REPRINTED FROM:
MISC. PAPERS LANDB.HOGESCH. WAGENINGEN 1968 No. 3, 25-50

PLANT PRODUCTION

C. T. de WIT

Instituut voor Biologisch en Scheikundig Onderzoek van Landbouwgewassen, Wageningen
Mededeling 390

PLANT PRODUCTION

by

C. T. DE WIT

Professor of Theoretical Agronomy
Agricultural University, Wageningen
Agronomist Institute for Biological and Chemical Research on Field Crops and
Herbage (IBS) Wageningen

A poor man's world

During idle periods in one of the military campaigns in Europe at the end of the Napoleontic time, CARL VON WULFFEN aus Pietzpuhl developed 'Das Statische Gesetz', in which the productivity of the land is understood as a resource that is depleted by cropping and replenished by natural factors and agronomic measures.

Historians may consider this law one of the famous dead ends in agricultural science, but it is the first and an excellent example of operations research in this field and it also summarizes the state of the art at a time when no artificial fertilizers were available in a remarkable dynamic fashion. (42, 43, 44).

Four quantities are considered, which are presented in a relational model as is nowadays customary in the management sciences (figure 1, left). The richness of the soil and the total yield since the beginning of the rotation, are two tangible quantities expressed in the same units. The rate of transfer from one state to another is governed by the yield in the current year. This yield in its turn depends on the richness and the activity of the soil, as presented by these lines of information flow. Obviously, the yield in one year feeds back on the yield in the next year by the decrease in richness.

This information-feedback system was quantified by an assumption which is given here in the form of a graph (figure 1, right). The richness in one year is presented along the horizontal axis and in the next year along the vertical axis. For zero activity the activity line coincides with the 45 degree line. The richness

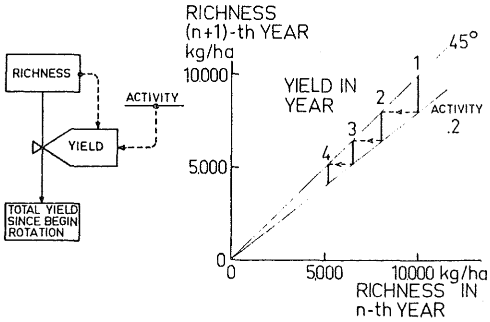


FIG. 1. A relational model and a graphical representation of 'Das Statische gesetz'.
'Man dividiere das Quadrat des Produkts der ersten Ernte mit. dem Minus der zweiten und es ergibt sich der Reichtum des Bodens. Dann dividiere man damit der Fruchtbarkeitsgrad den der Boden durch Hervorbringung der ersten Ernte haben musste und es ergibt sich sein Thätigkeitsgrad'.

is then the same in successive years and the yield is zero. The dotted line presents an activity of 2. This means that in a year when the richness is 10.000 kg/ha, the yield is 2000 kg/ha, and the richness 8000 kg/ha next year. This produces a yield of 1600 kg/ha and a decrease in richness to 6400 kg/ha and so on, gradually downwards till exhaustion.

The richness and activity of the soil was obtained by VON WULFFEN by determining the yield in two successive years, and by growing two crops side by side it was possible to express the richness and activity for any crop in terms of a standard for which rye was chosen. Likewise he compared various cultivation practices. The richness of the soil could be restored again by fallowing and applying manure. Again it was possible to express the value of these measures in terms of rye equivalents. Thus a challenging link between theory and experiment was established, which led to considerable experimentation.

More complicated situations were considered. He took into account that a part of the yield was sold and a part was transferred through the animal to the manure yard from where it was returned to the individual fields, depending on the amount of manure available, the richness and activity of the soil and the crop to be grown. The source of richness due to fallowing was rather a mystery. Whatever the complications, it remained possible to present the whole farm in what we now call an open recursive system, in which the rates of transfer and the management decisions depended in a unilateral, causal way on the state of the system and the market situation.

The consequences are presented graphically for the simple case of yearly cultivation of rye (figure 2). Each year, the richness is replenished at a certain rate by the return of manure and by fallowing. Starting from a poor soil, the yield and the richness increases until the 'Beharrungspunkt' or the stationary state was achieved. Starting from a rich soil richness and yield decreased gradually to the same Beharrungspunkt. Hence, in due course a stationary state for the richness and the yields was obtained which did not depend on the original richness of the soil, but could be evaluated by keeping careful records of the farm operations. This theory formed the starting point for VON THÜNEN to develop his theory of marginal utility and the concept of the 'Isolierter

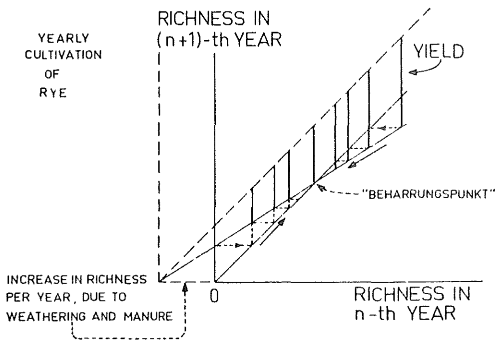


FIG. 2. The approach of the dynamic equilibrium (Beharrungspunkt) of a farming system according to VON WULFFEN.

Staat' in which the localization of the type of farming under influence of the distance to and the size of the market was explained (39) (figure 3).

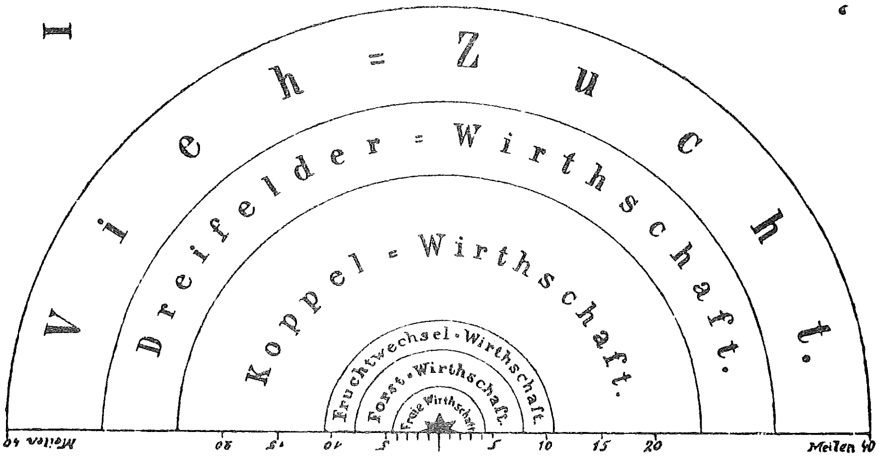


FIG. 3. The isolated State of VON THÜNEN in which the location of the type of farming is determined under the influence of the distance to and the size of the market.
'Man denke sich eine grosse Stadt in der Mitte einer fruchtbaren Ebene gelegen, die von keinem schiffbaren Flusse oder Kanale durchströmt wird. Die Ebene selbst bestehe aus einem durchaus gleichen Boden, der überall der Kultur fähig ist. In grosser Entfernung von der Stadt endigt sich die Ebene in eine unkultivierte Wildniss, wodurch dieser Staat von der übrigen Welt gänzlich getrennt wird'.

This dynamic insight in a human endeavour was perhaps only surpassed thirty years ago by that of KEYNES in his 'General Theory of Employment, Interest and Money'(23), an approach which has – at least to an outsider – much in common with 'Das Statische Gesetz'.

It was stressed by VON WULFFEN that the richness of the soil was not measurable, but could only be determined by keeping track of all farm operations, although contemporaries tried to associate it with the humus content of the soil. However, it is fair to remark that at present very similar dynamic approaches are used in humus research, be it that any reference to VON WULFFEN is lacking (24).

Without outside manures, the yield appeared to be about 700 kg of rye per hectare at the 'Beharrungspunkt'. This yield level could be increased to about 2000 kg per hectare by the Flemish method of agriculture, a very sophisticated system in which the more marginal land was reserved for animal husbandry, cash crops were alternated with forage crops and the manure was carefully saved for the arable land (38).

This careful management of the soil was not practiced everywhere. As for instance in Missouri where according to an indignant writer in the Cultivator of 1849 (2) '...Farming is executed according to the regular skinning system: scratch over a great deal of soil... cultivate none. And where some farmers have the foresight and sagacity to avoid hauling manure by building their stables over a ravine by which they are drained so that each shower abates the nuisance'. Here the farmers had the soil to begin with, which European farmers should like to make with their manures. Although much land was wasted in this way it must be realized that the rapid expansion of agriculture made the development possible of an urban population in the East of the United States; in other words: hoarded capital was transformed into working capital.

Mineral nitrition

The breakthrough came in 1840, when Liebig collected all the evidence that plants needed only water, minerals and nitrogen out of the root medium and killed with intelligence and sarcasm the theory that humus as such was a plant nutrient. He formulated the famous law of the minimum (27) (figure 4).

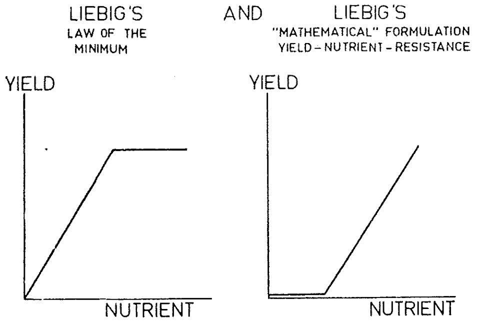


Fig. 4. Liebig's law of the minimum. 'Die Höhe des Ertrages eines Feldes steht im Verhältniss zu demjenigen zur völligen Entwicklung der Pflanze unentbehrlichen Nahrungsstoff welcher im Boden in kleinster Menge vorhanden ist'.

Curiously enough, his mathematical formulation said that the yield was proportional to the nutrition minus all the resistances that prevent the use thereof, which is the law of the minimum in upside-down form.

But more serious errors of judgement were made. Liebig's patent manure contained phosphate in a rather insoluble form and did not contain any nitrogen, because he presumed that there was sufficient ammonia around, especially in the air to serve the needs of the plants. Moreover, Von Wulffen's conception, rightly based on an analysis of the results of experiments, degenerated into a kind of balancing system in which it was thought to be sufficient to replace the minerals which were removed with the crop in order to maintain the fertility of the soil.

No wonder that Lawes (26) of Rothamsted remarked that 'the contempt the practical farmer feels for the science of agricultural chemistry arises from the errors made by its professors'. Lawes and Gilbert based their conclusions mainly on the results of field experiments and came up with much better and sensible advice than Liebig, who qualified these Englishmen as 'fertilizer manufacturers'. Like the qualification 'amateur scientists' by Hudig (20) this was meant as an insult. However, their approach, characterized by freedom from prejudice became traditional in England and led in the twenties of this century to the development of the 'analysis of variance' by R. A. Fisher, (16) a brilliant mathematician at the experimental station founded by Lawes and Gilbert. And this statistical theory is one of the main contributions of agriculture science to science at large.

Work of both schools showed that the plant-soil relationships were much more complicated than originally supposed, and at the beginning of this century the study of the physical, chemical and micro-biological aspects was well established. But this research did not provide the farmer with a straight-forward answer on the question how much plant nutrients could be mined from the soil and how much had to be added out of the fertilizerbag.

Their needs were served 50 years ago by MITSCHERLICH, who supposed that the form of the yield response curve (figure 5) depended only on the kind of fertilizer and was independent of crop species, soil and other conditions (30). This enabled him to calculate how much fertilizer had to be applied in the field on basis of pot experiments in the greenhouse. Because he based his calculations only on yield determinations, this approach was appreciated by the agronomists, but soil science was too far advanced to get away with it without severe criticism. The controversy stimulated the evaluation of chemical soil and plant analyses on basis of fertilizer experiments in situ and this shows that a theory needs not to be correct to be useful, but MITSCHERLICH was not the man to appreciate such a point of view.

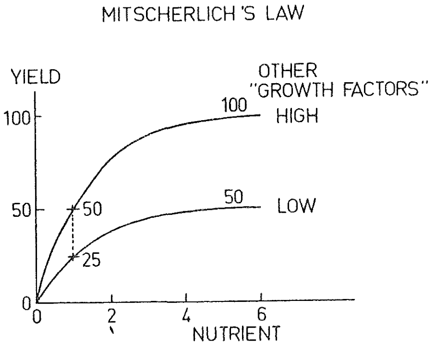


FIG. 5. MITSCHERLICH's law.

The Soil Fertility Institute in Groningen has truly pioneered in the field of soil fertility. In 1919, HUDIG introduced the electro-chemical determination of the pH of the soil, which enabled the lime-requirement to be estimated and the pitfall of overliming to be avoided. This was followed by the development of methods to determine the phosphate, potassium and magnesium status of the soil, so that now a basis for advisory work is available, which ranks among the best.

However, the situation remained obscure for nitrogen. Nitrogen is subjected to such a high turnover rate between the organic, ammonium, nitrate and elementary form in the soil medium that the approach which was so successful for the more stable elements failed with this one. It appeared that for this element and to a less extent for potassium a regular essay of the nutrient status of the plant on basis of leaf analysis is indispensable at the present high application levels (25) to avoid the damaging results of overdosing. How the situation has changed in the course of time is best illustrated by comparing the composition

1000 kg GRASS CONTAINS ON

	POOR SOIL	WELL-FERTILIZED SOIL
	11 kg N	40 kg N
	11 kg K_2O	40 kg K_2O
	3 kg P_2O_5	10 kg P_2O_5
OR	25 kg +	90 kg +

OF PLANT NUTRIENTS
EXPRESSED IN TRADITIONAL FASHION

FIG. 6. The uptake of nutrients by grass.

of grass, grown on a poor and on a well fertilized soil (figure 6). Under poor conditions 1000 kg of grass contains about 25 kg of plant nutrients and this is about the amount released by one hectare of exhausted soil in one year. Well fertilized grass contains 90 kg of nutrients per 1000 kg, so that a yield of 10.000 kg per hectare needs 900 kg of nutrients. The increased supply of artificial fertilizers provided indeed the leverage for the spectacular increase in yield in Europe during the last 80 years (figure 7).

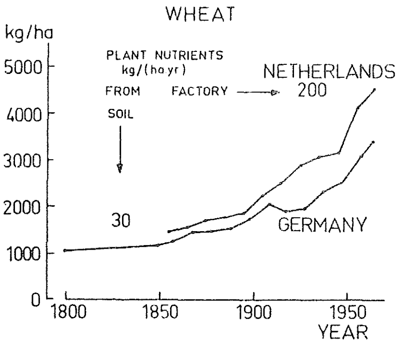


FIG. 7. Yields of wheat in two European countries. (Sources: official statistical year books and BITTERMAN (3).

Conservation

From the beginning farmers recognized the importance of good drainage in humid regions and good irrigation in arid regions and were able to develop the ways and means for this, and this may be the reason why the development in the field of water management has not been very revolutionary. Advances in this field are mainly due to the increased capability of moving water and earth.

There is a continuous interest in the economy of water use. In irrigated areas, a large proportion of the water may be lost even before it reaches the field: this is sheer waste. However, once on the field, part of the water has to move downwards out of reach of the roots to carry away the salts that would otherwise accumulate to a harmful level at the surface, this especially so under conditions of no financial constraint on the use of fertilizers. The failure to recognize this problem or the impossibility to do something about it still compels many farmers to leave their fields.

Large areas of arable land are also lost by wind- and water erosion, a process considerably promoted by intensive cropping systems and the too liberal use of the plough and other tillage implements. At least the major grain crops may be grown without any tillage at all, provided effective herbicides are used.

These zero-tillage methods may become one of the major tools in controlling erosion, especially in the grain belts of the world.

Potential photosynthesis

Many experiments are still carried out to show that without proper treatment yields are only a fraction of the normal, but more and more attention is paid to the crucial question how high yields may be under conditions where all soil factors are at their optimum, and to judge on this basis how much room there is for improvement.

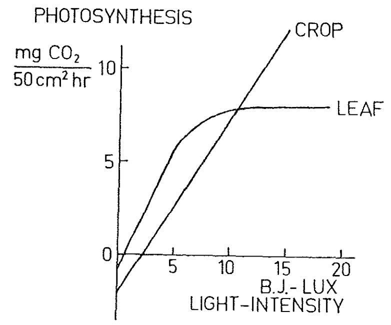
The sun rather than the earth is harvested under these conditions, as was already clearly expressed by ROBERT MAYER (29) who wrote in 1845: 'Die Natur hat sich die Aufgabe gestellt das der Erde zuströmende Licht im Fluge zu haschen, und die beweglichste aller Kräfte, in starre Form umgewandelt, aufzuspeichern. Zur Erreichung dieses Zweckes hat sie die Erdkruste mit Organismen überzogen'.

It was recognized (28) that plants perform better under high than low light conditions, but only in the beginning of this century research was far enough advanced for BLACKMAN to be able to formulate the principle of the limiting factors of carbondioxide assimilation: at low light intensities the photosynthesis of a leaf is proportional to this intensity and independent of the carbondioxide concentration, but at high light intensities the reverse may be true.

Plants use their photosynthesis products to grow and as long as new leaves are formed and contribute to the interception of more light this occurs in an exponential fashion. But crops are often planted so densely that after some time a closed canopy is attained, in which new leaves do not contribute to the interception of more light, but increase the mutual shading and from then on a crop is bound to grow at a more or less linear rate.

Such canopies display their leaves in every direction. The way in which the light is distributed over the individual leaves was first seriously considered by BOYSEN JENSEN (6) who summarized his views in 1930 in the monumental monograph 'Die Stoffproduktion der Pflanzen'. Firstly he determined the relation between the photosynthesis of a single leaf of mustard and the light intensity and found the familiar saturation curve. Then he measured in comparison the photosynthesis of a canopy consisting of 3.5 cm^2 leaves per cm^2 soil surface in their natural position. The respiration of this crop was about three times higher than that of horizontal leaves (figure 8). At low light intensities the slope of both curves was the same. But the photosynthesis of the single leaf was at its maximum at light intensities, in which the photosynthesis rate of the crop continued to increase, because of the slanted position of the leaves and mutual shading. Hence, the performance of the crop surpassed considerably that of the single leaves in the higher light ranges.

By keeping balance sheets, based on measurements in the laboratory and in the field, BOYSEN JENSEN came to the conclusion that the gross photosynthesis of a crop surface may amount to 300 kg carbohydrates per ha per day during the growing season in this part of the world. The potential growth rate of the



(Boysen Jensen, 1932, 1949)

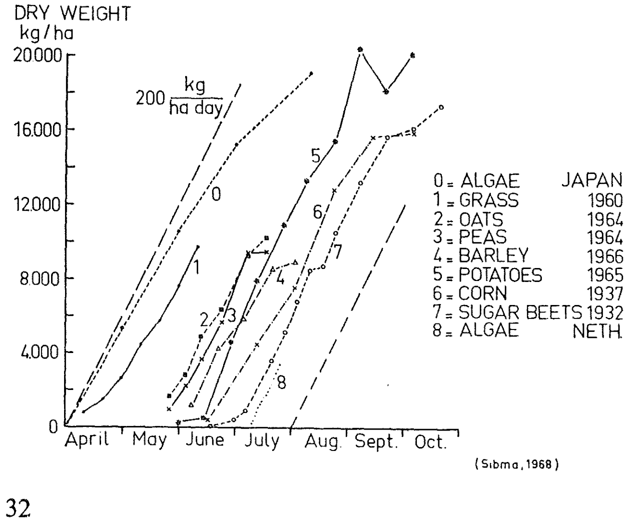
FIG. 8. The photosynthesis of horizontal displayed leaves and a crop of mustard (6).

crop was estimated at 200 kg per ha per day, taking respiration and the growth of roots into account.

Since then experimental techniques have been refined beyond recognition, and paper and pencil have been replaced by the computer. Present models enable a better evaluation of distribution of the light over the individual leaves of a canopy, depending on the height of the sun, the condition of the sky, the canopy architecture and the photosynthesis function of the individual leaves (41).

It has been found in this way that the influence of variations in the canopy structure often is disappointingly small. The estimate that the gross photosynthesis of a closed crop surface is about 50.000 kg per ha for the growing season in the Netherlands is therefore reasonable for many crops. The potential production of overground parts will then be about 25.000 kg per ha per year, which amounts to an average growth rate of close to 200 kg per hectare per day during 150 days. Hence, BOYSEN JENSEN's estimates still stand unchallenged.

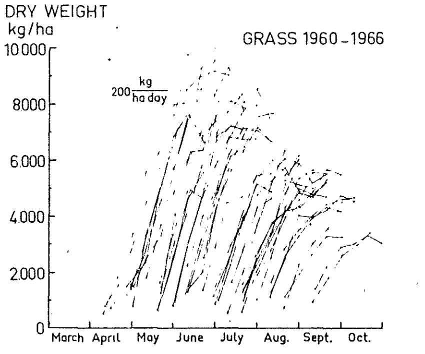
This conclusion is corroborated by a comparison of the growth rate of various crops under near optimum conditions in the Netherlands (figure 9). Oats, barley, Indian corn, peas, potatoes, sugar beets, grass and algae grow all



(Sibma, 1968)

FIG. 9. Growth rates of various crops in the Netherlands and of algae in the Netherlands and Japan (36).

at a rate of about 200 kg per hectare per day and differences in dry matter yield are mainly due to differences in the length of the growing period. The influence of the weather is also surprisingly small as is clearly shown by an impressive series of growth curves (figure 10) of grass swards throughout the seasons of 1960–1966. All the growth rates are again close to 200 kg per ha per day, except at the beginning when there is no closed crop cover and at the end when the leaves seem to deteriorate.



(Alberda, 1968)

FIG. 10. Growth rates of grass swards in the Netherlands (1).

Pastures

Taking this into account ALBERDA (1) came to the conclusion that a total production of grass of 20.000 kg dry matter/ha is possible in the Netherlands, an amount which has actually been achieved. This is in good agreement with the estimate of DICKINSON (12) about 120 years ago, in case of the proper species being frequently cut and liberally supplied with a mixture of water and horse urine by means of a London water cart. Indeed considerable amounts of fertilizer are necessary: about 800 kg of nitrogen and 8000 kg of potassium are taken up on the process of producing this 20.000 kg of grass with 25 percent protein.

This potassium may give problems. The element is absorbed by clay and humus so that hardly any may be lost by leaching on many soils. If the farmer is unfortunate enough to have a good storage system for liquid manure, practically all the potassium is returned to the field, and together with the potassium entering the farm with outside food and an occasional potassium fertilization, he may end up with too much potassium in the soil. This potassium may interfere with the uptake of magnesium by the plant and by the animal, so that the danger of grass tetany is a true one (22). Fortunately, nitrogen losses in the manure and soil are larger and this enables the farmer to control the nitrogen content of the grass to some extent, although his freedom in avoiding the growth of grass with an excessive nitrogen content is uncomfortably small, if he is aiming at high yields.

Grazing cows have the habit of walking and disposing of their waste on their own dining table. The surface which is maltreated in this way increases linearly

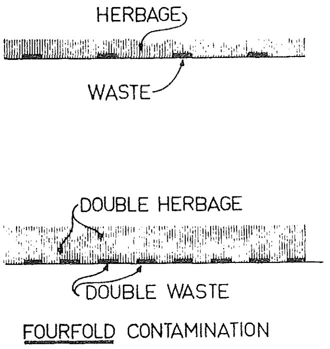


FIG. 11. Waste on the dining table.

with the yield, but the amount of plant material suffering increases in a quadratic fashion (figure 11). The digestive tract of every animal is infected with parasites, eggs are excreted with the faeces and consumed again with the grass. Their number is at a stationary and harmless level under systems of extensive grazing, but under intensive grazing such a high percentage of bites may contain larvae that an explosive development of parasites takes place at the expense of especially the young animal (37).

These difficulties already occur at the present yield level of 8000 kg/ha and in due course may force the farmer to switch over to stock feeding in summer.

In regions where crop and animal husbandry occur in close proximity the farmer may be able to use or sell his farm-yard manure, but in other regions he may soon come into the situation in which he has to pay for the privilege to get the waste hauled away and we are approaching the situation in which it would be wise for the farmers 'to have the foresight and sagacity to built their stables over a ravine (or the sea for that matter) by which they are drained so that each shower abates the nuisance'.

Technological production

Such problems may arise during the process of converting a possible 20.000 kg of dry matter in the form of grass into 2.500 kg dry matter in the form of animal products. Since NAPOLEON III offered in 1839 a price for 'the discovery of a substitute for butter, suitable for the marine', industry has worked on the problem and achieved the making of a vegetable 'butter analogue' which is much cheaper than animal butter and comparable in quality and taste. Likewise, fine leather and wool analogues are available and at present we seem to be at the stage where meat analogues may be marketed much cheaper than the classical product (40). Taste and texture of these analogues are good and the nutritional quality of the protein can be upgraded by adding industrially produced amino acids. Economic extraction of sufficiently pure proteins from grass seems difficult, so that the future of intensive grassland husbandry does not look too bright, unless this is remedied.

The proteins in algae are said to be more easily extractable and because the production is also high, there is a continuous interest in the growth of algae.

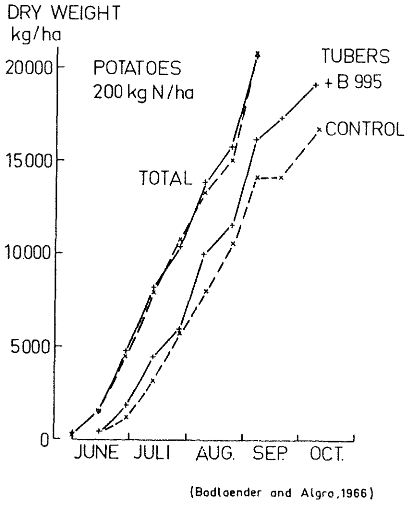
Small scale experiments showed that yields of about 30.000 kg/ha on a yearly basis and about 20.000 kg/ha on a seasonal basis are possible with this crop in the Netherlands (31). However, the necessary technical installations are probably more complex than conditioned greenhouses, so that the costs of production may be estimated at more than 100.000 guilders per hectare per year. With a protein content of 50 percent, this amounts to 10 guilders per kg protein, if one indeed succeeds in maintaining potential rates. This is prohibitively high compared to the cost of good quality protein in concentrates of oil seeds, remaining after extraction of the oil for butter analogues. It is also prohibitively high, because 20.000 kg dry matter per hectare per year may be produced in the form of vegetables at a cost in this order of magnitude.

Potatoes

High yields can also be obtained with potatoes. A long living variety has to be chosen, and the seeds should be sprouted in spring, so that at the beginning of June a closed canopy is achieved. Under favourable conditions the crop is then able to accumulate weight at a rate of 200 kg per ha per day during summer and to maintain growth until the first killing frosts.

The liberal supply of water and minerals, necessary to maintain the green canopy, results in considerable stem growth so that a too small portion is obtained in the form of tubers. At present attempts are made to control this excessive growth by means of chemical growth retardants, and it may appear feasible (figure 12) to transfer in this way over 80 percent of the dry matter to the storage organs so that the tuber yield may be increased up to 19.000 kg dry matter or 90 tons of potatoes per hectare. This amounts to 40 percent of the potential photosynthesis.

So many things may go wrong along the line, that even on selected experimental fields it is not possible to obtain such yields at every attempt. But on the



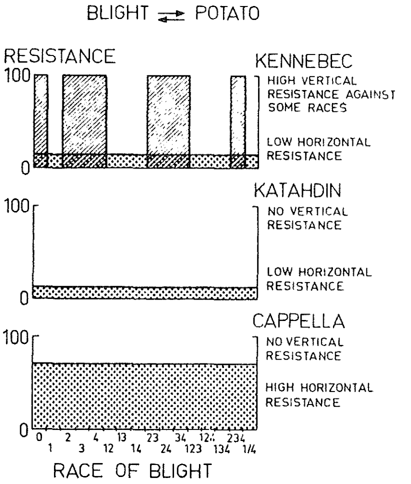
(Bodlaender and Algra, 1966)

FIG. 12. Growth rate of potatoes and the influence of a growth retardant (4).

other hand, this maximum yield is so much higher than the present 50 tons/hectare on good farms in the Netherlands that the trend of increasing yields can be maintained for many years. Although plant breeding will be essential in this, its present contribution should not be overrated. After all, the most prominent variety – Bintje – is already 60 years old.

Potatoes much more than any other crop are subjected to diseases, crop losses being estimated at around 25 percent in this part of the world. Virus infections are at present pretty much under control due to the pioneering work of Prof. QUANJER of this University 50 years ago. Nematodes were supposed to be kept under control by a three years' rotation, but it is now apparent that a more positive approach aiming at the introduction of nematode-tolerant varieties and the use of systemic nematicides is necessary to enable the cultivation of potatoes at the present scale in the Netherlands.

Bordeaux mixture has been used against potato-blight since 1882, but repeated spraying is cumbersome and not sufficiently effective in late summer and autumn, so that more or less blight resistant varieties have to be introduced to achieve higher yields. Vertical and horizontal resistance (33) can be distinguished (figure 13). Vertical resistance may be 100 percent effective, is specific for the various races of the fungus and mainly controlled by a few major genes. Horizontal resistance is never 100 percent, consists out of various elements reducing the multiplication rate of all races of the fungus and is controlled by many minor genes. Breeders mainly aim at varieties with 100 percent vertical resistance, but are in this process not able to screen their varieties on horizontal resistance, so that new races of the fungus that break vertical resistance may spread at a disastrous rate.



(Von der Plank, 1963)

FIG. 13. Horizontal and vertical resistance of potato varieties against various races of blight (33).

More detailed knowledge of epidemology may enable fungi to be tolerated and crop losses to be controlled by using varieties with a reasonable horizontal resistance in combination with hygienic agricultural practices and the use of chemicals. A remark not only meant for blight in potatoes but also for rust in small grains.

Small grains

Growth rates of close to 200 kg per hectare per day may be obtained also with small grains. In case of winter wheat, this is possible during the 90 days from the beginning of May to ripening around the first of August, so that a total dry matter yield of 18.000 kg per hectare is achievable.

The dry matter formed up to flowering at about the 20th of June is used for the vegetative structure and the dry matter produced after flowering may be recovered in the seed. Hence, under favourable conditions only 50 percent of the total dry matter produced or 9.000 kg per hectare can be obtained in the form of seeds. In regions where the radiation is higher and the period from flowering to ripening longer than in the Netherlands, as is the case in the North of Italy and the North -West of the United States 20 percent higher yields may be expected (7).

To achieve such yields, it is necessary to keep the crop surface green up to the end of July, which is only possible if sufficient water and nutrients are available and diseases are absent. However, a high nitrogen supply may lead to leafy plants, which are not only susceptible to lodging, but in which the vegetative growth encroaches upon seed formation. Although grain yields of 8.000 kg per hectare may still be obtained, the fraction of seed in the harvest will be too low then.

Already 125 years ago ROBERTS remarked (34) in his excellent price essay on the growth of wheat that early nitrogen applications yield too much straw and that many farmers apply the soot out of the London chimneys as a topdressing in May rather than in March. Present experience at a 4 times higher yield level confirms the wisdom of this. It is indeed worthwhile to supply the crop during its vegetative stage with just enough nitrogen for ear formation and subsequently to keep the crop surface green as long as possible by a topdressing with N shortly before ear emergence. In this way crops with a relatively high seed yield and low straw yield are obtained. However, the fertilizer level is at present so high and labour so scarce that it is often difficult to carry out such a fertilization scheme.

Under those conditions, however, a similar effect may be obtained by spraying chemicals, like CCC, that retard the vegetative growth and divert more dry matter to the seed (figure 14). This again is an example of the phenomenon surprizing perhaps for an older generation that fertilizers are so cheap, that there is much more need for growth retardants than growth stimulators in modern agriculture.

In his price essay ROBERTS also remarks that the most productive wheat varieties seem to tiller the least. He recommends a short variety with the characteristic name of Piper's Thickset for rich land, whereas the more leafy types are better used on land with a light crop. The amount of seed expressed as a percentage of the total production varied in his experiments from 35 to 46

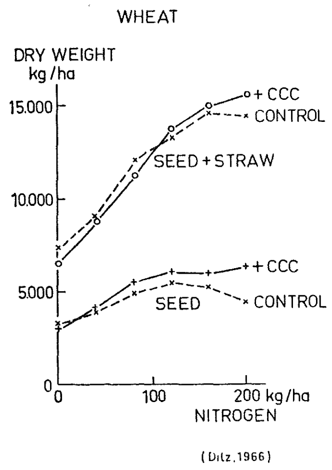


FIG. 14. The seed yield of small grains in dependence of nitrogen fertilization and the influence of a growth retardant (12).

percent. The tendency to select short stiff varieties with a high seed fraction holds up to the present time: plotted against the year of their introduction (figure 15), the relative seed yield of the varieties used at present in the Netherlands increases, whereas the relative straw yields decreases, as is illustrated here for oats.

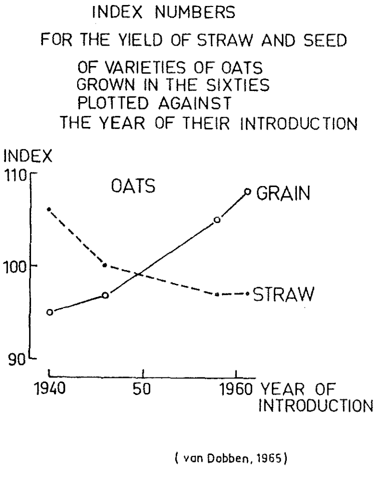


FIG. 15. The success of breeding for more seed and less straw (40).

As for wheat, Juliana an old Dutch variety is outperformed in this respect by Heines VII and Felix, more modern varieties with short and stiff straw and not too leafy. In spite of this the present percentage of seeds is not higher than 100 years ago. Obviously the continuous improvement of varieties in this respect has been counterbalanced by the opposite effect of the improved nutrient supply.

This illustrates that it is rather futile to calculate how much of the yield increase over the last 100 years is due to breeding, increased fertilizer use or other factors. It is therefore fitting that most investigators attempting this, divided the almost 2 percent per year about equally among the claimants (19).

Rice

History repeats itself for rice, but now more consciously. A great deal of paddy is grown on wet but poor soils in the tropics. These are puddled as long and as deep as possible to make the most of the nutrients and to control weeds. Plants from the nursery are then planted in the mud at a rather wide distance compared to other grains. All this trouble gives around 1000–1500 kg of paddy per hectare and much more straw than the farmer needs.

The suitable varieties have a very high tillering and rooting capacity, but they are also tall and leafy and very susceptible to lodging. Hence they cannot stand high nitrogen fertilization and have a hulled seed fraction of only about 30 percent. However, there also are semi-dwarfs with short and stiff straw that can stand high fertility levels and which have close to 50 percent of their dry matter in hulled seeds, so that the edible portion is about the same as that of wheat.

The International Rice Research Institute in the Phillipines obtained (21) grain yields of 9500 kg paddy/ha with their recent semi-dwarfs. These are day-neutral varieties taking independent of their time of sowing only about 100 days in the field, so that at least on paper three crops may be grown in one year in suitable tropical regions. In due course annual yields of 24.000 kg hulled rice can be expected there.

Heterosis

However small the plants, the main stem and tillers of the small grains always terminate in an inflorescence that carries the seed, so that these plants can stand the miniaturization, occurring in dense plantings, without reduction of the fraction of seeds (figure 16). On the contrary, the main stem and tillers of Indian corn or maize terminate in a male inflorescence, whereas the branches that arise from the nodes above the soil surface may terminate in a female inflorescence, normally already initiated when the stem is still growing. But this does not occur in dense plantings, because a too large part of the photosynthetic products is then monopolized by the stem itself. The amount of dry matter

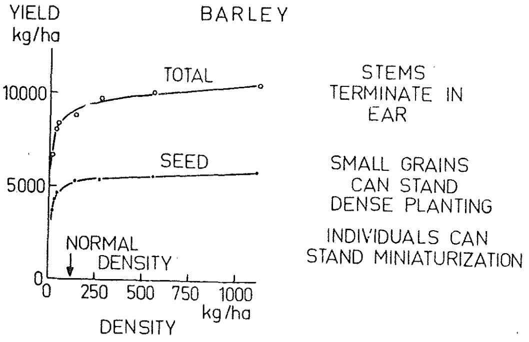
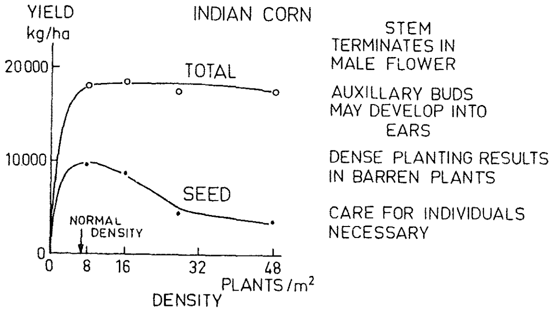


FIG. 16. A spacing experiment with barley up to extreme high densities.



(Crosmann, 1967)

FIG. 17. A spacing experiment with Indian corn up to extreme high densities (10).

which is ultimately recovered in the seed may become disastrously low under those conditions (figure 17). To obtain a good yield, it is always necessary to keep a green crop surface after flowering as long as possible, but in case of corn it is also necessary to achieve this with a small number of stems of uniform size.

Since 1930, this has been considerably facilitated by using heterosis or hybrid vigour, originally defined by SHULL (35) as 'the greater capacity for growth frequently displayed by crossbred species as compared to those resulting from inbreeding'. This phenomenon could be used so successfully in corn, because this is a cross-pollinating species of which the male inflorescences can be easily removed. Likewise hybrid vigour is valuable in Brussels sprouts of which the marketable part is also formed by the auxiliary buds. In general it may be said that the heterosis effect is particularly useful in those cases in which the growth rate in earlier stages or the size of the individual plants is of importance.

Rice, wheat, barley and oats are self-pollinating and therefore necessarily inbreds. However, the knowledge of the genetics of fertility and flowering has advanced to such an extent that it is at present possible to produce hybrids of these species under field conditons, although this is much more costly than with crossbreeding species. And indeed these species show considerable hybrid vigour, but this phenomenon is not so profitable here contrary to Indian corn and Brussels sprouts, because small grains can stand miniaturization. At the International Rice Research Institute in the Phillipines hybrids of rice have been obtained which yield 50 percent more than the highest parent when planted wide apart, as is customary if only few seeds are available. However, the hybrid vigour manifested itself by a high tillering capacity and leafiness and these are properties which proved to be not very useful. Forwarned, a field experiment was executed at normal densities and indeed it was found that at the earlier stages the hybrid did much better than both parents, but this advantage disappeared in the crop situation and in the end the hybrid yielded distinctly lower than the parents (figure 18).

Of course, this does not mean that hybrid varieties of these self-pollinating crops are not worth looking at. After all, many desirable plant characteristics are governed by dominant genes and it may be more economical to realize a promising combination in a hybrid variety than in a pure line. Moreover,

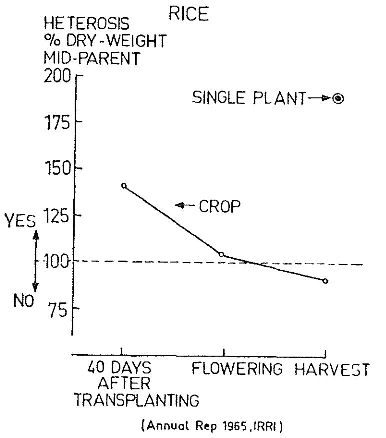


FIG. 18. The relative unimportance of heterosis for plant species that can stand miniaturization, illustrated with an experiment with rice (21).

variations in photosynthesis (figure 19) are genetica controlled, and it is not unlikely that heterosis with respect to this may exist. This should be particularly valuable in the crop situation.

Whole-plant physiology

This would mean breeding for yield ability, a field in which up to now most advances have been made by simple selection. Especially with grains, breeding has been restricted to yield stability by continued development of varieties more or less resistant to rust and other diseases, to adverse weather conditions and to lodging on basis of a thorough genetic analyses of the available material. However, BROEKEMA (8) already remarked in his inaugural address at this University in 1923, that 'the direct application of genetics to increase the yield ability has to fail because of our lack of knowledge of the detailed morphological and anatomical structure and the physiological characteristics of the plant material' and that 'as long as this is the case Mendelism is doomed to be relatively barren'. He realized that the use of yield components as tillers per hectare, seeds per head and weight of seed is misleading, or that it is necessary to breed for income and not for purses.

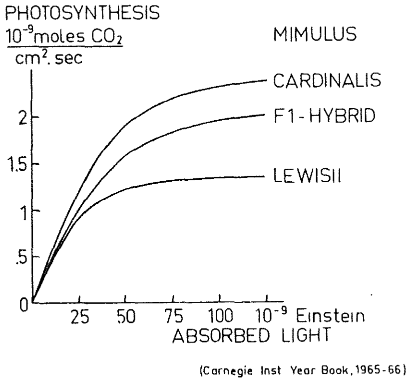


FIG. 19. Photosynthesis functions may be genetically controlled (9).

BOONSTRA (5), probably the first crop physiologist in the field of plant breeding, already 40 years ago drew attention to factors like photosynthesis, respiration, adsorption, translocation and transpiration. He embarked upon a careful analysis of the strong and weak points of the most productive varieties of peas, beets and potatoes in order to base a breeding program on this. The work had to be stopped because of the war. This is the more unfortunate, because the physiological know-how has rapidly increased since then, but the fertile link between physiologists and plant breeders is still too often lacking.

There is a difference in approach. Field trials are rightly the traditional tools of crop scientists and plant breeders, but these do not enable a sufficiently detailed analysis of the chain of events leading from primary causes to ultimate effect. The plant physiologist simplifies the experimental situation by control of the environment and simplifies the problems by studying the effect of environment and variety on the rate of individual processes rather than ultimate results. For instance, the effect of temperature is considered on growth and development rate rather than on yield, and the effect of varietal differences in canopy architecture is analysed on photosynthesis rate rather than on ultimate production. Of course, he does this in the firm belief that in due course it will be possible to come up with an integrated view to fill the gap that exists at present between the plant physiologist and the agronomist and plant breeder, but the ways and means to achieve this have not been sufficiently explored at present.

System synthesis

It may be possible to formulate the problems in terms of an open, recursive system, so cleverly used by VON WULFFEN 150 years ago, at a time when limited knowledge and limited computing capability only allowed for the distinction of a few levels and rates of transfer and made it necessary to advance in time with huge steps of a year.

Since then, the basic knowledge has advanced considerably and the computing capability is now so large, that it is worthwhile to consider open, recursive models of plant and crop growth in such detail that time steps in the order of one hour are necessary. This means that every hour the rates of photosynthesis, respiration and translocation, the rates of leaf, stem and root growth and the rate of development are calculated from the state of the crop and the environmental conditions. These rates are used again in calculating the new state of the crop in the next hour. In this way it is possible to integrate the present state of crop physiological knowledge and to extrapolate the results of the experiments in the laboratory under controlled conditions to field conditions. A comparison of simulated growth with actual growth in experiments reveals gaps in our knowledge. But experimenting with the model shows where to the best of our knowledge research and breeding efforts should be directed.

The crop scientist may thus use simulation to synthesize facts learned from observation of system elements into a complex model, which performance is a prediction of the behaviour of the whole system. The approach may prove to be especially useful in fields such as micro-meteorology soil fertility, epidemiology and crop husbandry in which a larger amount of spade work has been done.

The model builder is not restricted to problems for which an analytical solution can be found and is therefore able to shift emphasis from solution techniques to results and conclusions. Simulation models are therefore open-ended, so that it is a relatively easy matter to combine models developed in different fields and to study in this way the behaviour of more complex systems, with less restrictions dictated by solution techniques (18).

The modern, fast speed, high memory computers should be of little use for these purposes without the proper simulation languages to facilitate programming. Many of these languages and associated new ideas are being developed by research workers in economy, sociology and management. These sciences may become an unexpected source of inspiration for natural scientists which are now somewhat one-sided orientated towards physics and chemistry.

At last we are again at the threshold of a decade in which the efforts of the natural scientist, the crop specialist and the agricultural economist and sociologist may be truly integrated, but now at a far more sophisticated level than VON WULFFEN ever dreamed of.

Food for the billions

It is worthwhile to consider the world food supply under the condition that maximum yields are achieved on a part of the arable land.

Potential photosynthesis in the Netherlands during one growing season is 50.000 kg per ha and potential yields of food averaged over various crops, are found to be not below 10.000 kg per ha or 20 percent of the potential photosynthesis (figure 20). Assuming that this fraction holds also for other parts of the world, the potential food production is guesstimated to vary from 2400 kg per ha up North to 25.000 kg per hectare in the tropics. On an average this amounts to 15.700 kg per ha which means that 50 people could cover at least their caloric needs from 1 hectare, taking into account 20 percent losses.

	NETHERLANDS	WORLD AVERAGE	
POTENTIAL PHOTOSYNTHESIS	50 000	78.000	kg/ha
FOOD	10 000	15 700	kg/ha
ENERGY	40	62.5	10^6 kcal / ha
PEOPLE	33	50	Number/ha

ARABLE LAND: PRESENT 11 % OF TOTAL LAND
RECLAIMABLE 7 % " " "
TOTAL 18 % " " "
25% OF ARABLE LAND OR .6 10^9 ha IN POTENTIAL
PRODUCTION IS SUFFICIENT FOR 30 10^9 PEOPLE
OR FOR 10 x PRESENT POPULATION

FIG. 20. Potential production.

The world is very large, but only a small portion is suitable for intensive production. The sea can be ruled out in this respect because of the long food chain between photosynthesis products and harvestable fish and because it is impossible to bring the nutrients in this large body of water up to a reasonable level. The polar ice caps, tundra's, mountain regions and desert, most of the sub-arctic green forests and savanna's, and large parts of the tropical rain forests and even of the soils in the temperate climates are unsuitable to reclaim. Only 11 percent of the land surface is at present cultivated and given the present technical means this can be increased with another 7 percent (32). The total land surface suitable for agriculture is therefore only 2.4×10^9 hectare. However, if we could succeed in bringing one fourth of this into potential production, this 4.5 percent or $.6 \times 10^9$ hectare should provide enough food for 30×10^9 people or 10 times the present world population and they should have still 75 percent of the arable land and the whole of the sea available to supplement their calories with proteins and to provide industrial raw materials.

Hence, to feed the billions, these high production rates are not necessary for years to come. However, high production levels and a concurrent decrease in the land surface used for agriculture may be necessary in due course for economic reasons and to ensure the supply of cheap phosphate fertilizers. But perhaps the most important aspect is that in this way the use of biocides and other potentially dangerous chemicals can be restricted to a few percent of the global surface.

A poor man's world

Compared to the potential production the present situation is indeed deplorable. In large parts of the world, the soil releases only 20–30 kg of plant nutrients per hectare per year. Like in Europe 100 years ago, this enables only yields of 1000–1500 kg of food per hectare, as may be illustrated by the irrigated rice yields that are at present obtained in India (figure 21). Like in Europe, artificial fertilizers have to provide the leverage for increasing yields. However, at present only 5 kg of nutrients per hectare per year are available (15) in the form of artificial fertilizers, compared to 200 kg in the Netherlands and it cannot be stressed enough that all attempts to increase agricultural production are futile unless fertilizer factories are built there where the suitable land is and the mouths are, and the infra-structure is created which enables the farmer to market his surplus. An integrated effort to increase agricultural production can only succeed within such a frame work.

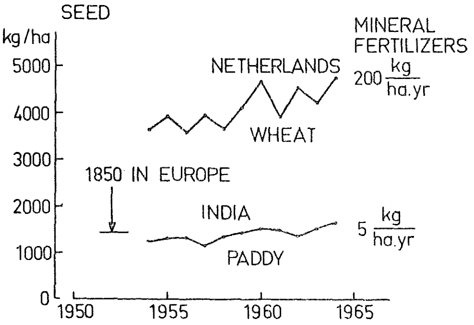


FIG. 21. The yield of low land rice (paddy) in India and wheat in the Netherlands. The yield of upland rice is so low that the average rice yields in India are somewhat less than 1000 kg per ha. (Sources: official statistical year book).

Without underestimating the value of irrigation in regions with irregular rainfall, it can be said that the supply of water is a secondary problem. After all, it is much cheaper and more sensible to provide the millions of hectares where water is now available with sufficient fertilizers than to build irrigation systems and fertilizer factories in the dry zones of the earth. Even India could become a food exporting country without extension of irrigation, if gradually sufficient fertilizers should be made available (17).

Literature

1. Alberda, Th. and L. Sibma: Dry matter production and light interception of crop surfaces III. Actual herbage production in different years as compared with potential values. *J. Brit. Grassl. Soc.*, 23 (1968), 206–215.
2. Bidwell, P. W. and J. I. Falconer: *History of agriculture in the Northern United States (1620–1680)*. New York, 1941.
3. Bitterman, E.: Die landwirtschaftliche Produktion in Deutschland, 1850–1950. *Kühn-Archiv* 70 (1956), Halle.
4. Bodlaender, K. B. A. and S. Algra: Influence of the growth retardant B 995 on growth and yield of potatoes. *Europ. Potato J.*, Vol. 9 (1966) 242–258.
5. Boonstra, A. E. H. R.: *Physiologisch onderzoek ten dienste van de plantenveredeling.* Thesis, Univ. of Utrecht, 1934.
6. Boysen Jensen, P.: *Die Stoffproduktion der Pflanzen*. Jena, 1932.
7. Briggle, L. W.: Breeding short stative, disease resistant wheats in the United States. *Eucarpia-Symposium*, Wageningen, 1967.
8. Broekema, C.: *Plantenveredeling en Wetenschap.* Inaugural Address Agr. Univ., Wageningen, 1923.
9. Carnegie Institute: *Annual Report of the Director of the Department of Plant Biology*, 1965–1966.
10. Crössmann, G.: Standraum und Stoffproduktion bei Mais. *Zeitschrift für Acker- und Pflanzenbau* 125 (1967) 3 : 232–253.
11. De Datta, S. K., J. C. Moomaw and R. S. Dayrit: Nitrogen response and yield potential of some rice varietal types in the tropics. *Int. Rice Com. Newsletter* XV (1966), 18.
12. Dickinson, W.: On a variety of Italian Rye-grass. *J. Royal Agr. Soc. of England*, Vol. 8 (1847).
13. Dilz, K.: Stikstofbemesting van granen. *Stikstof* 5 (1966), 174–187.
14. Dobben, W. H. van: Systems of management of cereals for improved yield and quality. *The growth of cereals and grasses*. Easter School Nottingham (1965), 320.
15. Fertilizer Association of India: *Production and consumption of fertilizers. Annual review* 1965–1966, New Dehli, 1966.
16. Fisher, R. A.: *Statistical methods for research workers*. 3nd ed. (1930), London.
17. Flach, M.: *Landb. verslag van onderzoek naar de mogelijkheden ter verbetering van de voedselproduktie in de Indiase deelstaat Maharashtra*. Gestencild verslag, Afd. Tropische Landbouwplantenteelt, L.H., Wageningen, (1967).
18. Forrester, J. W.: *Industrial dynamics*. Cambridge (Mass.) 1962.
19. Heady, E. O. and L. Auer: Imputation of production to technologies. *J. of Farm Economics*, 48 (1966) 309.
20. Hudig, J.: *Liebig's oorspronkelijke inzichten bevestigd.* Voorlichtingsdienst Superfosfaat Wageningen, 1967.
21. International Rice Institute: *Annual report* 1965. Los Banos, Laguna, Philippines.
22. Kemp, A.: Over het ontstaan en de preventie van hypomagnesemie bij rundvee. *Tijdschr. Diergeneesk*. deel 87, afl. 8, 1962.
23. Keynes, J. M.: *The general theory of employment, interest and money*. New York, 1936.
24. Kortleven, J.: Kwantitatieve aspecten van humusopbouw en humusafbraak. *Versl. Landb. Onderz.* (Wageningen) 69.1, 1963.
25. Kostic, M., W. Dijkshoorn and C. T. de Wit: Evaluation of the nutritional status of wheat. *Neth. Journ. Agr. Sci.* 15, 1967, 267.
26. Lawes, J. B.: On Agricultural Chemistry. *Journ. of the Royal Agr. Soc. of England*, Vol. 8, 1847, 226.

27. Liebig, Justus von: *Die Grundsätze der Agricultur-Chemie mit Rücksicht auf die in England angestellten Untersuchungen.* 2nd ed., Braunschweig 1855.
28. Loomis, W. E.: Die photosynthese der Grünen Pflanzen. Historical Introduction. W. Ruhland (ed.) *Handbuch der Pflanzenphysiologie* V, 1, 85–112. Berlin, 1960.
29. Mayer, R.: *Die organische Bewegung in Ihren Zusammenhang mit dem Stoffwechsel.* Heilbronn, 1945.
30. Mitscherlich, E. A.: *Die Bestimmung des Düngerbedürfnisses des Bodens.* 3rd ed., 1930.
31. Oorschot, J. L. P. van: *Conversion of light energy in algae culture.* Thesis Agr. Un. Wageningen 1955.
32. Pehrson, G. O.: Limited land in the world food supply in: T. Greer (ed.). *Genis to Genus. IMC-Symposium,* Sokie, 1965.
33. Plank, J. E. van der: *Plant diseases: Epidemics and Control.* New York, 1963.
34. Roberts, E.: On the management of wheat (Prize essay). *Journ. Royal Agr. Soc. of England,* Vol. 8, (1847). p. 60–77.
35. Shull, G. H.: What is heterosis. *Genetics* 33 (1948) 439.
36. Sibma, L.: Growth of closed green crop surfaces in the Netherlands. *Neth. J. Agric. Sc.* 16 (1968), 211–216.
37. Sonneveld, A.: *Research Project No. 395* (1967). I.B.S.-Wageningen.
38. Slicher van Bath, B. H.: *De agrarische geschiedenis van West-Europa (500–1850).* Utrecht 1960.
39. Thünen, J. H. von: *Der isolierte Staat in Beziehung auf Landwirtschaft und Nationalökonomie.* Darmstadt, 1966 (reprint 3nd ed., Berlin, 1875).
40. Trouw en Co.: Enige actuele aspecten van eiwit-voorziening van mens en dier. *Mededelingen,* Amsterdam, Jan. 1966.
41. Wit, C. T. de: Photosynthesis of leaf canopies. Agr. Res. Rep. (Wageningen) 663, 1965.
42. Wulffen, C. von: Ideeen zur Grundlage einer Statik des Landbaues. *Mögl. Annalen,* 1823, Bnd XI, 391.
43. Wulffen, C. von: *Die Vorschule der Statik des Landbaues.* Magdenburg. 1830.
44. Wulffen, C. von: *Entwurf einer Methodik zur Berechnung der Feldsysteme.* Berlin, 1847.

Discussion

Prof. Doorenbos: There is rather a big difference between horticulture and agriculture. The accent in horticulture is more on quality and the accent in agriculture is more on quantity. This has practical consequences.

In 1930, the difference could be defined as follows: in agriculture and horticulture people were striving towards the optimum yield, optimum in relation to the labour and the costs, but in agriculture, the economic optimum was often and usually very far from the optimal production of the plant. While in horticulture, when you aim at optimal production from the economic point of view, you always have to grow the plants in such a way that you are very close to maximum production. This morning, Dr. De Wit has talked on the potential production of the plant and here agriculture and horticulture come very close together again. I think that we are ahead in horticulture, and therefore I come to my question. In horticulture, we have come to the point that during the 150 days we obtain almost a maximum yield, as all environmental conditions are kept optimal.

Our problem now is to attain this yield during the remaining part of the year, especially in floriculture and vegetable growth. I think that Dr. De Wit is pessimistic because you have put the potential photosynthesis at about the same value for all different crops. At present, we do not grow tomatoes during the winter but after breeding, we could do so; e.g. ten years ago, lettuce was not grown during the winter time, but at present it is. To summarize, what do we do during the remaining part of the year?

Dr. De Wit: Light during the winter time is a limiting factor and I do not think that the use of artificial light will be economical. Of course, lettuce is a good example, but it is not an example of calorie production, but of packing water in a highly palatable form. As far as the breeding problem is concerned, the main co-operative project between plant breeders, geneticists and physiologists, is to study how the photosynthesis function is genetically controlled. Of the gross photosynthesis, 40 to 50% is lost to respiration and it may be possible to breed varieties with smaller loss. This means a genetical study, but at present this is not done by the plant breeders, geneticists and physiologists.

Prof. Morris: Are there not further considerable improvements obtainable from breeding crops that can be better utilized especially by ruminants (grasses with better digestability) and perhaps also maize being better balanced for human nutrition (high lysine)?

Dr. De Wit: Many agricultural practices tend to crops which are better utilized by animals and there are, as far as the forage crops are concerned, such large differences between the different plant species, that I am not so sure that within species, selection will really contribute in this respect. The second part is the protein quality. We may improve the quality by breeding and by adding amino acids. The second may be cheaper because with breeding, this may happen at the cost of the calorie production. Calorie production, being the main constituents of fodder, comes first and protein comes second because the need may be reduced by adding proper amino acids.

Mr. Koopman: With reference to your discussion on the various proteins available in traditionally cultivated and future crops like algae, what is your opinion about the difference in *biological value* which, in general terms of 'completeness' is supposed to be considerably higher for animal than vegetable protein?

Dr. De Wit: This is a similar question. With a good balance, the protein needs can be reduced to 37 g per person per day. This can be done with the assistance of the industry and not so easily with agriculture.

Dr. Bruinsma: Would the phosphate supplies allow for the large fertilization increases necessary for the enhancement of crop production?

Dr. De Wit: To make use of phosphate rock of low concentration will be expensive. When we have a higher production on a smaller area, we need less phosphate for most of the phosphate is fixed or lost. It will not be a serious problem: the farmer has to buy more expensive phosphate and the consumer may have to pay more. It is advisable to read Prof. van Schuffelen's lecture: *Kunstmest voor Voedsel* (1965).

Dr. Wokes: What proportion of the total land available for food production should be used to obtain food for direct human consumption to ensure optimal yields and the most efficient attack on the world food problem.

Dr. De Wit: I do not think that an attack on the world food problem at present should start with selecting really the good soils which are the soils from which we may get the optimum production. I calculated how large the yield can be, but not to advocate directly to go to a smaller area and optimum yields. The solution of the world food problem has to come from all the areas which are suitable for a consistent increase in yield. When in due course there is too much soil, marginal soils will be abandoned for economic reasons, e.g. in the USA this is happening. Let me emphasize that, so long as the food problem is not a technical problem in the first place, but a social-economic problem.

Dr. SCHUURMAN: In all cases under natural conditions, root development will restrict the result of higher fertilization. Do you agree?

Dr. DE WIT: No. BROUWER has shown the existence of shoot/root equilibrium. How much root does a plant really need? After removing part of the roots, the plant stops producing shoot and increases its root production. On soil with a low fertility level, the plant, therefore, gets more root and less shoot. By applying artificial manure, the root/shoot ratio is reduced by a higher shoot production. This is an example where the growth rate of the root and the shoot is functionally controlled. When the fertility level of the soil is sufficiently high, the water balance becomes the controlling factor.

Prof. DE WILDE: I missed in your talk the regulatory mechanisms within a vegetation, with regard to growth, and the effects of growth form on the level of yield.

Dr. DE WIT: I will refer partly to the previous questions. The highest economic yield is not obtained at optimum plant growth and therefore the farmer has even to go to the use of less manure, creating sub-optimum growing conditions. At present, there is a big gap between the plant breeders and agronomists and plant physiologists. The last two should suggest morphological goals for the plant breeders, but at present, they cannot. In a physiological field, there is too much lack of knowledge about the possibilities of plant breeding in this respect. It is possible to solve distribution problems with chemicals and to create in this way, desired morphological changes.

Mr. SCHEYGROND: Your example of Bintje is a great exception. Most top-varieties have a short life, often not longer than five years. Bintje is still a top variety for its consumption quality, not for its yield.

Dr. DE WIT: Bintje is a very good example because it is such an old variety. Five years is the maximum for many varieties because we are not breeding for yield ability, but for vertical resistance. It may be quite possible to breed varieties which exist for more than five years if we can apply another method of resistance breeding. The work on the disease epidemology by ZADOKS (Department of Plant Pathology, Wageningen) is important in this respect. The breeders do not like this short life-time of varieties and hope that something can be done about it.

Dr. SINGH: On the premise that vegetative processes in plants are most productive, would it be safe to assume, that potatoes etc., would be more productive than cereals? Provided, of course, that optimum soil and nutrient conditions are made available in comparable climatic conditions.

Dr. DE WIT: Root and tuber crops are the best crops. They yield two times more than grain crops. The protein content of the potato and sweet potato is sufficiently high when raised by an application of nitrogen fertilizers. The protein content may then reach a level of 10% of the dry matter and that is a reasonable protein content compared with small grains. Therefore, in the tropics such crops can be of importance in solving calorie problems.

Prof. FERWERDA: I agree with this but in the humid tropics, it is not yet possible to cultivate root and tuber crops permanently as it is done for grain crops, e.g. rice.

Prof. WASSINK: In agriculture, the energy conversion is the primary problem, whereas the primary problem in horticulture is to manage formative effects. I am quite optimistic that in future (maybe over a hundred years), artificial light can be applied and that we can grow agricultural crops on 2 to 3% of the area potentially available. I think that it is possible that potentially available sources of energy could be stored and re-distributed in a possible economical way in the far future; for instance, storing of excess solar energy, natural gas and nuclear energy. Sunlight is the best, although nuclear energy can replace it to some extent. Therefore, in future, we can also have agriculture in a bad time of the year just like horticulture, and then agriculture and horticulture, with help of technology, can be united.

Dr. DE WIT: I do not like to reveal lack of fantasy by looking into the future. In case of nutrient supply, the industry provides necessary constituents to agriculture. But, if we have cheap energy, industry and agriculture may compete with each other because this cheap energy cannot only be used for light in agriculture, but also in the industry to produce cheap industrial food products, and for cheap transport over larger distances. Why should we burn crude oil to provide light for growing oil crops? Why not use crude oil to make vegetable products directly. It will be very difficult to store solar energy. At present, the biological conversion of solar energy is 8% and in industry, we cannot yet reach this high percentage from a diffuse energy source with cheap methods, but perhaps in future it may become possible if it appears worthwhile.

Prof. MORRIS: I was interested in Dr. DE WIT's discouragement in the possibilities of the animal scientists and the agronomists and the crop breeders getting together to breed crops that can be better utilized. Maybe you do not need better grasses in Holland, but in Indiana, we do. We shall use better grasses to produce more beef. We hope that by breeding, we shall get better grasses. In maize, we have a gene, Opaque-2, conditioning a 12% protein level. This maize is fed to pigs. It is also grown in Brazil for human consumption and this is much better than telling the people to use soya bean meal or to use meat. In the mid-west of the USA, the farmer believes that he can produce maize with a high lysine level, cheaper than factories can make artificial amino acids. These synthetic proteins can be fed to monogastric animals, and that includes man.

Dr. DE WIT: If we grow grasses under optimal nutrient conditions, all common grasses have a high protein content. There are no big differences. However, under low nitrogen conditions (Indiana?), the differences will show up. The danger is that an improved plant which gives a high protein content, does so because it yields less; it takes up the same amount of nitrogen and has then a higher protein content. The same is true for some plants which are drought resistant. Such plants do not yield very much under any condition. Under dry conditions, the water is more evenly distributed over the whole growing period of such plants. We should be very careful with the correlations; low yield-drought resistance, low yield-high protein content and so on. The opaque-2 gene in maize really improves the quality of the protein so helping to reduce the amount of needed protein from 70 to 37 grams.

Prof. DE VRIES; May I contribute to the problem of feeding animals as an inbetween of feeding people. For instance, in farm management with some crops, e.g. alfalfa yields 10 cuts per year, in a desert area. You will get a high protein content in the plants and this is a very good animal forage. In Australia, by using subterranean clover and a supply of some trace elements, a change was obtained from one sheep per four acres to four sheep per one acre, resulting in an increase of 16 times, due to the introduction of this leguminous plant. *Stylosanthes*, 'the Townsville lucerne', discovered in Queensland, has changed the economic potential of Northern Australia. When we have enough space, grasses and these leguminous plants may yield sufficient and inexpensive food production. Formerly, we were told that mixed farming was necessary, but at present, I think it is possible to separate agriculture from animal husbandry, just as we did with the poultry and the Finnish people are doing with cattle. Is mixed farming still needed?

Dr. DE WIT: The difficulties with growing leguminous crops are caused through their lack of persistency. Pests and weeds increase in time and this holds also for alfalfa. It will be difficult to keep a good mixture of clover and grasses. Clover is often crowded out except when the mixture is grown at a low fertility level. In Australia, glycine, a leguminous species, may dominate, but the total yield is then lower than the yield of fertilized grass. What is better – to have clover in a mixture which fixes nitrogen, or to buy this fertilizer. In the Netherlands, the clover is not necessary for grassland. Here, we only cultivate a mixture of some grasses and may even end up in monoculture, as with cereal growing. At present, there is a tendency to move away from mixed farming. This is an economic problem. The farmer prefers probably mixed farming (at least I do) but specialization is needed. In the case of animal farms, we get a big problem in what to do with the manure, so specialization leads to a waste problem and this is expensive.

Prof. FERWERDA: When wages of people are the same and transport is cheap, we may reach a point at which the highest yield (per unit of surface area, per unit of time and per man) will determine the place where a certain crop must be grown.