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Fertilizing for High Yield POTATO

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Potato

Fertilizers for Yield and Quality

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Introduction

The potato is an important food crop, more particularly in the temperate zone, especially in Europe and the USSR. Between 1950 and 1989, the cultivated area decreased by 20% but production increased by 12% because average yield increased from 11 to 15.3 t/ha. The crop is demanding of soil nutrients and has a particularly high requirement for potassium - the tubers remove 1½ times as much potassium as nitrogen and 4 or 5 times the amount of phosphate. For instance a yield of 37 t/ha (average over 23 French experiments) removed 113 kg N, 45 kg P_2O_5 and 196 kg K_2O per hectare. The quantity of nutrients taken up by a crop is not necessarily an indication of responsiveness to fertilizers but the potato, because its root system is relatively poorly developed in relation to yield is extremely responsive to all nutrients. For this reason it has been widely used in field experiments designed to compare the nutrient requirements of different soil types and of soils in relation to soil analysis. Thus, there is available a mass of data from field experiments reaching back over many years. Though most of our information of practical importance concerning the fertilizer needs of the potato was available many years ago, we confine ourselves in this bulletin to recent literature, much of which, it must be admitted, only serves to confirm what was known earlier. This limitation means that where there has been relatively little investigation of a particular problem during recent years the reader may receive an unbalanced impression of the balance of the evidence and he is advised to consult earlier publications as for instance "The Manuring of Potatoes" by G. Gruner (1963).

Chapter 1 deals with the general points of the importance of the crop, geographical distribution, potential and actual yields and utilization.

Chapter 2 is concerned with the nutrient requirements of the crop as indicated by total uptake in tubers and above-ground parts and the pattern of uptake through the growing season (3.3) which indicates that there are critical periods during which nutrient uptake is particularly rapid, imposing a strain on soil reserves, and as indicated by removal in the tubers (3.2) which indicate the quantities of nutrients which should be applied to maintain soil fertility.

Chapter 3 is concerned with effects on yield, commencing (3.1) with discussion of crop development, it then deals (3.2) with the effects of the individual major elements and trace-elements and, most importantly, with their interactions (3.2.6) on tuber yield. Section 3.3 discusses how fertilizer effects may vary with such factors as cultivar, planting density, rotation, soil type and the availability of water.

Chapter 4 is devoted to effects on the quality of the crop. This is a complex matter, some aspects of tuber quality being superficial, such as tuber size and weight, susceptibility to mechanical damage, but nevertheless important; other aspects of quality are indicated by tuber composition which can be described quantitatively by analysis; yet other aspects of quality, such as taste are only subjective. The whole question is complicated by the fact that the desired quality varies according to the purpose for which the potatoes are required (*e.g.* table, processing industrial or seed) and that it is subject very much to personal preference.

Chapter 5 deals with the effects of fertilizers on disease and pest resistance and tolerance of, or ability to combat, physiological stress.

Time and method of application of fertilizer can have important effects as discussed in Chapter 6.

Because they may be useful in diagnosing troubles, the principal nutrient deficiencies are described in Chapter 7.

The potato being such a demanding crop, it is particularly necessary that the fertilizers used should be correctly balanced. Applying the correct quantity of balanced fertilizer is the first requirement for achieving optimum yield and doing so will give potatoes of acceptable quality.

The object of this booklet is not to give recommendations for fertilizers which must vary greatly according to local conditions. Rather, it is to discuss various aspects of fertilizer effects from a consideration of the recent literature. It is hoped that this discussion will be helpful to those who are engaged in investigating problems of the potato crop by providing a summary of recent world literature.

1 The importance of the potato crop

1.1. Importance in relation to other principal crops

In terms of area planted, the potato is the twelfth most important crop in the world (18.07 million hectares in 1989, Table 1); in terms of total production it occupied 6th position at 277 million t, between sugar beet (306 mio.) and barley (169 mio.). It is a high yielding crop, the world average being 15.3 t/ha, the third highest yielding crop, on the basis of fresh matter, after sugar cane (60.2 t/ha) and sugar beet (35.6 t/ha).

1.2. Area planted, production and yield 1948/52 and 1989

Between 1948/52 and 1989 the total world area planted declined by 20% (Table 2). While the importance of the crop declined more or less markedly in Europe, the USSR and N. and C. America, there has been some increase in S. America and the area planted in Africa has more than doubled.

Table 1. Area planted, yield and production of principal crops in the world in 1989 (FAO, 1989)

Crop	Area planted (1000 ha)	Yield (t/ha)	Production (1000 t)
Wheat	225 951	2.4	538 056
Rice	146 455	3.5	506 291
Maize	129 664	3.6	470 318
Barley	71 962	2.3	168 964
Soya	58 298	1.8	107 350
Sorghum	44 441	1.3	57 976
Millet	37 464	0.8	30 512
Cotton	32 193	1.5	49 085
Dry beans	26 974	0.6	15 872
Oats	23 167	1.8	42 197
Groundnuts	20 093	1.1	22 594
Potato	*18 070*	*15.3*	*276 740*
Sugarcane	16 723	60.2	1 007 184
Sugarbeet	8 599	35.6	305 882

Despite the shrinking area, world production has actually increased by 12% in the same period, production now being higher in all regions except Europe and the USSR. This increase in production has been due to a general improvement in yield from 11 to 15.3 t/ha (+39%) but, though this increase is considerable, it is not so great as the increase in yield by the principal cereals (Table 3).

The potential yields of present-day varieties, estimated at 85-100 t/ha for potato, 75-85 t/ha for beet and 12-15 t/ha for wheat (Evans, 1977) are far above the yields commonly obtained in practice. World average yields in 1989 were only 1/6 of the potential for potato, 1/6 for wheat and 2/5 for sugar beet. However, yields of 85 t/ha or more have already been obtained on the "blue-print" system in England (Evans, 1977).

1.3. Geographical spread of potato growing

Europe and the USSR together produced 63% of the total world crop in 1989, but the crop is very widely grown in every continent altogether in over 100 countries (FAO, 1989). Only 27 countries grow more than 100'000 ha (Table 4), and 67% of the crop is grown in 6 of them: USSR, Poland, China, Germany, the USA and India, in descending order. Mean yields vary considerably between countries, from 5.2 to 41.5 t/ha for the countries listed in Table 4, the highest yield being in the Netherlands.

1.4. Utilization of the crop

A major part of potato production is usually used for human consumption. Human consumption of potatoes has however declined in the industrialized countries as the standard of living has increased. In these countries, an increasing proportion of the crop is used for the manufacture of products such as crisps, oven-ready chips, dehydrated potato powder.
Thus, in West Germany the consumption of fresh potatoes per head decreased from 157 kg in 1954/55 to 92 kg in 1974/75 whereas the consumption of processed potatoes increased from 1 to 15 kg/head during this period (Bittelmann, 1974).
In temperate regions, there is a distinction between early potatoes, planted as early as possible in the spring and harvested early to get a high price, and maincrop potatoes which are harvested later and give a higher yield due to the longer growing period but which attract a lower price.
Another major use for potatoes is as stockfeed, mainly for pig fattening. Besides this potatoes are also used by industry, especially for starch production. Finally, since up to about 10% of the harvest is needed for seed, the production of seed potatoes is very important in areas suitable for this purpose.

Table 2. Area planted, yield per hectare and total production of potatoes for the world and by regions 1948/1952 and 1989 (FAO, 1970; FAO, 1989)

	Area planted (1000 ha)			Yield (t/ha)			Production (1000 MT)		
	1948/52	1989	Change	1948/52	1989	Change	1948/52	1989	Change
Europe	9 501	4 790	- 50%	13.7	21.5	+ 57%	130 155	102 984	- 21%
USSR	8 574	6 200	- 28%	9.4	11.6	+ 23%	80 239	72 000	- 10%
Asia	2 625	4 607	+ 76%	6.9	13.3	+ 93%	18 000	61 416	+241%
North and Central America	852	735	- 14%	15.0	28.4	+ 89%	12 741	20 837	+ 64%
South America	740	912	+ 23%	6.0	12.6	+110%	4 431	11 453	+158%
Africa	224	779	+248%	5.7	8.6	+ 51%	1 266	6 722	+431%
Oceania	60	48	- 20%	10.2	27.7	+172%	609	1 328	+118%
World	22 576	18 070	- 20%	11.0	15.3	+ 39%	247 440	276 440	+ 12%

Table 3. Mean yield of several crops 1948/52 and 1989 (FAO, 1970, FAO, 1989)

Crop	Average yield (t/ha)		Increase %
	1948/52	1989	
Wheat	1.0	2.4	140%
Rice	1.6	3.5	119%
Maize	1.6	3.6	125%
Sugarbeet	21.3	35.6	67%
Potato	11.0	15.3	39%

Table 4. Area planted and yield in the main producing countries in 1989 (FAO, 1989)

Country	Area planted (1000 ha)	Yield (t/ha)
Africa		
Algeria	120	8.6
North America		
Canada	112	24.6
USA	518	32.2
South America		
Argentina	112	23.2
Bolivia	127	5.2
Brazil	156	13.5
Colombia	175	15.7
Peru	19.3	8.8
Asia		
Bangladesh	121	10.3
China	2 602	11.5
India	918	15.8
Iran	105	13.3
Japan	123	30.1
Korea (Dem. Rep.)	155	13.2
Turkey	190	20.5
Europe		
Czechoslovakia	170	18.6
France	190	30.3
Germany	649	26.2
Italy	127	20.2
Netherlands	165	41.5
Poland	1 858	18.5
Portugal	123	8.8
Romania	325	22.2
Spain	274	19.1
United Kingdom	178	35.8
USSR	6 200	11.6
Yugoslavia	294	8.0
Total	16 280	

2. Nutrient requirements of the crop

2.1. Uptake of nutrients

Potassium is the nutrient taken up in the greatest quantity; the crop also takes up much nitrogen and appreciable amounts of calcium, phosphorus, magnesium and sulphur.
Maximum uptakes by different varieties in Japan range between 91 and 120 kg/ha N, 32 and 55 kg/ha P_2O_5 and 140 and 267 kg/ha K_2O (KALI KENKYU KAI, 1980). In England, potatoes grown on the 'blueprint' system and giving the very high yield of 77.7 t/ha took up 350 kg/ha N, 95 kg/ha P_2O_5 and 450 kg/ha K_2O (Anderson and Hewgill, 1978). Brazilian experiments with 6 varieties showed the following uptakes (kg/ha N, P_2O_5, K_2O, CaO, MgO, S): nitrogen 102-166, phosphorus 30-62, potassium 207-367, calcium 37-80, magnesium 16-25 and sulphur 17-38.

2.2. Removal of nutrients in tubers

The tubers remove much potassium, usually 1½ times as much as nitrogen and 4 or 5 times as much as phosphorus. Removals of magnesium, sulphur and calcium are much less but still significant.
23 experimental crops in France (Loué, 1977) giving a mean yield of 37.3 t/ha tubers removed in the tubers on average: 113 kg N, 45 kg P_2O_5, 196 kg K_2O, 7 kg CaO and 13 kg MgO, respectively 3.0, 1.2, 5.2, 0.2 and 0.3 kg per tonne tubers (Figure 1). Motta Macedo (1976) reports the following removals in kg/ha for 6 varieties grown in Brazil: N: 55-81, P_2O_5: 23-41, K_2O: 118-192, CaO: 5-14, MgO: 4-7 and S: 9-21. 14 experiments in the Punjab-India (Grewal and Singh, 1979) gave a mean yield of 28.75 t/ha tubers which removed an average of 91 kg/ha K_2O.
At very high yield levels, nutrient removal in tubers is very high and Anderson and Hewgill (1978) report a yield of 90 t/ha, obtained at Stockbridge House in 1973 which contained in the tubers 306 kg N, 93 kg P_2O_5 and 487 kg K_2O.
So far as concerns trace-elements, Wiliams *et al.* (1960) cited by Harris (1978) report that a 20 t/ha crop at Rothamsted removed 44 g copper, 42 g manganese, 0.74 g molybdenum and 99 g zinc. Motta Macedo (1976) reports removals of 273-1121 g Fe and 2-17 g copper per hectare.

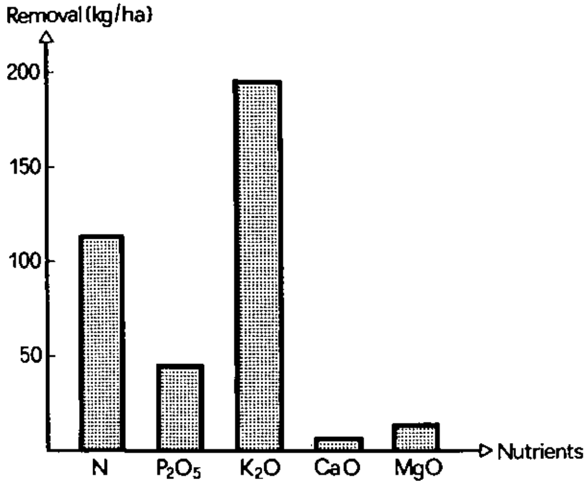

Fig. 1. Removal of nutrients in tubers.

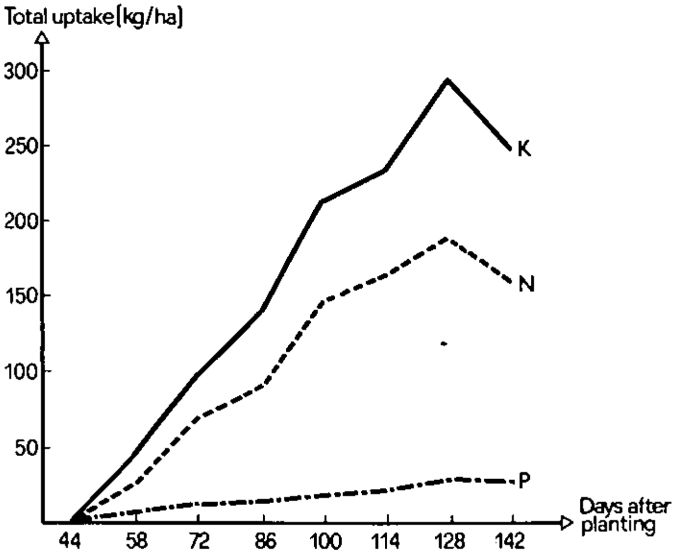

Fig. 2. Development of total nutrient uptake by crop through the season.

2.3. Pattern of nutrient uptake

Harris (1978) studied the uptake of nutrients during growth in an English experiment (Gunasena, 1969) and his results for total uptake (tubers + tops) are illustrated in Figure 2. Uptakes of nitrogen, phosphorus and potassium reached a maximum 128 days after planting.

Ezeta and McCollum (1972) in Peru observed that daily uptake rates were at a maximum for nitrogen between 95 and 137 days from planting and for potassium between 95 and 116 days. At this critical time, the crop took up 2.5 kg N and 6.6 kg K per ha per day.

3. The effects of fertilizers on growth and yield

3.1. Growth

3.1.1. Leaf area and photosynthesis

Gunasena and Harris (1971) showed that nitrogen considerably increased leaf area index and leaf area duration. A similar beneficial effect of nitrogen on leaf area index was also observed by Kushizaki (1975) and Ngugi (1972) (cited by Harris, 1978). Kushizaki (1975) also noted a favourable effect of phosphorus on leaf area index. Gunasena and Harris (1971) found that potassium increased leaf area index and leaf area duration, though the effect was less than that of nitrogen. Kushizaki (1975) and Haeder and Forster (1974) also found a favourable effect of potassium on leaf area index.

Goncharik and Urbanovich (1971, cited by Smith, 1977) showed that photosynthetic rate was reduced in nitrogen deficiency. Haeder *et al.* (1973) and Haeder and Forster (1974) found that potassium favoured photosynthesis and the translocation of assimilates from leaves to tubers.

3.1.2. Tuber initiation

Gunasena and Harris (1971) mentioned that tuber initiation was retarded by the application of 220 kg/ha N at planting in the variety Craig's Royal (early) though the main crop variety Pentland Dell was not similarly affected.

Krauss (1980) showed in solution culture that tuber initiation was inhibited when N was supplied continuously (N concentration in the solution kept above 1 mmol/l), but took place when the N supply was discontinuous (N supplied for 3 days followed by 6 days without N). Similar results for nutrient solution culture were cited by Krauss and Marschner (1976) and Sattelmacher and Marschner (1979).

Gunasena and Harris (1971) could find no definite effect of potassium on tuber initiation with Craig's Royal and Pentland varieties.

3.1.3 Other aspects of growth

Gerdes *et al.* (1975) found that N fertilizer lengthened the growing period expressed as days from planting to leaf senescence. Kudelja and Wirsing (1976) mentioned that maturity was delayed by the application of N fertilizer particularly in years with dry periods during growth of the crop.
Haeder *et al.* (1973) observed that potassium increased the ratio tubers: tops and Haeder and Forster (1974) showed that plants adequately supplied with K were better able to utilize available water (Figure 3).

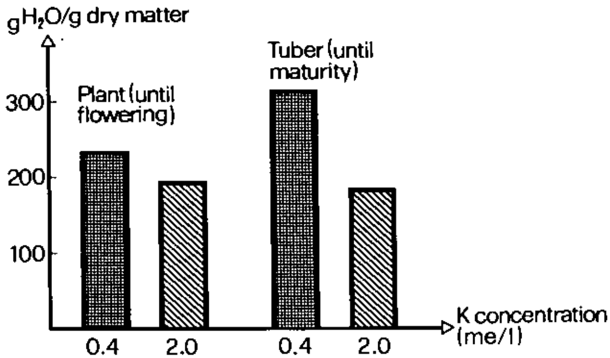

Fig. 3. Effect of K concentration in nutrient solution on water economy of potatoes.

3.2 Yield

The mean effects of nitrogenous, phosphatic and potassium fertilizers on tuber yield derived from series of experiments comprising a minimum of ten annual results are listed in Appendix Tables 1-3.

3.2.1 Nitrogen

From Appendix Table 1 which contains a total of 936 experimental results (792 from 6 developed countries and 144 from 7 developing countries), it can be calculated that applying up to 100 kg/ha N increases yield on the average by 20% (Table 5), while 101-200 kg increases yield by 32% and 201-300 kg by 36%. Expressed as kg tubers per kg N applied, the response is 76, 61 and 49 when N is applied at 1-100, 101-200 and 201-300 kg/ha.

Table 5. Mean effects of nitrogen, phosphorus and potassium on yield derived from appendices 1-3

	Mean yield increase	
	%	kg tubers/kg nutrient
kg N/ha		
1-100	20 (205)	76 (285)
101-200	32 (844)	61 (844)
201-300	36 (96)	49 (96)
kg P_2O_5/ha		
1-100	7 (221)	30 (298)
101-200	10 (424)	22 (439)
201-300	9 (32)	11 (32)
kg K_2O/ha		
1-100	14 (726)	32 (769)
101-200	10 (621)	16 (634)
201-300	11 (213)	13 (201)

( ) No. annual results

3.2.2 Phosphorus

610 experimental results (466 from 4 developed countries and 144 from 7 developing countries) are presented in Appendix 2. Applying up to 100 kg/ha P_2O_5 increased yield by 7%, 101-200 kg/ha by 10% and 201-300 kg/ha by 9% as compared with control (Table 5). The average returns per kg P_2O_5 applied are 30, 22 and 11 kg tubers with 1-100, 101-200 and 201-300 kg/ha P_2O_5.

3.2.3 Potassium

1267 experimental results (607 from 8 developed countries and 660 from 10 developing countries) are indicated in Appendix 3. As shown in Table 5, yields are increased by 14, 10 and 11% for rates applied of 1-100, 101-200 and 201-300 kg/ha K_2O, respectively. That the average effect of potassium on yield was greater with 1-100 kg/ha K_2O than with higher rates is due to the strong effect of this nutrient in experiments carried out in several developing countries like Korea, India and Kenya where it was tested at rates inferior to 100 kg/ha. For instance, 77 kg/ha K_2O increased yield by 66% in South Korea (average of 56 experiments). 1 kg K_2O produces 32, 16 and 13 kg tubers when 1-100, 101-200 and 201-300 kg/ha K_2O are applied. An example of the effect of potassium on yield is shown in Plate 1.

3.2.3.1 Effect of the form of potash

The mean effects of the different forms of potassium fertilizer, derived from a minimum of 3 experimental results, are listed in Table 6. It appears that when potash is applied at up to 200 kg/ha K_2O, KCl gives a higher yield than K_2SO_4, while at rates above 200 kg/ha K_2O the reverse is generally the case. Superior yields from KCl, as compared with K_2SO_4, have also been reported by Bruchholz (1976) and by the Cooperativa Agricola de Cotia (1980 b, c), though Garin (1979) obtained better yields with K_2SO_4.

3.2.4 Magnesium

Simpson *et al.* (1973) in Scotland report increases in yield of 500 kg/ha from the application of 54 kg/ha Mg (Table 7). In West Germany, Putz *et al.* (1976) found that 42 kg/ha MgO increased yield by 3% on the average of 16 experiments.

3.2.5 Trace elements

Smith (1977) has reviewed the literature on this subject and concludes that trace elements such as boron, copper, molybdenum, manganese, iron, zinc, cobalt can have favourable effects when soils are low in these elements.

3.2.6 Nutrient interactions

Loué (1977) concluded that interaction between nitrogen and phosphorus is usually negligible, but Yadav and Tripathi (1973) and Gervy (1970) report strong positive interaction between N and P.

In 17 years of a long-term experiment at Aspach (France) (Loué, 1977) positive interactions between N and K were recorded in 15 years and negative in 2. The potato crops in this experiment received regular dressings of farmyard manure in addition to fertilizers. The mean value of the N x K interaction over the 17 years was +2.3 t/ha tubers (Table 8). The same author mentions other experiments in which the N x K interaction was usually positive. Yadav and Tripathi (1973) recorded N x K interaction amounting to 4.44 t/ha tubers in India (Table 9).

3.2.7 Yield components

The effect of manuring on the size and weight of tubers is dealt with in chapter 4. Here we are concerned with tuber number.

Table 6. Effects of forms of potash on tuber yield (t/ha)

Rate of K_2O (kg/ha)	KCl	K_2SO_4	Difference (K_2SO_4-KCl)	No. of experiments or annual results	Reference
181	33.2	32.8	-0.4	68	*Hahlin and Johansson (1973)*
542	33.8	34.2	+0.4		
224			+1[a]	15	*Putz et al. (1976)*
108	37.6	36.9	-0.7	13, var. Bintje	*Højmark (1977)*
217	38.3	38.5	+0.2		
325	38.1	38.7	+0.6		
108	36.9	36.2	-0.7	11, var. Saturna	*Højmark (1977)*
217	38.3	37.0	-1.3		
325	38.2	36.8	-1.4		
180	30.3	29.6	-0.7	6	*Bruchholz et al. (1979)*
280	33.78	32.45	-1.33	5	*McDole et al. (1978)*
560	33.48	32.88	-0.6		
152	24.4	23.3	-1.1	4	*Rowberry and Ketcheson (1978)*
	27.83	29.83	+2.0	3	*Sharma et al. (1976)*
123	33.7	31.8	-1.9	3	*Loué (1977)*
246	38.6	36.9	-1.7		
370	38.6	38.6	0		
200-230	44.6	46.5	+1.9	3	*Temme (1970b)*

Table 7. Effect of magnesium on tuber yield

kg Mg/ha	Yield mean of 13 experiments t/ha
0	23.9
13.5	23.5
27	24.1
54	24.4

Table 8. Average nitrogen x potassium interaction on long term experiments at Aspach

Treatment N	K_2O	Yield 17 year av.	Effect of K_2O	Interaction NxK
kg/ha		t/ha	t/ha	t/ha
50	0	25.6		
50	200	31.8	6.2	
150	0	27.4		
150	200	35.9	8.5	2.3

Table 9. Nitrogen x potassium interaction

Treatment (kg/ha) N	K_2O	Yield (t/ha) - average of 2 experiments	Effect of K_2O (t/ha)	Interaction NxK (t/ha)
0	0	21.81		
0	150	23.66	1.85	
200	150	33.60		
200	150	39.89	6.29	4.44

Table 10. Effect of rate and form of potash on tuber number per plant

kg K_2O/ha	No. of tubers per plant			
	cv. Bintje - mean of 13 experiments		*cv.* Saturna mean of 11 experiments	
	KCl	K_2SO_4	KCl	K_2SO_4
0	15.0	15.0	15.1	15.1
108	15.2	15.0	15.6	15.6
217	15.5	15.5	16.0	16.0
325	15.2	15.4	15.9	16.4

Gerdes *et al.* (1975) and Gajek (1971) observed that applying nitrogen increased tuber number per plant, while Gajek did not find a similar effect of phosphorus. In Denmark, Højmark (1977) found that potash slightly increased tuber number (Table 10), while at 270 kg/ha K_2O, potassium sulphate gave somewhat more tubers than potassium chloride. Gajek (1971) also reports that potassium had a favourable effect on tuber number.

3.3 Factors affecting yield response to fertilizers

3.3.1 Variety

The nitrogen response of 40 varieties has been studied in a series of experiments in Poland (Rostropovicz and Fotyma, 1978) and three groups having high, medium or low nitrogen requirement were distinguished, the optimum rates being 120-150, 100-120 and about 90 kg/ha N, respectively.
W. German experiments on 4 sites over three years showed that increasing nitrogen from 80-160 kg/ha N increased yield by 2, 11 and 13%, respectively for the varieties Astrid, Maritta and Bodenkraft (Hunnius and Munzert, 1979). 12 experiments in Norway showed that increasing the N rate from 39 to 119 kg/ha increased yield of Pimpernel, Kerrs Pink and Ås by 12, 17 and 22% (Baerug and Enge, 1971). Similar effects are reported by Hunnius *et al.* (1971) and Grewal (1975).
Grewal and Sharma (1978b) found that the variety F-6370 was much more responsive than other varieties to potassium (Figure 4). Ekeberg and Rønsen (1973) report similar variation in K response. In Denmark, Højmark (1977) found that potassium applied as KCl had a greater effect on the yield of Saturna than of Bintje, though there was no marked difference in response between the varieties when K was applied as K_2SO_4 (Table 11).

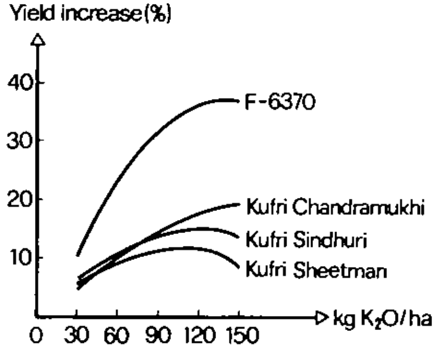

Fig. 4. Effect of potassium on yield of various cultivars.

3.3.2 Planting density

Maximum yields were obtained at 199 kg/ha N at a density of 34 600 plants per hectare and at 299 kg/ha N at densities of 46 100 and 64 600 (Ngugi, 1972).

3.3.3 Previous cropping

Furunes (1978) in Norway found that cropping history affected the response of potatoes to nitrogen and potassium but did not affect phosphate response (Table 12). Nitrogen fertilizer had a much greater effect when potatoes followed potatoes or a cereal than when they followed grass. In contrast, the effect of potassium was greatest after grass.

3.3.4 Soil nutrient content

Berryman (1973) in England found that response to phosphorus depended on soil P content, being 5 t/ha with soil P index 1-2, 3.3 t/ha at index 3 and 1.3 t/ha at index 4-5.

Beljaev (1979) in the USSR found that response to potassium depended on soil exchangeable K content (Table 13) and similar results were obtained in Canada (Giroux *et al.*, 1982) and in Norway (Furunes, 1975) (Figure 5) in experiments in which increasing the potash dressing from 120 to 240 kg/ha K_2O increased yield by an average of 1.42 t/ha at K_{AL} values of 10 or less but had no effect on yield at higher soil levels. Siebold (1971) reports that heavy dressings of potash had spectacular effects on yield on a soil which fixed potassium strongly (Table 14).

3.3.5 Soil moisture

Soil moisture content greatly affects fertilizer response as shown by the following examples:

Gerdes (1975) in East Germany found that nitrogen response of 2 varieties at 6 sites of 3 years was increased by irrigation (Table 15). Van der Paauw (1958) in the Netherlands showed that the effect of potassium fertilizer depended on the number of days without rain in May to July inclusive. With 45 dry days, K increased the yield by 60% but with 60 dry days the corresponding increase was more than 100% (Table 16). Yadav and Tripathi (1973) found that in India irrigation increased the response to nitrogen and also improved phosphate response and response to potassium. Rostropovicz and Fotyma (1978) in Poland found that the efficiency of N fertilizer was reduced by both drought and excessive rainfall.

Table 11. Effect of potassium on yield (relative yield) of two cultivars

kg K_2O/ha	Relative yield (K_0 = 100)			
	cv. Bintje - mean of 13 experiments		*cv.* Saturna - mean of 11 experiments	
	KCl	K_2SO_4	KCl	K_2SO_4
0	36.4 = 100 (36.4 t/ha)	36.4 = 100 (36.4 t/ha)	35.1 = 100 (35.1 t/ha)	35.1 = 100 (35.1 t/ha)
108	103	101	105	103
217	105	106	109	105
325	105	106	109	105

Table 12. Effect of nitrogen, phosphorus and potassium on tuber yield (t/ha) as affected by previous crop

Treatment	Rate kg/ha	Previous crop: Potato		Cereals		Grass	
N	0	20.62*	(100%)	19.33**	(100%)	24.59***	(100%)
N	60	26.49	(128%)	25.79	(133%)	28.12	(114%)
P_2O_5	0	23.87	(100%)	22.98	(100%)	26.02	(100%)
P_2O_5	34	25.55	(107%)	24.56	(107%)	27.50	(106%)
K_2O	0	25.05	(100%)	23.31	(100%)	24.63	(100%)
K_2O	120	25.49	(102%)	24.77	(106%)	27.71	(113%)

* Average of 10 experiments
** Average of 19 experiments
*** Average of 10 experiments

Table 13. Yield response (%) to applied potash as related to soil exchangeable K content

No. of annual results	Soil content exch. K (mg/100 g)	Yield response (%) K-rate (kg K_2O/ha)			
		30	60	90	120
234	< 10	7.4	12.2	27.8	21.6
512	10-20	7.0	8.3	12.5	12.5
55	> 20	3.3	12.2	12.2	3.8

Table 14. Effect of potash fertilizer on yield on a strongly K-fixing soil

kg K_2O/ha	Yield (t/ha)
0	8.37 (100%)
300	16.83 (201%)
600	26.39 (315%)
900	28.76 (344%)

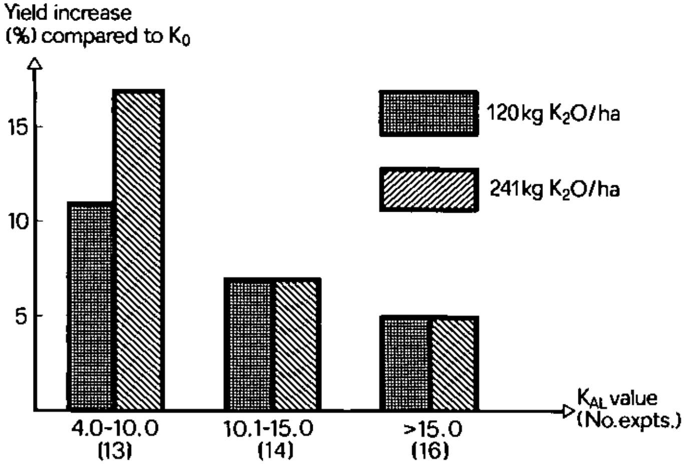

Fig. 5. Effect of potassium on yield as affected by soil K content.

Table 15. Effect of irrigation and nitrogen fertilizer on yield (t/ha)

mm water per irrigation	kg N/ha:0	60	150	240	330
0	315	365 (116%)	419 (133%)	450 (143%)	456 (145%)
20	349	416 (119%)	487 (140%)	527 (151%)	533 (153%)
30	357	431 (121%)	510 (143%)	549 (154%)	550 (154%)
40	373	444 (119%)	520 (139%)	560 (150%)	563 (151%)

Table 16. Effect of rainfall on yield response to potash (t/ha)

kg K_2O/ha	No. of rainless days from May to July		
	45	50	60
0	25.0 (100%)	24.0 (100%)	20.0 (100%)
400	40.0 (160%)	40.5 (169%)	41.0 (205%)

Table 17. Yield (t/ha) at various rates of potash in presence and absence of farmyard manure

kg K_2O/ha	No manure	Manure
0	11.0	26.6
200	29.4 (+167%)	35.2 (+32%)

Table 18. Development of responses to nitrogen, phosphorus and potassium in long-term experiments

Country Date commenced	Year	Yield increase (%)			Reference
		N	P_2O_5	K_2O	
Netherlands (1918)	1918	52	1	2	Boswijk (1976)
	1924	61	20	113	
	1930	52	27	133	
	1936	64	25	245	
	1942	79	20	223	
	1947	104	19	426	
	1958	150	23	285	
	1967	138	23	223	
	1974	113	0	178	
Poland (1923)	1924-26	24	12	42	Dobransky (1976)
	1953-55	3	0	22	
	1962-65	65	44	85	
	1972-73	118	17	106	
Switzerland (1949)	1955			58	Walther and Hofer (1980)
	1965			219	
	1973			570	
West Germany (1959)	1961			6	Kick and Poletschny (1975)
	1971			232	
	1973			278	
England (1960)	1960		10		Eagle (1974)
	1965		10		
	1970		43		

Table 19. Mean effect (10 experiments) of phosphorus and potassium on yield in 1965 and 1969

Treatment Nutrient	kg/ha	Yield (t/ha) 1965	1969
P	0	28.0 (100%)	24.4 (100%)
P	36	29.6 (106%)	26.3 (108%)
P	72	30.7 (107%)	27.3 (112%)
K	0	28.3 (100%)	24.7 (100%)
K	80	29.5 (104%)	26.3 (106%)
K	160	30.4 (107%)	27.0 (109%)

3.3.6 Farmyard manure

Boyd (1959) showed that applying farmyard manure reduced response to nitrogen and phosphorus and greatly reduced the response to potassium. Thus the responses to N, P and K in the presence of manure were, respectively 67, 29 and 22% of the responses without manure. Loué (1977), in a long-term experiment in France, found that farmyard manure reduced the response to 200 kg/ha K_2O from 167% without manure to only 32% with manure (Table 17). The corresponding average figures for 11 years in another long-term experiment were 107 and 37% response to 209 kg/ha K_2O in the absence and presence of farmyard manure respectively.

The responses to fertilizer listed in Appendix Tables 1-3 were generally recorded in the absence of farmyard manure.

3.3.7 Duration of experiments

Table 18 shows how responses to nitrogen, phosphorus and potassium have developed over time in some long-term experiments. The effect, particularly of potassium has increased greatly owing to soil impoverishment in the plots which receive no fertilizer potassium. Boguszewski and Gosek (1971) compared the effects of P and K in the first and fifth years of 20 experiments in which potatoes were grown in rotation with other crops. Their results (Table 19) showed responses of 10 and 12% to 72 kg/ha P_2O_5 and of 7 and 9% to 160 kg/ha K_2O in the first and fifth years, but yields in the 5th year were affected by drought which reduced differences between treatments.

4. Effects of fertilizers on quality

4.1 Superficial properties of tubers

4.1.1 Tuber size

Potaoes grown for the table should not contain a large proportion of small tubers, preparation of which involves a high loss in peelings. Small tubers are removed when the crop is riddled for the market and can only be used for stockfeed. Neither should there be too many over-large and misshapen tubers, the ideal crop consists of moderate and uniformly sized tubers and this applies also to potatoes grown for crisping, etc. Potatoes grown for seed should not be too large.

The effects of fertilizers on tuber size are complex; they may affect the number of tubers initiated and, hence average size; they may also affect the size of the individual tuber *per se*. As with other aspects of fertilizer response, the effects vary much with soil fertility and with variety. In general, nitrogen and potash tend to increase size while phosphate tends to increase number.

4.1.1.1 Nitrogen

Results obtained in West Germany by Hunnius and Munzert (1979) are shown in Table 20. In this series of experiments the increase in large tubers (>55 mm) was at the expense of the medium sized, but, on one other site with 3 cultivars over 3 years increasing N from 80 to 120 kg/ha increased the proportion of tubers above 55 mm from 21 to 27% with only a very slight effect on the medium sized fraction but a large reduction (13 to 9%) in small tubers (< 35 mm). Svensson *et al.* (1973) in Sweden (Figure 6) found that increasing the rate of N increased large tubers at the expense of medium sized. Tähtinen (1978) in Finland and Grison and Fourbet (1973) in France have reported that increasing the rate of N increases the proportion of large tubers (>55 mm, >45 mm respectively). In England, Archer *et al.* (1976)

Table 20. Effect of rate of nitrogen on tuber size distribution

kg N/ha	<35 mm	35-55 mm	>55 mm
80	3	49	48
120	3	44	53
160	3	42	55

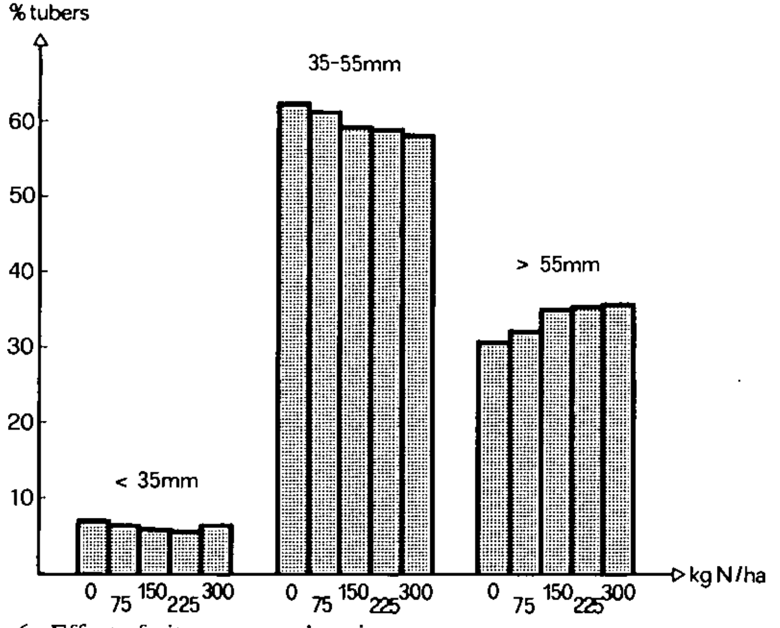

Fig. 6. Effect of nitrogen on tuber size

obtained 79.2% marketable tubers without N and 86.5% with 188 kg/ha N in a series of 16 experiments. In a long-term experiment at Aspach, France over 17 years, N fertilizer increased the proportion of marketable tubers (Garaudeaux and Chevalier, 1975) and Loué (1977), also in France, quoted 4 experiments in which N increased and one in which it decreased the proportion of marketable tubers (>35mm). Others, e.g. Varis (1973a), Dubetz and Bole (1975) and Vitosh *et al.* (1980) found that N had no effect on the proportion of large tubers (>50 or 55mm). In the USA Wilcox and Hoff (1979) found that N increased tubers over 48 mm in one experiment and reduced it in another one.

4.1.1.2 Phosphate

In England, Archer *et al.* (1976) found no effect of P on the proportion of marketable potatoes in 16 experiments and Varis (1973a) reports that P did not affect tuber size. But, in a pot experiment in Canada Dubetz and Bole (1975) found that increasing the rate of P_2O_5 from nil to 223 kg/ha increased the proportion of tubers above 51 mm from 42 to 51%. Loué (1977) observed that P tended to slightly increase the percentage of marketable tubers in 2 experiments.

4.1.1.3 Potassium

Normally potash increases the average size of tuber and, hence the proportion of marketable tubers. Archer *et al.* (1976) found the proportion of marketable tubers rose from 84.4 to 85.6 to 86.6% as K application was increased from nil to 188 and 282 kg/ha K_2O (average of 16 experiments). Tähtinen (1978) found the percentage of tubers above 55 mm increased from 24.7 to 26.2 when K application increased from 50 to 220 kg/ha K_2O (average of 6 experiments). Increases of the proportion of large tubers were also recorded by Grison and Fourbet (1973), Ekeberg and Rønsen (1973), Temme (1970), Mirswa et al. (1981), Soni *et al.* (1980) and Sadaphal *et al.* (1973); but Varis (1973a) found that K did not affect tuber size.
In the long-term experiment at Aspach (Garaudeaux and Chevalier, 1975) marketable tubers increased on the mean of 17 crops from 86.7% without K to 90.1% when twice the amount of K removed was applied. Loué (1977) found that K increased the proportion of marketable tubers by greater or lesser amount in 6 out of 7 experiments in France.

4.1.1.3.1 Form of potash fertilizer

Temme (1970b) quotes 3 experiments in the Netherlands in which the proportion of large tubers (over 55 mm) was increased from 27 to 28% by substituting K_2SO_4 for KCl at 200-230 kg/ha K_2O. 2 demonstrations in

Brazil (Cooperativa Agricola de Cotia, 1980b and c) showed a similar effect (KCl 80.0 and K_2SO_4 82.3% tubers over 40 mm at 232 kg/ha K_2O), while Sadaphal *et al.* (1973) in India found that K_2SO_4 compared with KCl reduced the proportion of tubers below 25.4 mm in one year but had no effect in another. Grison and Fourbet (1973) found no effect of form of potash on tuber size (>45 mm) when the fertilizer was applied in winter.
Earlier work in the United Kingdom (Henderson, 1965; Gething, 1968; Holmes, 1972) indicated that substituting sulphate of potash for the chloride reduced the proportion of both very large and undersized tubers indicating a particular advantage for sulphate of potash for the seed crop.

4.1.1.4 Magnesium

Applying magnesium to low Mg soils in W. Germany (Hunnius *et al.*, 1977) increased the proportion of large tubers at the expense of medium sized (Table 21), while Simpson *et al.* (1973) in Scotland found no effect of Mg on tuber size in 13 experiments.

Table 21. Effect of magnesium on tuber size distribution (average of 2 *cvs.* at 2 sites over 3 years)

kg MgO/ha	<35 mm	35-55 mm	>55 mm
0	12	71	17
80	13	65	22
160	12	65	23

4.1.2 Tuber weight

Increasing N application from 90 to 180 kg/ha increased the proportion of tubers in the range 113 to 454 g (White *et al.*, 1974); a similar favourable effect of N on tuber weight was observed by Gajek, 1971.
In W. Germany, Bachtaler and Hunnius (1971) found that rate of P fertilizer had no effect on the average tuber weight but Gajek (1971) found that P fertilizer increased tuber weight.
Variable effects of K fertilizer on tuber weight have been reported. Thus, McDole (1978) and McDole *et al.* (1978) found in one experiment that applying 280 kg/ha K_2O increased the proportion of tubers over 113 g while the form of potash (KCl or K_2SO_4) had little effect and in another that applying 168 kg/ha had no effect on tuber weight, while applying double this rate reduced the proportion over 113 g and that the form of potash was without effect. White *et al.* (1974) report that increasing K fertilizer increased the proportion of tubers between 113 and 454 g, while Gajek (1971) found no effect on tuber weight. In India, Sharma *et al.* (1976) and

Grewal and Sharma (1980) found in 4 experiments that K fertilizer increased the proportion of tubers over 75 g, while the form of K had no effect.

4.1.3 Mechanical damage to tubers

Mechanical damage during harvesting reduces the value of potatoes and is a cause of loss in storage.

4.1.3.1 Effect of nitrogen

Hunnius and Bachthaler (1977) in West Germany found that mechanical damage was slightly reduced by applying N as calcium ammonium nitrate but that when a mixture of this with calcium cyanamide was used damage was increased; these experiments covered 2 sites and 2 varieties over 3 years. Böhmig *et al.* (1975) in East Germany found that increasing N tended to increase susceptibility to damage but that the effect varied with season (experiments at 6 sites with 2 varieties over 2 years). Varis (1972) found that increasing N reduced resistance of the skin.

4.1.3.2 Effect of phosphorus

Hunnius and Bachthaler (1977) - 3 years trials on 2 sites with 2 cultivars - found that a high rate of P fertilizer reduced damage, % damaged tubers being 23.5, 24.4 and 21.7 at 0.80 and 160 kg/ha P_2O_5. Similarly, Fivkov (1978) in the USSR found that applying 120 kg/ha P_2O_5 reduced damage in mechanically harvested potatoes.

4.1.3.3 Effect of potassium

Hunnius and Bachthaler (1977) found on a soil well supplied in potassium that increasing the K dressing markedly reduced damage from 33.9% without K fertilizer to 24.7% with 270 kg/ha K_2O (Figure 7). Damage was also reduced by applying 120 kg/ha K_2O in the Russian experiments mentioned above.

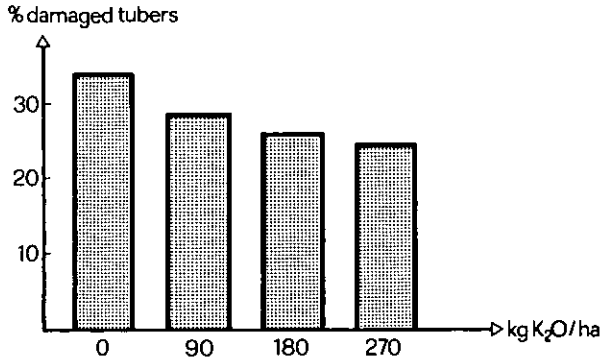

Fig. 7. Effect of potassium on percent damaged tubers (average of 2 years).

4.1.4 Tuber colour (internal blackening)

The effect of nitrogen and potash fertilizers on internal blackening has been studied by many workers. The blackening is caused by the oxidation of phenolic substances, notably tyrosine and melanine, which takes place during handling or when the tubers are cut or peeled. The dark patches, grey-blue to black, appear two to three days after the cells have been damaged and Wegener *et al.* (1979b) have shown that their incidence is increased when tyrosine and dry matter contents are high. The condition is variously described by different authors as black spot, internal blackening, enzymatic blackening or browning.

4.1.4.1 Effect of nitrogen

Rinno *et al.* (1973) in East Germany found that increasing nitrogen had an unfavourable effect on the colour of juice expressed from the tubers and that tyrosine content of the tubers was raised (Table 22). In Finland Tähtinen (1978) found that uncooked tubers 24 hours after cutting showed a darker colour as the N rate increased from 50 to 150 kg/ha N (Table 23). On the other hand, in East Germany, Zänker *et al.* (1975) found that nitrogen tended to reduce blackening in 2 years out of 3. Loué (1977) found that nitrogen fertilizer reduced blackening in tubers stored without riddling but increased it when they were riddled before storing:

% tubers affected by internal blackening

	N applied	(kg/ha)
	75	225
no riddling	92.9	86.0
riddled	15.9	28.9

Enge and Baerug (1971) and Rostropovicz (1978) report that nitrogen adversely affected colour of tubers and Ciecko (1974b) found that N increased blackening of tubers juice. On the other hand Wegener *et al.* (1979a) observed that N had no effect.

Table 22. Effect of nitrogen on juice colour and tyrosine content of tubers (mean of 7 experiments)

kg N/ha	Juice colour	Tyrosine content of tubers (mg/100 g)
0	40	50
40	43	60
80	46	74
120	56	78
160	62	77

Table 23. Effect of nitrogen on tuber colour (averages of 14 experiments)

kg N/ha	Tuber colour*
50	5.1
150	4.6

* Scored from 1 to 9; 1=entirely black, 9=absence of blackening

4.1.4.2 Effect of phosphorus

Phosphorus appears to have no effect (Ciecko, 1974b).

4.1.4.3 Effect of potassium

There is much evidence that potash fertilizer reduces susceptibility to internal blackening. In 4 long-term experiments in East Germany (Rinno *et al.*, 1972), potassium improved colour of tuber juice, decreased tyrosin content of tubers and increased their chlorogenic acid content (Table 24). They also found in the 7th year of a long-term experiment that potassium counteracted the effect of nitrogen in increasing internal blackening. The results for tubers receiving 140 kg/ha P_2O_5 are presented in Figure 8. Prummel (1981) reports a decrease of the index of internal blackening (=1/6 x %, [light +2x moderate +3x strong blackening]) from 10.7 without K to 7.3 and 5.1 with 300 kg/ha K_2O applied as KCl in autumn or winter (average of 43 experiments). In England, on a soil low in potassium (Anon., 1977), the percentage of tubers of 57 to 70 mm showing internal blackening was 34.8% without K and 24.9 and 26.2% with 251 kg/ha K_2O as KCl and K_2SO_4 (average of 2 *cv.* over 2 years). Potassium also somewhat reduced the number of surface bruises.

Table 24. Effect of potassium on juice colour of tubers and on tyrosine and chlorogenic acid content (average of results obtained in 4th-6th year of 4 long-term experiments)

kg K_2O/ha	Juice colour	Tyrosine content (mg/100 g)	Chlorogenic acid content (mg/100 g)
0	73	135	3.5
80	60	111	4.5
160	47	78	3.7
320	51	81	4.4

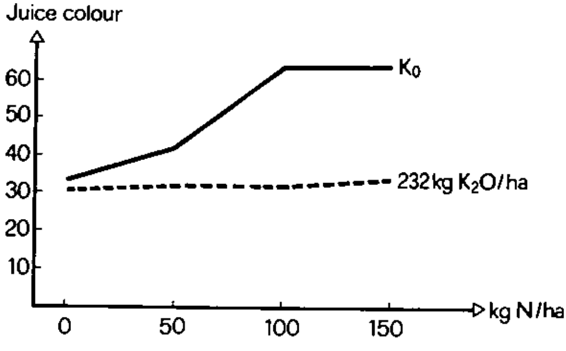

Fig. 8. Effect of nitrogen and potassium on juice colour of tubers.

According to Palmer and Stevens (1980), potassium applied in autumn or 6-8 weeks before planting considerably reduced the percentage of tubers of 60-70 mm with internal blackening in a 4 year experiment on a soil low in K (Table 25). Loué (1977) also reports that potassium greatly reduced internal blackening (Table 26).

Grison and Fourbet (1973) from France quote % blackened tubers as 37.9, 33.7 and 29.4 from plots receiving 0, 150 and 300 kg/ha K_2O respectively. From the Netherlands, Prummel (1973) and Temme (1970b) both report a favourable effect of K fertilizer in reducing blackening. Kunkel *et al.* (1973) mention that in experiments carried out over 16 years in the USA, K almost always reduced blackening. On the other hand Tähtinen in Finland (14 experiments) and Enge and Baerug (1971) in Norway found on soils rich in K that potash fertilizer had no effect. Dwelle *et al.* (1977) in the USA report no effect in two experiments but a favourable effect of potash in a third on a soil with a lower K content. Birkmann (1974) and Mirswa *et al.* (1981) also found that K fertilizer reduced internal blackening and Ciecko (1974b) mentions that K application reduced the blackening of tuber juice. In long-term experiments reported by Baerug and Enge (1974) and Wegener *et al.* (1979a) K improved tubers colour. Several workers have related the incidence of internal blackening to the K status of the crop. In the Netherlands, Alblas (1973) and Van Loon and Meijers (1973) both mention that the susceptibility to internal blackening is reduced as soil K content increases. The former also examined leaf K content and found that the percentage of slightly or non-affected tubers ranged between 7 and 27% when leaf K content was below 0.4% and between 91 and 93% at leaf contents above 0.5%. Aeppli and Keller (1978) in Switzerland found by examining 132 samples of different cultivars that susceptibility to blackening increased as tuber dry matter content rose and K content decreased and this was confirmed in later experiments at 5 sites with 4 varieties (Aeppli and Keller, 1979). Prummel (1969) reports that internal blackening decreased with increasing tuber K content, as illustrated in Figure 9; this was confirmed by Prummel (1982). Vertregt (1968) mentions that, in general, tubers with a K content below 2% were very susceptible to internal blackening while the incidence was nil or very slight at tuber contents above 2.5% K.

4.1.4.3.1 Effect of form of potash

In England (Anon, 1977) KCl was more effective than K_2SO_4 in reducing internal and superficial blackening, the results concerning internal blackening are shown in Table 27. In the Netherlands blackening was also more reduced by KCl (Temme, 1970), but in the USA, on a low K soil, Dwelle *et al.* (1977) found K_2SO_4 to be the more effective.
The effect of potash and of the form of potash on internal blackening is illustrated in Plate 2.

Table 25. Mean percentage of tubers (60-70 mm) affected by internal blackening (1976-1979)

Time of application	kg K_2O/ha			
	0	200	400	600
Autumn	33.2	20.4	15.1	12.1
6-8 weeks before planting	33.5	22.5	19.6	13.9
At planting	31.0	28.4	27.3	24.2

Table 26. Effect of potash on internal blackening

Trial	kg K_2O/ha	Tubers not riddled		Tubers riddled	
		% severely affected	% not affected	% severely affected	% not affected
Omiécourt	0	27.3	41.4	59.7	16.0
1965	150	4.0	86.7	25.3	28.0
	300	0.3	91.4	14.7	44.6
	450	1.3	94.0	6.0	56.0
Omiécourt	0	25.6	49.6	45.2	14.6
1971	120	5.7	81.2	31.5	14.3
	240	0.0	86.3	13.1	30.6
	360	0.0	92.9	15.2	25.4

Table 27. Effects of KCl and K_2SO_4 on internal blackening (% affected) of tubers (57-70 mm) (mean of 2 *cvs.* over 2 years)

Form of potassium	kg K_2O/ha					
	0	126	251	377	502	628
KCl	34.8	30.3	24.9	17.0	13.3	12.8
K_2SO_4	34.8	30.9	26.2	23.4	18.2	19.6

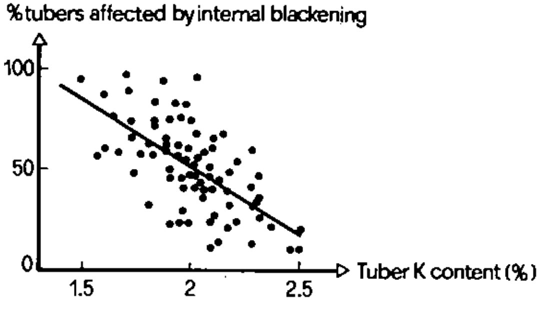

Fig. 9. Tuber K content and percentage of tubers affected by internal blackening.

4.2 Tuber composition

4.2.1 Dry matter content

High dry matter content is particularly to be desired in potatoes for processing (crisp manufacture, oven ready chips, dehydrated potatoes).

4.2.1.1 Effect of nitrogen

Except for Müller (1977b) who found in pot experiments that increasing nitrogen application increased dry matter content, all other reports show that nitrogen reduces dry matter content. There are very many results to this effect and we mention here only those which appear to be of major importance. Dry matter content was reduced by 1% by 120 kg/ha N in Norway, as shown in Table 28 (Furunes, 1975). Norwegian results are also discussed by Baerug and Enge (1971): In one series of trials with 3 cultivars on 12 sites dry matter contents were 23.8 and 23.0% respectively with N applications of 39-52 and 130-169 kg/ha N. Similar results were obtained in 2 other series one with a single cultivar at 14 sites, the other on 6 sites with 3 cultivars. Again in Norway dry matter contents were 24.5% with 40 kg/ha N and 23.6% with 120 kg/ha (Ekeberg, 1972). Dry matter content was affected to a smaller extent by nitrogen applied in addition to farmyard manure in the Aspach long-term experiment, as shown in Table 29 (Loué, 1977).

4.2.1.2 Effect of phosphorus

Effects reported are slight and variable. Hahlin and Johansson (1973) found that P slightly increased D.M. content in 64 experiments (20.0, 20.1 and 20.2% with 0.92 and 183 kg/ha P_2O_5); Furunes (1975) found no effect in 46 trials, while Ekeberg (1972) in 9 experiments found that applying 108 kg/ha P_2O_5 compared with nil reduced dry matter content from 24.2 to 24.0%.

4.2.1.3 Effect of potassium

Applying potash usually reduces tuber dry matter content but the effect is often less marked than is that of nitrogen. Because the number of results is very large we again confine ourselves to mentioning only the more important. Much work has been done on this problem in Norway and of this, Table 30 is an example (Furunes, 1975). Mean dry matter contents in 9 other experiments (Ekeberg, 1972) were 24.2, 24.0 and 23.9% at 0, 75 and 148 kg/ha K_2O and in another series (Ekeberg and Rønson, 1973) with 5 cultivars they were 24.7, 24.5 and 24.2% at 0, 84 and 169 kg/ha K_2O. In Denmark, Højmark obtained the results shown in Figure 10. In this experiment the effect of K_2SO_4 was less pronounced than that of KCl particularly at high K_2O rates. In the long-term experiment at Aspach (Loué, 1977) mean dry matter contents over 17 years were 22.9, 22.4 and 21.8 for applications of 0, 100 and 200 kg/ha K_2O in addition to farmyard manure.

Table 28. Effect of nitrogen rate on dry matter content of tubers (average of 46 experiments)

kg N/ha	Dry matter content
0	23.4%
60	22.9%
120	22.4%

Table 29. Effect of increasing nitrogen rate on dry matter content of tubers (average of 17 annual results)

kg N/ha	Dry matter in tubers
50	22.49%
100	22.39%
150	22.19%

Table 30. Effect of potash on dry matter content of tubers (average of 46 experiments)

kg K_2O/ha	Dry matter content
0	23.2%
120	22.9%
241	22.7%

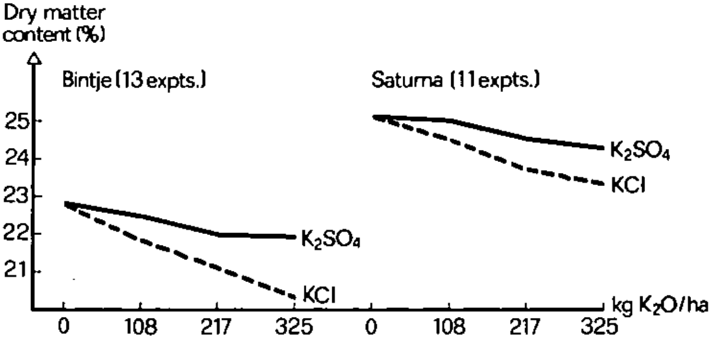

Fig. 10. Mean effect of rate and form of potash on dry matter content of tubers in 2 series of experiments.

Prummel (1981) obtained the following dry matter contents in 43 experiments:

kg/ha K_2O	Autumn application	Spring application
0	22.4%	22.4%
150	22.1%	21.8%
300	21.9%	21.4%

In 4 earlier experiments, he found no diminution from 100 or 200 kg/ha K_2O though it fell by 0.8% when 400 kg was applied (Prummel, 1973). Temme (1970a) reports that dry matter content was increased to a variable extent when up to 200 kg/ha K_2O was applied in 4 out of 7 trials, while it was reduced in the other three. Alblas (1973) also in the Netherlands found that dry matter content decreased as leaf K content and soil K content increased.

4.2.1.3.1 Effect of form of potash

Using sulphate of potash usually gives a higher dry matter content than muriate. A summary of the main results available is given in Table 31. The effect of SO_4 as against Cl is usually more marked at high rates of application.

4.2.1.4 Effect of magnesium

Putz *et al.* (1976) in West Germany found that applying 42 kg/ha MgO did not affect dry matter content but in Finnish experiments (Varis, 1972c) increasing magnesium (0, 60 and 120 kg/ha MgO) reduced it slightly (20.0, 19.5 and 19.8% respectively).

4.2.2 Starch content

Generally speaking, starch content moves hand-in-hand with dry matter content. Köster and Ohms (1979a) advise that optimum starch contents are 13.5 to 14.5% for table potatoes and 16.0% for potatoes for crisps. Usually starch content is much more determined by variety than by fertilization.

4.2.2.1 Effect of nitrogen

Several workers have found that moderate rates of nitrogen enhance starch content while heavier rates depress it. An example is in the following figures from Polish experiments over 3 years (Ciecko and Mazur, 1974):

N_0	13.6%
N_{60}	14.0%
N_{120}	13.4%
N_{180}	13.4%
N_{240}	12.8%

In another series (Ciecko, 1974a) N had no effect up to 150 kg/ha but depressed starch content at 250 kg/ha. Müller (1977b) in pot experiments found an increase from 0.75 to 3 g N per pot and a decrease at 6 g/pot. Accórding to Munzert (1982) N had no effect on a site with high N reserves while it decreased starch content at another site. Black and White (1973) in Canada found that N applied at up to 151 kg/ha had no effect. Kushizaki (1975) found no effect at 40 kg/ha N and a decline at higher rates of N.

Table 31. Effect of form of potash on dry matter content of tubers

Rate of K_2O (kg/ha)	KCl	K_2SO_4	Difference	No. of experiments or annual results	Reference
181	20.1	20.7	0.6	64	Hahlin and Johansson (1973)
542	18.6	20.0	1.4		
108	21.8	22.5	0.7	13	Højmark (1977)
217	21.1	22.0	0.9		
325	20.3	21.9	1.6		
108	24.5	25.0	0.5	11	Højmark (1977)
217	23.7	24.5	0.8		
325	23.3	24.2	0.9		
224			0.5	10	Putz *et al.* (1976)
120	22.48	22.48	0	3	Loué (1977)
246	21.68	22.89	1.21		
370	20.88	21.73	0.85		
200-230	20.7	21.2	0.5		Temme (1970b)
	21.9	22.6	0.7	3	Sharma *et al.* (1976)
232	18.48	19.18	0.7	2	Cooperativa Agricola de Cotia (1980b and c)

Although numerous cases are reported of reduction of starch content by N application, only the most important observations are discussed here. Results of Swedish experiments (Svensson *et al.*, 1973) are given in Figure 11 showing clearly that increasing N reduces starch content while Table 32 quotes results obtained by Hunnius *et al.* (1971) in West Germany where starch content was reduced by 0.3 to 0.4% according to variety. Hunnius and Munzert (1979) found values of 15.9, 15.7 and 15.5% starch content at 80, 120 and 160 kg/ha N (average of 3 cultivars for 3 years on 4 sites). Tähtinen (1978) in Finland observed that increasing N from 50 to 150 kg/ha reduced starch content from 17.9 to 16.8%.

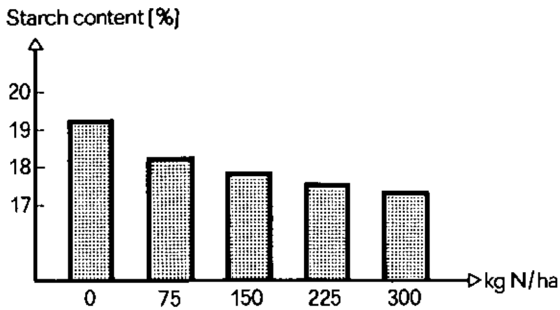

Fig. 11. Effect of increasing N fertilizer on starch content of tubers (average of 18 experiments).

Table 32. Mean effect of nitrogen rate on starch content in 4 cultivars

Cultivar	kg N/ha		No. of annual results
	60	120	
Feldeslohn	15.1%	14.7%	17
Irmgard	15.6%	15.3%	17
Lori	16.1%	15.8%	17
Désirée	15.2%	14.9%	12

4.2.2.2 Effect of phosphorus

Solle (1980) in West Germany found that applying 120 kg/ha P_2O_5 as against nil increased starch content from 11.9 to 12.8% (4 year means). Kushizaki (1980) in Japan mentions that in 3 experiments starch content increased from 13.2% with no phosphate to 13.3, 13.5 and 13.8%, respectively with 50, 100 and 150 kg/ha P_2O_5. Varis (1972a) and Ciecko (1974a) also found that P fertilizer positively affected starch content. Loué (1977), on the other hand, in one experiment obtained no effect.

4.2.2.3 Effect of potassium

More often than not, increasing dressings of potash reduce starch content though it should be pointed out that in some cases the effect is only very slight or non-existent at moderate rates of dressing. K can reduce starch content through an increased water content in the tubers although potassium activates enzymes involved in starch formation (Forster, 1981). For example, in East Germany (Bruchol*z et al.*, 1979), starch content was not affected by 72 kg/ha K_2O but was decreased by 0.2 and 0.6% with 144 and 216 kg/ha K_2O. In 8 other experiments they reported that starch content declined from 13.7% at 72 kg/ha to 13.5 and 13.2% at 144 and 216 kg/ha K_2O.

Essentially similar results to the above have been reported by: Kushizaki (1975) - no effect or a slight diminution when the rate of K_2O reached 150 kg/ha; Rinno *et al.* (1973) (11 experiments in East Germany) - 16.3% in the absence of K fertilizer and reductions of 0.6, 1.1 and 1.6% by 80, 160 and 320 kg/ha K_2O; Tähtinen (1978) (14 experiements in Finland) no effect from 50 to 100 kg/ha K_2O, but 0.3% reduction from 50 to 200. Other similar reports are by Black and White (1973), Varis (1972 a and c), Ciecko (1974 a), Loué (1977), Gajek (1971) and Mirswa *et al.* (1981).

Figure 12 shows results from an irrigation trial with varying rates of K fertilizer in Poland (Nowicka, 1980): contrary to the behaviour in the dry crop increasing potash increased starch content of the irrigated crop except at 270 kg/ha K_2O.

Several reports are available of positive effects of potassium on starch content: Shukla and Singh (1976 a) (India) an increase of 0.35% by increasing K application from 60 to 180 kg/ha K_2O; Siebold (1971) (West Germany) a marked increase of + 1.7 and + 2.3% from heavy dressings of 300 and 600 kg/ha K_2O on a strongly K fixing soil; Graf Ballestrem (1977) (Kenya); Mengel (1969) increases of 0.4, 0.6 and 0.7% by applying 120, 160 and 200 kg/ha K_2O (average of 89 trials). According to Prummel (1981) starch content was increased by K_2SO_4 (30-300 kg/ha K_2O) on a soil low in K, the

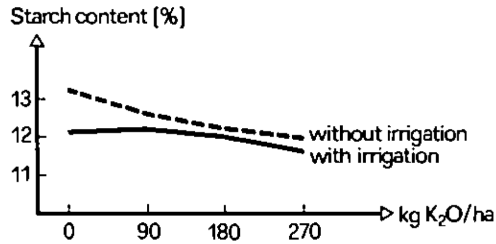

Fig. 12. Effect of irrigation and potash on tuber starch content (average of 3 annual results).

highest starch content being obtained with 90 kg/ha K_2O. In another experiment, starch content was clearly higher with K_2SO_4 than with KCl (Figure 13). Kushizaki (1975) observed no effect of K on starch content. Köster and Ohms (1979 a and b) related starch content of tubers grown on different soils to soil and tuber K contents, the relation was negative in both cases. Less negative relations are reported by Munzert *et al.* (1982).

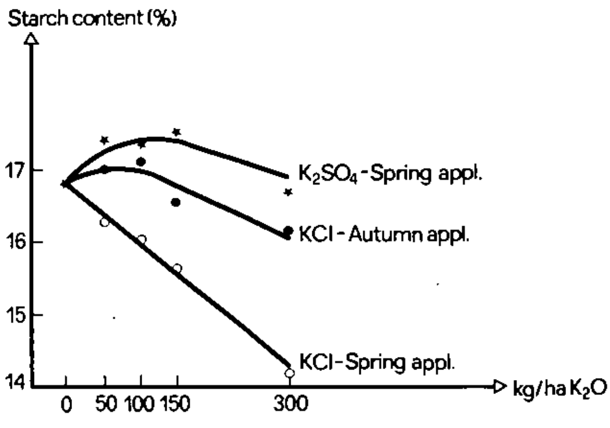

Fig. 13. Effect of potash form and time of application on starch content of tubers.

Table 33. Effect of form of potash on starch content of tubers

Rate of K_2O (kg/ha)	KCl	K_2SO_4	Difference	No. of experiments or annual results	Reference
151	12.9	13.9	1.0	24	Varis (1970)
224			0.3	10	Putz *et al.* (1976)
180	13.0	13.67	0.67	6	Bruchholz *et al.* (1979)
	16.5	16.9	0.4	3	Sharma *et al.* (1976)
232	16.39	16.16	-0.23	2	Cooperativa Agricola de Cotia (1980b and c)

4.2.2.3.1 Effect of form of potash

The mean effects from many trials are given in Table 33, from which it is seen that normally sulphate gives a higher starch content than muriate. Other authors reporting a positive effect of K_2SO_4 compared with KCl are Achmedov and Vyal'ko (1971), Garin (1979) and Prummel (1981).

Ivanov and Boradich (1972) observed no such effects while the same is reported by Bruchholz (1976). Working with nutrient solutions, Header (1976) showed that the effect of SO_4 in increasing starch content was mainly due to improved translocation of metabolites to the tubers, thus, 24 hours after applying $^{14}CO_2$, 21% of the assimilated label was found in Cl tubers compared with 39% in SO_4 tubers.

4.2.2.4 Effect of magnesium

Varis (1972 c) from Finland found slight reductions in starch content by applying magnesium - 15.0% at 0, 14 and 60 or 120 kg/ha MgO. Hunnius *et al.* (1977) concluded from 29 experiments, that the effect of magnesium varied according to site, and Beck (1975) found that Mg had no effect on second early and late maincrop cultivars but that it reduced starch in very late maincrop cultivars.

4.2.3 Specific gravity of tubers

Specific gravity of potatoes is often taken as an indication of dry matter content (and/or starch content), frequently authors describing fertilizer effects on quality confine themselves to quoting specific gravity values. In Canada, Dubetz and Bole (1975) found that increasing nirogen in pot experiments reduced specific gravity as was also found in the USA by Kunkel *et al.* (1973). White et al. (1974) in Canada on the other hand concluded that increasing N application from 90 to 134 and 180 kg/ha increased specific gravity from 1.094 to 1.095 and 1.096.

In the same pot experiments, Dubetz and Bole (loc. cit.) found that phosphorus increased specific gravity.

Potash fertilizer reduces specific gravity but the reduction is less when K_2SO_4 is substituted for KCl. Thus McDole *et al.* (1978) in the USA give values (mean of 4 cultivars) of 1.085 without K fertilizer and of 1.079 and 1.080 for potatoes receiving 280 kg/ha K_2O as KCl and K_2SO_4 respectively. White *et al.* (1974) and Kunkel *et al.* (1973) also found that K fertilizer reduced specific gravity. Rowberry and Ketcheson (1978) applied 152 kg/ha K_2O by placement both as KCl and K_2SO_4 and obtained the following values (mean of 4 years): no potash 1.084; KCl 1.082 and K_2SO_4 1.085. Two trials in Brazil (Cooperativa Agricola de Cotia, 1980b and c) gave values of 1.053 and 1.065 with 232 kg/ha K_2O as KCl and K_2SO_4 respectively.

4.2.4 Protein content

The amino-acid composition of potato protein and the relatively high content of essential amino-acids confers a biological value of the same order as that of animal protein (Müller, 1973).

4.2.4.1 Effect of nitrogen

Protein content, usually expressed as a percentage of dry matter, is very favourably affected by nitrogen fertilizer. Zänker *et al.* (1975) in East Germany found crude protein contents (% of dry matter) of 8.14 and 9.66 at 60 and 240 kg/ha N (experiments at 6 sites over 3 years). Somorowska and Kakowska-Lipinka (1972) in 15 experiments in Poland obtained protein contents in fresh material of 1.68, 2.15 and 2.29% at 0, 120 and 180 kg/ha N. Similar results have been reported by Wilcox and Hoff (1970), Mica (1971), Enge and Baerug (1971), Jürgens (1971), Westerlind (1974) cited by Aakeberg (1975), Rinno and Richter (1975), Rexon (1976) and Rinno *et al.* (1976). Mica (1971) and Wilcox and Hoff (1970) found that N fertilizer increased true protein.

In a pot experiment, Eppendorfer (1978) found that increasing N fertilizer improved crude protein digestibility.

Some workers have studied the effect of N fertilizer on the nutritional value of potato protein expressed by the essential amino-acids index (EAAI). Baerug *et al.* (1979) (6 sites, 3 cultivars, 3 years) obtained values for this index of 64, 64 and 62 at 50, 100 and 150 kg/ha N. Rexen (1976) examined the effects on 33 cultivars over 1 or 2 seasons in Denmark applying approx. 110 kg/ha N compared with approx. 180 and found that EAAI was reduced by increasing N in many cultivars and not affected or slightly raised in others. Wünsch and Hunnius (1980) applied 0.5 and 5 g N per pot in a pot experiment and observed that increasing N had no effect on EAAI in 3 cultivars but reduced it slightly in a fourth. Eppendorfer (1978) reporting on another pot experiment found that increasing N reduced EAAI.

4.2.4.2 Effect of phosphorus

Mica (1971) in Czechoslovakia, found that increasing P_2O_5 application from 44 to 220 kg/ha reduced crude protein in the fresh matter from 1.64 to 1.30% with a similar effect on true protein.

4.2.4.3 Effect of potassium

Results reported are somewhat contradictory. Shukla and Singh (1976b) in India reports a positive effect of K with crude protein contents of 10.64, 10.98 and 11.28% of d.m. at 60, 120 and 180 kg/ha K_2O. Nowicka (1980) in Poland found that potash increased protein content in the absence of irrigation but had no great effect when the crop was irrigated (Figure 14). According to Enge and Baerug (1971) in Norway there was no effect on crude protein in 3 varieties when they increased the potash dressing from 50 to 150 kg/ha while Mica (1971) found a reduction in crude and true protein contents of fresh material when potash was increased, the values were 1.42 and 1.30% at 58 and 289 kg/ha K_2O.

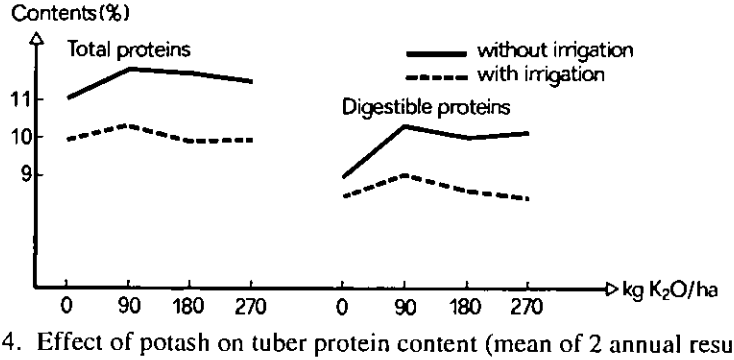

Fig. 14. Effect of potash on tuber protein content (mean of 2 annual results).

Varis (1973 b) reports that K_2SO_4 compared with KCl increased tuber protein content in two cultivars, the mean value (% of fresh material) being 1.65% with K_2SO_4 and 1.49% with KCl.

4.2.5 Reducing sugar content

According to Stricker (1971) reducing sugar content (glucose + fructose) of potatoes for crisps should not exceed 0.25% and of those for chips and dehydration it should not exceed 0.5%.

Rinno *et al.* (1972) in East Germany in 5 trials found reducing sugar contents of 0.37, 0.43 and 0.49% at 0, 40 and 80 kg/ha N but the content did not rise with further increase of N up to 160 kg/ha (0.43 and 0.46% respectively at 120 and 160 kg/ha) Kamal *et al.* (1974 b) observed that N fertilizer increased reducing sugar content, while Müller (1977) found no effect in pot experiments.

Kamal *et al.* (ibid.) mention that P fertilizer increased the reducing sugar content.

3 East German experiments reported by Rinno *et al.* (1972) showed that increasing K fertilizer tended to reduce the reducing sugar content (0.46, 0.37 and 0.42% with 0, 160 and 320 kg/ha K_2O) but Kamal *et al.* (1974 b) found that K increased the content.

Stricker (1971) concluded that the form of potash (KCl and K_2SO_4) had no effect on the reducing sugar contents of potatoes stored in different ways, while in one experiment in Brasil (Cooperativa Agricola de Cotia, 1980 a, b, c) K_2SO_4 reduced the content, having no effect in two other trials.

4.2.6 Lipid content

Nowicka (1980) found that 180 kg/ha K_2O applied with farmyard manure at 25 t/ha greatly increased the lipid content of potatoes (Table 34).

Table 34. Effect of potasium on lipid content of tubers (average of 2 years results)

kg K_2O/ha	Lipid content % Without irrigation	With irrigation
0	0.33	0.24
90	0.38	0.28
180	0.47	0.39
270	0.46	0.40

4.2.7 Fibre content

Nowicka (1980) found that increasing the potash dressing applied in addition to farmyard manure, increased the fibre content of tubers, the effect being less marked when irrigated (Table 35).

Table 35. Effect of potassium on fibre content of tubers (mean of 2 years results)

kg K_2O/ha	Fibre content % Without irrigation	With irrigation
0	1.91	2.00
90	2.47	2.09
180	2.45	2.17
270	2.57	2.19

4.2.8 Vitamin content

Müller (1977 b) observed that N applied in pot experiments had no effect on vitamin C content of potatoes. There are reports Ciecko, 1974 b; Ciecko and Mazur, 1974 that N applied in experiments over 3 years reduced vitamin C. A favourable effect of phosphorus on vitamin C content was noted by Ciecko (1974 b) and by Tashkodzaev (1975) cited by Smith (1977) while Klein *et al.* (1980) found that applying P increased the ascorbic acid content.
In two Indian experiments (Shukla and Singh, 1976 a) vitamin C levels were 20.4, 20.8 and 21.1 mg/100 g fresh material at rates of 60, 120 and 180 kg/ha K_2O. Other favourable reports of the effect of potassium on vitamin C and/or ascorbic acid contents are by Jundulas *et al.* (1975), Protashchik and Dmitrieva (1976) and by Sharma *et al.* (1976). In experiments over 3 years in Poland (Ciecko, 1974 b) applying 50 kg/ha K_2O increased vitamin C; 100 kg/ha left it unaffected, while 150 and 300 kg/ha reduced it.
Sharma *et al.* (1976) from India report ascorbic acid contents of 20.0 and 19.0 mg/100 g fresh weight with K_2SO_4 and KCl respectively.

4.2.9 Alkaloid content

Ahmed and Müller (1979) found that increasing the level of N fertilizer in pot experiments had no appreciable effect on solanine content but reduced the content of α-chaconine. The content of both was increased by applying potash.

4.3 Cooking quality of tubers

4.3.1 Texture

The desirable texture of potatoes after cooking is very much a matter of personal preference and in any case depends on the method of cooking and the purpose for which the potatoes are required. Some have a preference for mealy mashed potatoes, while others who prefer a boiled potato which keeps its shape would regard the former as undesirable because it readily disintegrates on boiling. In general, high dry matter, high starch potatoes tend to give a mealier product after cooking. It should also be pointed out that differences between cultivars are very much greater in respect of these aspects of quality than are differences which may be induced by varying fertilizer treatment.

Tähtinen (1978) in 14 experiments and Varis (1972 b) observed that increasing nitrogen reduced *mealiness* while Enge and Baerug (1971) observed the opposite. The effect of increasing nitrogen is to reduce the tendency to *disintegration* (fall) on boiling, as reported, for instance by Enge and Baerug (1971), Varis (1972 b), Kudelja and Wirsing (1976).

According to Hahlin and Johansson (1973) phosphate fertilizers made potatoes more likely to *fall on boiling* and increased *dryness* of the final product. Varis (1972 b) found that phosphate application increased *mealiness* and *disintegration* on boiling.

The effect of increasing potassium is usually to reduce dry matter and starch content (see 4.2.1.3 and 4.2.2.3) so that, where authors have commented on effects of K fertilizer on texture it has usually been to the effect that increasing K reduces disintegration on boiling and reduces mealiness while giving a moister final product.

Table 36 (Højmark, 1977) shows that increasing K reduced the tendency to *disintegrate* and that this effect was more pronounced with KCl than with K_2SO_4 at high K_2O rates. Disintegration on boiling was studied in 7 experiments by Bruchholz (1976) and the mean indices of disintegration were 1.54, 1.36 and 1.41 with 0, 120 and 240 kg/ha K_2O (1=no disintegration, 4=complete disintegration). He also mentions 8 experiments where the index of disintegration was 1.54 with KCl and 1.72 with K_2SO_4. Hahlin and Johansson (1973) also mention that potassium reduced disintegration while substituting K_2SO_4 for KCl had no effect. Enge and Baerug (1971) report that potassium reduced disintegration while Varis (1972 b) found no effect.

Tähtinen (1978) in 14 experiments and Bruchholz (1976) in 7 experiments observed that potassium reduced *mealiness*. The same is reported by Varis (1972 b) while Enge and Baerug (1971) found no effect on soils rich in potassium. K_2SO_4 produced a somewhat more mealy potato than KCl in series of experiments reported by Varis (1970) (experiments over 4 years at 3 sites with 3 *cv.*) and by Bruchholz (1976) (8 experiments). According to Højmark (ibid) and Hahlin and Johansson (1973), *dryness* of cooked tubers was reduced by potassium, this effect being more pronounced with KCl than with K_2SO_4.

Table 36. Effect of rate and form of potash on tuber disintegration (average of 3 experiments)

kg K_2O/ha	Index of disintegration	
	KCl	K_2SO_4
0	2.1	2.1
90	1.3	1.3
180	0.2	1.1
270	0.2	0.7

4.3.2 Flavour

Flavour is a subjective matter and therefore difficult to describe in quantitative terms. The usual procedure is to submit samples to a tasting panel who allot marks, but there must always be some doubt as to the reliability of results since personal preferences are so variable.

The generality of results seems to indicate that increasing the nitrogen dressing adversely affects flavour to some, usually small, degree, e.g. Tähtinen (1978), Enge and Baerug (1971), Jonsson and Johansson (1971), Varis (1972 b) but there are reports, e.g. Kudelja and Wirsing (1976) that it has no effect.

Varis (1972 b) and Hahlin and Johansson (1973) mention that P fertilizer somewhat improved flavour.

Tähtinen (1978) found no effect of potassium on flavour in 14 experiments. Bruchholz (1976) mentions 7 experiments where the flavour index (1=very good, 4=bad) was 2.11, 2.35 and 2.25 with 0, 120 and 240 kg/ha K_2O and he obtained a slightly better flavour with K_2SO_4 than with KCl in 8 experiments. Rowberry and Ketcheson (1978) found no effect of potash or of the form of potash. Varis (1972 b) and Hahlin and Johansson (1973) mention an adverse effect of potassium on flavour. Varis (1970) observed that K_2SO_4 improved flavour in comparison with KCl (experiments over 4 years at 3 sites with 2 *cv.*); this is also reported by Hahlin and Johansson (1973).

4.3.3 After-cooking blackening

This, which is usually more pronounced at the stem and end of the tuber and sometimes spreads throughout the flesh is due to the formation of a black pigment which is an iron compound.

4.3.3.1 Effect of nitrogen

Berryman *et al.* (1973) from two series of 6 and 8 experiments in England found that increasing N application had no effect and Tähtinen (1978) in Finland found the same in 14 experiments. Polish workers (Rostropovicz and Fotyma, 1978) found that N fertilizer increased after-cooking blackening and Enge and Baerug (1971), Varis (1972 b) and Holm (1978) came to the same conclusion.

4.3.3.2 Effect of phosphorus

In England, Berryman *et al.* (loc. cit.) found no effect of P in 6 experiments but in the other series of 8 trials P reduced blackening from 16% without P fertilizer to 9 and 11% with 56 and 112 kg/ha K_2O. Hahlin and Johansson (1973) also found that P decreased the incidence while Varis (1972 b) found no effect.

4.3.3.3 Effect of potassium

Reports of increasing K fertilizer decreasing blackening are given by: Berryman *et al.* (1973) (Table 37), though in another series they reported no effect; Varis (1972 b); Hahlin and Johansson (1973); Protashchik and Dmitrieva (1976); Holm (1978) and Mirswa *et al.* (1981). Other authors: Tähtinen (1978), Højmark (1977) and Baerug and Enge (1974) observed no effect of potassium on after-cooking blackening.

Table 37. Effect of potash on after-cooking blackening (% blackened tubers)

kg K_2O/ha	Means of 6 experiments	8 experiments
0	18	13
113	16	13
226	14	10

4.3.3.3.1 Effect of form of potash

Varis (1970), in Finland, found less tendency to after-cooking blackening in K_2SO_4 than in KCl treated potatoes (blackening index 0.9 respectively 1.2) in a series of experiments lasting 4 years with 2 cultivars on 3 different soil types. Højmark (1977) reports no effect in 13 experiments in Denmark but Hahlig and Johansson (1973) report in favour of K_2SO_4.

4.3.4 Crisp colour

Crisps should not be too dark coloured. A high content of reducing sugars, which react with amino acids to produce a dark pigment (see 4.2.5) is therefore undesirable. A striking example of the effect of potash fertilizer on crisp colour is given in Table 38 from Højmark (1977). Increasing K improved colour and K_2SO_4 was more effective than KCl. Varis (1972 b) found that nitrogen improved colour while phosphate and potash had no effect, whereas Plate 3 shows an improvement of crisp colour under the effect of potash.

Table 38. Effect of rate and form of potash on crisp colour

Crisps manufactured in	Kg K_2O/ha	Colour index* Bintje (13 expts.)		Saturna (11 expts.)	
		KCl	K_2SO_4	KCl	K_2SO_4
August	0	5.7	5.7	7.3	7.3
	108	6.6	5.9	8.1	7.6
	217	6.9	6.4	8.2	7.6
	315	7.3	6.9	8.5	7.8
December	0	4.7	4.7	6.7	6.7
	108	6.2	5.3	7.9	7.3
	217	6.8	6.2	8.4	7.9
	315	7.6	6.3	8.8	8.4
February	0	4.7	4.7	6.7	6.7
	108	5.7	5.1	7.4	7.0
	217	6.2	5.6	8.0	7.5
	315	6.8	5.7	8.0	7.3

* Scored 1-10; 10=light colour

4.4 Storage behaviour

Reports on the effect of N fertilizer on storage losses of potatoes indicate that it tends to increase losses. One example from Schnieder (1972) is given in Table 39. Böhmig *et al.* (1975) found in 2 experiments storage losses of 6.9,

Table 39. Effect of nitrogen on storage losses

kg N/ha	Losses (%)
0	8.7
40	8.4
80	9.2
120	9.9
160	10.3
200	10.4

9.4 and 10.9% at N levels of 0, 150 and 330 kg/ha. Negative effects are also mentioned by Autorenkollektiv (1973) cited by Kudelja and Wirsing (1976). Amberger (1968) found that potash fertilizer reduced storage losses, related to reduction in the activity of catalase and peroxidase (Table 40). A positive effect of potassium is also reported by Mirswa *et al.* (1981).

Table 40. Effect of potash on dry matter losses in storage

kg K_2O/ha	Dry matter loss	Enzyme activity	
		Peroxidase	Catalase
0	20.3%	1.5	13.2
100	5.6%	1.3	5.6
200	6.0%	1.1	6.0

4.5 Summary of effects of fertilizers on quality

We have attempted to summarize the effects described in this chapter in Table 41. The farmer's first consideration should be to apply fertilizers to increase yield and hence his net profit and for this it will almost invariably mean applying all the three nutrients N, P and K. If the fertilizers are correctly balanced, the result will normally be to improve overall quality. So far as potash fertilizer is concerned, it is worth remarking that the use of sulphate rather than muriate of potash usually gives a higher quality tuber.

Table 41. General tendencies of effects of N, P and K and form of K on quality

Criterion	N	P	K	Form of K (K_2SO_4-KCl)*
Proportion marketable tubers	+	O	+	
Mechanical damage to tubers	Variable	-	-	
Internal blackening	+		- (O)	+
Dry matter content	-	Nil or variable	-	+
Starch content	-	+	-	+
Protein content	+		Variable	
Vitamin C content		+	+	
Disintegration on cooking	+		-	O
Mealiness of cooked tubers	-		-	+
Dryness of cooked tubers			-	+
Flavour of cooked tubers	Poorer		Nil or poorer	Improved by K_2SO_4
After cooking blackening	O (+)	O -	O (-)	-
Crisp colour			Improved	Poorer with K_2SO_4
Storage losses	+			
Specific gravity of tubers			-	+

+ increase - decrease
O no effect * Difference between values with K_2SO_4 and KCl

5. Effects of fertilizers on plant health

In general, it is true to say that balanced fertilizer applied in the correct amount improves plant health and hardiness, in some cases by making infection by pest or disease less likely and in all cases because the improved vigour conferred on the plant by adequate nutrition enables it to recover more quickly from the effects of pest, disease or other adverse circumstance.

5.1 Fungal diseases

- Late blight *(Phytophthora infestans)*

Some interesting results by Böhming *et al.* (1975) in East Germany are quoted in Table 42; the figures indicate seasonal variation in the effect of N. Varis (1972 b) found that tuber blight was slightly increased by N fertilizer and unaffected by phosphorus and potassium. Szcotka *et al.* (1973) found in solution culture that increasing K in the solution from 25 to 150 ppm reduced leaf resistance while further increase to 400 ppm increased it, there being no difference between KCl and K_2SO_4. Herlihy (1970) found that resistance to blight was reduced by N fertilizer and increased by phosphate.

Table 42. Effect of nitrogen on % leaves affected by late blight (mean of 2 *cvs.* on 6 sites)

Year	Kg N/ha				
	0	60	150	240	330
1970	25.1%	25.5%	42.7%	26.0%	21.9%
1971	19.2%	19.7%	11.9%	10.5%	7.5%
1972	5.0%	5.5%	4.8%	2.4%	1.2%

- Powdery scab *(Spongospora subterranea)*

Wenzl and Reichard (1974) studied in 1963 the effects of nitrogen, phosphate (basic slag) and potash in a long-term experiment begun in 1959. They found the disease to be favoured by nitrogen, reduced by phosphate and slightly reduced by applying 225 kg/ha K_2O. Liming reduced the percentage of disease-affected tubers in many experiments in Austria (Wenzl *et al.*, 1972).

- Rhizoctonia *(R. solani)*

Varis (1972 b) found the percentage tubers affected to be increased by both nitrogen and potassium and decreased by phosphorus, but Böhmig (1975) found that increasing nitrogen reduced the attack.

- Dry rot of potato *(Fusarium coeruleum)*

Langerfeld (1973) inoculated tubers from plots which had been under the same fertilizer treatments for ten years and found that the condition was favoured by nitrogen and potassium but unaffected by phosphorus (Table 43).

- Verticillium wilt *(V. albo-atrum and V. dahliae)*

O'Sullivan and Reyes (1980) found that this was not affected by N fertilizer.

Table 43. Effect of nitrogen, phosphate and potash on development of Fusarium

Treatment (kg/ha)			Severity index
N	P_2O_5	K_2O	
0	100	200	2.70
80	0	200	3.74
80	100	0	2.62
80	100	200	3.78

5.2 Bacterial diseases

- Common scab *(Streptomyces scabies)*

The evidence appears contradictory. Wenzl and Richard (1974) found that in their long-term experiment started in 1959 nitrogen slightly increased scabby tubers in 1963 and appreciably increased it in 1970. While Böhmig *et al.* (1975) report that nitrogen had no effect, Varis (1972 b) found that nitrogen reduced the severity.

In the long-term experiment mentioned above, Wenzl and Richard observed that basic slag favoured scab in 1963 and 1970 (more severely in 1970) but in another experiment begun earlier they found that while hyperphosphate increased it a little and basic slag increased it markedly, superphosphate had no real effect; the differences can be ascribed to effects on soil pH (Table 44) (Wenzl *et al.*, 1972). Davis *et al.* (1976) mention that triple super-phosphate greatly reduced scab, for instance in one experiment the percentage of tubers having more than 10% of their surfaces affected was 26% and 11% without and with 168 kg/ha P_2O_5. Varis (1972 b) also found that phosphate reduced scab. Wenzl and Richard (1974) obtained no effect of potassium in 1963 and 1970 in their long-term experiment and Varis (1972) reported similarly though Davis *et al.* (1976) found that potash appreciably increased scab. Liming increased scab in several experiments reported by Wenzl *et al.* (1972).

Table 44. Effect of form of phosphate on soil pH and scab incidence

kg P_2O_5/ha	Form of P fertilizer	pH (KCl)	Scab index
0	-	5.05	2.9
100	Superphosphate	5.15	3.1
100	Hyperphosphate	5.22	3.7
100	Basic slag	5.62	5.0

- Blackleg *(Erwinia carotovora)*

As shown in Table 45, Böhmig *et al.* (1975) found that increasing nitrogen reduced the number of affected plants.

- Brown rot *(Pseudomonas solanacearum)*

Mahmoud *et al.* (1976) in two pot experiments observed that brown rot was much reduced by nitrogen and phosphate but unaffected by potash.

Table 45. Effect of nitrogen on blackleg incidence - no. affected plants per plot (mean of 2 *cvs.* on 6 sites)

Year	kg N/ha				
	0	60	150	240	330
1970	1.92	1.39	0.86	0.76	0.56
1971	4.57	4.08	3.47	3.20	3.41
1972	4.84	4.13	2.92	1.63	1.08

5.3 Virus diseases

On the evidence of field experiments in the Netherlands, Schepers and Beemster (1976) came to the conclusion that there is no reason to suppose that normal applications of nitrogen, phosphorus and potassium as applied to obtain optimum yield would have any adverse effect on the rate of virus infection of seed tubers. In Portugal, Quelhas dos Santos (1979) reports on an experiment in which, one month after emergence, plants on the NP treatment were severely affected by leaf-roll while those on the NPK plots were normal; the eventual yields were respectively 11.23 and 27.85 t/ha.

5.4 Physiological disorders

Nelson (1970) found in the USA that applying potash on a soil high in potassium reduced the percentage of hollow hearts (Table 46), the effect being particularly evident in 1965 when incidence of the condition was high.

Table 46. Effect of potassium on % tubers with hollow hearts

kg K_2O/ha	Year			3 year mean
	1965	1966	1967	
0	26.0	17.3	2.4	11.4
74	15.9	14.7	1.5	8.0

5.5 Cold

In an Indian experiment, Saini (1978) found that frost damage to leaves was 16% and 20% at 0 and 200 kg/ha N and 19 and 17% at 0 and 200 kg/ha P_2O_5, while applying 200 kg/ha K_2O reduced frost damage from 38 to 7%. In 14 experiments in India, Grewal and Singh (1980) found a negative correlation (r= -0.89) on plots receiving no K fertilizer between available soil

K and frost damage to leaves. The index (no damage=0, 100% damage=4) varied between 1.1 and 3.2 at soil K below 114 mg/kg and between 0.4 and 0.6 at soil K above 124 mg/kg. Applying potash greatly reduced the damage (Figure 15). Jackson *et al.* (1982) also report that K made leaves more resistant to frost.

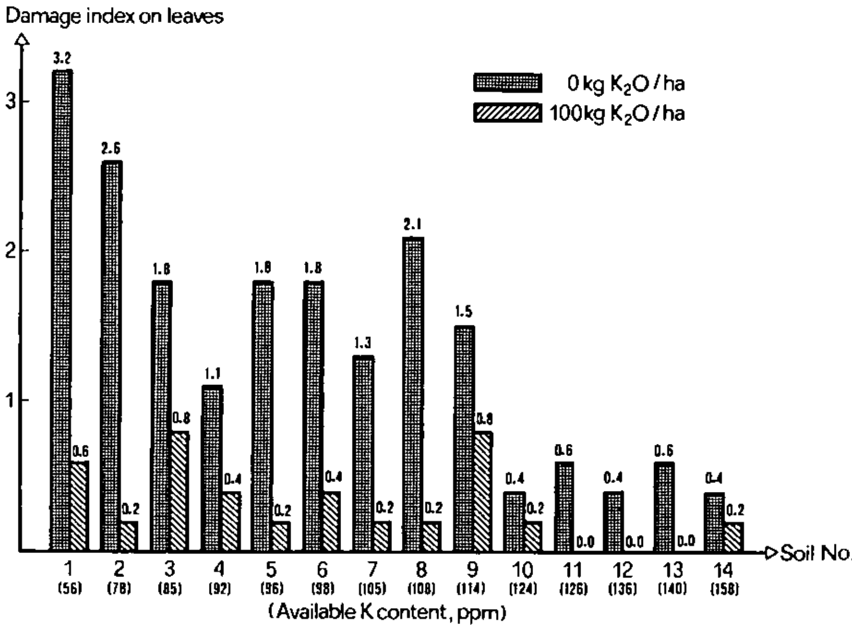

Fig. 15. Effect of potassium on frost hardiness of potato leaves.

6. Method and timing of applying fertilizers

6.1 Method

Højmark's (1976) results obtained in Denmark are quoted in Table 47. Placement had a beneficial effect as compared with broadcasting a compound fertilizer at low and medium rates of application but not at high rates. The same author (1972) found placement of NPK more effective in 9 out of 15 experiments.

In the USA Dunton (1971) found no advantage from placement when 10-10-10 fertilizer was applied at 1124 and 1686 kg/ha; the results for two cultivars at 1124 kg/ha are quoted in Table 48.

Table 47. Effect of method of application of a compound fertilizer on yield (mean of 4 sites over 3 years)

Rate of 14-4-17 (kg/ha)	Tuber yield (t/ha)		Yield increase due to placement (%)
	Broadcast	Placement	
357	9.0	12.2	36%
714	15.9	17.7	11%
1071	19.1	19.3	1%

Table 48. Effect of method of application of compound fertilizer (10:10:10) on yield

Application method	Yield (t/ha) - mean of 3 annual results	
	Cv. Pungo	*Cv.* Superior
Placement	26.20	15.27
Broadcast after ploughing* and worked in	24.61	15.61
Broadcast just before ploughing	26.82	16.45
Broadcast in January	27.37	17.32

* Ploughing was at the end of February or beginning of March

Favourable effects of placement of N are reported by Grewal *et al.* (1979); of phosphorus placed in the furrow as compared with broadcast or banded by Verma and Grewal (1978) and of potash by the same authors in 1979.
Advantages in favour of placing NPK have been reported from Finland by Varis and Lanetta (1974) and from France by Crosnier (1973) citing I.T.P. (1970), but, as Crosnier says, fertilizer should not come into direct contact with the seed tubers as there may be some phytotoxicity.

6.2 Timing of application

6.2.1 Nitrogen

Table 49 quotes W. German work (Hunnius and Munzert, 1979) and shows that on brown earth soils applying part of the N dressing at the stage when leaf cover was complete was disadvantageous, though the same workers found that on a sandy soil with 3 varieties over 3 years yield was increased from 32.6 to 34.2 t/ha N was applied in split dressings. Table 50 gives results from Sweden (Svensson *et al.*, 1973) showing no benefit from splitting or late application. Loué (1977) in a long-term experiment at Ablis compared applying 160 kg/ha N either as one dose or two applications of 80 kg/ha in April and May; the latter treatment reduced yield by two t/ha from 32.9 t/ha. Gunasena and Harris (1979) in England obtained results on a sandy soil in agreement with those of Hunnius and Munzert (1979) on the sandy soil; splitting a 220 kg/ha N dressing increased the yield of the early cultivar Craig's Royal by 21% and of the maincrop Pentland Dell by 11%; in these

Table 49. Effect on yield of splitting nitrogen application (mean of 36 annual results)

Application	kg N/ha	Yield (t/ha)
Single	120	48.9
Split	80 + 40	47.5
Single	160	49.4
Split	80 + 80	48.4

Table 50. Effect on yield of splitting and timing of nitrogen applications (mean of 18 experiments)

Before planting	4 weeks after planting	Dose of N (kg/ha)		
		10 weeks after planting	15 August	Yield (t/ha)
150	-	-	-	33.7
75	-	75	-	32.5
75	-	-	75	32.5
225	-	-	-	33.7
150	-	75	-	34.0
150	-	-	75	33.4
-	150	-	-	33.1

experiments there was an advantage (22% for the early and 12% for the maincrop) in applying all the fertilizer N late. Grewal *et al.* (1979) in India found an advantage in splitting a dressing of 120 kg/ha N but no such effect at lower rates of 40 and 80 kg/ha.

6.2.2 Potassium

In England, on a sandy soil, (Anon., 1977) emergence of potatoes was delayed when KCl was applied a few days before planting but not when it was applied 6 to 8 weeks before planting. Results in another experiment (Palmer and Stevens, 1980) averaged over 3 years showed that it was preferable to apply a part or even the whole of the potash dressing either in autumn or at least 6 weeks before planting (Table 51) and it is suggested that in dry springs potash applied at planting is less easily available. Further, applying 600 kg/ha K_2O as KCl at planting retarded early growth of the crop though it had no marked retarding effect if applied in autumn or 6 to 8 weeks before planting. Gunasena and Harris (1971) found that splitting the potash dressing of 220 kg/ha K_2O improved the yield of an early cultivar (Craig's Royal) by 14% though it had little effect on the maincrop Pentland Dell. Yield of both cultivars was improved by 5% when K was applied late rather than early. According to Prummel (1981), yields were slightly higher with autumn than with winter application of KCl in 43 experiments (50.1 and 50.8 t/ha with 150 and 300 kg/ha K_2O applied in autumn and 49.9 and 50.4 t/ha with 150 and 300 kg/ha K_2O applied in winter). Temme (1970b) observed that applying 200-230 kg/ha K_2O as KCl in the autumn gave a yield of 46.8 t/ha compared with 44.6 t/ha when the potash was applied at planting.

Table 51. Effect of time of application of potash on yield (t/ha) - mean of 3 annual results

Time of application	kg K_2O/ha			
	0	200	400	600
Autumn	25.0	31.0	33.2	34.8
6-8 weeks before planting	24.5	31.8	33.5	34.5
At planting	23.4	29.7	30.4	31.5
Split*	23.1	31.2	34.3	35.6

* 100 kg K_2O/ha at planting, remainder in previous autumn

Soni *et al.* (1980) also found splitting the potash dressing to be favourable while Mazur and Ciecko (1979) found no difference between applying the potash (either KCl or K_2SO_4) either before autumn cultivation or in spring before planting.

Several workers recommend applying KCl several weeks before planting or in the preceding autumn to allow time for the leaching of chloride.

7. Nutrient Deficiencies

7.1. Deficiency symptoms

a) Nitrogen

Initially pale green colouration of leaf margins and tips, the foliage eventually turns pale yellow. Growth is reduced and leaf-fall premature (Loué, 1977; Grewal, 1975; Gruner, 1963).

b) Phosphorus

Growth is retarded particularly in the early stages. Foliage dark green and in severe cases the lower leaves turn purple. Leaflets do not develop normally (Loué, 1977; Grewal, 1975)

c) Potassium

Internodes shortened; leaves bluish-green in colour, later older leaves turn yellow with brown margins and apices. Later necrotic batches appear (Loué, 1977; Grewal, 1975; Gruner, 1963) (Plates 4 and 5).

d) Magnesium

Lower leaves more lightly coloured than normal, first on the tips and margins of leaflets and then extending between the veins with, later, necrotic patches between the veins (Loué, 1977; Gruner, 1963).

7.2. Varietal differences

Ekeberg and Rønsen (1973) in Norway showed that cultivars differed greatly in susceptibility to K deficiency (Table 52).

Table 52. Severity of K deficiency symptoms in various cultivars

Cultivar	kg K_2O/ha	
	0	84
Kerrs Pink	4.0*	2.5
Pimpernel	3.5	2.0
King George V	2.0	1.0
Ora	2.0	1.0
Parnassia	1.5	1.0

* 0 = no symptoms

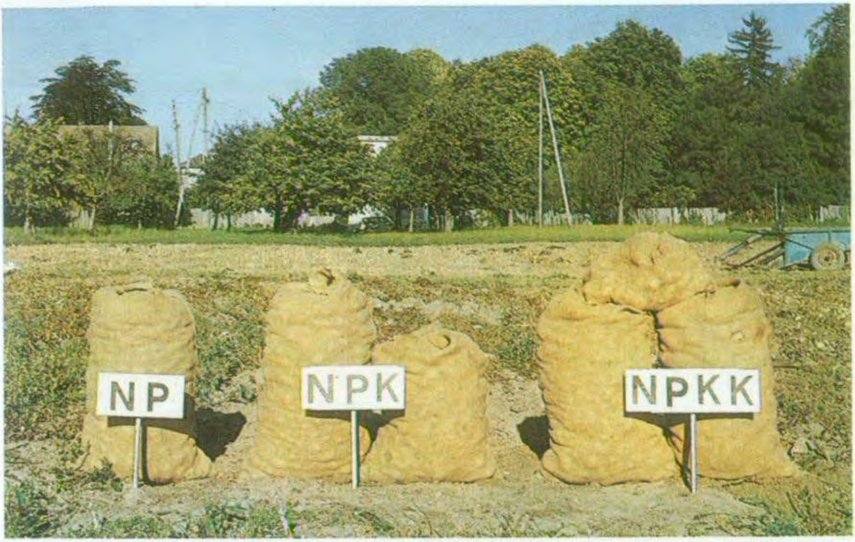

Plate 1. The potato is one of the most K-demanding crops; hence large yield responses to potassium can be expected (left: NP without potash, middle: NP+140 kg K_2O/ha, right: NP+266 kg K_2O/ha).

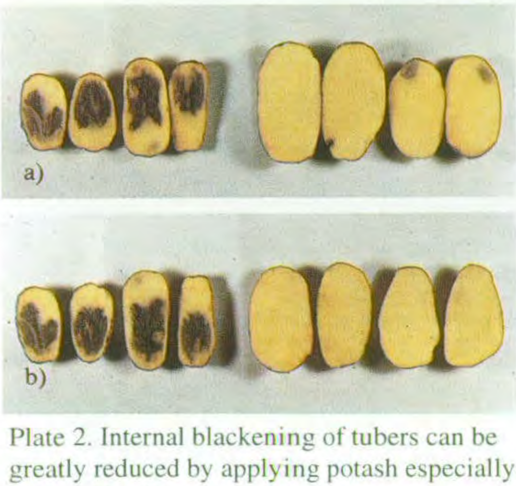

Plate 2. Internal blackening of tubers can be greatly reduced by applying potash especially on low K soils.

a) left: NP, right: NP+K as muriate of potash (KCl)

b) left: NP, right: NP+K as sulphate of potash (K_2SO_4)

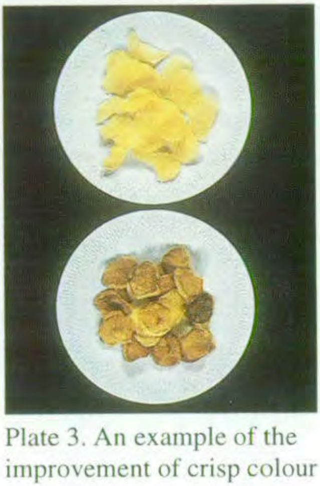

Plate 3. An example of the improvement of crisp colour by potassium application. The crisps made from potatoes which received potash (above) are bright golden brown.

Plate 4. Reduced growth, reduced flowering and bluish-green foliage are the first visible symptoms of potassium deficiency.

Plate 5. With increasing potash deficiency, internodes are shortened, leaves bend downward and turn yellow, and later necrotic patches appear.

8. World fertilizer practice

8.1. Recommendations

A summary of recommendations has been attempted in Appendix 4. These recommendations vary greatly according to soil type, soil nutrient status, whether or not farmyard manure is available, availability of irrigation and the purpose for which the potatoes are intended.

In countries where the average national yield exceeds 25 t/ha, the N and P_2O_5 rates recommended for potatoes for human consumption are generally between 100 and 160 kg/ha. The potash rates recommended are usually higher, they generally exceed 200 kg/ha K_2O and can go up to 1000 kg/ha K_2O. In countries with average yields lower than 20 t/ha, the recommended rates of nitrogen and phosphorus tend to be lower. In several of these countries, the recommended fertilization is unbalanced. For example, in contrast to what is observed in countries obtaining high yields, the rates of K_2O recommended are lower than those of N and P_2O_5.

8.2. Fertilizer practice

Appendix 5 shows average rates of N, P and K used in practice.

Table 53 shows that the dressings of nitrogen, phosphorus and especially potassium are large in countries where yields exceed 25 t/ha and the corresponding N:K ratio is 1:1.34. In countries with yields inferior to 20 t/ha, the fertilizer rates are lower an din particular less potassium than nitrogen is applied (N:K ratio: 1:0.79).

Table 53 Average N, P_2O_5 and K_2O rates applied in countries with yields higher than 25 t/ha or lower than 20 t/ha (calculated from Appendix 5)

Yield (t/ha)	No. countries	Average rate applied (kg/ha)		
		N	P_2O_5	K_2O
> 25 t/ha	5	131	116	175
< 20 t/ha	13	112	87	88

These figures show that increased crop production needs higher fertilizer dressings since higher yields remove more NPK.

9. Appendices

Appendix 1. Mean effect of nitrogen on yield

Country (No. of annual results)	kg N/ha	Yield (t/ha)	Yield increase %	kg tubers/ kg N	Reference
Europe					
E. Germany (36)	0	34.9			Gerdes *et al.* (1975)
	60	41.4	19	108	
	150	48.4	39	90	
	240	52.2	50	72	
	330	52.6	51	54	
England (26)	0	26.9			Webber *et al.*(1976)
	75	33.5	25	88	
	150	36.1	34	61	
	225	36.8	37	44	
England (16)	0	32.6			Archer *et al.* (1976)
	126	40.4	24	62	
	188	42.1	29	51	
England (16)	0	34.20			Farrar and Boyd (1976)
	75	39.87	17	76	
	150	42.46	24	55	
	225	42.73	25	38	
Ireland (19)	0	38.7			Gately (1971)
	45	43.2	12	100	
	90	45.2	17	72	
	135	47.2	23	65	
Norway (46)	0	21.73			Furunes (1975)
	60	26.91	24	86	
	120	28.50	31	56	
Poland (600)	0	22.8			Roztropowicz and Fotyma (1978)
	120	30.4	33	63	
Poland (15 = 3 sites × 5 *cvs.*)	0	33.9			Somorowska and Kakowska-Lipinska (1972)
	60	37.4	10	58	
	120	37.2	10	28	
	180	34.8	3	5	

Country (No. of annual results)	kg N/ha	Yield (t/ha)	Yield increase %	kg tubers/ kg N	Reference
Sweden (18)	0	28.3			Svensson *et al.* (1973)
	75	32.0	13	49	
	150	33.7	19	36	
	225	33.7	19	24	
	300	33.1	17	16	
Asia					
Cyprus (17)	0	26.0			Krentos and Orphanos (1979)
	60	32.4	25	107	
	120	34.6	33	72	
	180	33.0	27	39	
India (35)	0	15.43			Raheja (1966) in: Raychaudhuri (1976)
	112	20.60	34	46	
Lebanon (25)	0			34	CEA-IPI-ISMA (1974)
	60				
Syria (12)	0				CEA-IPI-ISMA (1974)
	80			14	
Turkey (28)	0				CEA-IPI-ISMA (1974)
	80			101	
Africa					
Sudan (12)	0	9.811			FAO
	80	12.230	25	30	
Latin America					
Colombia (15)	0				CEA-IPI-ISMA (1974)
	60			64	

Appendix 2. Mean effect of phosphorus on yield

Country (No. of annual results)	kg P_2O_5/ha	Yield (t/ha)	Yield increase %	kg tubers/ kg P_2O_5	Reference
Europe					
England (16)	0	38.0			Archer *et al.* (1976)
	100	39.9	5	19	

Country (No. of annual results)	kg P_2O_5/ha	Yield (t/ha)	Yield increase %	kg tubers/ kg P_2O_5	Reference
England (16)	200	41.6	9	18	
	300	42.9	13	16	
	400	42.3	11	11	
	500	42.7	12	9	
England (16)	0	40.80			Farrar and Boyd (1976)
	100	40.97	0.4	2	
	200	41.73	2	5	
	300	42.38	4	5	
Norway (46)	0	24.42			Furunes (1975)
	34	25.78	6	40	
	69	26.57	9	31	
Norway (10)	0	34.02			Ekeberg (1972)
	55	34.90	3	16	
	108	35.99	6	18	
Poland (112)	0	26.40			Roztropowicz and Fotyma (1978)
	120	28.70	9	19	
Poland (90)	0	27.30			Roztropowicz and Fotyma (1978)
	120	31.51	15	35	
Poland (60)	0	24.10			Roztropowicz and Fotyma (1978)
	120	26.48	10	20	
Poland (48)	0	26.9			Boguszewski and Pieczyrak (1968)
	36	29.0	8	58	
	72	30.0	12	43	
Sweden (68)	0	30.1			Hahlin and Johansson (1973)
	92	32.7	9	28	
	183	33.8	12	20	
Asia					
Cyprus (17)	0	30.5			Krentos and Orphanos (1979)
	60	31.4	3	15	
	119	32.0	5	13	
	179	32.2	6	9	
India (35)	0	20.60			Raheja (1966) in: Raychaudhuri (1976)
	112	22.07	7	13	

Country (No. of annual results)	kg P_2O_5/ha	Yield (t/ha)	Yield increase %	kg tubers/ kg P_2O_5	Reference
Lebanon (25)	0				CEA-IPI-ISMA
	60			27	(1974)
Syria (12)	0				CEA-IPI-ISMA
	80			8	(1974)
Turkey (28)	0				CEA-IPI-ISMA
	80			30	(1974)
Africa					
Sudan (12)	0	12.230			FAO
	40	14.048	15	45	
Latin America					
Colombia	0				CEA-IPI-ISMA
	142			39	(1974)

Appendix 3. Mean effect of potassium on yield

Country (No. of annual results)	kg K_2O/ha	Yield (t/ha)	Yield increase %	kg tubers/ kg K_2O	Reference
Europe					
Denmark	0	36.4			Højmark (1977)
(13, *cv.* Bintje)	108	37.6	3	11	
	217	38.3	5	9	
	325	38.1	5	5	
Denmark	0	35.1			Højmark (1977)
(11, *cv.* Saturna)	108	36.9	5	17	
	217	38.2	9	15	
	325	38.2	9	10	
England (26)	0	33.0			Webber *et al.*
	100	34.9	6	19	(1976)
	200	35.4	7	12	
	300	35.9	9	10	
England (16)	0	35.9			Archer *et al.* (1976)
	188	40.9	14	27	
	282	41.6	16	20	

Country (No. of annual results)	kg K_2O/ha	Yield (t/ha)	Yield increase %	kg tubers/ kg K_2O	Reference
England (16)	0	39.72			Farrar and Boyd (1976)
	113	41.25	4	14	
	226	41.88	5	10	
	339	41.93	6	7	
Germany (Dem. Rep.) (12)	0				Bruchholz (1974 and 1976)
	60		9		
	120		16		
	180		18		
	240		15		
Germany (Fed. Rep.) (30)	0	27.5			Braunschweig, von (1972)
	120	30.8	12	28	
	160	31.7	15	26	
	220	33.8	23	29	
	280	35.4	29	28	
Netherlands (43)	0	48.5			Prummel (1981)
	150	50.1	3	11	
	300	50.8	5	8	
	600	52.3	8	6	
	1200	52.2	8	3	
Norway (46)	0	24.34			Furunes (1975)
	120	26.04	7	14	
	241	26.39	8	9	
Norway (50=10 expts. with 5 *cvs.*)	0	28.77			Ekeberg and Rønsen (1973)
	84	30.31	5	18	
	169	31.55	10	16	
Norway (10)	0	33.44			Ekeberg (1972)
	75	35.20	5	23	
	148	36.24	8	19	
Poland (116)	0	26.10			Roztropowicz and Fotyma (1978)
	120	27.89	16	15	
Poland (68)	0	24.70			Roztropowicz and Fotyma (1978)
	120	26.74	8	17	

Country (No. of annual results)	kg K_2O/ha	Yield (t/ha)	Yield increase %	kg tubers/ kg K_2O	Reference
Poland (48)	0	27.1			Boguszweski and
	80	28.8	6	21	Pieczyrak (1968)
	160	29.8	10	17	
Poland (34)	0	24.10			Roztropowicz and
	120	26.08	8	17	Fotyma (1978)
Sweden (68)	0	30.9			Hahlin and
	181	33.2	7	13	Johansson (1973)
Asia					
India (35)	0	22.07			Raheja (1966), in:
	56	22.93	4	15	Raychaudhuri (1976)
India (15, local *cv.*)	0	6.898			Prasad and
	30	7.002	2	3	Mahapatra (1970)
	60	7.260	5	6	
India (15, *cv.* Red Patna)	0	9.656			Prasad and
	30	10.149	5	16	Mahapatra (1970)
	60	11.033	14	23	
India (14, crop affected by frost)	0	23.9			Grewal and Singh
	51	27.2	14	65	(1980)
	102	28.7	20	47	
India (10, *cv.* Up-to-date)	0	10.494			Prasad and
	30	11.344	8	28	Mahapatra (1970)
	60	11.777	12	21	
Lebanon (25)	0				CEA-IPI-ISMA
	120			0.1	(1974)
Pakistan (35)	0	12.193			Manzoor Elahi Raja
	40	13.484	11	32	and Abdul Hamid
	80	14.028	15	23	(1973), in: Kemmler (1978)
S. Korea (56)	0	9.10			Hong (1977)
	77	15.07	66	78	
Syria (12)	0				CEA-IPI-ISMA
	80			8	(1974)

Country (No. of annual results)	kg K_2O/ha	Yield (t/ha)	Yield increase %	kg tubers/ kg K_2O	Reference
Turkey (28)	0				CEA-IPI-ISMA
	80			19	(1974)
Africa					
Kenya (116)	0	15.615			Mathieu (1974)
	60	17.750	14	36	
Kenya (68)	0	11.401			Mathieu (1974)
	60	13.369	17	33	
Kenya (18)	0	11.077			Mathieu (1974)
	67	12.407	12	20	
Sudan (12)	0	15.744			FAO
	40	17.882	14	53	
Latin America					
Colombia (15)	0				CEA-IPI-ISMA
	60			21	(1974)
Ecuador (186)	0	9.832			FAO (1974)
	22.5	10.557	8	32	

Appendix 4. Fertilizer recommendations (kg/ha N, P_2O_5, K_2O) in various countries

Country	N	P_2O_5	K_2O	Remarks	Reference
Europe					
England	0-220	100-350	100-350	Maincrop	MAFF (1979)
	0-180	200-350	60-250	Earlies, industrial and seed	
France	120-180	150-180	150-200	Earlies with FYM	Gros (1979)
	80-140	80-120	150-200	Maincrop with FYM	
	100-170	100-140	180-240	Maincrop no FYM	
	30- 70	100-120	120-150	Seed crop with FYM	
	45-100	125-160	160-190	Seed crop no FYM	
Germany (F.R.G.)	150-200	120-150	200-320	Early crop	Ruhr-Stickstoff AG (1980)
	100-140	120-150	200-320	Maincrop	
	80-120	120-150	200-320	Seed crop	
	100-160	120-150	200-320	Industrial and forage	
Germany (G.D.R.)	100-140	92-128	96-135	Early crop	Rinno (1973)
	80-120	92-137	96-145	Maincrop	
	40-100	46-115	77-193	Seed crop	
	130-160	104-128	125-154	Starch production	
	150-190	103-131	145-183	Forage	
Greece	160	120	100		ISMA (1979)
Ireland	100	100	200		ISMA (1979)
Netherlands*	0-330	30-240	0-1000	Maincrop	Consulentenschap voor Bodemaangelegenheden in de Landbouw (1982)

Country	N	P_2O_5	K_2O	Remarks	Reference
Sweden	123	160	193		ISMA (1979)
Switzerland	80-140	120	300	Maincrop, forage and industrial	Hasler *et al.* (1979)
	60-100	70	210	Seed crop	
USSR	60-120	60-120	60-120	Non chernozem soils	Anon. (1978)
Asia					
Bangladesh	168	112	112		Mahk *et al.* (1978)
India-Himachal Pradesh	75-100	75-125	80-125		Rajoo and Singh (1978)
Indonesia	100	100	50		De Geus (1973)
Iran	90	45	-		De Geus (1973)
Israel	120-160	100	240		De Geus (1973)
Japan-Alluvial soils	80-120	140-150	120	+20t/ha FYM	Kali Kenkyu Kai (1980)
Japan-Volcanic soils	60-110	170-180	120	+20t/ha FYM	
Japan-Organic soils	50- 90	140-160	110-120	+20t/ha FYM	
Pakistan-Punjab	168	112	84		Kemmler (1978)
Philippines	30	30	60		Abad
S. Korea	100	100	120		Assoc. for Potash Research (1980)
Taiwan	150-200	150-200	240-360	+15t/ha compost	Su (1972)
Turkey	100-150	60-100	60-120		IPI Program to Turkey (1980)
America					
Brazil-Goias	80-120	150-225	50- 75		Yamada (1980)
Brazil-Paraná	60-100	20-120	60-150		

Country	N	P_2O_5	K_2O	Remarks	Reference
Brazil-São Paulo	60-100	150-350	45-135		
Brazil-Cerrado soils	150	450	200		
Colombia	200	390	90		ISMA (1979)
Dominican Republic	124-190	124-240	0-320		Free *et al.* (1976)
Mexico	60	120	60		De Geus (1973)
Peru	120-200	80-200	0-120		Castañeda (1977)
USA-Florida	168-269	224	224-325	Mineral soils irrigated	Montelaro (1975)
	134-201	180	180-247	Mineral soils not irrigated	
	0	60-180	90-270	Organic soils	
	67-134	134	134-201	Marly soils	
USA-Massachusetts	179-202	146-302	146-302		Lorenz and Maynard (1980)
USA-'Mid-Atlantic States'	157	112-224	168-336		
USA-New Jersey	140-168	56-224	56-336		Anon. (1974)
Africa					
Mauritius	78	78	120		Bazelet (1980)
South Africa	70-150	40-120	0-150		Bazelet (1980)
Zimbabwe	0-160	0-310	0-130		De Carvalho (1971)

* Fertilizer recommendations in the Netherlands are very sophisticated, especially in the case of potassium; therefore they vary greatly according to soil texture, nutrient contents and to the intended use of potatoes.

Nitrogen: Soil reserves are taken into consideration and the following amounts are recommended: 330 kg/ha N - 1.5 × the soil reserve for main crop potatoes and 140 kg/ha N - 0.6 × the soil reserve for seed potatoes.

Phosphate: Seed potatoes should receive higher rates than main crop potatoes and 30-240 kg/ha P_2O_5 are recommended for industrial potatoes.

Potassium: The following rates are recommended (kg/ha K_2O):

	Main crop potatoes	Starch production
Sandy and peaty soils	50-300	0-250
Clay soils <10% organic matter and alluvial clay soils	60-380	0-200
Clay soils >10% organic matter	0-280	0-220
Loess	0-340	0-140
Recent Zuiderzeepolder	0-280	0-200
K-fixing soils	210-530	150-350

In order to reduce internal blackening of tubers, higher rates are recommended on clay soils, i.e. 110-1000 kg/ha K_2O on soils <10% organic matter and 50-960 kg/ha K_2O on soils >10% organic matter. Seed potatoes should receive higher potassium dressings than main crop potatoes except on sandy and peaty soils where 50-300 kg/ha K_2O are recommended.

Appendix 5. Fertilizer rates (kg/ha N, P_2O_5, K_2O) used in various countries (FAO, 1988)

Country	N	P_2O_5	K_2O	Remarks
Africa				
Algeria	210	180	180	
Egypt	248	62	-	
Mauritius	156	156	240	
Nigeria	21	8	7	
Togo	90	80	100	
America				
Chile	77	70	-	
Dominican Republic	110	95	95	
Guatemala	129	58	193	
Mexico	77	98	-	
Trinidad and Tobago	100	75	60	
Uruguay	67	87	20	
Venezuela	102	102	145	
Asia				
Bangladesh	55	-	68	
Cyprus	200	130	50	
Japan	105	173	110	
Oman	96	48	-	
Turkey	104	92	15	
Europe				
Austria	130	80	200	
Bulgaria	160	170	90	
Denmark	140	69	180	
Finland	70	200	120	
Hungary	202	135	287	
Ireland	140	236	289	
Spain	150	80	55	
Sweden	98	77	142	Food Factory
	92	61	110	
United Kingdom	186	187	258	

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