Neth. J. agric. Sci. 18 (1970) 49—61

Plant Physiology, and some aspects of future agriculture[1]

E. C. Wassink

Laboratory for Plant Physiological Research, Agricultural University, Wageningen, the Netherlands

Received 12 July 1969

Introduction

In the frame of the celebration of the 50th anniversy of the Agricultural University at Wageningen in 1968, a symposium was held on 'Agricultural sciences and the world food supply'. This symposium offered a considerable number of points of interest to plant physiologists, especially to those who, like the author and his collaborators, have studied problems of large-scale solar energy conversion and biomass production and their morphogenetic implications (Butt, 1968; Gaastra, 1958, 1963; Kok, 1952; van Oorschot, 1955; Wassink, 1954, 1957, 1959a, b, 1960, 1963, 1964, 1965a, b, c; Wassink and Wassink-van Lummel, 1953; Wassink et al., 1953).
During the extensive discussions following the symposium lectures, several interesting remarks were offered; for the present I will single out only one: that agriculture (in the temperate zone) confines itself to the use of around 150 days per year, while horticulture long ago succeeded in increasing this number to over 300. The obvious comment to this remark was that the 150 days to which agriculture largely confines itself are those receiving most of the annual solar radiation and hence least limiting for growth by lack of energy and low temperature. For the plant physiologist and probably also for the economist, the primary purpose of agriculture is energy fixation (or biomass production) whereas that of horticulture is sophistication, viz playing on the formative possibilities of individual plants, separate strains, and species. This includes the well known facts that agriculture occupies much larger spaces than horticulture and that the price per unit dry weight obtained for the final product in general is much lower. Here, the popular comment may be remembered that the vegetable grower is very good at selling water (admittedly with a nice taste) at good prices!
The above comments may serve to introduce the subsequent considerations to which a plant physiologist is led with respect to some aspects of agricultural development in the future. Some contemporary developments turn out to be well in a line with these considerations. It seems to be the plant physiologist's privilege to disregard, in first instance, short-term social and economic implications, at least their elaborate discussion.
First returning to the '150 days' problem stated above, it may be said that the relative lack of solar energy, and low temperature in the winter season in the temperate zones of the earth offers a considerable hindrance to an efficient use of the winter season for biomass production. In order to overcome this it would require cheap energy sources to become available on a large scale so that large amounts of light and heat could be more or less economically supplied in addition to the amounts

[1] Communication 280, Laboratory for Plant Physiological Research, Agricultural University, Wageningen.

naturally provided. It should be stated that the term 'economically' does not refer to any contemporary or detailed economic system or situation: one day it may be so, or the type of agriculture may have been developed in such a way that it is more 'economical' to supply large-scale energy than to leave the system unused for part of the time — as it is already now, for instance, in large industrial factories with respect to day and night. This aspect, certainly, is also of considerable interest with respect to future agricultural development, but we will leave it alone for the present.
Possibilities for any further type of agricultural development will have to deal with the problems of primary processes of biomass production and the efficiency of solar energy conversion, and with the technical possibilities nowadays available. The latter already manifest themselves to some extent in present-day developments, and we will have to mention some of them.

Scale enlargement

The first remark to be made is that present-day intensive mechanization, in all aspects of society where it enters, leads to a considerable scale enlargement and, at the same time, often to a decrease in diversity and flexibility. Also in agriculture this scale enlargement has started already: farms are increasing in size and decreasing in number, and optimal agricultural yields with respect to field area and to unit human labour, originally far apart, are quickly approaching each other. In the future, almost certainly, much further scale enlargement and much more intensivation and scientific approach will be required and expected.
In many parts of the world, especially in the rather densely populated and more 'developed' ones, the existing rural scenery largely consists of a composite mosaic of human settlements, small agricultural areas, small pieces of mostly planted woods, and usually small and damaged pieces of landscapes with hints of almost 'natural' biotopes, housing 'wild' plants and animals. A century, or even 50 years ago, the balance between these units was still such that several types of wild plants and animals could survive in such 'natural' spots, and especially the smaller species, like insects, could feed also on agricultural crops (Stratton Porter, n.d.). The composite occupational pattern was a major attraction of the traditional landscape, and indeed probably was the one best adapted to the limited means of transport and soil fertilization then available. The small size of these possibilities, moreover, prevented human agricultural activities to spread out in an intensive way to any distance from settlement nuclei, thus leaving mostly rather vast seminatural or only superficially exploited areas in between. Additionally, it curtailed extensive increase in (human) population. For the Netherlands, maps of the second half of the 19th Century still reveal this very clearly, especially in regions of poor soil conditions or difficult water management. [1] More could be said about this, but seems unnecessary for the present purpose.
Even before the 2nd World War, in the Netherlands and probably elsewhere under similar conditions, this situation was in a rapid process of change, mainly for two reasons: the availability of artificial manure, and the development of motorized road traffic. It is beyond the scope of this article to deal in detail with these aspects, but it may be remarked that these new possibilities gave rise to a logical, but nevertheless rather distressing development from a more general viewpoint, viz the more or less

[1] See for instance, Topographical Map of the Netherlands, scale 1 : 50,000 (in sheets), editions of 1880–1900, a good illustration of the above text, e.g. in sheet No 17 (Beilen).

complete consumption or devastation of nearly all freely accessible rather 'natural' areas, not only the smaller ones but also the originally larger and more interesting areas between the primary settlements. Besides this, agriculture spread out over soils, probably not eminently suitable, entailing some difficult economic consequences.
The most distressing aspect of this development seems to be that it does not immediately contain a development in principle, nor in real scale enlargement, i.e. by orders of magnitude. Gradually spreading all over the world, it is apt to lead to complete destruction of natural and seminatural biotopes everywhere, just by logical consequence of the existing possibilities, but without offering a reasonable issue. One further distressing aspect seems to be that, before the final phase is reached, borderline effects of poisoning and contamination by excess nutrients and pesticide chemicals will tend to disturb and unrecognizably alter still existing remainders of biological equilibria.
As a consequence of the present-day mosaic pattern of various sorts of uses, this seems unavoidable and uncontrollable.

Biologically sensitive groups of organisms, and by no means the least attractive ones, gradually, and sometimes rather suddenly show a disturbing tendency to run down in number and quality in densely populated countries. In the last 30 years, various phanerogams, earlier fairly common, have become much rarer by reduction of suitable habitats in size and number; this is sad but not yet alarming. Much more distressing is the decline of entire interesting groups of organisms, in a rather non-specific way upon a decrease in the general quality of the environment. In the last decades, most lichens and first of all the more highly organized ('shrubby' and 'leafy') ones have fairly completely disappeared from wide, more or less densely populated areas. Much more recently, in this country, and elsewhere in western Europe, especially so in the last five years, butterflies and moths have disappeared at a disturbingly rapid rate, also previously very common ones, even so that newspapers have paid attention to it (Wassink, 1967). The exact reasons are not easy to trace, since bad summers can affect the picture. However the phenomenon seems so indiscriminate with respect to species that it is to be feared that not even the liberal application of agricultural pesticides is the main cause but rather a still far more general pollution of air, water and soil by exhausts of industry and traffic. For a long time, loss of natural beauty has not been taken very serious, but there are some recent signs that this is changing now, and the realization seems growing that the imponderable things nature used to offer freely, may be of equal importance for human well-being as technical achievements, so that it is of vital importance not to loose too many of them.

For all these reasons, we will try to approach the problem from the opposite side, starting from the point of overall estimation for necessary agricultural biomass and the areas required to grow it, at first leaving the present state out of consideration.

Total area requirement for agriculture (food production)

Provisionally, we will assume that in areas destinated for agricultural production, agricultural yields will not be essentially superior to the ones now attained by traditional (good) agricultural practice, i.e. the recovery of about 1% of the incident solar radiation, as far as suitable for photosynthesis, in the crop. Furthermore, we will assume an average daily requirement per human being of 2.10^3 kcal, and a world population of 5.10^9 human individuals (allowing a cocnsiderable increase beyond the present number).
According to the above assumptions, we may estimate an average annual crop of 10^4 kg CH_2O/ha, equalling 4 tons of C which represent 4.10^7 kcal (Rabinowitch, 1945).
The assumed human population will require per annum: $5 \times 10^9 \times 365 \times 2 \times 10^3$ kcal $= 3.65 \times 10^{15}$, or 4×10^{15} kcal. Considered as primary production, the area required therefore is $4.10^{15}/4.10^7 = 10^8$ ha $= 10^6$ km^2.

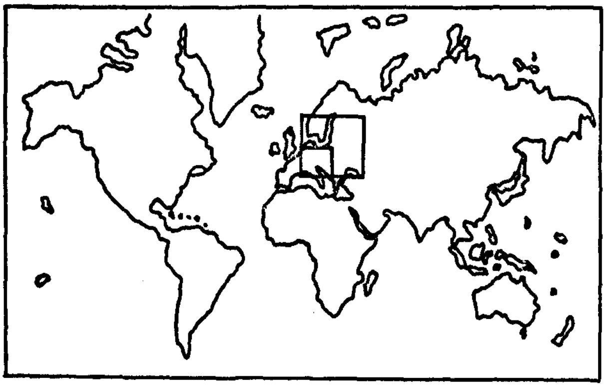

Fig. 1 An area of 2000 × 2000 km, and a 'net area' of 1000 × 1000 km, required for total human food and other agricultural needs, as explained in text, projected on a world map.

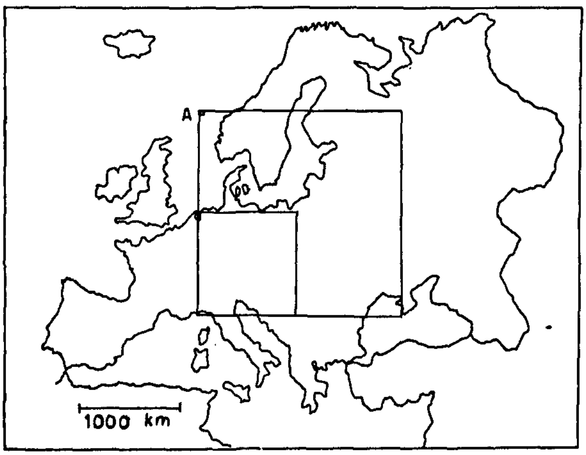

Fig. 2 An area of 2000 × 2000 km, and one of 1000 × 1000 km (see Fig. 1 and text), projected on a map of Europe (the map simplified from: J. Perthes, Taschenatlas, adapted by H. Habenicht; 29th ed., Gotha, J. Perthes, 1893). At A the size of a single 'unit' of 30 × 40 km as explained in text.

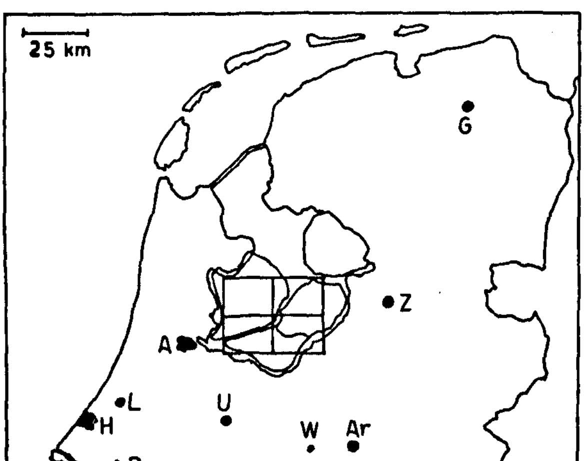

Fig. 3 A 30 × 40 km unit and a 'net unit' of 15 × 20 km (see text) projected on a map of the Netherlands, in the area showing the Lake Ysel polders, now in the process of reclamation. Some of the larger surrounding cities indicated by letters: A = Amsterdam; Ar = Arnhem; G = Groningen; H = The Hague; L = Leiden; R = Rotterdam; U = Utrecht; W = Wageningen; Z = Zwolle. It is seen that the 3 Southern polders together have about the size of the 30 × 40 km unit, and thus could form a nearly ideally suitable experimental attempt towards the ideas developed in this paper. The south eastern polder is being reclaimed already, the south western one is in the process, the western one now is still open. A rather large city (Lelystad) is under construction at about the meeting point of the three polders, and could serve as city and industrial centre as outlined in the paper. (Cf. also van Kampen (1969) for some ideas about management.)

This, certainly, is a large area, and, of course, it would for various reasons be impractical to think of this area as a single closed unit somewhere, for instance in view of the different climatic requirements of the various crops. On the other hand, it does seem inadvisable for further thinking to split up the total area too far. We, therefore, will provisionally assume 3000 units [1] of 300 km^2 each, i.e. each 15 $\times$ 20 km. Each of such units thus covers 30,000 ha, and will yield 3.10^8 kg CH_2O, or 3.10^5 tons, equalling 1.2×10^5 tons of C. These represent 1.2×10^{12} kcal, sufficient for about 2.10^6 humans.

It should be remarked that the estimated total area of 10^6 km^2 represents the 'actual primary production area' which will have to be enlarged for various reasons, as:

1 Accessibility of substructures in each unit (roads, railroad, water, barns), and enlargement required because of unusable parts of the biomass produced;
2 Areas required for non-direct human requirements, e.g. wood production;
3 Areas required for secondary production (cattle growing).

We will provisionally estimate that each of these items will as such require an additional area of the same size; in total this will enlarge the area required by a factor 4: the area required for the units would thus become 1200 km^2 and the total area 4.10^6 km^2 (see Fig. 1–3). [2] This still is only about 3 % of the total land surface on earth. [3]

Planning of the postulated units

It is not unlikely that each single unit should provide facilities for a large variety of purposes, as mentioned above, such as: 1. human food production; 2. cattle growing; 3. wood production; 4. additional purposes as fruit growing.

The required number of 3000 of these units offers the possibility for a large spread over the earth's surface, and will allow and also require to adapt the use of a unit as well as possible to the prevailing edaphic and climatic conditions. It is easy for thinking, to adhere rather strictly to the unit size outlined and the rectangular shape. Adaptation to local conditions, however, should not be eliminated, and variation in both area and shape can, to some extent, be practical, and will not change the general outlook on the problem as long as the orders of magnitude remain the same. A river or brook might border the plot, or even run through it which may be advantageous as long as the river is clean and pollution by activities in and outside the plot is carefully avoided (see below).

It seems advisable, from the beginning, not to consider these units as 'farms' in the traditional sense, but rather as large scientific and industrial enterprises, and their set-

[1] The extremely small magnitude of this number and the fundamental difference from the present situation becomes evident if one realizes, that the present number of 'farms' in the Netherlands is of the order of 100,000! It is clear, moreover, that the situation would not change fundamentally if, for some reason, in the future, the estimated number would have to be multiplied by 2 or 3.

[2] This area (4.10^8 ha) is supposed to feed 5.10^9 humans or about 12 per ha. This figure is about twice that computed along different lines by Clark (1967) on the basis of the comparatively rich American diet (5.5 persons/ha). There is still rather wide disagreement about the exact values of these numbers (Clark, 1967, p. 57–78). It should be emphasized that this point is not very relevant to our present discussion since it is in the same order of magnitude, and that our main purposes are for the present to develop the principle of crop production with the aid of a small number of large and specialized units.

[3] It should be kept in mind that not all land surface is 'inhabitable' (see Stamp, 1958).

up and management probably would have much in common with major international industries, in several respects: mechanization and serialization and other labour-saving and apparatus-controlled provisions should be used on a large scale and in an advanced and sophisticated scientifically designed fashion, based on fundamental and applied research adapted to the purposes of the unit, much as in large industrial plants (see below).

The number of units to be planned in each individual country will largely depend on its edaphic and climatic conditions, and should bear some reflection upon its geographical size and the amount of its population. Extensive international contacts between the various units would be necessary for research purposes, and optimal use of possibilities.

The planning of each unit of roughly 30 $\times$ 40 km^2 should go into great detail and result from the consultation of a large number of scientists from various disciplines, such as plant physiologists.

Roads, accessibility, buildings, water management and fertilization outfit, plantation schemes of the considered crops, etc. will have to be laid out. Certainly, each unit will require railroad and probably shipping contact, aside of the necessary road system. Moreover, it will require an elaborate and well equipped research lobaratory, for both sciences and arts (economics), which will fully specialize on all aspects of the enterprise, and probably will require 20 to 50 academic people, besides technical staff. General problems can be studied in a group, related to several units, located not too far apart. It appears useful to include university workers and their laboratories in the study of basic problems as much is possible.

The above superficially sketched outline seems to offer several advantages over the traditional farming systems (more or less the same advantages as every large-scale possibility over the ancient smaller ones): more possibilities of adapted research and development of new techniques, more economic management and, above all, the much better possibility in taking measures to prevent any contamination of the biosphere (air, soil and water) outside the actual plant, which requirement will become a necessity for every human enterprise within a foreseeable future.

It should be stressed that no one is supposed to 'live' in the cultivation area of the unit, some sort of 'city' or 'campus' for the permanent research workers and employees will have to be built in a corner of the enterprise, e.g. in connection with the research laboratory and the experimental area or — perhaps preferably — linked to an existing preferably rather large settlement.

Some plant physiological remarks, and selection of sites

Crop plants require different conditions, and a worldwide system of planning would enable to choose suitable sites, best adapted to certain combinations of crops.

If a 1200 km^2 unit comprises areas of agriculture, cattle growing, horticulture and silviculture, each of these detail areas should in itself make as close a (sub)unit as possible, and be guided by separate but closely interrelated sections of the research station. Certainly, especially in the beginning, these big units should concentrate on the production of major crops. The economy of the unit will probably be best if a very small number of crops takes up the major part of the area. In the larger countries, the units are likely to be differentiated according to special (agricultural, horticultural or silvicultural) production types. It should be stressed that a principle idea is that the units, notwithstanding their large size, should produce optimal yields, as now reached mainly on small areas. This seems possible by a close link with basic research to this purpose.

The research laboratory must have elaborate phytotron, greenhouse, plant and animal breeding facilities, and experimental fields and mobile units for microclimatological and crop-physiological research, and probably computer facilities. It will probably altogether occupy a surface of 100 to 400 ha (i.e. 0.1 to 0.3 % of the total surface of the unit).

Plants thrive on sunlight, water, CO_2 and minerals. The latter are provided by the soil. Another importance of the soil is its water binding and transporting capacity and its heat exchange properties. These physical aspects probably will gradually become the most important ones, minerals being already now largely supplied artificially. It seems feasible that it will become possible, if required, to improve soil structure largely by artificial means. The availability of soil water will be important, its adequate regulation, conservation and distribution will have to be worked out. Solar energy, CO_2 and temperature in the agricultural sector provisionally will have to be taken as nature supplies them, but a better insight into their role and co-operation in dry matter production, morphogenesis and linkage to genetic factors may well lead to a more adequate use. In horticultural areas of the enterprise, manipulations with these factors appear well feasible already now.

Developments in present-day horticulture have already led to greenhouses of the order of 1 ha with regulated air conditioning, watering and nutrient supply. It seems feasible that the units under discussion in this article may contain complexes of about 100 such greenhouses in close connection as subunits with several central regulations.

The research will have to be in part basic, in part directly applied to the practical running of the enterprise as a closed unit. The introductory assumptions previously described in this article were the traditional basic yields as obtainable by now with the 'normal' agricultural crops and techniques.

Basic research in the unit should comprise among other things:

1. Genetic research in the crop plants used;
2. Factors determining the efficiency of solar energy conversion and its changes during the season;
3. Techniques of irrigation and sprinkling in forms suitable to the nature and the size of the enterprise;
4. Studies in artificial soils and the application of nutrients (it does not seem excluded that, gradually, the entire set-up might be driven on a continuous supply of nutrient solution to an artificial 'soil' developed to suit extremely large units);
5. Pasture research and cattle breeding problems, tree breeding and tree growing problems, investigations into large-scale fish culture in connection with the situation and possibilities within the unit;
6. Research into efficient coordination and optimization of factors of biomass production, within the scope of the enterprise;
7. Studies in the ways along which agricultural wastes (not directly usable parts of the crops) may be used most efficiently from the viewpoint of secondary food production or for industrial purposes including studies in, for instance, leaf protein production;
8. Research in non-traditional production types (e.g. algal mass culture) and in biological conversion of wastes;
9. Basic actions of herbicides and growth substances, on plants and animals;

10. The protection of the internal (within the enterprise) and especially the external biosphere against pollutions of any sort;
11. Mechanization and tool development research adapted to the size of the unit, including international rationalization of sizes and shapes, similar to what is being done now, for instance in railway supplies;
12. The economics of units of the suggested type and its limitations;
13. The international aspect of the planning and its international coordination for which the framework of the International iBological Programme and its successive developments may furunish the suitable background and discussion forum.

An important question, certainly, is the effect that the setting up of a unit of the planned type may have on current agriculture as still proceeding simultaneously in smaller enterprises. As such, the factual discussion of this sort of questions is beyond the scope of this article. The remark, however, may be made that this problem does not seem fundamentally different from the one arising from big industrial enterprises from whatever type they may be, developing amidst a large number of fundamentally smaller ones.

Another important point seems to be whether industrial handling of agricultural products and wastes should proceed on or in the immediate neighbourhood of the enterprise. This is not specifically relevant to the purpose of this article, but it seems logical and very advantageous from the point of view taken. These processing units then should be concentrated on a special area, thus minimizing transport difficulties and facilitating the suppression of bad effects with respect to the biosphere.

Some further notes on location and general planning

Visualizing an enterprise of the type outlined would certainly benefit very much from discussion and research as carried on for several years in the frame of the International Biological Programme, and the undertaking of the establishment and the running of a unit could, on the other hand, be one fascinating outcome of this Programme.

Certainly, a first series of such units scattered over the earth's surface, would necessarily have a tentative character, since much developing research will have to be done. Since, however, the primary type of production is meant to be traditional, except for its size, production can start more or less immediately after thorough genral planning and subdivision of the area. Since the latter, and its smooth further adaptation to the requirements and development, will belong to the general task of the research team itself, it seems logical to start with the building and equipping of the research unit.

Developing everything that is required for the proper running of a unit of the type discussed in an optimal scientific and economic way, appears, in the first instance to natural scientists, a challenge which as a human effort is not inferior to the challenge of space research.

Concerning the location, one probably feels that a suitable site of the required size may be more easily found in the generally less densely populated 'developing' countries than in the more densely populated highly 'developed' ones. However a few remarks should be made in this respect:

1. 'Virgin' nature or more or less 'natural' communities should not be destroyed for the purpose since these are likely to be the most precious elements in the environment of mankind in future.
2. Virgin soils, e.g. those reclaimed from the sea or otherwise, appear extremely suitable.

3. Especially in the initial stages, the foundation of an enterprise of the sort discussed seems especially indicated in countries that already possess a highly developed scientific, agricultural, and technical level.

It should be stated once more that the purpose is not to create a very large farm, but an attempt at a new type of integration of various branches of natural sciences and economics towards the purpose of achieving the most favourable efficiency, both of human labour and used area for food production in a combined effort, on a large but still limited and concise area. The large size advocated for these plots is not arbitrary; apart of the necessity for warranting sufficient research to be payable, in the future the most worth-while aspect probably will be the minimizing of borderline effects, thus counteracting pollution of the neighbourhood.

Stress should be laid on the fact that units like this should come into the main production line slowly, first enter a stage of exploration, and only gradually will take over from the older type, more or less like nuclear energy power plants, amidst the old types of energy generation.

Some people feel that it would never be possible to establish such a plant in already habited areas, since it would require displacing persons, perhaps even entire villages, uproot roads etc. The answer seems to be that such things already happen in cities for big traffic or industrial enterprises, for which many houses may be turned town, or streets removed, without much concern. This does not mean to say that this is altogether nice, but if planned with due caution, it probably is better than to let things go so far as to a complete destruction of the entire natural environment and of the biosphere which, in densely populated industrial areas does not seem far off.

In the Netherlands, it would be of great interest to attempt at the establishment of an 'extremely large size' unit in one of the Lake Ysel polders, now still in the stage of reclamation, and to reserve an area of the required order of magnitude for this purpose. The more so since initial phases of this sort of development already are available in the temporary government exploitation in large units (i.e. 20,000 ha which is in the right order of magnitude) during the first years in which the soil still does not give optimal agricultural yields.

The present trend is to divide these large units later on into 'normal' size farms for private exploitation. From the viewpoint taken in this article this appears as a step backwards.[1] Continuation and stabilization of such a unit would offer an extremely interesting start of a development as advocated in this paper.

The question as how to deal with a set-up as proposed, in all its aspects, is beyond the scope of this article which mainly wants to stress the possibility of its foundation on sound plant-physiological reasoning. Clearly, the enterprise should be 'public' as much as possible, and the government, directed by its advisers, should have a major, if not an all-comprising say in the whole matter. It does not seem excluded that private farmers' corporations might join in raising an enterprise as suggested, albeit probably with government support. Active support of United Nations organizations would be of great profit, also to guarantee the best international relationships. Private farmers might be visualized to be encouraged to exchange their existing farms for participation in the enterprises both in terms of capital and labour or one of these two, in correspondence with the real need of the enterprise.[1] This encouragement would be especially in place

[1] Quite recently an interesting theoretical study has been published on aspects of harvesting in a large unit (van Kampen, 1969). It may serve as an example of the type of studies suggested under the items listed above (p. 55–56).

for farms that occupy areas which lately were still covered by more or less natural communities and are in part located on the lighter soils. This situation holds in the Netherlands and probably also in other densely populated countries. It would appear justified to 'decultivate' these areas [2] and to encourage recovery of spontaneous plant and animal communities, thus gradually increasing the areas with 'recreative' value.

Probably, on the one hand, only sufficiently large cities, with adequate cultural development, and on the other hand sufficiently large areas with sufficiently 'natural' and at least not obviously 'regulated' appearance and contents of wild animals (also invertebrates) and plants ultimately offer recreative values of satisfactory level.

It appears appropriate to add that a general tendency of life seems to be to lead consistently to a continuous increase in improbability, in complexity of structure, and hence to a decrease in entropy [3]. This goes against the 2nd law of thermodynamics, and owing to the increased insight in thermodynamics of open-chain processes, we know that the mentioned tendency requires a constant flow of energy production to counteract the mentioned law and to keep up the structure. This tendency seems obvious in the individual life of organisms, where the failure to fulfill these requirements leads to the victory of parasites or to internal disorganisation, resulting in (temporary) illness or, ultimately, death.

In a similar way, we may visualize that species may die out if for some reason their vitality (their power to counteract the tendencies of the 2nd law) decreases, or if the vitality of competitive species rises more than their own.

Society, a result of activities of living organisms (especially human beings), seems to obey much the same rules. During development of mankind it has assumed increasing complexity and increased use of energy. (The maintenance of a 'modern' technicalized society requires not only about 30 times the amount of energy needed for the direct daily needs of its individual members but also considerable 'brain power' which may probably also be qualified as decrease in entropy.) Failures in understanding these tendencies in the life of individuals leads to 'frustrations', and if no adequate restauration comes in due time, to 'breakdowns', and ultimately to insanity, crime and suicide. If sufficiently large and in part well informed parts of a society feel that way, the result may be uproars, revolutions and wars, and ultimately the complete victory of the (temporarily and in the required respect) best adapted race or group of individuals over one or more others, and probably (temporarily) to a tremendous increase in entropy (any type of 'chaos').

A so far little disputed property of the trend of evolution is its irreversibility. This also holds for society, whether we like it or not, and also here increase in complication and in structure, and hence increased energy requirement, results. In this frame, the proposed idea of agricultural development towards concentrating upon super-large and technically efficiently run enterprises seems to fit very well, and appears distinctly advanced over the present state of small enterprises, rather randomly scattered between other human activities which appears to represent an underdeveloped state as compared with, for instance, industry.

Certainly, the development will have to be a gradual one, and sociologists will have to find means to decrease undue stress upon individuals. This, however, does not decrease the necessity to devote considerable thinking to these problems, since the ultimate aims discussed in this article will become increasingly inescapable.

It should be added that developments as approached, for instance in South America, to divide up large areas of land into very small units exploited as small private farms, may be felt as considerable immediate improvement of living conditions; however in the frame of thoughts developed in this article, they do not seem to offer a reasonable issue and may turn out to be disastrous in a somewhat further future. Scientifically planned super-size production areas, in close co-operation with the inhabitants, may well offer a more reasonable issue, especially with respect to bioresources and biosphere.

People may hesitate to adopt the idea that in the future we will not have farms everywhere, but

[1] Like in many analogous places, the simpler word 'plant' strongly suggests itself here, but has been deliberately avoided in order to prevent confusion with the term 'plant' as a botanical object.

[2] The idea of abandoning farms on soils with marginal existence possibilities as suggested here, is also to be found in more traditional progress plans, like that of Dr Mansholt for Western Europe, aiming at farms of 60 to 100 ha in size.

[3] For a scientific discussion of backgrounds and related problems, see for instance de Groot (1951, § 77 etc.).

large food-producing enterprises of great concentration and concise planning. Ultimately, it is not much more strange than that we do not have any more small car (wagon) factories in each village, or small lamp workshops in each street, but a few very large enterprises scattered over the world, providing everybody everywhere with these things.

It should be observed that a necessary complement of any future planning of food production is a control of the world population. Increased knowledge of food requirements, human physiology and pathology, and pesticides have markedly increased the possibilities of death rate control in the past 5 to 10 decades. Accepting this to be practised and developed further along with continuous development of natural sciences, inevitably necessitates birth rate control as well. Opinions may widely differ with respect to the ways to achieve this; all this would seem not to disturb the fact as such. I do hope that the presentation in this article, pointing out that a rather small part of the earth surface could provide the present (and still a somewhat enlarged) population with sufficient food, does not seduce people to the conclusion that we still can permit ourselves a vast increase in number. Various aspects, briefly touched upon also in this article, rather indicate that we are about to have reached a viable maximum. Possibilities for non-harmful further increase seem to depend largely on improvement of food production methods, which as such are already variously being studied [1] and quite feasible (possibly up to 2 or 3 times in first instance).

World-wide large-scale plannings in various branches of human effort seem to be of utmost importance to reconcile the existance of a highly developed technicalized society with the primary necessities of life for plants, animals and human beings which require only moderate, well controlled and restricted affection of the biosphere. Every sort of approach to these problems will require deep and extended studies; the attempts to continue, such as the work of the International Biological Programme as one aspect of this, and to extend its scope, should be most heartily encouraged.

We may visualize that part of the frustrations apparent in various activities of young people today, essentially are connected with a feeling of running towards an abyss, and indeed one can only hope that the development of the other scientific disciplines engaged will be able to keep pace with the increase in technical possibilities, especially those of destruction, not only by bombs but also by land 'reclamation', house building and its allies!

It should be observed that ideas like creating new 'working places' by developing industries to compensate for those lost in agriculture, from a general point of view offers a poor solution in that it will contribute to still increase the rate of biosphere destruction, and therefore rather soon will have to be recognized as old-fashioned, both in economical and sociological respect.

Additionally, it may be observed that the re-establishment of spontaneous vegetation on decultivated soils offers several interesting problems, both for ecology and plant physiology, the study of which still is very much in its beginning. Work along this line is in progress in our laboratory for some years. This comprises especially experiments on light intensity effects, carried out both in experimental plots established in the laboratory fields, and in spontaneous vegetations on some of the North Sea Islands, in co-operation with national IBP projects under section PT. Preliminary results are available and under preparation for publication (Wassink, in prep.).

It is difficult to make a fair guess about the capital investment necessary to start a unit; this amount should be best supplied by the related government which, on the other hand, might well borrow (part of) it from interested sources. The virgin soil envisaged should in first instance be put at the disposal of the enterprise by the responsible government.

It may be visualized that, within 100 or 200 years [2], most of the bulk production of main food stuffs may be taken over by large-planned enterprises as envisaged, with the obvious advantage that the habitable area can allow itself large uninterrupted fairly 'natural' spaces and that, additionally, pollution of the biosphere by agricultural prac-

[1] Studies of this kind have received extensive attention in several contributions at the Symposia on Productivity of Photosynthetic Systems at Trebon (Czechoslovakia) and at Moscow (USSR), in September 1969.

[2] Maybe this estimate will turn out too high; circles closely related to Einstein in 1920 estimated that practical use of nuclear energy probably would not take place within 100 years, while actually it started within 30 years (Moszkowski, 1922).

tice will be much more easily avoided. No doubt, besides this, also pollution by industry and traffic will have to be severely curtailed; essentially, no one should be allowed to spoil another's biosphere to any appreciable extent!

The necessity of this requirement receives considerable support from frequent reports on larger and smaller calamities, from the recent 'Rhine scandal' (involving the death of millions of fishes) to things like a tank vehicle, capsizing on the road and spilling poison into a brook alongside or a farmer cleaning spraying implements in a ditch etc., appearing more or less daily in newspaper and wireless information.

It appears satisfying that wide circles now are devoting considerable interest to maintainance and, where necessary, improvement of conditions of the biosphere (see Anon., 1969). This matter will require considerable efforts in the near future, continuing approaches already attempted from various sides in the past few years, especially in the frame of the International Biological Programme.
Moreover, recent articles too numerous to be quoted in detail stress the necessity of preventing air pollution. [1]
The suggestions given in this article are meant as a contribution on a plant-physiological basis to the problem of producing increasing amounts of food in a world which at the same time should remain, or become again, a place of beauty with a varied and interesting animal and plant life, where a possibly still increasing number of human beings will be able to live healthily and happily together with the other creatures.

Summary

A plant-physiological consideration based on yields of solar energy conversion is given, which shows that the total area required for feeding the world's human population according to present agricultural practice and nutritional standards is relatively small: around 2000 × 2000 km² (including roads, etc.; actually the area required for primary production of human food is only $^1/_4$ of this).
It is suggested that a renewed approach to agricultural production may benefit from the planning, in various parts of the world, of 3000 units of about 30 × 40 km², each mainly devoted to a limited number of crops, and mediated by their own research stations with extensive facilities for basic and applied research on natural science and economic aspects, and thorough international co-operation.
Some consequences of this suggestion are preliminarily discussed, mainly in order to draw attention to the matter.

Acknowledgment

The author gratefully acknowledges favourable comments received from a few collaborators and friends upon a perusal of drafts of this article.

References

Anonymous, 1969. Intergovernmental Conference of experts on the scientific basis for rational use and conservation of the resources of the biosphere (Unesco House, Paris, 4–13 September 1968). Final report, Paris.

Butt, M. A., 1968. Vegetative growth, morphogenesis and carbohydrate content of the onion plant

[1] We will not refrain, however, from drawing attention to several quite recent articles related to this subject in *Landbouwkundig Tijdschrift* 81 (1969) 137–162.

as a function of light and temperature under field and controlled conditions. *Meded. Landb-Hogesch. Wageningen* 68–10, pp. 211 (Thesis).

Clark, C., 1967. Agricultural productivity in relation to population. In: G. Wolsterholme (Ed.), Man and his future. Churchill, London (paperback ed.).

Gaastra, P., 1958. Light energy conversion in field crops in comparison with the photosynthetic efficiency under laboratory conditions. *Meded. LandbHogesch.* 58(4), pp. 12.

Gaastra, P., 1962. Photosynthesis of leaves and field crops. *Neth. J. agric. Sci.* 10: 311–324.

Groot, S. R. de, 1951. Thermodynamics of irreversible processes. Amsterdam, North Holland Publ. Cy.

Kampen, J. H. van, 1969. Optimizing harvesting operations on a large grain farm. Thesis, Wageningen.

Kok, B., 1952. On the yield of *Chlorella* growth. *Acta bot. neerl.* 1: 445–467.

Moszkowski, A., 1922. Einstein, Einblicke in seine Gedankenwelt. Berlin, Fontane, pp. 33–49.

Oorschot, J. L. P. van, 1955. Conversion of light energy in algal culture. *Meded. LandbHogesch. Wageningen* 55: 225–276.

Rabinowitch, E. I., 1945. Photosynthesis, Vol. 1. New York, Interscience, p. 9.

Stamp, L. D., 1958. The measurement of land resources. *Geograph. Rev.* 48: 1–15.

Stratton Porter, G., n.d. (about 1912). Moths of the Limberlost. London. Hodder & Stoughton, (pocket ed.), pp. 255.

Wassink, E. C., 1954. Problems in the mass cultivation of photoautotrophic microorganismsm. In: Autotrophic microorganisms. *4th Symp. Soc. gen. Microbiol.* (London, April 1954). Cambridge, 1954, p. 247–270.

Wassink, E. C., 1957. The study of plant growth in controlled environments. In: Control of the plant environment. *Proc. Symp. Easter Sch. agric. Sci. Univ. Nott.* (15–17 April 1957, p. 36–57. Butterworth, London.

Wassink, E. C., 1959a. Efficiency of solar energy conversion in field crops. Paper 9th Int. botan. Congr., Montreal, Canada, 19–29 August 1959, Section 11, Physiology, Abstr. Vol. II, p. 424–425.

Wassink, E. C., 1959b. Efficiency of light energy conversion in plant growth. *Pl. Physiol.* 34: 356–361.

Wassink, E. C., 1960. The effect of light intensity on growth and development of *Gladiolus*. In: B. Chr. Christensen & B. Buchmann (Eds), Progress in photobiology. *Proc. 3rd Int. photobiol. Congr.* (Copenhagen, 1960), p. 371–378.

Wassink, E. C., 1963. On some quantitative relationships between anatomy and light-induced formative differences in *Gladiolus* stems. *Meded. LandbHogesch. Wageningen* 63 (16), pp. 8.

Wassink, E. C., 1964. Rendement van de omzetting der lichtenergie in laboratoriumproeven en bij de groei van gewassen. *Meded. LandbHogesch. Wageningen* 64 (16), pp. 33. (Dutch, with English summary. With extensive reference list.)

Wassink, E. C., 1965a. Light intensity effects in growth and development of tulips. *Meded. Landb-Hogesch. Wageningen* 65 (15), pp. 21.

Wassink, E. C., 1965b. Some introductory notes on *Taraxacum officinale* as an experimental plant for morphogenetic and production research. *Meded. LandbHogesch. Wageningen* 65 (16), pp. 15.

Wassink, E. C., 1967. Waar zijn de vlinders gebleven? (Where did the butterflies go?) *Veluwepost*, Wageningen, 4 successive issues, September/October, 1967 (in Dutch).

Wassink, E. C., 1968a. Light energy conversion in photosynthesis and growth of plants. In: F. E. Eckardt (Ed.), Functioning of terrestrial ecosystems at the primary production level. *Proc. 1st Int. Symp. Ecosystems* (Unesco, Copenhagen, 24–30 July, 1965). Paris, Unesco.

Wassink, E. C., 1968b. Some simple equipment for comparative studies on growth and morphogenesis of plants in field experiments. In: F. E. Eckardt (Ed.), Functioning of terrestrial ecosytems at the primary production level. *Proc. 1st Int. Symp. Ecosystems* (Unesco, Copenhagen, 24–30 July, 1965). Paris, Unesco.

Wassink, E. C., 1968c. Effects of light intensity and plant density on dry matter production and morphogenesis of higher plants. *Proc. 5th Int. photobiol. Congr.* (26–31 August, 1968). Abstracts, p. 12, Ae-6. Hanover, N.H.

Wassink, E. C. Preliminary notes on biomass production and morphogenesis of plants in spontaneous vegetations. In preparation.

Wassink, E. C. & L. E. Æ. Wassink-van Lummel, 1953. The action of light intensity and night temperature on the flowering of bulbous irises (Wedgwood) and tulips. *Rep. 13th Int. hort. Congr.* (London, 1952). London, p. 969–981.

Wassink, E. C., B. Kok & J. L. P. van Oorschot, 1953. On the yield of light energy conversion in Chlorella cultures as compared with higher plants. In: J. S. Burlew (Ed.), Algal culture from laboratory to pilot plant, p. 55–62. Publ. 600, Carnegie Institute of Washington, Washington, D.C.

Wellensiek, S. J. (Ed.), 1968. Agricultural sciences and the world food supply. *Misc. Pap. Landb-Hogesch. Wageningen* 3, pp. 111.