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Mineral Fertilization, Yield and Quality of Vegetables

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A. Field grown vegetables

1. *Introduction*

There is a great variety in vegetables, and as many of them are of local importance only, the exact number of vegetable crops cannot be estimated.

In some West European countries vegetables are sold partly through auctions, as in Denmark, Western Germany and Belgium. In the Netherlands the whole vegetable production is sold by market auctions, the total turnover being more than 750 millions of guilders in 1965 (1 million guilders equals approximatively £100000).

Table 1 Production and turnover of the most important vegetables in the Netherlands in 1965

	Production in 1000 tons	Turnover in millions of guilders
Tomatoes*	311	280
Cucumbers*	181	113
Lettuce**	107	100
Brussels sprouts	47	32
Cauliflower	50	26
Carrots	88	26
Gherkins***	20	21
Asparagus	7	20
Chicory	23	17
Endive	41	17
Cabbage (savoy, red and white)	143	17

* Glasshouse crops ** Mainly from glasshouses *** Partly from glasshouses

In Holland tomatoes and cucumbers are only cultivated as glasshouse crops. Lettuce is grown in the open in spring, summer and autumn, while there is a glasshouse crop in autumn, winter and spring. Of the total lettuce production 70% is grown under glass, making 90% of the total turnover. Other vegetables are less important, being grown in glasshouses or under frames (e.g. endive and carrots) though frames are not commonly found nowadays.

The development that had occurred with gherkins (pickling cucumbers, Essiggurke in German, cornichon in French) may be taken as typical. Gherkins were formerly cultivated only as an out-door crop, but in 1962 some growers started cultivation in glasshouses.

By 1965 more than 30% of the production of gherkins came from glasshouses, and the acreage of gherkins under glass during 1966 is estimated to be 200 ha = 500 acres. This development, also to be traced in Belgium, is the more typical as gherkins are grown for canning purposes only. It appears that, in spite of increasing competition in the Common Market, a product for the canning industry can be cultivated economically under glass.

2. *Quality*

The products brought to the auction by the growers must meet certain requirements for quality and grading. Each lot is tested by inspectors. The requirements for grading and quality are published by the *Centraal Bureau voor Tuinbouwveilingen (Central Office of Horticultural Auctions) (Anon. [1])*; they are much the same as the OECD-norms. This cannot be said, of course, for those products for which the partners of the Common Market did not reach agreement until now, such as gherkins and cabbage.

Since 1924 the whole vegetable production is sold through auctions, so one can easily understand that Dutch growers are most familiar with grading and quality, it is a question of to be (export) or not to be (disqualified). Due to the perfection of the grading system individual lots are collected into big ones of uniform quality, as is done with tomatoes and cucumbers.

At the auction the products are evaluated visually on the basis of external and internal quality; only weight and size are measured. Methods of determining taste, firmness and other aspects of quality are under study and will possibly come into use in the future.

Before discussing the quality of various vegetables, I would like to describe quality as differences in characters that will lead to differences in price at the market auctions.

2.1 *Quality problems of vegetables due to fertilization*

2.1.1 Tomato

Ripening disorders (blotchy ripening and green back). The literature was recently reviewed by *Woods [44]*. Climatic conditions influence these disorders *(Venter [40])*, but potassium is of particular importance *[9, 16, 17, 20, 24, 30, 38, 43, 45]*. The influence of nitrogen will be discussed subsequently. The influence of phosphate on fruit color is negative according to most references *[16, 17, 45]*. At low levels in the soil, phosphate application resulted in an increase in yield and better quality, when a green back variety, *Cromco*, was used *(Nagels* and *Roorda Van Eysinga [24])*. It is possible that there are differences in response to phosphate between green back and no green back varieties, as *Woods [45]* also indicated. Using the variety *Potentate*, *Winsor [42]* found decreasing green back with increasing phosphate application, but other fruit characters were influenced unfavorably.

Blossom-end rot occurs when the osmotic pressure of the soil solution is high and is also influenced by other circumstances, such as climatic conditions. Fruits with blossom-end rot have a low calcium content. The literature on this subject was reviewed by *Spurr [36]*.

Cracking. According to recent research work in the USA, cracking can be controlled by spraying with $CaCl_2$ *(Dickinson* and *McCollum [11])*, as is also the case with blossom-end rot *(Geraldson [14])*. Spraying with calcium salts in order to control cracking or blossom-end rot is not practised in Holland and probably also not in other West European countries. In glasshouse cultivation both problems are of minor importance and are controlled by proper regulation of soil moisture.

Ghost-spots (Botrytis cinerea Pers. ex. Fr.) can probably be controlled indirectly. As was found by *Verhoeff [41]*, mycelial development of *B. cinerea* in tomatoes decreases at higher nitrogen levels. The development of *Botrytis* being decreased, one can expect that sporulation will be less and hence the incidence of ghost-spots will decrease.

Calcium *(Stall [37])*, potassium *(Winsor [42])* and a mixture of potassium and magnesium sulphates *(Clay* and *Hudson [8])* are also of influence in this respect.

Potato blight (Phytophthora infestans de By) is not an important problem with glasshouse tomatoes, but sometimes occurs. In a fertilization experiment it was found by the author that a smaller percentage of fruits were diseased with higher nitrogen applications.

Table 2 Influence of increasing applications of nitrogen on total yield and yield of tomato fruits with potato blight

N applications in kg per 100 m²	0	2	4	8	Statistical evaluation Linear effect	Quadratic effect
Total yield in kg per plant	5.72	6.54	6.65	6.51	P = 0.03	P = 0.02
Fruits with Phytophthora in kg per 10 plants	0.74	0.61	0.52	0.30	P = 0.02	n.s.

Ribbed and hollow fruits are sometimes observed in tomato crops on soils after steam sterilization. It is thought that the primary cause is too vigorous growth on such soils. By leaching after steaming and by heavy dressings of fertilizers especially of potassium salts the growers try to impede growth and to improve fruit quality. At the *Glasshouse Crops Research Institute* in Littlehampton (UK) the hollowness of the fruits is measured as a percentage of fruits floating in water. More information will become available when the results of a long term NPK-factorial experiment are published *(Winsor [42])*.

2.1.2 Cucumber

Except for bitterness, there are only a few references concerning quality problems with this crop. Bitterness is no longer a problem as seedgrowers have succeeded in breeding varieties free from bitterness. The literature, partly consisting of references which are not readily available, has been reviewed by the author *(Roorda van Eysinga [29])*. Generally speaking the literature is not very consistent.

Fruit shape. The potassium level of the soil may influence "underdevelopment" of the end of the fruits. According to *Anstett [2]*, however, "underdevelopment" is observed at low potassium levels, and according to *De Koning [18]* at high levels.

It was also found by *Anstett [2]* that bottle-neck shaped cucumbers occur at low nitrogen levels in the soil.

Fruit size is smaller with higher nitrogen fertilization *(Roorda van Eysinga [29])*.

Fruit colour is influenced unfavourably by low potassium levels in the soil *(De Koning [18])*. A high pH and a low nitrogen level in the soil are also thought to affect the colour unfavourably.

2.1.3 Lettuce

Tipburn. According to recent Dutch investigations several types of tipburn may be recognized *(Termohlen [39])*; at least one of these types may be influenced by a high salt content in the soil.

Bolting is sometimes observed when the phosphate status of the soil is low, but the response is closely linked with variety. As was shown by *Bensink [5]*, nitrogen also influences the change from the vegetative to the reproductive phase of the lettuce plant. In our experiments at different holdings we did not observe this penomenon.

Discoloration of the leaves by authocyanin at low temperature and low phosphate status of the soil is well known with some varieties, e.g. the Maikönig-group (see also *Rodenburg [26]*).

A tulip-shape of lettuce heads is often observed when lettuce is grown on steam sterilized soil. Some soils are more troublesome than others in this respect. This problem is thought to be connected with nitrogen feeding (steamed soils contain a high amount of ammonia), with leaching or perhaps the time of leaching (soil rewettability), and perhaps with manganese toxicity.

Manganese toxicity (after steam sterilization). Steam sterilization increases the content of readily soluble manganese in the soil. Typical symptoms of manganese toxicity are described in the literature. The problem has been studied by *Messing [23]* at Littlehampton and is still under study at the *Naaldwijk Experiment and Research Station* (see Annual Report 1964 and 1965 *[25]*) and at the *Institute for Soil Fertility* (see Annual Report 1963 and 1964 *[15]*).

Magnesium deficiency symptoms are mentioned by *Van den Ende [13]*; the symptoms may be especially noticeable when the variety Proeftuins' Blackpool is grown on wet soils. Though the symptoms are typical by those of magnesium deficiency, a causal relationship has not yet been established.

2.1.4 Brussels sprouts

The firmness of the sprouts is influenced adversely by high nitrogen application. According to *Shepherd [34]* this effect can be counteracted to some extent by potassium nutrition. This potassium effect was not found by others *(Barnau Sijthof [4], Buishand [7])*.

Internal rot. According to *Leuchs [21]* potassium can accelerate the healing of wounds and thus indirectly decreases the attack of mould fungi.

2.1.5 Cauliflower

This crop reacts sharply to adequate soil fertility. Whiptail as a deficiency symptom of molybdenum is well known.

Buttoning occurs with low nitrogen fertilization *(Shoemaker [35])*.

Browning of the curd is well known as a symptom of boron deficiency. According to *Van den Ende [12]* this problem is also found in soils with an excessive salt content. In the case of boron deficiency hollow stems are also observed.

Riceyness. This problem is related to excess of nitrogen together with unfavourable climatic conditions *(Van Assche* and *Van der Linden [3])*.

2.1.6 Gherkins

Though gherkins belong to the same genus as cucumbers, they differ from the latter in the smaller size of the fruit and the need for pollination. Due to the close relationship between the two crops, more or less the same quality problems are to be expected.

Fruit shape Shortage of nitrogen results in fruits with a converted slightly curved end *(Dearborn [10])*.

Fruit size is influenced by nitrogen supply *(Matsuzaky* and *Hayase [21])*.

Fruit colour. The fruit colour turns pale green under conditions of nitrogen deficiency *(Dearborn [10])*.

2.1.7 Asparagus

In Europe asparagus is cultivated in ridges and white spears are harvested. Work has been done on the taste and the texture of the spears, but the results are doubtful. Even the influence of fertilization upon yield is controversial. According to research workers in Michigan, USA *(Brown* and *Carolus [6])*, only small amounts of fertilizers are needed, as asparagus uses nutrients very economically by re-storing them in the rootstock during the winter. According to investigations made by the author *[28]*, fertilizers are effective if ploughed in deeply before planting. This is especially important for insoluble nutrients as there are no roots in the upper soil layer.

2.1.8 Endive

Discoloration of the leaves. In endive crops, planted late in the season, a chlorosis of the older leaf margines occurs, due to magnesium deficiency as is described by *Knoppien [19]*.

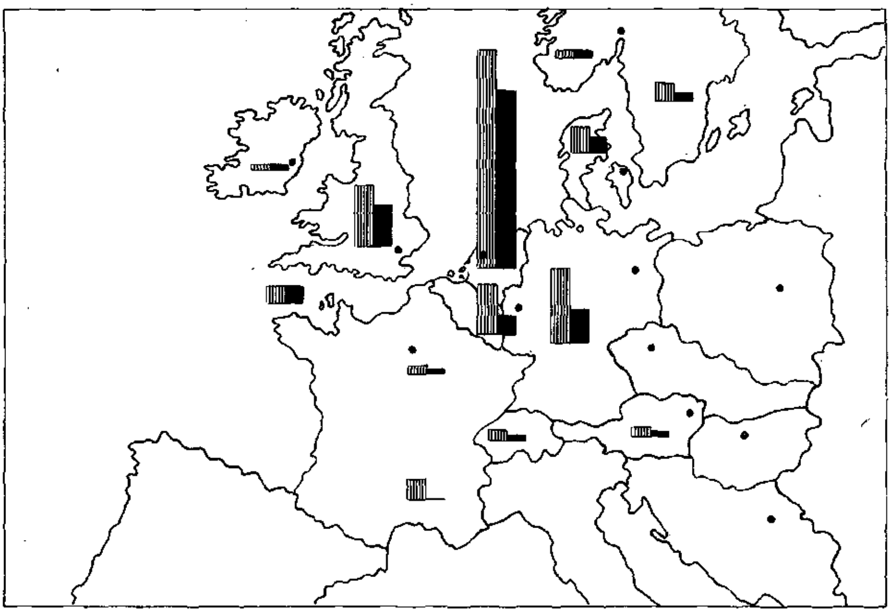
B. Fertilization, yield and quality of glasshouse vegetables

1. *Introduction*

Especially in the field of vegetable cultivation under glass the Netherlands take a leading position. The glasshouse acreage in different countries in Europe is indicated in figure 1.

The requirements for imported glasshouse vegetables in surrounding countries are largely supplied by Dutch growers; 75% of the cucumbers imported into the United Kingdom and about 95% of the lettuce are grown in Holland. Similarly 70% of the tomatoes and 90% of the cucumbers imported into Western Germany are grown in Holland.

Vegetables grown under glass have a better quality than those grown in the open, as climatic conditions can be controlled to a large extent.



Total glasshouse acreage

Used for vegetable production

½ cm = approximately 1000 ha equals 2500 acres

Fig. 1 Map showing the glasshouse acreage in European countries (figures estimated a few years ago)

With one exception there are no differences in principle between fertilization under glass and out of doors. The exception is the CO_2-release from manures. Theoretically such a release influences the CO_2-content of the air in glasshouses and hence the growth of the plants. A preliminary study on this subject was published by *Seeman [33]*.

In practice there are many differences between fertilization under glass and that in the open. The great difference is the glasshouse climate, especially the absence of natural rainfall, which leads to salinisation of the soil. To overcome this problem, soil leaching is a normal practice in the autumn. Ten years ago, hose watering was the usual system in Dutch glasshouses, but nowadays sprinkler irrigation is widespread. This change has been a silent revolution and seems much more of an improvement than, for example, enrichment with carbon dioxide. The easy supply of water—pushing a button is often sufficient—gives the possibility of regular watering, resulting in high percentage of soil moisture. According to investigations by the author *[27]* in 1959, with 15 fertilization trials on different nurseries, the average optimal nitrogen application for lettuce appeared to be 0.4 to 0.6 kg N per 100 m^2. At this time sprinkler irrigation was not adequately used. In 1963–1964 the optimal nitrogen application appeared to be 1.5 kg N per 100 m^2, as was concluded from 16 trials *[31]*.

The introduction of the sprinkler irrigation system made it possible to programme watering electronically. In order to save labour, sprinkler irrigation systems are also combined with equipment to apply liquid fertilizers. The question of whether this method of applying fertilizers is superior to the traditional way as plant growth and production are concerned has not as yet been studied sufficiently.

As glasshouse vegetable production requires much labour and a high investment, the cost of fertilizer hardly influence the total cost of production. In agricultural production it is common practice to apply such an amount of fertilizers that the costs for more fertilizers are not defraid by the extra returns. In vegetable production, especially under glass, it is common practice to apply fertilizers at, or even above, the rates at which maximal production can be obtained.

The danger of over-fertilization and salinisation makes some special forms of soil analysis necessary. For glasshouse soils in the Netherlands soil samples are analysed for, among other things, total salts (conductivity measurement), chloride and water soluble nitrogen. A so-called complete analysis is desirable for applying base dressings. The estimation of chloride content is especially useful in flat areas near the sea coast, where the water is often brackish. A so-called short analysis is made for determining the amount of top dressing. In this analysis the total salt content as well as the figure for water soluble nitrogen and potassium are determined. In analysing samples of glasshouse soils extraction with water is most popular in the Netherlands.

Due to differences in age of the glasshouse, in soil type and for various other reasons soil fertility varies greatly. The nitrogen status of the soil can change from high to zero by leaching. The big differences in soil fertility indicate the necessity for fertilization experiments with crops grown under glass, giving spectacular results in some cases. In the literature it is sometimes stated that glasshouse nutritional trials must be long-term experiments *[17, 20, 38]*. In the author's opinion this is not necessary. By choosing suitable sites and making marked differences in the quantities of nutrients applied, experiments with one crop can give quite clear results. Simple fertilizer trials are used by the author in glasshouses on various nurseries with differing levels in the soil nutrients. In order to study interactions, long-term fertilizer trials are perhaps better. It proved possible, however, to lay down short-term trials of large shape on growers holdings under conditions prevailing in Holland. Carrying out experiments at different holdings gives the advantage of choice of soil nutrient status.

2. *Lettuce*

At least for lettuce crops grown during the winter, the yield, that is to say the head weight, can be considered as a quality characteristic. Nitrogen has a great influence on mean head weight. The optimal application, running from 0 to 2 kg nitrogen per 100 m^2, depends of course upon the readily soluble nitrogen content of the soil. For lettuce this should be 90 ppm nitrogen. Phosphorus can be of great importance. Heavy dressings, up to 10 kg P_2O_5 per 100 m^2, are necessary in glasshouses newly built on poor soils formerly used for arable cultivation or as meadows, and also on reclaimed soils. For soils in older glasshouses having a high phosphate status hardly any phosphate is necessary.

Under the circumstances prevailing in commercial nurseries in Holland, potassium and other nutrients are of little, if any, importance. The total salt content of the soil should be as low as possible.

3. *Cucumber*

Organic material is important, being widely used by many growers. The extreme is cultivation on straw bales (figure 2).

As large quantities of organic material are applied, nutritional studies are

Fig. 2 Cucumbers on straw bales

difficult. On the one hand nutrient deficiency is not to be expected, on the other hand it will be difficult to apply fertilizers in excess as the soil contains a high amount of organic material. The same holds true for fertilization in the nurseries. According to the literature the uptake of nutrients by a cucumber crop is strongly correlated with the production *[32]*. The nutrient uptake by crops grown with two levels of farmyard manure is compared in table 3.

Table 3 Nutrient enrichment of the soil by manure and nutrient uptake by the crop

kg per 100 m²	N	P_2O_5	K_2O	MgO
Supplied by 2000 and 5000 kg FYM respectively	10–25	5 ½–12 ½	10–25	2–5
Uptake by crops with yields of 10 and 30 kg per plant respectively (approximately 20 and 60 fruits)	1 ½–4 ½	1–3	3–10	½–1

From this comparison the need for fertilization can be predicted. At the start of cultivation nitrogen application may be necessary as the nitrogen from the manure will not be available to the plant at this time. With strawy manure it is even possible that nitrogen is fixed. When production is high, and when moderate quantities of manure were used a top dressing with potash is valuable. The time of application of this topdressing is influenced by the watering, but it will be somewhere in the middle of the cultivation period. At this stage additional nitrogen is probably not required as nitrogen will be released from the manure.

Previous experiments suggested that, for cucumbers, a moderate level of soluble nitrogen and of potassium is necessary in the soil. It also appeared that, with regular use of manures, only a small amount of fertilizer need be applied.

4. *Tomato*

Considering yield, nitrogen is the most important nutrient. Being easily moved by soil moisture, the amounts of the nitrogen required particularly in topdressings, depend on whether the crop is grown under wet or dry conditions. Unpublished data obtained by the author show that the content of water soluble nitrogen in the soil should be about 100 ppm.

As with lettuce, phosphate is especially important when the soil is used for a glasshouse crop for the first time. With tomatoes, however, the quantity to apply may be smaller than with lettuce. The influence of phosphate on quality has already been discussed.

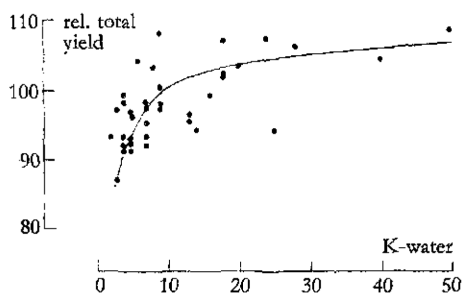


Fig. 3 Relation between relative total yield and content of water-soluble potassium (mg K_2O per 100 g dry soil) estimated in soil samples just before starting the experiments

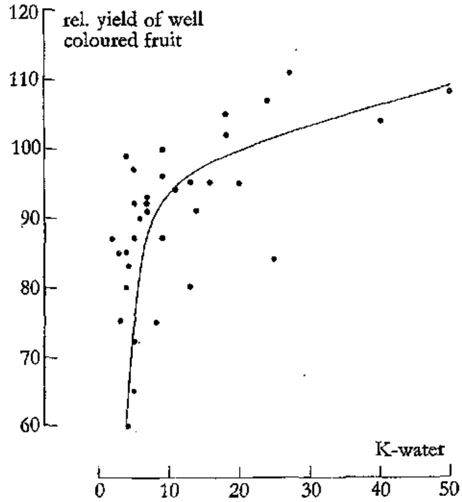


Fig. 4 Relation between relative yield of well-coloured fruits and content of water-soluble potassium (mg K_2O per 100 g dry soil) estimated in soil samples just before starting the experiment

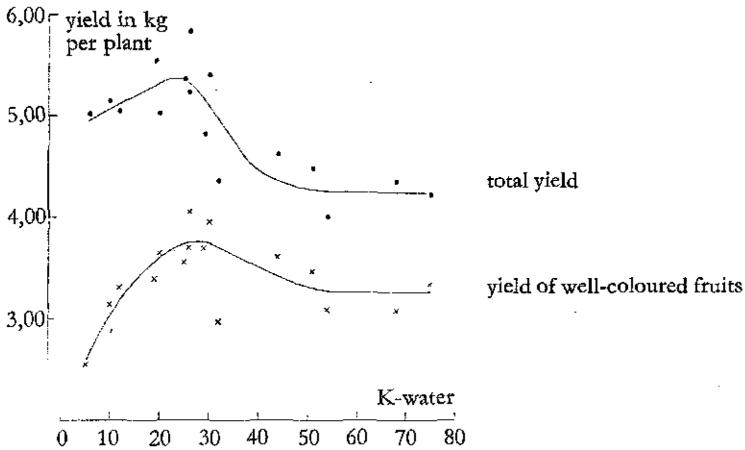


Fig. 5 Relation between content of water-soluble potassium (mg K_2O per 100 g dry soil) at the time of first picking and total yield and yield of well-coloured fruits respectively

Potassium influences the total yield (see figure 3) only when the potassium status of the soil is low. The yield of well-coloured fruits is clearly influenced by potassium, as is shown in figure 4. In both these figures data for the relative yields have been plotted against the content of water-soluble potassium in the soil at the time of starting the experiments.

In order to obtain the highest yield of well-coloured fruits a higher potassium level in the soil is needed than for obtaining the highest total yield. The results of a potassium fertilization experiment in a slightly acid sandy soil are shown in figure 5.

When the potassium status of the soil is low, large amounts of potassium, up to 30 kg K_2O per 100 m^2 are necessary.

Recent nitrogen fertilization experiments have shown that with small nitrogen applications, more fruits fall off owing to attack by *Botrytis cinerea*; a clear influence of potassium was not found in this respect (table 4). The influence of nitrogen on *Botrytis* attack has been found on a range of different soil types. In a long-term NPK factorial trial at the *Glasshouse Crops Research Institute* in Littlehampton (UK) many plants were lost at the lowest nitrogen and the lowest potassium levels due to stem invasions by *Botrytis cinerea* (*Winsor [42]*).

On loam and silt soils it was found that nitrogen can have a favourable influence on quality (see table 4*b*). According to the literature, nitrogen has no effect *[30, 38]* or even an unfavourable one in this respect *[17]*.

Table 4 Results of a nitrogen potassium factorial trial on a river clay loam with a low initial nutrient status. Nitrogen applied as nitro-chalk, potassium as sulphate of potash

(a) Total yield in kg per plant

kg N per 100 m^2	kg K_2O per 100 m^2: 0	7½	15	30	Mean
0	2.13	1.22	0.89	1.40	1.41
2	2.47	2.86	2.84	2.88	2.76
4	3.12	3.32	3.21	3.46	3.28
8	3.16	3.04	3.35	3.20	3.19
Mean	2.72	2.61	2.57	2.73	

Statistical evaluation: nitrogen, linear and quadratic effect significant at $P < 0.01$; potassium, no significant effects; interaction, N-linear × K-linear significant at $P = 0.04$

(b) Percentage of well-coloured fruits

kg N per 100 m²	kg K_2O per 100 m² 0	7½	15	30	Mean
0	96	98	99	98	98
2	63	87	82	90	80
4	91	96	95	91	93
8	98	99	96	98	98
Mean	87	95	93	94	

Statistical evaluation: nitrogen, quadratic effect significant at $P < 0.01$; potassium, linear effect significant at $P = 0.10$; interactions, N-linear × K-linear significant at $P = 0.02$

(c) Percentage of fallen fruits, due to Botrytis attack

kg N per 100 m²	kg K_2O per 100 m² 0	7½	15	30	Mean
0	4.9	6.0	4.1	5.1	5.0
2	4.9	5.0	4.2	5.9	5.0
4	4.0	4.0	3.6	3.4	3.8
8	4.0	2.9	3.7	3.4	3.5
Mean	4.5	4.5	3.9	4.4	

Statistical evaluation: nitrogen, linear effect significant at $P < 0.01$; potassium and interactions, no significant effects

The reason why nitrogen sometimes gives an increase in percentage of well-coloured fruits is not fully understood. It is well known that an increase in the osmotic pressure of soil moisture can be obtained by nitrogen application to the soil resulting in a small decrease in total yield together with an increase in the percentage of well-coloured fruits *(Clay* and *Hudson [8])*. In some recent experiments on loam and silt soils, with a low nitrogen level, a higher nitrogen application promoted growth, increased total yield but also the percentage of well-coloured fruits. According to leaf analysis, the higher nitrogen application does increase the nitrogen and the potassium content of the leaves.

The nitrogen/potassium ratio appears to be important according to some references (e.g. *Danvig* and *Pedersen [9]*, and *Winsor et al. [43]*), the latter workers using trickler irrigation, but generally speaking in practice this nitrogen/potassium ratio is of little importance *(Strømme [38], Roorda van Eysinga [30])*.

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SUMMARY

Quality problems in relation to the fertilization of vegetable crops—important according to the turnover at the Dutch market auctions—are summarized.

Particular attention is given to the fertilization of the three most important glasshouse crops, namely tomatoes, cucumbers and lettuce.

ZUSAMMENFASSUNG

Diese Arbeit untersucht die Qualitätsprobleme in Verbindung mit der Düngung derjenigen Gemüsearten, die auf Grund der Umsätze auf den holländischen Marktauktionen von großer Bedeutung sind.

Besondere Beachtung wird der Düngung von drei wichtigen, unter Glas gezogenen Gemüsearten geschenkt (Tomaten, Gurken und Kopfsalat).

RÉSUMÉ

Ce travail traite des problèmes de qualité en rapport avec la fumure des cultures maraîchères importantes du point de vue de leurs chiffres d'affaires sur les marchés hollandais.

Une attention particulière est vouée à la fumure des cultures en serre les plus importantes (tomates, concombres et laitues).

RESUMEN

En este trabajo se resume el problema de lá calidad en relación con la fertilización de cosechas de vegetales importantes de acuerdo con las transacciones sul mercado holandés.

Se concede especial atención a la fertilización de las tres cosechas más importantes cultivadas en invernaderos, principalmente tomates, pepinos y lechuga.