing value manifests itself in the 4 or 5 yearly hay-harvests. After harvesting, the crop is removed from the experimental field, in order to make room for the aftergrowth. Thereby the potash supplies of the turf are wasted, as the potash level of the soil is subsiding year by year. In perennial experiments with permanent grass, the excess yield obtained from the potash fertilization is therefore measured against a constantly falling yield level in basal-fertilized clover grass.

The excess yield obtained from potash fertilization of clover grass will, therefore, largely depend upon what potash level the soil has when the experiment is started. This will appear from the experiments made with permanent grass on land rich in humus, as stated below.

Table 2 Grassland Section (Græsmarkssektionen) 1940-1947

Potassium figure	Proportional yield Basal-fertilization = 100	
	80 kg K_2O	160 kg K_2O
Under 3.9	118	128
4.0–5.9	119	124
Over 6.0	108	108

Where the potash level of the soil is lowest, profitable excess yields have been obtained at 160 kg K_2O per ha, whereas no profitable excess yields have been obtained if the potash level is above 6.0 based on potassium figures.

In the rotation of crops clover fields are normally in grass for 1 or 2 years. The result of potash fertilization of those fields, which usually lie on mineral soil, is shown below.

Table 3 The Jutland Farmers' Unions (Jydske Landboforeninger) 1930-1958

	Yield and excess yield with a supply of 40 kg K_2O per ha	
	kg dry matter per ha	
	Potassium figure under 4.0	Potassium figure over 4.0
Basal-fertilized	48.8	63.0
40 kg K_2O per ha	6.6	3.4
80 kg K_2O per ha	2.6	0.6
120 kg K_2O per ha	1.4	0.2
160 kg K_2O per ha	1.0	0.0

The yield of basal-fertilized clover grass is largest where the potassium figure of the soil exceeds 4.0. However, the excess yield per 40 kg K_2O supplied per ha is constantly falling at both potash levels.

About 150 kg K_2O per ha can be used to advantage if the potash figure is below 4.0, about 100 kg if the potash figure from 4–6, and about 50 kg per ha for maintenance if it is from 6–10, whereas no potash is applied if it is 10 or higher.

The above results are obtained by measuring clover grass devoid of nitrogen fertilization.

If clover or pure grass are forced by means of large quantities of nitrogen fertilizers, and the field is utilized for hay-harvest only, a considerable amount of potassium will be eliminated from the soil.

Table 4 Grassland Section (Græsmarkssektionen) 1958–1960

	kg N per ha per year	Potassium figure at close of experiments	kg dry matter per ha for 2 years
Clover grass	0	4.3	114.9
Pure mixture of grasses	0	5.8	67.6
Pure mixture of grasses	75	4.4	108.0
Pure mixture of grasses	150	3.1	150.6
Pure mixture of grasses	300	3.1	206.1

It will be seen from the results of experiments with 2-year clover as shown above, that the dry matter yield and the potash level of the soil go rather well together, in reverse order.

The potash figure averaged 9,6 at the start of the experiments. The experiments have in total been fertilized with 400 kg K_2O per ha in the 2 experimental years.

From the results given in Table 4 it appears that the mowing of clover grass and strongly nitrogen-fertilized grass will rapidly exhaust soils with a normal potash level of accessible potassium, unless considerable quantities of potash salt are supplied to replace what is removed with the crops.

The removed K_2O amounts to about 75 kg per ha for each hay-harvest.

If the results of the mowing experiments are transferred direct to the pastures, there is a great danger of overestimating the potash requirement of the clover grass.

The grazing cattle only use a small percentage of the potash contained in the dry matter of the grass for their metabolism. What remains is returned to the greensward with the manure and urine of the animals. Thereby the potash circulation of the grass field is improved and built up, and the potash level of the soil is raised considerably by a plentiful supply of potassium.

The investigation below has been made of permanent grass in mineral soil. The grass fields are 5–40 years old, and have been utilized exclusively for grazing.

It appears from the figures that the percolation of the easily soluble potash salt is very slow, just as the washing out of potassium of permanent grass fields is insigni-

Table 5 Grassland Section (Græsmarkssektionen) 1939

Potassium figure in layer of soil	kg K_2O per ha and year		
	below 100	100–200	above 200
0– 5 cm	13.2	21.4	27.0
5–10 cm	7.4	12.8	18.0
10–15 cm	6.0	9.9	13.1
15–20 cm	4.6	7.6	9.5
Average	7.8	12.9	16.9

ficant under Danish conditions. Add to this that the clover grass in putting out new roots every spring starts draining the soil from above, while grass roots from previous periods of growth are slowly rotting.

This network of grass roots in the upper layers of soil, formed during several periods of growth, is very well known through the ploughing up of old grass fields. Besides, the extrication of the potassium content of these roots, when they are mineralized, no doubt considerably increases the content of potassium in the upper layer of the soil.

The high potassium content of the uppermost 5 or 10 cm to a certain extent explains the fact that the potassium content of the dry matter of the grass is highest in spring, when the soil is watery right up to the surface. The results also explain that symptoms of potash deficiency may be found in clover plants in dry summers, when the upper layers of the soil are drained of water, and even in fields with a rather high potash level.

From the results stated in Table 5 it appears that a fertilization with more than 100 kg K_2O per ha and year raises the potash level considerably, if the fields are used for grazing only.

On the other hand, the mowing experiments showed that no profitable excess yield can be expected from a potash fertilization when the potash figure exceeded 6.0.

Furthermore, as far as the clover is concerned, large reserves of accessible potassium in the soil will result in a luxury consumption of potassium.

Table 6 Joint report (Fællesberetningen) 1960

Potash figure	Per cent potassium (K) in the dry matter
Under 7.5	2.35
7.6–10.0	2.66
10.1–12.5	2.78
12.6–15.0	2.92
Over 15.0	3.11

The grazing animals will scarcely be harmed by a high potassium content in the dry matter of the grass, as they are capable of excreting large quantities every day.

It cannot be ignored, however, that an adverse balance between monovalent and divalent cations in the grazing animals' gastrointestinal canal may be caused by a high potassium content in the dry matter of the grass. Many scientists are of the opinion that this may involve risks of grass tetany.

This danger is greatest where a high content of potassium in the dry matter of the grass goes together with a low content of magnesium. The low content of magnesium is particularly found in grass growing in humus soil or sandy soil, or grass, poor in clover.

Based on the results of the experiments and investigations recorded, the experience of potash fertilization of clower grass in Denmark during the last few years may be concluded in the following points:

1. At the supply of potash fertilizer for clover grass, a sharp distinction is made between haying and grazing.
2. For grazing a potash figure of 6–8 is aimed at.
3. For haying 75 kg K_2O per ha per hay-harvest are supplied provided the potash figure is below 6–8.
4. For each unit, which the potash figure rises, or falls below 6–8, 75 kg per ha of K_2O are deducted or added.

Auxiliary information

The fodder-value of 1 crop unit corresponds to 100 kg barley. 1 unit of the potash figure corresponds to 1 milliequivalent potassium per 2500 g air-dried soil.

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Potassium in Swedish ley husbandry – some results from field trials

ELIEL STEEN, UPPSALA

Introduction

The development in Swedish agriculture during recent years is characterized by, amongst other things, the diminishing number of dairy cows at the same time as there has been an increase in the cultivation of cash crops. In addition the number of horses has also strongly declined. The result has been an increased removal of plant nutrients from the land and a diminished supply of farmyard manure. Another characteristic feature is that the artificial manure has become more concentrated concerning N, P and K, while the secondary plant-nutrients and trace-elements have consequently decreased.

The result of these changes has been that the balance between different plant nutrients has changed, so that a negative nutrientbalance has developed or has become more accentuated, for example in the cases of sulphur and magnesium. The increase of commercial potash has not risen in proportion to the reduced supply of farmyard manure, which has resulted in smaller amounts of this plant-nutrient being used than during the last twenty years. Table 1 illustrates these circumstances.

Table 1 The relationship between farmyard manure and artificial manure in Sweden during the last 25 years

Plant nutrient		Thousands of tons (1 ton = 1000 kg) In farmyard manure	In fertilizers	Sum
1938/39	N	80	28	108
	P	37	27	64
	K	195	29	224
1952/53	N	64	72	136
	P	30	45	75
	K	156	57	213
1962*	N	56	112	168
	P	26	47	73
	K	137	71	208

* Approx. calculation after 12 per cent reduction in the number of cattle units from 1952 to 1962

Thus there is no doubt that in many cases the cultivation of leys in Sweden draws from the potassium reserve in the soil, not least on clayey soils and clay soils. On lighter soils and peat soils there is only a small reserve to draw from and a certain maintenance with potassium is therefore unavoidable.

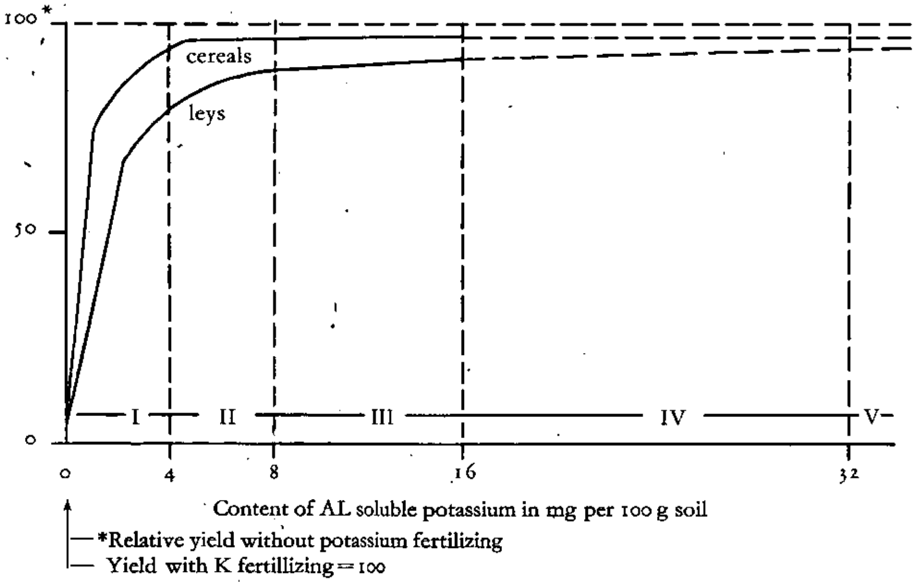
There is another circumstance worth mentioning. In Sweden we have 2.6 million cattle but only 0.17 million sheep. Furthermore the stall feeding period for dairy cows is as long as 8 months. Swedish ley husbandry, which uses 41 per cent of the acreage available, is therefore at first hand engaged in producing winter fodder, that is hay and silage. Only at second hand the leys are aimed for grazing, which of course is of great importance for the potassium manuring problems.

A survey of the latest from Swedish field trials with potassium fertilizing of leys should be preceded by a short presentation of the new soil-mapping method which has been used for some years in Sweden. This means that the method for determining potassium, Egnérs monochloracetic acid method, has been replaced by two extractions, one with ammoniumlactate-acetic acid, the other with hydrochloric acid. The former gives easily available potassium, the latter gives the potassium reserve. The chemical analytic procedures have been prepared by Professor Egnér in collaboration with German and Dutch institutes. The sampling technique in the field has been developed by *Dr. Fredriksson* after extensive investigations on Swedish soils.

From the results of the analyses the easily available potassium in the soil can be tabulated in five classes (K–AL) and also the reserve of potassium can be shown in five similar classes (K–HCl).

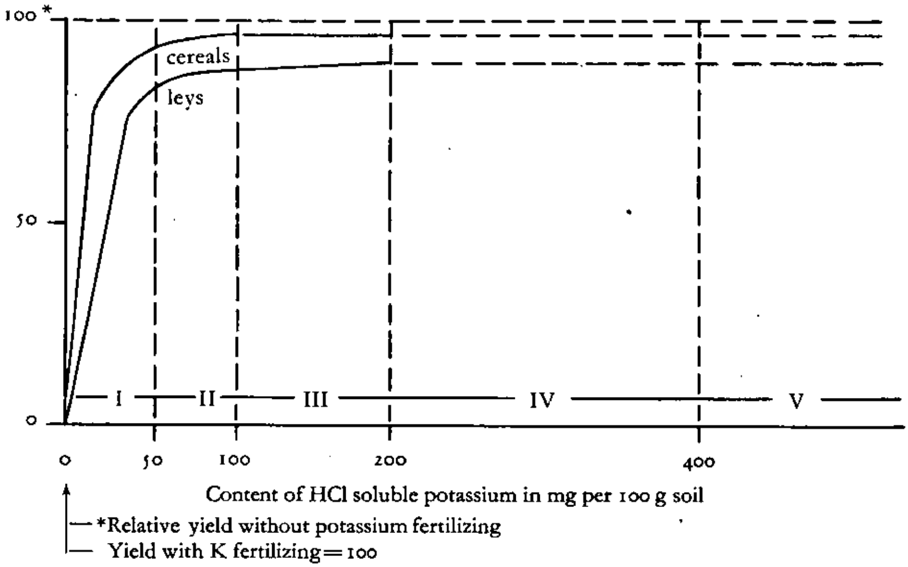
The new method means not that the old one was wrong but that it was incomplete. The earlier used monochloracetic acid method gave only the easily available part of the soil potassium and comprised only the first 5 inches of the soil profile. The new method accounts for a profile 40 inches deep.

Figure 1



The new method of soil-mapping is at present being tested in field trials with different crops, different amounts of potash, and store fertilizing compared with annual top dressing. *Fredriksson* (1961) has made a diagram of some of these trials which, in the case of leys, amounts to about 500 separate harvest years. The relative yield is compared with the AL- and HCl-classes of the soil. A clear and statistically significant relationship between the relative yield and the potassium value is present for both K–AL and K–HCl (fig. 1 and 2). The two diagrams are sufficient to show that the yield in leys fertilized with potash is closely correlated with the content of easily-soluble potassium as well as the reserve-potassium in the soil.

Figure 2



Connection between quantity of K manure and yield

In research material from 1959 and earlier the potassium analyses of soil samples have been done according to the monochloracetic acid method. A very comprehensive material has been prepared by *Gunnarsson (3)* consisting of 1441 trials in leys and he has prepared statistical analyses regarding the effect of 100 kg of muriate of potash on the yield of leys at different soil potassium values according to Egnérs older method. The results are reproduced in figure 3.

Gunnarsson's analyses clearly show that the correlation is good even with monochloracetic acid, which determines easily soluble potassium. The increase of yield decreases exponentially in accordance with Mitscherlich's equation and asymptotically approaches a limit value with increasing potassium values. The result can be interpreted as a double effect of the potash manuring. One of which is directly connected with the potassium status of the soil (potassium values) and which consequently approaches zero at high potassium values. Relatively seen this effect is about the same for the different crops tested. Another effect seems to be indepen-

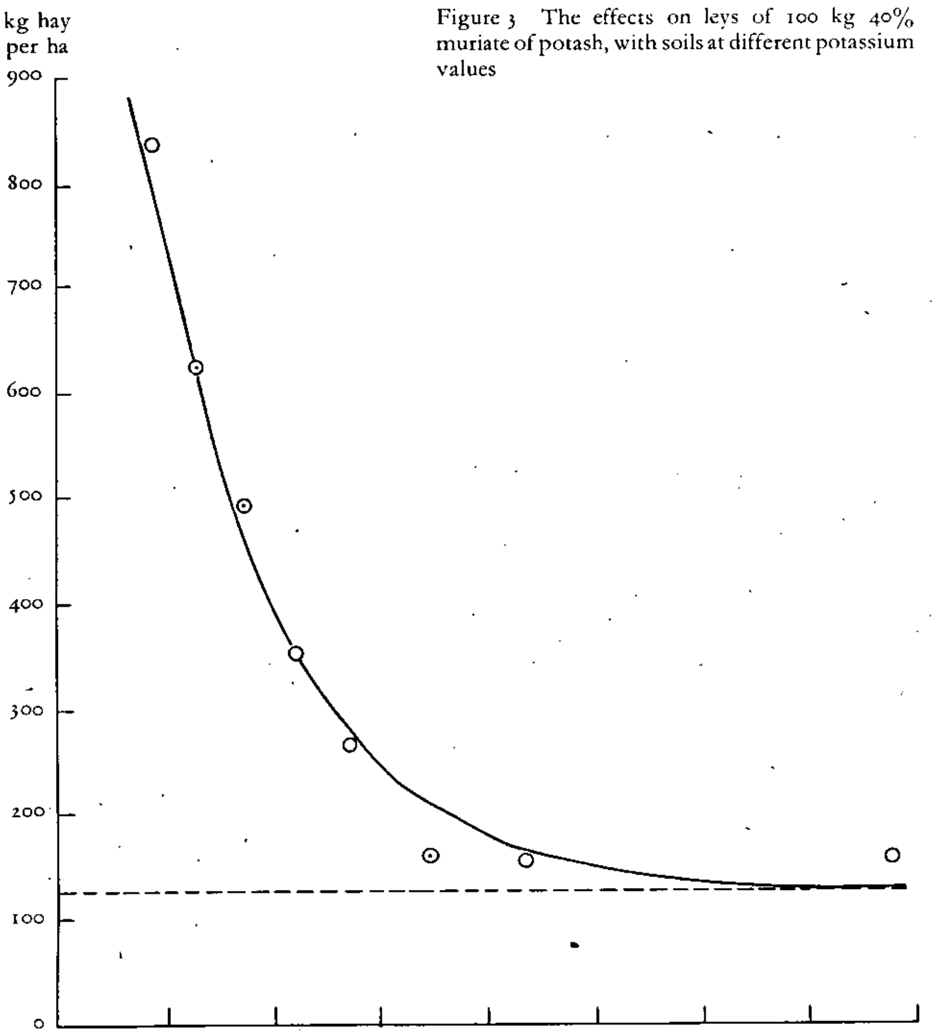


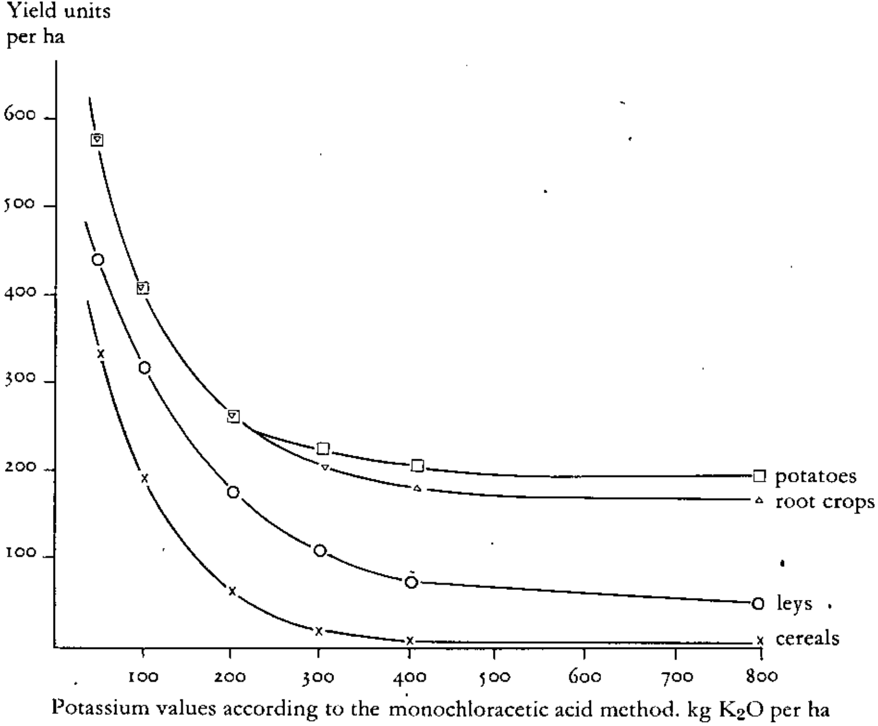
Figure 3 The effects on leys of 100 kg 40% muriate of potash, with soils at different potassium values

Potassium values according to the monochloracetic acid method. kg K_2O per ha

dent of the potassium values of the soil but which is characteristic for different crops. In leys this effect is an increase of 130 kg of hay, for sugar beet 700 kg roots, etc. This is illustrated by the diagram in figure 4, which compares different crops with the increase calculated in harvest units. Gunnarsson will not deny that at least some of the favourable influence is due to the effects of chloride.

In another earlier publication *Hallerfors (4)* shows the clear relationship between the harvest increase in leys when fertilized with potassium and the clay content of the soil. The pile diagram in figure 5 shows the average yield increase from 783

Figure 4



trials in leys in western Sweden with different clay content classes after application of 100 kg muriate of potash per hectare. The diagram is a striking illustration of the close connection between the clay content and the potassium value of the soil.

Trials with increasing quantities of potassium entirely relate to earlier material. The new trials have not yet been compiled. In the earlier trials the potassium content of the soil has often been somewhat briefly summarized, causing a close analysis of the relationship between the yield and the soil potassium to be rather difficult to carry out. Two of the trial series are, however, worth attention. In Table 2, 129 trials from southern Norrland, divided into mineral- and peat-soils, are given.

The profitable limit here appears to have been reached at 200 kg on mineral soils and 300 kg peat soils.

A similar material of 71 trials from Norrbotten given in Table 3 shows an increased yield even with the highest application, 500 kg per ha, but the increase is so small that the yield hardly pays for the extra potassium, compared with the other series.

The recommended fertilizer application to leys generally lies between 75 and 300 kg 50 per cent muriate of potash per hectare and year. Only for peat soils and sandy soils in the lowest potassium classes are larger quantities recommended. On many clay soils an average of not more than 50 kg per ha is recommended. Consideration must natu-

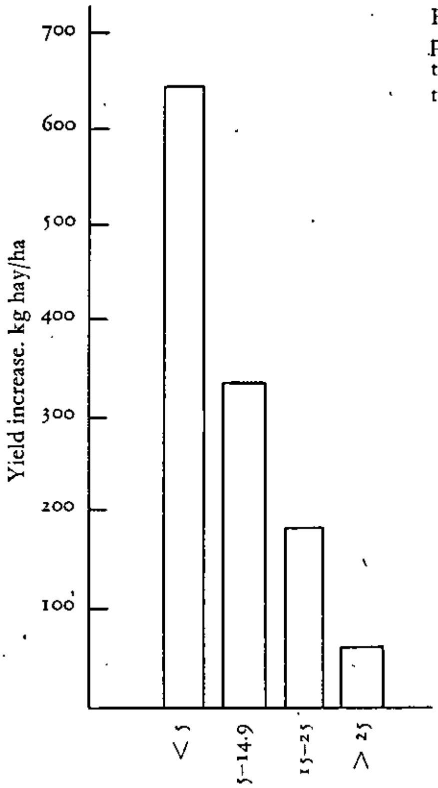


Figure 5 Average yield increase after application of 100 kg 40% muriate of potash to leys on soils with different clay contents

rally be given to the supply of farmyard manure. This increases from the South towards the North, and is calculated to contribute with 50 to 60 per cent of the potassium in Southern and Central Sweden and with 75 per cent in Norrland.

Table 2 Yield increase compared with unfertilized, kg hay per ha

Soil type	kg of 40 per cent muriate of potash per ha			
	100–150	200	300	400
Mineral soil	300	450	500	550
Peat soil	650	950	1500	1500

After *H. Linder* (1956)

Table 3 Yield increase compared with unfertilized, kg hay per ha

Soil type	kg of 40 per cent muriate of potash per ha			
	100–150	200	300	400
Mineral soil	705	775	770	890
Peat soil	1175	1300	1350	1425

After *H. Danell* (1952)

The problem of storage manuring with K

A not unimportant part of the actual potassium problems concern the movability of the potassium ion in the soil together with leaching with rain water, competition with other ions for the soil colloide and fixation in the clay minerals. A number of investigations in potexperiments have been done in Sweden concerning these problems, whereby even ley plants have been used. It would, however, take too long to discuss this work more closely which has been carried out by *O. Johansson (6)*, *H. Nömmik (7)*, and *S. Ståhlberg (8)* amongst others. From the results should be mentioned, however, that the controltrials in the field often gave a considerably weaker result for the different treatments than the potexperiments. The difficulties of transferring experiences from potexperiments to field conditions have also been discussed by *Fredriksson (2)*, who has prepared a special method for frame trials in order to obtain higher accuracy in the field trials.

A practical problem of interest is, however, the leaching of potassium and the possibilities of store fertilizing for several crops or for the entire rotation. Investi-

Table 4 Yield increase compared with unfertilized, at fertilizing with 50 per cent muriate of potash in first year ley given as top dressing and store fertilizing

	200 kg per ha divided into		400 kg per ha divided into	
	100*+100**	200+0	200+200	400+0
Increase	420	100	450	250
Difference		—320		—200
	16 trials		32 trials	

* cover crop ** ley 1

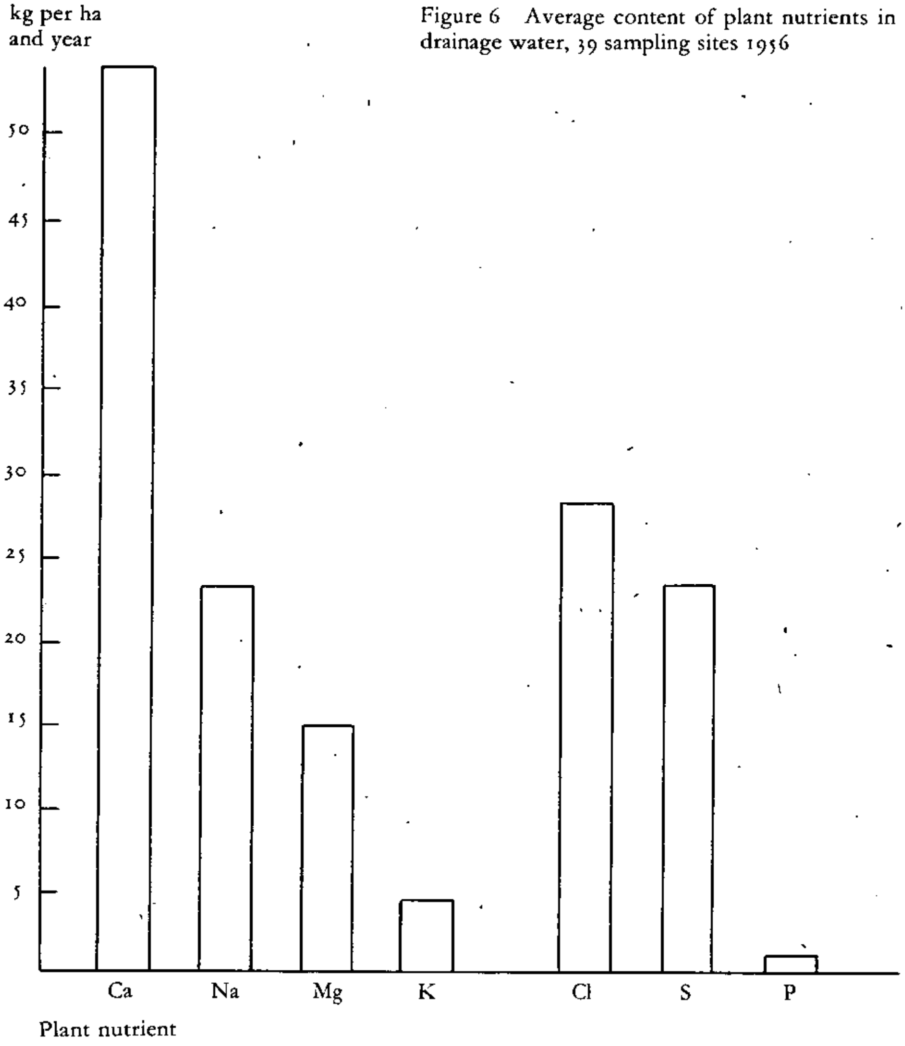


Figure 6 Average content of plant nutrients in drainage water, 39 sampling sites 1956

gations by *Wiklander (9)* and colleagues show that the leaching of potassium is considerably more restricted than earlier believed, which is illustrated by figure 6.

Trial series are being carried out with store fertilizing in different rotations with two or three year leys. Some preliminary figures are given in Tables 4 and 5.

The two Tables show that an annual top dressing is somewhat more favourable than store fertilizing. There is, however, only a small percentage in the difference.

Table 5 Yield increase compared with unfertilized in first and second year ley at fertilizing with 50% muriate of potash given as top dressing and store fertilizing

	Ley 1		
	600 kg per ha divided into		
	400* +200**	600+0	
Increase Difference	240	10 —230	
	32 trials		

* cover crop   ** ley 1

	Ley 2 600 kg per ha divided into			
	200+200+200	400+0+200	400+200+0	600+0
Increase Difference	550	680 +130	440 —110	430 —120
	35 trials			

Institute of Plant Nutrition and Management 1963

An interesting question regarding store fertilizing with potassium concerns autumn versus spring applications. Present data show here that the autumn application gives a somewhat smaller yield. According to Table 6 the spring application gives 250 kg hay per ha more than the autumn application on average for first and second year leys, i.e. approximately 4 per cent of a normal hay crop. The difference does not have to be exclusively a question of leaching of the potassium which was applied in the autumn. The spring application should give a better result because the applied potassium becomes superficially bound to the organic material and thus

Table 6 Autumn fertilizing with potash compared with spring fertilizing
The increase compared with unfertilized and the difference
Autumn–spring, kg hay per ha

Ley year	Autumn	Spring	Spring more than autumn	Number of trials
I	420	700	280	23
II	620	850	230	30
III	870	1110	240	9
Average I–III	580	830	250	62

Institute of Plant Nutrition and Management is quickly available to the superficial grass roots as soon as growth starts in the spring. In practice farmers calculate that the difference between autumn and spring application is unimportant and prefer autumn applications with PK-fertilizers because of working conditions.

Interaction between K and other elements

The interaction between potassium and other plant nutrients in leys has not been the subject of more extensive field investigations. Most of that which has been done is confined to pot trials. *Gunnarsson (3)* has, however, compiled figures from 256 field trials in leys concerning the interaction between potassium and phosphorus which had been interpreted in earlier investigations as mainly negative. *Gunnarsson's* work indicates instead a less positive interaction between the two plant nutrients, i.e. 30 kg hay per ha, without, however, any completely significant results being obtained.

The antagonism between potassium and ammonium ions in field trials has only been slightly studied.

A series of trials from Southern Sweden have been carried out which, however, mainly deal with other crops than leys. These trials show that the nitrogen effect is greater from NO_3-nitrogen than from NH_4-nitrogen on account of the negative influence of the K-ion on NH_4. In the same way a lower yield is obtained from potash with a simultanious application of sulphate of ammonia than with nitrate. *(S. Jansson, 5.)* More trials in leys illustrating this are of interest to make these problems clearer, as there is an increase in the use of ammonium fertilizers.

Potash manuring and quality of the grass

The problem of potash fertilizing in ley husbandry has, however, not only a quantitative aspect. There are also different problems regarding quality. Attention in recent years has been directed on problems concerning this, but there is not much of interest to report from the Swedish investigations. According to analysis the potassium content in the hay crop varies within wide limits, completely in agreement with experiences in other countries. The potassium content in hay is normally 1.7–1.8 per cent of the dry matter, in ley grazing 2.75–3.0 per cent. Extreme values can be found on grazing leys in the spring when the content can reach 6 per cent, at least in certain species. The relationship between the content of easily soluble potassium in the soil and the potassium content in the grass is also clear, although more penetrating investigations into this have not been carried out. The seasonal variation of the potassium content in the grass has been especially investigated in grazing leys, together with other more important minerals. A representative graph for potassium is given in figure 7. The lowest potassium content is found in the spring. On the whole it decreases during the summer but there is often a weak increase in the late summer, i.e. a graph with two peaks is obtained which is of the same type as the curve for seasonal variation of the pasture growth. The opposite type, i.e. a gradual increase during the growing season, is often seen in the graph for magnesium and calcium. Changes during the growth period between different minerals in the grass bring the discussion onto the effect of the intensive fertilizing

Figure 7 The seasonal variation of the potassium content in the grass

Average of 20 trials 1954–1958

systems on the balance between different plant nutrients. It is well known that the high potassium content in the grass often results in the content of other minerals being lower. The proportions between calcium, magnesium, potassium and sodium have been the subject of many investigations during recent years, particularly in respect of the intensive fertilizing with nitrogen. Some figures from trials in progress with high nitrogen applications to grass in pure stand are given here, particularly as they differ somewhat from the normal. The trial is on heavily fertilized soil with high potassium and phosphorus values. The soil is a humus rich loam with a very good structure. The results for one of the grasses, Timothy, can serve here as an example. The figures are given in Table 7 where it can be seen that the increased nitrogen fertilizing resulted in a noticeable increase in the contents of calcium, magnesium and potassium. Sodium did not change significantly and the phosphorus content increased slightly. In meadow fescue and cocksfoot there was also a very strong increase in the sodium content. The ash content does not change to any great extent which means that the content of other ash constituents, which are not mentioned here, are reduced.

The organic part is also very clearly influenced by the nitrogen fertilizing. A characteristic is that the nitrogen content (crude protein) increased but the content of easily soluble carbohydrates (inredos) declined. That the content of plant fibre does not change to any great extent is an evidence of the harvesting being carried out at approximately the same stage of development. It can also be worth mentioning that the yield of dry matter at the highest nitrogen applications reached ten to twelve thousend kg per ha and year. The trial shows that a pure grass stand which has received very high nitrate applications can produce a ley crop which, from the quality point of view, is not worse than the legume-dominated ley and which has not a worse mineral balance than the weakly nitrogen-fertilized grass. The result may naturally not be generalized. It shows, however, that when the chemical and physical conditions in the soil are optimal, the risk for lapses in quality of grass is

Table 7 The effect of increasing amounts of calcium nitrate on the chemical composition of timothy
Harvest taken at the grazing stage
The figures show the average of 5 harvests in 1962 and dry matter percentage

Constituent	Kg nitrogen per hectare and year as 15.5 per cent nitrate				
	0	125	250	375	500
Calcium	0.56	0.58	0.69	0.76	0.77
Magnesium	0.13	0.14	0.17	0.20	0.21
Potassium	2.77	3.18	3.46	3.66	3.72
Sodium	0.011	0.007	0.011	0.011	0.011
Phosphorus	0.37	0.38	0.41	0.41	0.40
Ash	10.7	10.3	10.9	10.9	11.0
Crude protein	14.1	16.1	25.1	25.1	26.8
Sugar (Inredos)	13.0	11.8	6.3	6.3	5.8
Crude fibre	21.2	21.9	21.3	21.3	20.9

E. Steen, 1962, Institute of Plant Husbandry

not so large as one will generally indicate. Such an optimal situation is, however, an exception and not the rule. This means that the plants can take up nutrients from the soil without restriction. The negative NO_3 ion, which plants take up in large quantities at nitrate fertilizing, is counterbalanced by all available cations and their content in the plant material increases without the relationship between potassium and the other cations being unfavourably altered.

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Potassium fertilizer for pasture land

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The quantities of potassium which are found in the different kinds of soil in Norway are not greater than that potassium has to be added everywhere to the soil in order to prevent decline of the crops. This is true both of grass and of the other agricultural vegetation.

What a practical agriculturist wants to know is what kind of potassium fertilizer he should use for grassland, what quantities give the best economic yield, and at what times the potassium fertilizer should be spread out. These are the principal questions which we have tried to answer by the pasture tests we have carried out. No general answers can be given – the climatic and soil conditions in our country are altogether too varied for that.

We shall in the following pages give some account of the experimental results we have reached hitherto.

Different kinds of potassium fertilizer

In our country there are in the main two kinds of potassium fertilizer which are sold. There is potassium fertilizer 41 per cent with a considerable content of chlorine – over 40 per cent. The potassium compound here is mainly KCl with a certain amount of NaCl. Further, there is potassium sulphate, K_2SO_4; this fertilizer contains 40–42 per cent K but little Cl, not more than 2.5 per cent. In the field experiments we have had at our disposal also German commercial fertilizer consisting of potassium carbonate ($KHCO_3$). This fertilizer is entirely free from chlorine and contains about 39 per cent K.

We shall first consider the three experiments carried out at Apelsvoll *(Grassland Experimental Station, Apelsvoll)* in 1961 and 1962. The soil at this station is a clayish mould, requiring relatively little potassium.

Potassium fertilizer 41 per cent and potassium sulphate were compared in one field at Apelsvoll in 1961.

kg dry matter per hectare

	41 kg K per hectare		82 kg K per hectare	
Without potassium fertilizer	Potassium fertilizer 41%	Potassium sulphate	Potassium fertilizer 41%	Potassium sulphate
5850	—80	+170	—230	+190

Apelsvoll, 1961

To a basic fertilizing with 900 kg nitrate of lime (15.5% N), divided into three sowings, and 200 kg superphosphate (8% P) there was added 41 kg and 82 kg K in potassium fertilizer 41 per cent and in potassium sulphate respectively. In the case of both quantities potassium sulphate gave the best result, as shown in the preceding table.

In 1962 two experiments were carried out at the station with different kinds of potassium fertilizer for pasture land. In the one experiment the basic fertilizer was 900 kg nitrate of lime (divided into 3 portions) and 400 kg superphosphate. The results were as follows:

kg dry matter per hectare

	41 kg K per hectare		82 kg K per hectare	
Without potassium fertilizer	Potassium fertilizer 41%	Potassium sulphate	Potassium fertilizer 41%	Potassium sulphate
6430	—500	—270	—230	+30

Apelsvoll, 1962

In the case of the second field, laid out in old pasture land and with a rather mixed stock of plants, and with 200 kg superphosphate per hectare and same amount of N as above, we obtained the following results in the same succession as above:

5850	+150	—90	+210	+450

Apelsvoll, 1962

The mean figures for these three fields show that potassium sulphate has had the best effect both in small and in great quantities.

	Smallest quantity K	Largest quantity K
Potassium sulphate less potassium fertilizer 41% = .	+80	+307

With the smallest amount K the difference is inconsiderable and uncertain; with the largest amount K there seems to be a more certain difference between the two kinds of fertilizer. Potassium carbonate has been present in one of the experiments at Apelsvoll. The result in this case was approximately the same as for potassium fertilizer 41 per cent.

The results from these few experiments must be taken with reservation, but the yield of crops gives nevertheless reason to continue work on these questions in future.

In the surrounding districts six experiments were carried out in 1962 with different kinds of potassium fertilizer for grassland. In five of these potassium sulphate gave on an average for both amounts of K approximately equally good or better effect than potassium fertilizer 41 per cent. For these five fields the mean figures in kg dry matter per hectare were:

Without potassium fertilizer	41 kg K per hectare		82 kg K per hectare	
	Potassium fertilizer 41%	Potassium sulphate	Potassium fertilizer 41%	Potassium sulphate
6504	+596	+496	+182	+558

	Smallest quantity K	Largest quantity K
Potassium sulphate less potassium fertilizer 41%	—100	+376

Also in the scattered fields potassium sulphate has had relatively best effect with maximum quantity of fertilizer. Potassium carbonate has been present in three scattered fields; the effect in this case seems to be approximately as for potassium sulphate. We reckon, however, that we shall have to continue these experiments before being able to give any definite advice to practical agriculturists. We regard it as an important aim of these experiments to get more reliable data in this field of work.

Experiments with increasing quantities of potassium

We shall here only consider the experiments which relate to increasing amounts of potassium fertilizer 41 per cent, as it is these which decidedly form the main body.

From the period 1948–1958 we had a series of tests with increasing quantities of K for grassland comprising altogether 42 annual reapings.

To all the fields there was given 132 kg N and 35 kg P as basic fertilizer. The amounts of potassium were 0, 49.5, 99.0 and 148.5 kg per hectare. As an average for all the fields we obtained the following crops:

kg K per hectare	0	49.5	99.0	148.5
kg dry matter per hectare	6200	+430	+500	+500

The fields lay scattered in different districts and the mean figures do not tell much for practical guidance. A closer examination of the results from the individual field has, however, afforded quite a good basis for evaluating the potassium requirements for grassland in the various districts and under different soil and climatic conditions. For inland regions with relatively dry climate we recommend from 100 to 200 kg potassium fertilizer 41 per cent on mineral soil. In coastal districts with greater precipitation we would increase this a little, from 200 to 300 kg per hectare. For washed-out sandy soil and for marshy soil still larger quantities are recommended, up to 400 kg per hectare. In this estimate we reckon that we do not recommend greater amounts of K for grassland than what the crop results advise. We say this because it is possible that under certain circumstances too strong potassium fertilization may lead to unbalanced mineral absorptions in the grass, which in its turn may have a harmful effect on the pasture animals.

Besides the said series with increasing amounts of K we have in recent years continued our researches in this sphere. The results do not appear to lead to any particular change in the general view we have on potassium supply, but by continuing the experiments we get constantly better knowledge of the need for this fertilizer under different soil and climatic conditions.

Different sowing times for potassium fertilizer on grassland

Besides the fact that it is necessary to know what kind of potassium fertilizer and what quantities should be supplied to the pasturages, it is also important to know at what time in the season of growth the best effect is obtained. The sowing times we have compared are sowing early in the spring, when growth begins, after the first grazing about the middle of June, and in the autumn after growth has ceased.

In an experiment at Apelsvoll from 1951 to 1958 spring fertilization and summer fertilization with potassium were compared. Spring fertilization gave a total crop of 5395 kg dry matter per hectare and sowing after the first grazing gave 5490 kg. This experiment was carried out on new-sown grassland. Fertilization with phosphorus and nitrogen was 27.5 and 93 kg valuable substance per hectare respectively. A new experiment was carried out in 1959, in which all three sowing times were compared. After spring fertilization with potassium the crop was 6127 kg dry matter per hectare; after the summer fertilization, 6123 kg, and after the autumn fertilization, 6295 kg dry matter. From four fields outside the experimental station we have 24 annual harvests, in which spring and summer sowings are compared. These fields were situated in coastal regions where the precipitation is considerably greater than at Apelsvoll. The results are given below (a).

Autumn fertilization with potassium has been tried in 5 fields altogether in elevated situations. In this series we have in all 22 annual harvests. These fields are laid out in meadowland at elevations of approx. 1500 to 2500 feet over sea-level. The average for the 22 years is given below (b).

(a) kg dry matter per hectare

	Potassium in the spring	Potassium in the summer
Average	4963	5090

(b) kg dry matter per hectare

	Spring fertilization	Autumn fertilization
Average	4776	4697

Sowing in the spring has been and is still the most usual. Our experiments show that it is a matter of indifference whether potassium fertilizer is sown in the spring, in the summer or in the autumn. In our advice to agriculturists we are wont to say that they can very well wait with potassium fertilization until later in the summer or in certain cases until the autumn, if labour considerations make this desirable.

Storage fertilization with potassium on grassland

By this we mean fertilization for more than one year at a time. We have compared annual spring fertilization with double quantity every second year in the autumn and quadruple quantity every fourth year in the autumn. In a more recent series we have also included treble quantity each year in the spring and in the autumn.

As an average for two fields in East Norway the results after 16 annual harvests (this is equivalent to two periods of 4 years in each field) are as follows (the average figures are here kg dry matter per hectare):

Annual spring fertilization 66 kg K per hectare	In the autumn every second year 132 kg K per hectare	In the autumn every fourth year 264 kg K per hectare
6294	6156	6108

It may be of interest to see what the crop was in the 1st, 2nd, 3rd and 4th year after autumn fertilization in these two fields. In the 1st year the crop, relatively to the spring fertilization, was +127 kg dry matter, in the 2nd year —165 kg, in the 3rd year —348 kg and in the 4th year —357 kg. Thus we have here a decline in year year and it looks as if there must have been some washing out.

In a similar experiment at Apelsvoll we have compared annual spring fertilization with storage fertilization every third year in the spring and every third year in the autumn. For the first 3-year period the results per hectare were as follows:

kg dry matter per hectare

	61.5 kg K annually in the spring	184.5 kg K every third year in the spring	184.5 kg K every third year in the autumn
Average	6038	6106	6179

The differences are, as will be seen, small and as it relates to only one 3-year period too great weight must not be attached to the figures. We think nevertheless that we have an indication that under conditions such as at Apelsvoll storage fertilization with potassium may have some value.

We shall here, too, look at the crop results in the 1st, 2nd and 3rd year after storage fertilization relatively to the annual spring fertilization. In order to compare the years better we insert relative figures.

	Spring fertilization annually	Spring fertilization every third year	Autumn fertilization every third year
1st year	100	103	103
2nd year	100	102	102
3rd year	100	99	102

It is generally speaking only in the case of storage fertilization in the spring that we have noticed a slight decline in the 3rd year after fertilization. For the present we are rather careful about advising storage fertilization with potassium. We shall wait until we have more data to hold to.

Effect of the potassium fertilizers on the dry matter in grassland

In our experiments with potassium on grassland we have found that fertilization with potassium 41 per cent has practically without exception lowered the percentage of dry matter in the grass. This is so irrespective of whether the yield of dry matter increased or decreased as a result of the fertilization. After 1961 we took up this question for closer examination at Apelsvoll.

We shall first look at some older series, with increasing potassium fertilization. The results come in part from Apelsvoll and in part from experiments we have carried out in other districts.

kg K per hectare	0	49.5	99	148.5
Percentage of dry matter, 18 annual harvests......	17.6	16.8	16.4	16.5
Percentage of dry matter, 24 annual harvests......	20.1	19.1	18.3	18.0

In another series we obtained these results:

kg K per hectare	0	32.8	65.6	98.4
Percentage of dry matter, 27 annual harvests	19.5	18.8	18.4	18.4

Also from other experiments with increasing potassium fertilization we were able to note a similar tendency. Suspicion went quickly in the direction of chlorine, especially when we found that potassium fertilizer administered in the autumn gave a higher percentage of dry matter in the crop than when administered in the spring.

As an average for 24 annual harvests we found the following:

	Without K	K given in spring	K given in autumn every 2nd year	K given in autumn every 4th year
Dry matter, %	18.0	17.3	17.6	17.6

In spring, summer and autumn sowings we found as an average for 3 years, 18.7, 18.7 and 19.1 per cent dry matter respectively. It appears that the precipitation between sowing and harvesting has great influence. We give below some results showing this influence. Years with little precipitation in the period May to September are compared with years with great precipitation in the same period. The series comprises altogether 24 annual harvestings.

kg K per hectare	0	99
Percentage of dry matter in years with max. precipitation (396 mm)	17.6	17.1
Percentage of dry matter in years with min. precipitation (254 mm)	19.6	18.1

Also in other fields we have obtained similar results and this strengthens the suspicion that it is the chlorine – which is of course easily washed out – that is the active substance in this respect.

The experiments we undertook in 1962 in this sphere had for their aim particularly to compare potassium fertilizers containing chlorine and those which did not contain chlorine. In four fields potassium fertilizer 41 per cent, potassium sulphate and potassium carbonate were compared. The average figures for 1962 were:

	Potassium fertilizer 41%	Potassium sulphate	Potassium carbonate
Percentage of dry matter	16.5	17.2	17.2

In three other fields only the two first-mentioned fertilizers were compared. The results were:

	Potassium fertilizer 41%	Potassium sulphate
Percentage of dry matter	18.7	19.1

In 2 pot experiments and 1 field experiment at Apelsvoll chlorine was added to non-chlorine potassium fertilizer for the purpose of ascertaining the effect. In the case of the field experiment we obtained the following results:

	Without potassium fertilizer	Potassium fertilizer 41%	Potassium sulphate	Potassium sulphate +HCl
Dry matter, %	18.5	16.9	18.3	17.4

A similar result was obtained from the pot experiments. In one of the experiments different fertilizers were tried with *Festuca pratense* as test plant, in the others with *Trifolium pratense.*

As an average for *Festuca pratense* the percentage of dry matter with chlorine-containing fertilizer was 21.8, and with chlorine-free fertilizer 22.5. For *Trifolium pratense* the figures are 19.5 and 19.9.

The experiments reported here show quite clearly that chlorine-containing potassium fertilizer and chlorine added to chlorine-free fertilizer have the effect of reducing the percentage of dry matter in pasture grass. No investigations have been undertaken by us to discover the reason for this fall. Some investigators think that the orifices in the breathing cells are affected; others that the osmotic pressure in the cells is altered.

The results from the pot experiment 1962:

	Percentage of dry matter	
	Festuca pratense	Trifolium pratense
Without potassium fertilizer	22.2	20.5
Potassium fertilizer 41%	21.6	19.6
Potassium sulphate	22.6	20.2
Potassium carbonate	22.3	20.0
Potassium nitrate	22.6	19.5
Potassium sulphate + HCl	21.9	19.3
Potassium carbonate + HCl	22.2	19.4
Potassium carbonate + NaCl	21.5	19.5

The question of interest in this connection is, however, whether this circumstance has any practical significance. If we reckon that ordinary good pasturage can give a grass crop of 30000 kg per hectare (weight before drying), a reduction in the dry matter percentage of 1 unit would signify a fall in the dry matter crop of 300 kg per hectare. Such a decline lies close to what we have found in our investigations. We can also look at the matter in this way, that we are not interested in producing grass with unnecessarily large water content. On the other hand, we must remember that under particularly dry growth conditions chlorine-containing fertilizer may have the effect of helping the plants to withstand the drought better. We saw indications of this last summer in the pot experiments with *Trifolium pratense*. It was found that the plant showed signs of withering if one did not give close attention to the watering. Such incipient withering was first seen in the case of the pots which had not received chlorine. This should indicate that the plants can manage with a smaller water supply when chlorine is added.

The experiments with chlorine-containing and chlorine-free fertilizer are continuing also in 1963. We reckon also that chlorine-free potassium fertilizer may have actuality as grassland fertilizer, but we must have more experimental results to build on before we can give any definite advice to agriculturists.

Sources used

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Output and grass/clover ratio of swards as influenced by potassium in conjunction with other treatments

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Grasslands differ from other crops in that they are usually comprised of a number of plant species each influenced to a different degree by environmental conditions. This makes fertilizer recommendations more difficult than for any of the arable crops. Any treatment in addition to affecting total yield may alter the contribution made to that yield by individual species. In this way the nutrient value of the herbage as well as the spread of production of the sward may be changed, all species not being the same in these respects. Moreover, grasslands are usually comprised of two very distinct types of plants – grasses and clovers – and where mineral fertilizer, or other treatment, alters the balance between these two groups it will also alter the supply of nitrogen to the sward through clover, and in this way have an indirect influence on yield and quality.

Potassium is a most important fertilizer in the latter respect. As shown by *Van der Paauw (13)* and since confirmed by many workers, notably *Rich* and *Odland (14)*, *Mulder (12)*, *Alten (1)*, *Fitzpatrick* and *Dunne (5)* and *Brown (3)*, the potassium requirement of clovers for unrestricted growth is much higher than that of grasses. Thus while the potassium status of a soil may be such as to support good grass growth it may be too low to promote vigorous growth in clover. This point is well illustrated by *Blaser* and *Brady (2)* who by the application of 83 lb K per acre to a potassium deficient soil increased clover yield in a mixed sward by almost five times while only increasing grass yield by a minor amount. Under deficiency conditions the clover contained a lower percentage potassium than the grasses but where potassium was added the percentage potassium in the clovers increased to a much greater extent than it did in the grasses. This is supported by *Drake et al. (4)* and *McNaught (11)* who found that under conditions of deficiency grasses were more efficient in securing their potassium requirement than clovers, despite the higher needs of the latter for potassium.

What of the potassium status of Irish soils, *McConaghy* and *McAllister (9)* on analyses of some 30000 samples in Northern Ireland found available K to be "low" in 30.2 per cent of cases, "medium" in 19.8 per cent, "medium high" in 30.5 per cent and "high" in 19.4 per cent, as judged by requirements for general cropping. They concluded "Fifty per cent of all soils had values below 10 mg K_2O per g. Crops grown on these soils should give good response to dressings of potassic fertilizers". Further, *Walsh et al. (15)*, in widely distributed trials on pastures in the Republic of Ireland, obtained definite yield and botanical responses to potassium in 44 per cent of cases, a doubtful response in over 31 per cent and no response in 25 per cent.

A number of experiments conducted by officers of the Field Botany Division of the Ministry of Agriculture for Northern Ireland are also of interest as regards the potassium fertilization of grassland. These experiments while not specifically designed to measure the influence of potassium did include potassic fertilizers at various levels, in various combinations with other fertilizers, under different methods of sward utilization and on soils of different potassium status.

Influence of nitrogen fertilization on soil and herbage potassium

In one of the trials referred to *Linehan* and *Lowe et al. (8)* measured yield and botanical responses of two swards of different seeding to six levels of nitrogen fertilization ranging from 0 to 350 lb N per acre per annum, in four equal dressings. One sward was seeded with a tall fescue/timothy/clover mixture and the other with a ryegrass/clover mixture; both were treated annually in spring with 36 lb P and 112 lb K per acre, and the herbage from all plots was cut and removed four times in each of the six seasons 1950 to 1955.

In the first year (1950) both swards were grass dominant at all levels of N and yields were almost directly related to the amount of N applied. Yields were similar and on the ryegrass sward ranged from 41.2 cwt dry matter per acre where no N was applied to 102.7 cwt at the highest level of N. On the fescue sward the corresponding range was from 46.9 cwt to 94.5 cwt. The response to applied N in the subsequent five year period, while different to that in the first year, was again similar for both swards. The averaged results for the two swards are presented for each of these years in Table 1.

Table 1 Mean annual total dry matter and clover dry matter yield obtained from two swards maintained under six levels of N fertilization in each of the five years 1951–1955 and over all years

		Nitrogen fertilizer in lb N per acre per annum					
		0	35	70	140	210	350
1951	Total dry matter	68.7	70.6	68.9	76.7	88.2	102.0
	Clover dry matter	38.7	31.8	26.6	7.3	2.1	1.1
1952	Total dry matter	70.1	71.0	73.4	73.8	83.4	100.1
	Clover dry matter	28.9	26.6	21.0	10.1	1.0	0.6
1953	Total dry matter	68.7	72.2	73.6	80.1	89.1	106.0
	Clover dry matter	19.2	12.2	9.3	4.2	0.7	0.1
1954	Total dry matter	46.4	48.2	50.6	59.0	68.6	82.0
	Clover dry matter	7.7	6.3	3.6	0.9	0.4	0.1
1955	Total dry matter	39.1	39.3	41.0	48.6	62.1	72.1
	Clover dry matter	12.0	8.5	3.8	1.6	0.7	0.0
All years	Total dry matter	58.6	60.3	61.5	67.6	78.3	92.4
	Clover dry matter	21.3	17.1	12.9	4.8	1.0	0.4

From Table 1 it will be seen that in each year clover comprised a high proportion of yield where no N was applied and that this proportion decreased with each increase in N fertilizer, clover being almost completely suppressed where 140 lb N or more was applied. It will also be seen that at all rates of N up to 140 lb there was no material increase in total yield, these applications being largely offset by the amount of N lost through the suppression of clover brought about by such applications.

McConaghy et al. (10) in a further study using the yield and botanical data available from this trial determined the influence of applied N on both soil and herbage, including their potassium content. As noted for yield and botanical data, again for soil and herbage data *McConaghy et al. (loc cit)* show that both swards reacted to N fertilizer in a similar manner. The available K value of the soil and the amount of K removed in the herbage under each treatment, averaged for the two swards, are shown in Table 2.

Table 2 Available soil K in parts per million, and amount of K removed in cwt per acre, under each of six levels of N fertilization

		Fertilizer treatment in lb per acre per annum					
		0	35	70	140	210	350
1950	Available K	130	123	120	107	92	91
	K removed...........	Data not available					
1951	Available K	127	117	119	115	100	99
	K removed...........	1.80	1.77	1.71	1.68	1.90	2.14
1952	Available K	123	136	135	132	116	106
	K removed...........	1.58	1.55	1.58	1.49	1.53	1.55
1953	Available K	107	100	99	93	92	92
	K removed...........	1.60	1.63	1.67	1.57	1.49	1.60
1954	Available K	73	72	70	67	65	66
	K removed...........	0.79	0.78	0.81	0.83	0.89	1.08
1955	Available K	Data not available					
	K removed...........	0.84	0.81	0.88	0.94	1.10	1.09

The data in Table 2 show that on this heavy soil, not noted for potassium deficiency and receiving 112 lb K per acre annually, there was a definite tendency for available soil K to decrease from year to year at each level of N application. On the other hand the amount of K removed in the herbage remained reasonably constant within years irrespective of N treatment except at the highest level of N where yields of grass dominant herbage were high. Under this latter treatment in three of the five years for which data are available, there was a considerable increase in the amount of K removed.

These two findings are in close agreement with the literature cited. That the lower yielding swards, containing clover, removed as much potassium as all but the highest yielding of the grass dominant swards is some evidence of the higher requirement of the former for potassium: And that clover declined over the years in the swards of low N treatment and never developed to any material extent in the swards of high N treatment may both have resulted from increased competition from the grasses for the decreasing supply of available K.

Influence of potassium fertilizer on sward yield and composition

The major effect of potassium on clover growth as compared with its effect on grass growth, and its indirect effect on yield and quality of the sward, is shown by the results in another trial conducted by *Linehan* and *Lowe (7)*. In this trial, on a medium loam soil of Silurian origin, various combinations of lime and fertilizers were compared on a sward seeded with perennial ryegrass and white clover. On test carried out immediately prior to the trial the soil was described as "medium sweet" at pH6.0, "medium high" in available P at 20 parts per million and "medium high" in available K at 91 parts per million. Under these conditions lime and phosphate treatments had no significant effect on yield or composition. On the other hand K treatments, despite the rating of the soil, showed major effects both when used alone and in conjuction with N. The rates of treatment were 168 lb K per acre, applied as an annual dressing in spring, and 208 lb N applied in six equal dressings each year. The herbage was cut and removed from all plots at equal date six times each year.

Table 3 Relative dry matter yield, clover content and crude protein value of herbage under each of four stated conditions of fertilization over the four years 1953–1956

Fertilizer treatment	Dry matter yield	White clover in dry matter	Crude protein in dry matter
lb/acre/annum	Relative	per cent	per cent
Nil	100.0	6.1	17.3
208 N..............	127.5	1.2	21.9
168 K.............	181.3	34.6	20.2
168 K+208 N	228.6	4.0	18.1

From the data in Table 3 it will be seen that where N alone was applied yield was increased by 27.5 per cent and that the already low clover contribution of 6.1 per cent was reduced to 1.2 per cent. Where K alone was applied yield was increased by 81.3 per cent and of this higher yield clover contributed 34.6 per cent. Where N was applied in addition to K the increase in yield was 128.6 per cent but here the contribution of clover was again of a low order amounting to only 4.0 per cent.

From these data it is clear that the original K status of the soil was too low to promote good sward growth, and that where N was withheld the main effect of added K was to increase clover growth. Here the actual yield of clover dry matter was increased by more than ten times, whereas the yield of grass was only increased by about 26 per cent. Moreover, not all of the latter increase can be attributed to the direct effect of K on the grass component as some part of it must have resulted from improved supply of N through clover.

Not only was the original K status of the soil too low for good clover growth but it also restricted the effect of N on grass growth. Thus it will be seen that N applied under these conditions of K deficiency increased total yield by 27.5 units but where N was added in addition to K yield increase due to N was 47.3 units. It will be noted that under both conditions of N fertilization the increases came entirely from the grass component of the sward, the yield of clover being much lower in each case.

These trials, in addition to showing the very beneficial effects of clover on sward yield, indicated the role played by K and N fertilizer on the clover component where the herbage was cut and removed. To further study these factors under actual grazing conditions *Linehan* and *Lowe (7)* conducted trials on three widely separated farms over the six years 1954–1959. Each of these trials was carried out on an area which had been used in previous years to measure output and study changes in soil and herbage under two systems of management, including fertilizer treatment. After ploughing and reseeding with a ryegrass/white clover mixture the sward under each condition of previous history was maintained under two fertilizer treatments which differed only as regards K and N. One of these treatments included K and N at commonly accepted rates (56 lb K + 58 lb N per acre per annum) while the other consisted of a heavy dressing of K only (168 lb K per acre per annum). In each case K was applied as a single dressing in spring while N was applied in three equal dressings. The plots, which were each one acre in area, were grazed on the principle of heavy stocking for short periods, yields being estimated as the difference between those calculated from sample clips taken before and after grazing in each period. On soil analyses at the beginning of the experiments available K values over all trials and plots ranged from 88 to 220 parts per million and averaged 125 parts per million. Summarised results for all three trials over both conditions of previous history in the six-year period 1954–1959 are given in Table 4.

The data in Table 4 show that, as in the former trials under cutting conditions again in these trials under grazing conditions, K fertilizer at a high level in the absence of N fertilizer stimulated clover growth and that under this treatment total dry matter yield was not significantly different from that obtained where K was applied at the lower rate in addition to N. Under these grazing conditions available soil K greatly increased over the period of the trial where the heavy annual dressing (168 lb) was given, whereas under cutting conditions in the former trials the tendency was for soil K to decrease at this level of K fertilization. Conversely, under grazing conditions, even the lower rate of K (56 lb) appeared adequate to maintain the original status where output was at the level obtaining in these trials.

These controlled experiments provided some evidence of the rather marginal level of K in a limited number of soils when judged by their ability to support

Table 4 Mean annual total dry matter and clover dry matter yield over the six years 1954–1959 and mean available soil potassium at the end of 1959 season, for each of two conditions of fertilizer treatment

Fertilizer treatment	Total dry matter yield (a)	Clover dry matter yield (b)	Available soil K
lb/acre/annum	cwt/acre/annum	cwt/acre/annum	ppm
58 N+56 K	51.7	7.5	198
168 K.............	48.5	13.6	479

(a) Yield difference not significant (b) Yield difference significant at $P<0.05$

good clover growth. To get a more general appreciation of soil conditions for clover growth some 16 observational trials were conducted at widely spaced centres embracing all the more common soil types. At each centre an area was seeded with ryegrass and white clover and on this area a number of fertilizer treatments were introduced. These trials were all sited in fields to be used for pasture, silage or both and, apart from fertilizer treatment, were subjected to the same management practices as the remainder of the field in each case. The plots were examined in spring, summer and autumn over the three years 1956–1958 and marks were awarded on a 0–10 basis for each of a number of characteristics, including clover vigour and clover/grass ratio. The data relative to the effects of N, K and N + K, where lime and phosphates were applied, are summarised in Table 5.

Table 5 Number of instances out of 132 observations for each of four fertilizer treatments where clover vigour and ratio of clover to grass came within stated values when marked on a 0–10 basis

Treatment	Clover vigour			Clover/grass ratio		
lb/acre/annum	5.0 or less	5.1 to 7.5	over 7.5	2.5 or less	2.6 to 5.0	over 5.0
Nil	34	62	36	54	70	8
116 lb N	26	63	43	91	32	9
168 lb K	18	50	64	40	70	22
116 lb N+168 lb K	19	51	62	75	46	11

While the data in Table 5 cannot be regarded as critical, nevertheless, that the number of instances of high clover vigour and high ratio of clover to grass were both greatly increased where K was applied in the absence of N is supporting evidence of the importance of K in maintaining swards of good grass/clover balance.

On the evidence presented by *McConaghy* and *McAllister (9)* and *Walsh et al (15)* it is probable that about 50 per cent of all Irish soils are too low in available K to support full clover growth. Collectively, the results in the present trials support this view. They tend to show that, under conditions of low nitrogen fertilization, the clover status of Northern Ireland grasslands could be greatly improved by the more liberal use of potash fertilizers and that, under such conditions, output could thereby be greatly increased. As expressed by *Hexter (6)* only where the clover component of the sward is growing without deficiency symptons can the potash status be regarded as satisfactory. Potassium, by encouraging clover, not only contributes directly to yield but further yield benefit is derived from the additional nitrogen made available by the greater amount of more vigorous clover present.

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The effect of pasture management on the uptake of potassium by different swards

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Introduction

Intensive grassland production in recent years has resulted in the appearance of potassium deficiency in many Irish pastures. From a comprehensive survey carried out by *Walsh et al. (1)* in a large dairying district where the fertility of the soils was above normal and where no distinct complexing problems with regard to potassium intake were present, it was found that 48 per cent of the soils were very low in potassium, 32 per cent low and only 20 per cent reasonably satisfactory. This problem of removal and K balance is now of special importance in this country with the institution of intensive management practices. Depending on the system of grassland management, large or small amounts of potassium may be extracted from the soil. It has been shown by *t'Hart (2)* that the amount removed under a grazing system is negligible compared with that removed under a cutting system. In the present paper findings are presented from two grassland experiments, one (Experiment 1) showing the effect of an intensive grazing management system on the potassium level in the herbage and the other (Experiment 2) the impact of various cutting systems on the removal of potassium in the herbage. Rainfall data are also presented for Experiment 1 in relation to seasonal variation of herbage potassium. Experiment 1 was carried out at Johnstown Castle, Co. Wexford and Experiment 2 at Grange, Co. Meath.

Experimental

The object of experiment 1 was to ascertain under grazing conditions the effects of varying levels of nitrogen on animal production, dry matter production and the uptake of major elements by the herbage. The complete experiment, begun in 1957 on a grass/clover sward, involves a comparison of the effects of different increments of nitrogen namely 0, 46, 92, 184, 368 1b N per acre per annum. A detailed report of this experiment has been written up by *Moloney* and *Murphy (3)*. For the purpose of this paper we have taken the nitrogen treatment (A) which was a grass/clover sward and the highest nitrogen treatment (B) which received an annual application of 368 lb N as ammonium sulphate per acre per annum since 1957. This was an all grass sward. We are presenting the results for 1959, 1960 and 1961. The basal manuring for both treatments is shown in Table 1.

The soil was a moderately well to imperfectly drained brown earth (slight mottling after 7 inches, strongly mottled after 20 inches) of medium base status – sandy loam to sandy clay loam derived from Irish sea drift of Saale age intermixed with solifluction materials.

Table 1

Year	P lb per acre	K lb per acre	Treatment	Time of application
1959	36	112	A and B	Mid-February
1960	27	56	A and B	Mid-February
1961	27	56	A and B	Mid-February

A system of intensive rotational grazing was practised whenever the herbage reached a height of 4–5 inches. Bullocks averaging 750 lb fasted weight and wether hoggets averaging 80 lb were used on this trial. The average clover percentage for treatment A was approximately 25 per cent and it was "fixing" the equivalent of 7 cwt sulphate of ammonia (21 per cent N) per acre per annum. Treatment B was the same sward as treatment A when the trial started in 1957 but by 1959 it was an all-grass sward as 368 lb N per acre in 1957 and 1958 had completely eliminated the clover. The potassium figures for treatments A and B are given in Table 2.

Table 2

	Available K – (sampling depth 0–2″)	
	A lb per acre	B lb per acre
1958	178	221
1959	270	200
1960	210	240
1961	200	180
Mean	215	210

The method at present being employed in our laboratory for the determination of potassium in the herbage consists of the wet ashing of plant material with sulphuric acid, hydrogen perioxide and selenium catalyst and the determination of potassium in the digest by a flamephotometer. The soil potassium is determined by the extraction of dried soil with Morgan's solution at pH 4.8 and then using a flamephotometer.

The object of Experiment II was to ascertain the effect of cutting pasture at different stages of growth throughout the year on the level of potassium in the herbage and on the total amount of potassium extracted for the year. The soil was a brown earth, imperfectly drained, loam to clay loam and of a high base status. It was carried out on two types of pasture namely a grass/clover sward and an old permanent pasture. Both of these swards had grazed the previous year and in 1959, the year in which the experiment was carried out, a dressing of 36 lb P, 112 lb K and 46 lb N was applied in mid-February.

The treatments were as follows:

A	Cut each time the sward reached 2″
B	Cut each time the sward reached 4″
C	Cut each time the sward reached 6″
D	Cut each time the sward reached 8″
E	Cut each time the sward reached 10″
F	Cut each time the sward reached 12″
G	Cut each time the sward reached 12″ + 2 weeks
H	Cut each time the sward reached 12″ + 4 weeks
L	Cut each time the sward reached 12″ + 6 weeks

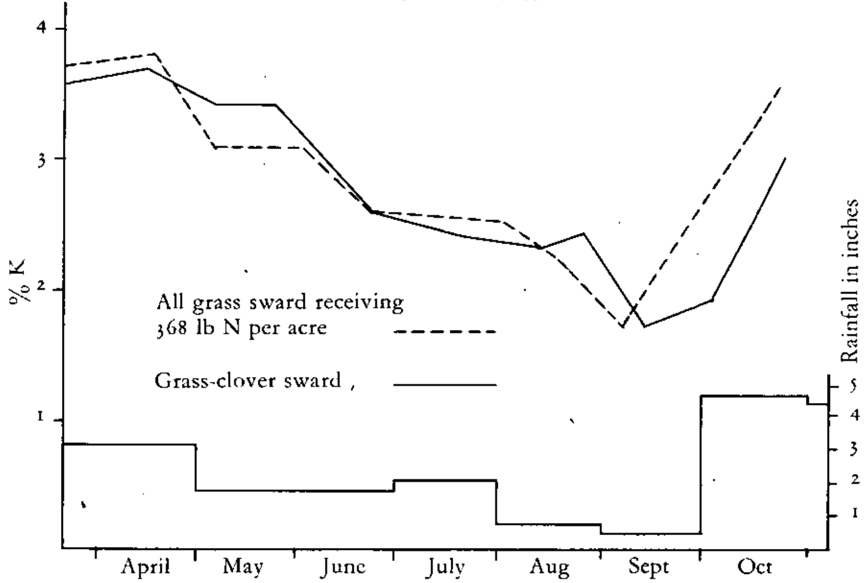
G, H and L were cut two, four and six weeks respectively after the swards had reached a height of 12″.

Results

Experiment I

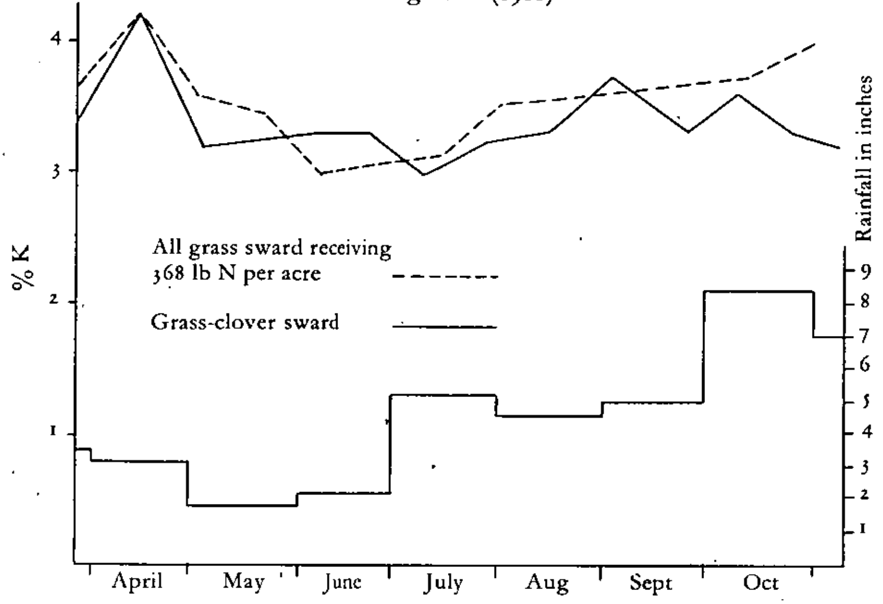
The levels of soil potassium are shown in Table 2. The mean levels of potassium were 215 and 210 lb of available K for treatments A and B respectively. Under the conditions here these would be classified as very high levels. The per cent K levels in the herbage throughout three grazing seasons are presented in figures 1, 2 and 3.

Figure 1 (1959)



Total monthly rainfall

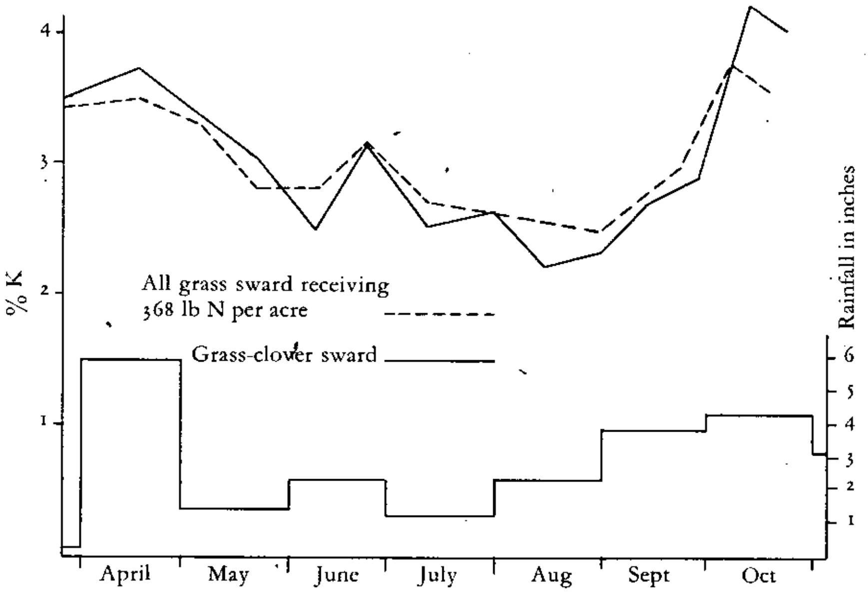
Figure 2 (1960)



Total monthly rainfall

Within each year there was no difference in the percent K in the herbage dry matter for treatments A and B. In 1959 and 1961 the percentage of K in the herbage dry matter showed large fluctuations during the grazing season whereas in 1960 it remained much more static. In early March 1959 the level of herbage potassium in both treatments was 3.75 per cent, by September it had decreased to 1.75 per cent and by late October it had increased to 3.4 per cent. Similarly in 1961 the level of potassium at the beginning of the grazing season was 3.5 per cent, by the end of August it had dropped to 2.5 per cent and in late October it was approximately 4.0 per cent in both treatments. In 1960 the level of potassium in the herbage at the beginning of the grazing season was 3.5 per cent in both treatments. At the end of August it was still 3.5, having shown very little variation in the intervening months, but by the end of Oktober it had reached 3.75 per cent. The mean rainfall for May, June, July and August was 1.6 and 1.8 inches per month for 1959 and 1961 respectively, whereas in 1960 the mean rainfall per month for the same period was 3.4 inches per month. *Barber (4)*, working in the United States, has found a relation between potassium availability and seasonal rainfall. Figures 4, 5 and 6 illustrate the amount of potassium extracted by the herbage for each grazing cycle. For the three years (1959, 1960 and 1961) the amount of potassium extracted by treatment B was much greater than treatment A for most grazing cycles, except the fourth grazing for 1960 where treatment A extracted 12 per cent more potassium than treatment B.

Figure 3 (1961)



Total monthly rainfall

Experiment II

The effect of stage of growth on the level of potassium in the herbage and also the effect of type of sward on the percentage of K in the herbage are presented in figure 7.

The K level follows the same pattern in both the old and new pasture until the 8″ stage of growth is reached. In the new pasture there is a sharp drop in the percentage of K from the 8″ to 10″ stage while for the old pasture the drop is more gradual all the way down to six weeks after it reached the 12″ stage. A curvilinear regression analysis showed that the relation was very highly significant for both pasture types and the regression line was different for the two.

The total amounts of K removed for the whole cutting season are presented in Table 3 for the two types of pasture.

Table 3 Total amount of potassium removed by herbage cuts (lb per acre)

	A	B	C	D	E	F	G	H	L
New pasture	90	138	140	137	143	140	150	133	128
Old pasture	79	132	136	153	150	167	157	151	154

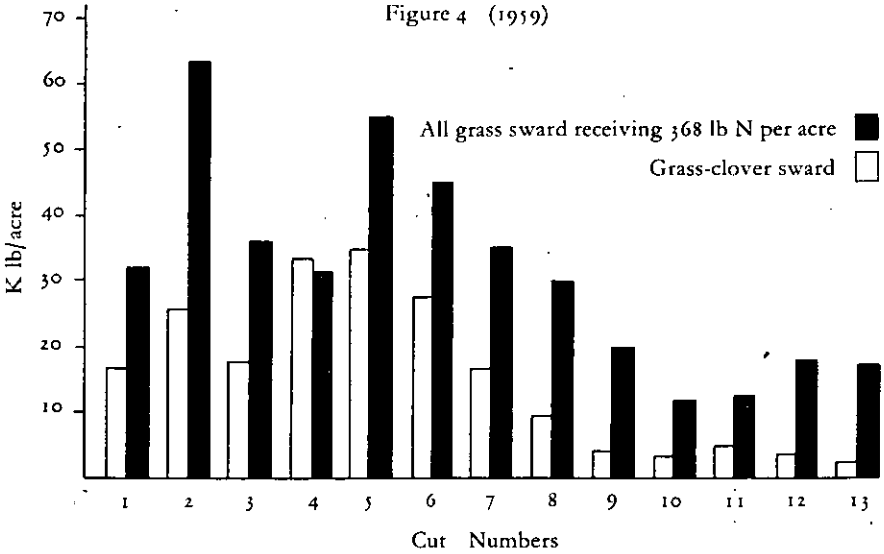


Figure 4 (1959)

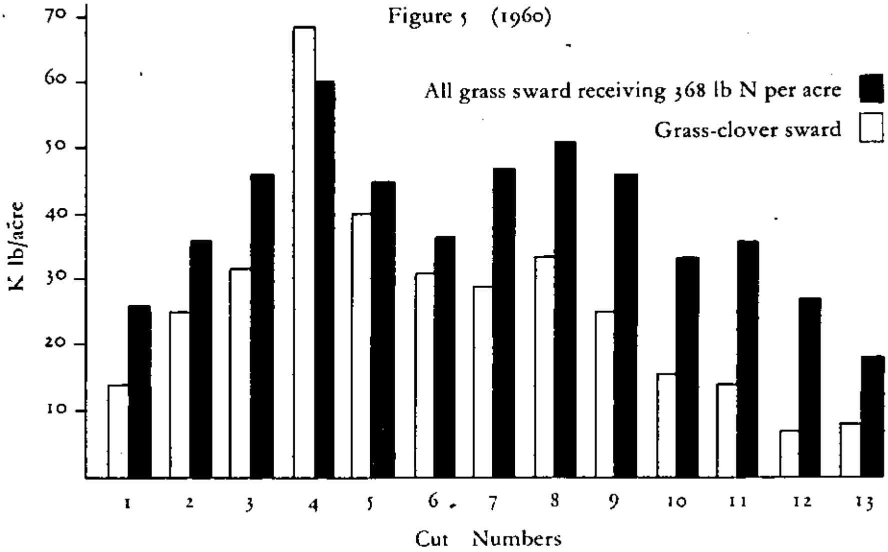


Figure 5 (1960)

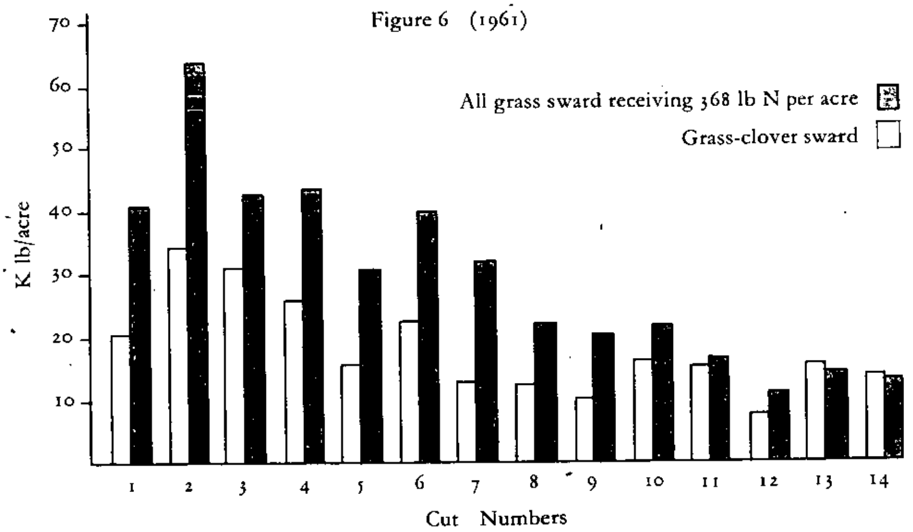


Figure 6 (1961)

The lowest amount of potassium was extracted by Treatment A and there appears to be very little difference in the amount of potassium extracted by the other treatments within each pasture type. The amount of potassium extracted by the old pasture is higher than that of the new pasture in all treatments except A, B and C. This appears to be due to a higher percentage of K in the herbage of the old pasture at the particular stages of growth.

The first cut was taken from Treatment L on the 1st July for the new pasture and on the 13th July for the old pasture. For the same period the total amount of K removed in this period by both treatments is presented in Table 4.

Table 4 Amount of K removed by treatments C and L up to mid-July (lb per acre)

	New pasture		Old pasture	
	Date of cutting	Amount of K removed	Date of cutting	Amount of K removed
L	July 1st	102	July 13th	134
C	20.4.1959	37	13.5.1959	48
C	19.5.1959	30	2.6.1959	30
C	3.7.1959	45	16.7.1959	38
Total K removed by treatment C for 3 cuts		112		116

In the new pasture treatment C, which was cut three times, extracted 10 lb more potassium than treatment L which was cut only once. In the old pasture treatment L extracted 18 lb more potassium than treatment C.

Discussion

In Experiment I there was no difference in the level of potassium in the herbage between treatment A and B within each year. *Walsh (5)* has given the critical level of potassium for cocksfoot swards as 1.8 and has quoted a critical level of 2.0 for wild white clover. In one grazing cycle in August 1959 a level as low as 1.75 per cent K was recorded in the experiment described. In all the other grazing cycles in each of the three years the level of potassium in the herbage was much higher than the above figure, indicating that under the soil conditions pertaining to this experiment there was a "luxury consumption" of potassium for both treatments. However, since the critical level of potassium for white clover is higher than that of grass, this "luxury consumption" was highest in treatment B. Work by *Walsh* and *Conway (6)* has shown that a combination of high nitrogen and potassium fertilization on a ryegrass sward was conducive to the lowering of blood serum magnesium values in grazing dairy cows. Work by *Kemp (7)* confirms these findings.

In order to intensify grassland production the use of high inputs of fertilizers is essential. Under grazing conditions the amount of potassium removed by the animal is very small. *t'Hart (2)* has quoted a figure of 0.6 kg K_2O/ha removed by fattening cattle putting on 300 kg liveweight gain as against 200 kg K_2O/ha for a 9000 kg hay crop. The annual application of potassium fertilizers, under a grazing management, and on non potassium "fixing" soils may therefore eventually give rise to "luxury consumption" of potassium by the herbage. This condition could lead to more frequent occurrences of hypomagnesaemia in grazing animals.

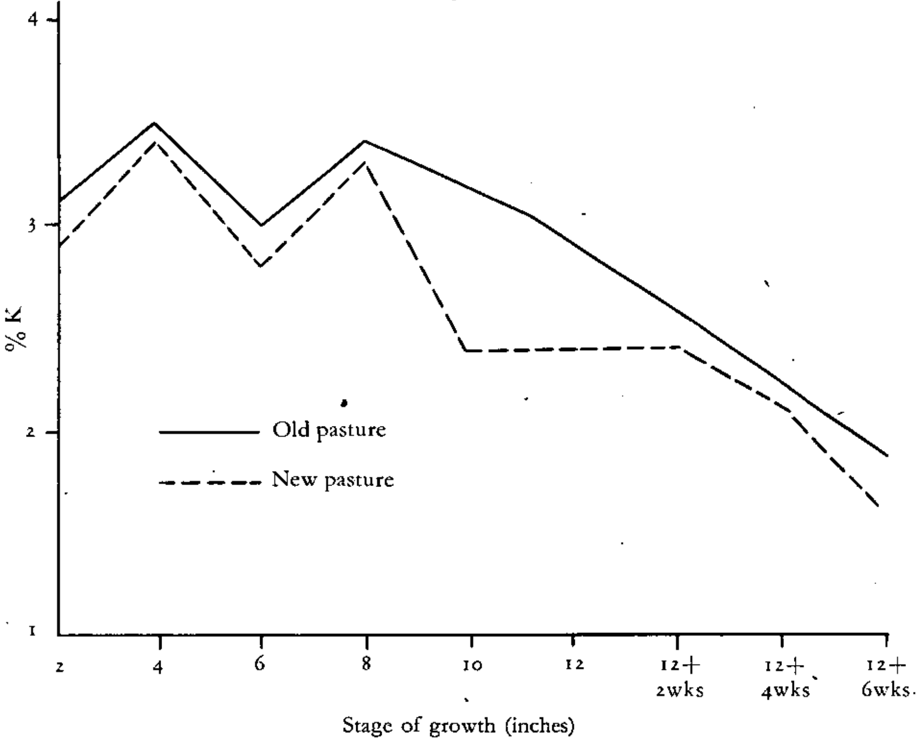
In Experiment II it was shown that under cutting conditions over 100 lb K was removed in either one or several cuts taken before mid-July. The alternation of grazing and mowing in an intensive system of grassland farming should lower the "build up" of available potassium in the soil and help in the reduction of the incidence of metabolic disorders such as hypomagnesaemia.

In 1959 the percentage of K in the herbage declined gradually from mid-April when it was 3.75 until mid-September when it was 1.75. The mean rainfall for this period was 1.4 inches per month whereas in October the rainfall was 4.7 inches and the level of potassium in the herbage rose to 3.4. In 1960 the percentage of K in the herbage varied only slightly throughout the grazing season and the mean rainfall from May to September was 3.7 inches per month but in comparison with 1959 when the mean rainfall per month from May to September was only 1.4 inches. For 1961 where the mean rainfall was 1.8 inches per month from May to August there was a similar decrease in the K content of the herbage as in 1959. Following a very heavy rainfall of approximately 4 inches per month for September and October there was again, as in 1959, a very rapid increase in the K content of the herbage.

From the results presented there appears to be a very close relationship between rainfall and the level of potassium in the herbage dry matter. For the nitrogen treated sward the amount of potassium extracted by the herbage during the three years was approximately 60 per cent greater than that extracted by the grass/clover sward. Since the percentage of K is approximately the same for both treatments, this increase in potassium extracted by the herbage is due to the greater production of dry matter from the nitrogen treated sward. From data presented in Table 4 it is shown that irrespective of the stage of growth at cutting the drain on the potassium reserves in the soil was over 110 lb K per acre for cuts taken before mid-July.

With systems of complete cutting and removal of herbage the extraction of K can be as high as 160 lb per acre as seen in Table 3. By repeating such a system the available K reserves in the soil could be lowered considerably resulting in a decrease of dry matter production. *Walsh et al. (5)* have shown from their work on the production of herbage for dried grass that potash deficiency, as revealed by soil and herbage analysis, was one of the major causes for a sharp decrease in dry matter production. They have also shown that the split application technique proved more efficient from the aspect of equalising the potassium level in the herbage. From a split application of 2 cwt (42 per cent K) in Spring and one cwt after each cut (three applications) the potassium content was more uniform throughout the season and not greatly the luxury threshold value. The amount of K applied in normal practice under Irish conditions is not sufficient to compensate for this

Figure 7



removal. As already discussed the alternation of grazing and mowing within a farming unit as required by modern intensive methods could help to a large extent to keep the levels of the soil more in equilibrium.

In Figure 7 the gradual decline in the K level in the herbage of the old pasture from the 8″ stage onwards is probably due to the fact that the old pasture was composed of a number of grasses all reaching their flowering stage at different times, whereas the new pasture was composed only of perennial ryegrass. The old pasture had a dense leafy "butt" at all stages after reaching the 8″ stage whereas the new pasture was very stemmy and rather thin at the "butt".

Acknowledgements

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The effect of different crop rotations on soil potassium levels

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It is generally recognised that a rotation of crops is important in the interests of good husbandry and the preservation of soil fertility. Removal of crops as occurs under tillage, reduces the supply of nutrients unless replaced by fertilizers and manures. However, when crops are consumed on the land as in the case of pasture or folding, only a small portion of the nutrients is lost – the majority are returned in faeces and urine. Obviously, therefore the kind of crop rotation can be expected to influence considerably the loss or accumulation of nutrients in the soil.

Mann and *Boyd (1)* and *Warren* and *Johnston (2)* have reported the findings of long term rotation experiments at Rothamsted and Woburn on this problem, especially with reference to potassium. They found that at Rothamsted, cut grass and lucerne leys decreased the readily soluble K in the soil, and the yield of potatoes following these crops was lower than after grazed ley: furthermore, at Woburn, grazed ley was found to increase the readily soluble K in the soil of a ley arable experiment, and a single dressing of farmyard manure also increased the soluble K level.

An experiment very similar to that at Rothamsted was laid down at Johnstown Castle in 1956. The purpose of this paper is to discuss the effects of the various crop rotations used in this experiment on the K balance over a period of six years.

Experimental

The experiment followed a very poor old pasture which had not been cultivated for many years. The soil was moderately well drained to imperfectly drained brown earth of medium base status, of sandy loam to sandy clay loam texture, derived from Irish sea drift of Saale Age intermixed with solifluction materials.

Treatments involved a comparison of six crop rotations, four of three years duration and two long term. The four three-year rotations were:

Grazed ley (LG)	New pasture grazed for three years.
Hay grazing (HG)	New pasture, cut for hay the first year and then grazed for two years.
New pasture (N)	Cut for hay each year for three years.
Arable rotation (A)	Comprising Italian ryegrass cut for hay, followed by oats, followed by sugar beet.

The two long term rotations were:

New pasture (R)	Grazed continuously.
Old pasture (G)	Grazed continuously.

To assess, the effect of the rotations on soil fertility, a test crop (T) rotation comprising, wheat, potatoes and barley followed each rotation (the two long term rotations R and G have not yet been test cropped). The laying down of the treatments was spread over three years. In order to ensure continuity in the experiment, half the number of plots laid down in the first year were sown to the first test crop (wheat). In the second year of the experiment (1957) a similar set of plots was laid down and again in the third year (1958). The purpose of this was to eliminate differences between years. The scheme of rotation and test crops (for each rotation) is shown in Table 1.

Table 1 Timing of rotations and test crops

Year	1st year		2nd year		3rd year	
1956	R_1	T_1				
1957	R_2	T_2	R_1	T_1		
1958	R_3	T_3	R_2	T_2	R_1	T_1
1959	T_1	R_1	R_3	T_3	R_2	T_2
1960	T_2	R_2	T_1	R_1	R_3	T_3
1961	T_3	R_3	T_2	R_2	T_1	R_1
1962	R_1	T_1	T_3	R_3	T_2	R_2
1963	R_2	T_2	R_1	T_1	T_3	R_3

R_1 R_2 R_3 = 1st, 2nd and 3rd years of each rotation
T_1 T_2 T_3 = 1st, 2nd and 3rd test crop

In the case of the four rotations subject to the test crops, the plots were subdivided giving four sub-plots and farmyard manure (FYM) and nitrogen were applied in a 2×2 factorial layout. The nitrogen levels were such as to give 368 and 172½ lb N per acre over six years and the FYM was applied as a single twenty tons per acre dressing to the potato crop in the testing rotation.

The grazing plots were grazed by sheep and grass yields were taken and herbage samples analysed before each grazing. Hay plots were usually cut twice for hay each year.

Results

Soil samples were taken at the end of each year and extracted by the Morgan method – sodium acetate acetic acid solution at a pH of 4.8. Potassium content was estimated using a flame photometer. Extractable calcium and phosphorus figures and the pH of the soil in water were also recorded. Only the potassium figures are presented here.

The levels of potassium after each year of treatment are shown in Table 2. Only the means of treatments that had significant F values (P = 0.05) in the analysis of variance are included.

Owing to the design of the experiment the difference between years was confounded with the difference between blocks.

Table 2 Extractable soil K levels (lb K per acre) 1st year

	LG	HG	H	A	LGt	HGt	Ht	At
	136	86	96	83	94	98	82	100

2nd year

	LG	HG	H	A	LGt	HGt	Ht	At	Mean
No FYM	175	140	89	133	129	110	105	117	125
FYM	173	131	90	131	144	155	167	170	145
Mean	174	136	89	132	137	133	136	144	

3rd year

	LG	HG	H	A	LGt	HGt	Ht	At	Mean
	N_1/N_2	N_1/N_2	N_1/N_2	N_1/N_2	N_1/N_2	N_1/N_2	N_1/N_2	N_1/N_2	
No FYM	238/236	169/218	56/52	159/143	119/107	98/101	92/ 96	103/110	131
FYM	272/260	233/177	56/61	175/184	141/115	124/145	110/138	138/155	155
Mean	252	200	56	165	120	117	109	126	

4th year

	LG	HG	H	A	LG	HG	Ht	At
	179	165	57	124	157	100	85	75

5th year

	LG	HG	H	A	LGt	HGt	Ht	At	Mean
No FYM	203	156	108	115	248	200	68	122	153
FYM	294	282	205	265	245	199	73	147	214
Mean.	249	219	157	190	246	200	71	134	

The figures for the first year are made up of soil analysis results from 1956, 1957 and 1958 i.e. they are the results of the first sampling of each plot after it had been laid down. The samples for the sixth year are those taken in 1961 and 1962 – two thirds of the total number of plots, as the other third of the plots had not reached their sixth year at the end of 1962.

Table 2 (continued) *6th year*

	LG	HG	H	A	LGt	HGt	Ht	At	Mean
No FYM	168	163	84	110	205	193	58	101	135
FYM.........	218	234	159	192	209	190	61	144	176
Mean	193	199	122	151	207	191	59	123	

Mean of N treatments	
N_1	N_2
165	146

LG = Ley grazing; HG = Hay for one year, grazing for two years; H = Hay for three years; A = arable rotation; t means that the test crops were sown for the first three years and then the rotations begun

The results from each year of the rotations subject to test crops were statistically analysed on an electronic computer. The experiment was treated as if there were eight rotations, four starting with the treatments proper and four starting with test crops. Table 3 shows the significant levels of the F value for treatments and interactions.

Table 3 *Significance of F values*

	Effect						
Year	Rotations (R)	N	FYM	R×N	R×FYM	N×FYM	R×N×FYM
1st	*						
2nd	*		**		**		
3rd	**		**				**
4th	**						
5th	**		**		**		
6th	**	**	**		**		

* F significant at P = .05 ** F significant at P = .01

In the first year only the rotations had different effects on the extractable soil potassium. These differences became more pronounced in succeeding years.

In the second and third, and again in the fifth and sixth, the farmyard manure showed its effect. The farmyard manure was applied in the second and fifth year. Its effect lasted into the third and sixth years but not into the fourth year. There was an interaction between the rotations and farmyard manure in the second and fifth and sixth year. The interaction in the second year was due to the fact that sub-plots that received FYM in the test crop section were compared with sub-plots in the rotation section that had not received FYM but were treated for the purpose of the analysis as if they did. In the fifth year the continuous hay rotation was more affected in potassium status by FYM than the other plots as the FYM was then applied to plots that had three hay crops taken off followed by a wheat crop that did not receive any potassium whereas the farmyard manure was applied in the second year to plots that were not so depleted.

The amounts of potassium added each year and totals for the three years of the rotation and the three years test crops are shown in Table 4 and the amounts removed during the second and third years rotation and the second and third years test crops are shown in Table 5. Complete figures are not available for the first three years of the experiment. The figures for removal by the testing rotation during the fourth, fifth and sixth years of the experiment, as shown in Table 5, will give some idea of the depletion by the test crops in years 1, 2 and 3 of the experiment which preceeded the rotations in years 4, 5 and 6.

Table 4 Amount of K added (lb per acre)

	LG	HG	H	A	R	G
1st year rotation	94.1	94.1	94.1	70.6	94.1	94.1
2nd year rotation	70.6	70.6	70.6	47.0	70.6	70.6
3rd year rotation	70.6	70.6	70.6	117.6	70.6	70.6
Total for 3 years rotation ...	235.3	235.3	235.3	235.2	235.3	235.3
1st year testing	0	0	0	0	70.6	70.6
2nd year testing	47.0	47.0	47.0	47.0	70.6	70.6
3rd year testing	23.5	23.5	23.5	23.5	70.6	70.6
Total for 3 years test crops ..	70.5	70.5	70.5	70.5	211.8	211.8
Total for 6 years	305.8	305.8	305.8	305.7	447.1	447.1

Table 5 Potassium removed in 3 years rotation (lb per acre)

	LG	HG	H	A
No FYM N_1	—	104.54	399.15	475.08
FYM+N_1	—	123.49	443.94	418.61
No FYM N_2	—	125.92	360.28	395.48
FYM+N_2	—	123.30	443.17	470.39
Mean	—	119.31	411.63	439.89

In the LG (continuous grazing) treatment all the potassium except that retained in the bodies of the animals was returned to the soil during the three years rotation in the form of dung and urine. The retention of potassium by the animals was not

Table 5 (continued) Potassium removal in 3 years testing (lb per acre)

	LG	HG	H	A
No FYM N_1	290.15	245.91	187.57	204.99
FYM+N_1	235.83	221.16	210.88	227.13
No FYM N_2	270.49	233.73	222.18	230.95
FYM+N_2	241.32	246.83	243.31	238.89
Mean	259.45	236.91	215.98	225.49

measured but the amount would be very small in comparison with that removed by cropping. The situation was similar during the second and third years of the HG treatment. The crops were removed completely from the H and A treatments during the three years.

Conclusions

The form of land utilization has a major influence on the potassium levels in the soil. Where moderate dressings of potassium (about 70 lb K per acre) are applied each year there is a rapid building up of readily available soil potassium under grazing conditions (Table 2) but this is not the case when a hay crop is removed each year – in fact there is a depletion of readily available soil K.

When the soil was subject to test cropping with low additions of K the available soil K fell slightly if the level had been built up by the previous treatment e.g. continuous grazing, but it increased if it had been previously depleted by taking hay crops in the preceeding years.

Continuous tillage whilst removing as much potassium as continuous hay (Table 5) did not have the same effect on available soil potassium.

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Communication

A note concerning the effects of potassium fertilisers on plasma magnesium levels of lactating sheep and on herbage potassium and magnesium concentrations

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Introduction

A number of references have tended to incriminate potassium fertilizers (and particularly when used in combination with nitrogen) as a causal agent in hypomagnesaemia in cattle. Generally, however, the rates of application investigated have been unrealistically high and their work has not really been to assess the effects of potassium applications as such but rather to find a method of herbage treatment such as would *induce* hypomagnesaemia in order that methods of control could be studied.

For example, *Bartlett et al. (1, 2)* applied 4 cwt of potassium sulphate per acre and found no hypomagnesaemia in the first year. In the second year of the experiment (when the fertilizer application was repeated) they used a hormone weed killer to eliminate the profusion of clover which this treatment created and three out of four cows then had plasma Mg values below 1.0 mg/100 ml. *Smyth et al. (9)* applied 2.75 cwt of muriate of potash but only found clinical cases of tetany in cattle when this was used in combination with 5.5 cwt per acre of nitrochalk (15.5% N). There were only three cows per treatment. *Kemp (7)* used potassium applications which included the following; in 1956, 270 lb K_2O/acre was applied in March followed by 135 lb K_2O/acre in August; in 1957, 180 lb K_2O was given with a further 90 lb in August. Again, a hormone weed killer was used to eliminate clover and herbs. There were no clinical cases of tetany in cattle in 1956 but in 1957 there were several cases which were confined to the high potassium plots. *Hvidsten et al. (6)* treated herbage with between 160 and 187 lb K_2O/acre in each of three successive years. Nitrogen application was also very high. In the first year there were no cases of tetany. The single cases which were found in each of the two successive years were confined to the high potassium treated plots. The average blood magnesium levels for these plots were less than those for cattle on plots without applied potassium.

In contrast, *Storry (10)* has reported no increased incidence of hypomagnesaemia in cattle grazing plots to which as much as 7 cwt of muriate of potash had been applied, together with either 10 cwt of nitrate of soda or 7 cwt of ammonium sulphate.

Almost all these experiments can be criticised in one or more important respects.

1. Excessively high rates of K applications have been used.

2. Elimination of clover growth (which had been encouraged by potassium application) by means of a hormone weed killer invalidates the results, in so far as a direct potassium effect is concerned.

3. Generally, only groups of 3, 4 or 5 cows have been used to graze unreplicated fertilized plots and, in consequence, the results are not capable of adequate statistical treatment.

4. There is some confusion between hypomagnesaemia and *clinical tetany* which is the only important criterion. Equally, there is an absence of definition in the literature concerning what constitutes the *normal* distribution of blood plasma magnesium levels in cows at grass. Treatments which supposedly reduce levels thus lack a basic definition of what constitutes normal.

Experimental

Over a period of three years the treatments 0, 1 (fully adequate), and 2 (excessive) cwt per acre of muriate of potash were applied per annum to plots of 0.4 acre. All plots received an uniform treatment of 3 cwt nitro-chalk (21 % N) per acre. The fertilizer treatments were applied about three weeks before grazing commenced. The three treatments were arranged in a randomised block layout giving up to six complete replications. Individual plots were grazed by four ewes and their lambs, generally around four weeks after parturition. Blood samples were taken at frequent intervals.

The results for the three years are given in the Table. The mean plasma magnesium levels quoted are in each case those found immediately before transference to the plots and those after three days grazing which experience shows to be the time when the greatest fall in plasma magnesium concentration (if it occurs) will have taken place. In the actual experiments *(Hemingway et al., 5; Ritchie* and *Hemingway, 8)* blood samples were taken at intervals of about three days over periods of several weeks.

Results

1. There were significant increases in herbage potassium concentrations in all three years resulting from the applications of potassium.

2. Only in the second and third years were there significant depressions in herbage magnesium concentrations as a result of the K applications.

3. In none of the three years were there any significant effects from potassium applications on either mean plasma magnesium values or on the proportion of ewes with very low values.

4. Plasma calcium values were unaffected by potassium applications in any of the three years of the experiment.

Discussion

Investigations into the distribution of plasma magnesium values in some twelve flocks of sheep around lambing time *(Hemingway* and *Ritchie, 4)* showed that the mean value (for some 400 ewes) was 1.7 mg/100 ml and the standard deviation was as high as ± 0.4. These values represent samples taken about six weeks after

Plasma magnesium levels (mg/100 ml) of lactating sheep before and after transfer to potassium fertilized herbage and herbage magnesium and potassium concentrations

	Muriate of potash (cwt/acre)			K effect
	0	1	2	
1961 Replicates..........	6	6	6	
Ewes/treatment	24	24	24	
Plasma Mg level...				
Before.....	1.74	1.85	1.69	Non-significant
After 3 days	1.54	1.63	1.51	Non-significant
Herbage Mg%	.175	.160	.165	Non-significant
K%	2.80	3.20	3.30	Significant
1962 Replicates..........	4	4	4	
Ewes/treatment	16	16	16	
Plasma Mg level				
Before.....	1.00	1.07	0.98	Non-significant
After 3 days	1.04	1.04	0.96	Non-significant
Herbage Mg%	.170	.156	.133	Significant
K%	2.23	2.79	3.01	Significant
1963 Replicates..........	3	—	3	
Ewes/treatment	12	—	12	
Plasma Mg level				
Before.....	1.23	—	1.16	Non-significant
After 3 days	1.00	—	0.83	Non-siginficant
Herbage Mg%	.193	—	.154	Significant
K%	2.40	—	3.60	Significant

lambing. Rather lower standard deviations were found before lambing but standard deviations could be as high as ± 0.7 mg/100 ml about two weeks after lambing.

In the current experiment, the least significant difference ($P = 0.05$) between any two groups of four ewes was 0.54 mg/100 ml in 1961, 0.46 in 1962 and 0.60 in 1963. Clearly, the greatest care is needed in interpreting the results of experiments using only 3, 4 or 5 animals grazing unreplicated plots. In experiments involving sheep of uniform age, and of close similarity in lambing dates, it might appear likely that differences between individuals would be less than those for a herd of cows with much greater variation in age, milk yield, stage of lactation, supplementary feeding, etc. *Rook (2)* has given data concerning the variation in plasma magnesium values of a herd of 38 cows five days after commencement of grazing. The range of plasma magnesium values was 0.5–2.8 (Mean = 1.8) and the standard deviation ± 0.54. Comparable data for a wide variety of herds has not been published, but individual variation is probably much less in housed cattle than in those at grass.

Apart from the statistical uncertainty in interpreting the results of grazing experiments of this type, much more information is required concerning the *normal* plasma magnesium level of grazing animals. *Ritchie* and *Hemingway (8)* have found that some 15 per cent of a total of 400 ewes in twelfe flocks had plasma magnesium values of under 1.0 mg/100 ml and no clinical cases of hypomagneseamic tetany were observed, apart from two ewes which had an accompanying severe hypocalcaemia. Some flocks were found to have as many as 75 per cent of ewes with values under 1.0 mg/100 ml and 50 per cent under 0.5 mg/100 ml. Whilst a high blood magnesium level will obviously be desirable, there seems to be no certainty that a low level will, of itself precipitate a clinical tetanic condition. Criticisms may also be made of grazing experiments conducted by a number of workers where a cow may be removed from an experiment when the plasma magnesium level falls to a low value. The inherent implication is that this was necessary to prevent the onset of a clinical condition of tetany, but in the absence of such clinical signs, there is no justification for this assumption.

In our experience, a combined hypocalcaemia and hypomagnesaemia is frequently involved in the clinical condition, in so far as sheep are concerned. This clinical condition might perhaps just as well be termed hypocalcaemia alone. *Storry* (1961) formed much the same conclusion in an experiment with grazing cattle. In his experiment with high rates of fertilizer usage (described above) there were no clinical cases of tetany, although many very low plasma magnesium values were recorded. Three cases of clinical tetany in an adjacent and more reasonably manured field were found to be due to combined hypocalcaemia and hypomagnesaemia.

More recently, *Butler (3)* has described the results of a survey of hypomagnesaemia in 108 herds of cattle in Scotland. Hypomagnesaemia (defined as 1.8 mg Mg/100 ml serum) was found in 41 per cent of the herds and clinical tetany occured in 25 per cent of the herds. Blood samples in this survey were obtained from 11 of the 48 non-fatal cases of tetany before treatment was given. Analysis of these showed that the range of blood magnesium values was 0.58–1.70 mg Mg/100 ml (mean 1.27). Much more significantly, in our view, the plasma calcium values of individual clinically affected animals ranged from 2.91 to 8.11 mg Ca/100 ml (mean 5.97). This would suggest that the primary clinical condition, in many of these cases, could have been hypocalcaemia rather than hypomagnesaemia.

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Conclusion

Report of Discussion Syndicate No 1

"Potassium availability in soils – method of determination"

Chairman: Professor M. Laudelout

Soil analyses for potassium as currently practised, were considered to be of value. A large number of the failures of the methods can be ascribed to poor sampling or misinterpretation of the results. Anomalies exist between laboratory results and field performance.

There was no enthusiasm for an exhaustive comparison of the extractants currently in use to overcome these anomalies. More progress was likely if both an intensity and a capacity measurement were used together in predicting effect of added fertilizer on potassium availability. The usefulness of both these measurements depends on the presumption that potassium supply is determined by potassium activity as measured in an equilibrium solution, whereas it is likely that in some soils it is also a function of various rate processes. Studies on the latter, especially of potassium supply, have so far been minimal, and it was considered that our knowledge of the mechanisms of potassium uptake will not advance without a considerable amount of research on rate processes, i. e. diffusion, as well as the study of ion equilibria.

There were no recommendations for new design of field experiments. A number of speakers did feel, however, that too much attention was being paid to yield response. More value might be obtained from these experiments if they were allowed a long time to reach equilibrium before soil measurements were made. More attention should be paid to the situation in the untreated soil.

Considerable concern was expressed on the sampling of pasture due to the non-uniformity caused by dung and urine patches. No new techniques were put forward other than random sampling. The group considered that shallow sampling was probably best, as fertilizers would not penetrate to lower depths on grassland. It was thought that the subject was covered in the literature, and no major investigations on sampling depth were necessary, although such a study might be needed to solve local problems.

J. Brogan, Recorder

Report of Discussion Syndicate No 2

"Soil-plant relationships"

Chairman: Professor G. Torstensson   Deputy Chairman: Dr. R. K. Cunningham

The group discussed the field of soil-plant relationships with reference to exchange capacity of roots, nutrient uptake by roots and the complex uptake pattern when different species are grown in intimate association as in grass-clover mixtures.

The group decided that, owing to the complexity of the grass-clover system under field conditions, discussion should centre on aspects of sufficiency and deficiency levels of potassium in grasses and clovers. The main question appeared to be why grasses survive under a low level of potassium supply where clovers fail. While many theories are advanced to explain this phenomenon, it was felt that useful experimental information could be obtained by a research approach along the following lines:

1. A pilot greenhouse experiment using varying grass-clover ratios grown in sand and supplied with a potassium nutrient range of from near zero to excess.
2. The findings of the pilot trial could be used as a basis for studying grass-clover relationships under field conditions on different soils.

P. McDonnell, Recorder

Report of Discussion Syndicate No 3

"Nutrient balance in relation to potassium use"

Chairman: Dr. T. Walsh

The subject was discussed under two main headings:

1. Nutrient balance in soils.
2. Nutrient relationships in the plant in relation to growth and quality factors.

The following are the main points that emerged from the discussion:

a) It was strongly emphasised that balance between cations in the plant should be considered against cation balance in the soil. Better definition of the balance desirable in both the soil and the plant should receive more attention.

b) Potassium is a key element in regulating nutrient intake from soil because of its interactions with other key elements such as calcium, magnesium and sodium. Whilst the K-Na interaction effects are reasonably well understood with regard to the K-Na changes in plants more information is required on K in relation to other nutrients and in particular other cations Ca-Mg.

c) In balance effects it is an open question whether we can consider cations alone rather than anions as well and more attention is needed in this regard. It is also desirable to consider both cations and anions individually and collectively in these interaction studies.

d) The group felt that more information on K release on different soil types is necessary as the soil character has a strong influence on soil-plant relationships both with regard to potassium uptake and balance effects in the plant. For poorly buffered soils in particular the investigation of K compounds that would release K slowly to avoid losses through soil leaching and luxury consumption is worthy of attention.

e) It was felt that due to the wide range of K levels which can occur in various herbage species particular attention should be paid to K at the so-called luxury consumption level. The group provisionally adopted a luxury threshold value of

2 per cent for herbage plants. Evidence of increased yield with special reference to carbohydrate above the 2 per cent has been reported. The group felt, therefore, that it was highly desirable to study the effects of increasing K levels above 2 per cent especially in regard to the organic composition in this connection. The interaction of elements in different plant species in terms of the interaction between individual elements and the collective interaction between a number of elements would need to be studied much further. Luxury consumption levels need much more precise definition.

f) Quality factors in herbage received much attention especially in relation to hypomagnesaemic tetany. Various points of view were put forward. It was pointed out that experimental evidence had shown that in most cases it is not possible under normal K dressings to depress the uptake of magnesium to a significant extent. Potassium application in relation to magnesium depression has given variable results in different places. A single application early in the season has been found, for instance, to give magnesium depression only in the third and fourth cuts from experimental plots in Britain, but the opposite effect has been found in the Netherlands where the magnesium was depressed in the very early stages. In this regard the potassium/magnesium balance in the soil must be known. High levels of a magnesium dressing are required to raise the magnesium level in the herbage. The stage of herbage growth at which measurements are made is very important. Whereas hypomagnesaemia has been induced by liberal dressings of nitrogen and potassium fertilizers in experiments the same effect has not been found universally. In this regard ammonium sulphate may be more effective than calcium, ammonium nitrate and the effects of sulphate of potash versus muriate of potash should be tried.

The whole question of hypomagnesaemia and whether so-called grass tetany and hypomagnesaemia are one and the same thing needs to be studied much more. Experiments with sheep in Britain have shown that tetany can develop at normal magnesium levels (0.7) in the blood plasma of the affected animals. The question arises on the extent to which mineral composition of herbage is connected with hypomagnesaemia. It was found in tetany studies in Ireland that above a certain level of ammonium N dressing biogenic amine levels in the plant were higher. More studies should be concentrated on the effects of K at high N levels. We must know more on the conditioning factors developed in the plant and on the agents and the processes responsible. Perhaps we are concentrating too much on the fertilizer aspect in this problem.

g) Apart from the question of hypomagnesaemia more information is needed on the K effect on quality in different crops and in this regard the influence of moisture on K uptake and its role in plant metabolism must not be overlooked. We also need more information on the factors which give K deficiency symptoms on which such reliance is placed in diagnosing deficiency of this element in herbage.

P. Ryan, Recorder

Report of Discussion Syndicate No 4

"Use of potassium in relation to grassland management and utilisation"

Chairman: Dr. A. Dam Kofoed

It was suggested that the subject be considered under the following headings:

a) qualitative aspects
b) quantitative aspects
c) effects from increasing the amounts of potassium fertilizer
d) effects of potassium on different crops and in different crop systems.

Quality for the grass producer was described as incorporating the following factors:

1. Chemical composition
2. palatability
3. digestibility
4. quality of the material digested by the animal.

With regard to hypomagnesaemia, it was mentioned that while potassium manuring may reduce the magnesium content of herbage, hypomagnesaemia is a complex condition and several aspects have to be considered such as intake of dry matter by the animal, amount of water in the herbage, total energy in the herbage and availability of the magnesium. It was emphasised that the problem of the effect of potassium on mineral composition of grass should be considered separately from the study of hypomagnesaemia in the animal. The effect of potassic fertilizers on the magnesium content of pasture herbage, especially in spring, was also an urgent problem.

Many of the problems of quality in relation to potassium fertilizing could be clarified more easily if single grass species were used rather than mixed swards. This might also apply to varieties within single species. It is more difficult to interpret results from mixed swards. In addition, the seasonal variation in the mineral content of various species should be studied. In considering this question of quality chemical composition alone is not sufficient–the performance of the animal must be taken into consideration. Distinction should be made between negative effects such as hypomagnesaemia and positive effects such as increasing the level of protein and the mineral content. Further, potassium affects photosynthesis and as a result both the amount and type of carbohydrate in the plant may be considerably affected. Bloat can be a more serious problem than tetany in young swards where the clover content is high.

With regard to quantitative effects of potassium fertilizing it was stressed that in grassland the sole criterion should not be total dry matter production. Attention should also be paid to chemical composition, the kind of sward resulting from the treatment and, animal production and performance. The following points were considered:

1. the effect of different levels of potassium fertilizer on soils of different potassium status

2. the effect of different potassium fertilizers on different crops
3. the frequency of application of these fertilizers
4. the kind of fertilizer most suitable for each crop
5. the interactions between N, P and K.

It was considered that soil type is of great importance and should be fully catalogued in all experimental work. Likewise, weather conditions, especially rainfall, should be fully recorded. The necessity for more data on the leaching of potassium from soil was discussed, especially the influence of soil type and rate of fertilizer application. The return of potassium to the soil by the grazing animal was considered and further research suggested on both the amount thus returned and its distribution. The question of potassium return to the soil by spreading farmyard manure and liquid manure was also raised. More information on this is needed. In this connection the possibility of the soil potassium level being raised by return of farmyard manure and liquid manure to a level rendering tetany possible was mentioned. The effects of these practices on nutrient balance both in the soil and plant were thought to be of special importance.

Some discussion took place on the different types of potassium fertilizer. The anion effect of different fertilizers is important and deserves further attention. In soil testing it was suggested that two values "available" and "reserve" potassium would be valuable. Plant analyses as an index of potassium availability in the soil and also as an indicator of the responses to be expected from fertilizing was mentioned. In this connection it was pointed out that the time of sampling for plant analysis must be standardised.

The different methods of applying potassium fertilizers having regard to the crop being grown were mentioned and further experimentation considered desirable. More investigations on the relative merits of storage fertilizing and frequent top dressing were considered necessary.

C. Masterson, Recorder

Author Index

Numbers *in italics* indicate that the paper has been written jointly with other scientists; their references are given in the bibliography at the number mentioned within brackets.