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THE AGRICULTURAL RESOURCE BASE[1)]

C.T. de Wit[2)]

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2) Department of Theoretical Production Ecology, Agricultural University, P.O.B. 430, 6700 AK Wageningen, the Netherlands.

Summary

Starting from the photosynthesis process of harnessing the radiation from the sun, the agricultural production potential is considered. It is shown that not so much the ultimate production potential is the problem, but the rate at which the agricultural production can be expanded compared to the increased demand for food.

The main reason that production is lagging behind in pour countries is the increased needs of material inputs that are only available in well developed economies and require considerable amounts of fossil energy for their production.

The energy balance of cultivation agricultural crops is definitely positive, but this may be otherwise when the whole process from cultivation to the manufacture of fuel is considered. Anyhow the area demand for energy plantations is so large, that only in exceptional cases, it is worthwhile to consider their development.

The cultivation of other feedstocks for the chemical industry is technical feasible, but in industrialized countries it does not pay enough and in developing countries it may compete with food.

Photosynthesis

Agriculture may be defined as the human activity that transforms solar energy into useful chemical energy by means of plants and animals. It is by far the most important activity to exploit this continuous source of radiation.

At the base of agriculture is the photosynthesis process that takes place in the green coloured chloroplasts of the leaves of plants. It requires 8 quanta of light (radiation in the wavelength region of 400-700 nm) to combine CO_2 and H_2O into CH_2O. The theoretical efficiency is therefore 25 percent, but due to unavoidable losses within the chloroplasts and the leaf structure, the maximum measured efficiency is about two third of this. Given the maximum light intensity of the sun of 3 Joule cm^{-2} min^{-1}, the photosynthesis could therefore amount to 20 g CH_2O m^{-2} hr^{-1}. However, due to the photosynthesis in the past which has resulted in our huge fossile energy resources, the CO_2 concentration in the air is now close to zero and therefore the transport of CO_2 to the chloroplasts in the leaves becomes limiting at higher light intensities. The maximum photosynthesis of leaves is therefore not more than 3 to 6 g CH_2O per m^{-2} hr^{-1} which is already reached at light intensities that are up to one-third below the maximum. The larger figure of these two hold for some tropical species as sugarcane and maize, but most agricultural crops are in the lower range.

A green crop, however, is not comparable with the green cloth on a pooltable, but consists out of small leaves which are more or less randomly distributed with respect to the rays of the sun and have a total surface which may be up to 5 times the soil surface that they cover. Moreover the radiation of the sun reaches the earth even on a bright day, partly in diffuse form. As a consequence the light of the sun is reasonable well distributed over a large leaf surface, so that the average light intensity that is received by the leaves of a crop is considerable lower than the light intensity on a horizontal surface. The leaves operate therefore closer to their maximum efficiency so that the photosynthesis of a crop surface at high light intensities is about 2 to 3 times larger than the maximum that can be reached by a single horizontal leaf.

The sugar that is produced in this photosynthesis process is not bagged as such, but used as a feedstock and as a source of energy by the crop for the growth of new organs and the maintenance of existing organs. Calculations based on the costs of formation of proteins, fats and cellulose and of maintenance of biochemical processes, show that in a good growing crop and in terms of weight about 30 percent of the original photosynthesis products are again lost by these processes.

Potential crop production

Apparently, the knowledge of the crop production system is sufficient to calculate with some confidence the production of a closed green crop surfaces which are well supplied with water and nutrients and of course assumed to be free from pests and diseases. Depending on the plant species, the chemical composition of the end-product and the climate this varies in the growing season from 10 g m^{-2} day^{-1} for an oil producing crop like soybeans to 40 g m^{-2} day^{-1} for sugar cane with a relative high maximum photosynthesis. For wheat the potential production rate during the seed filling stage is about 20 g m^{-2} day^{-1} and since this period may extend to 50 days, the potential yield of this crop is about 1000 g m^{-2} or for those of you with a farmers background 10.000 kg/ha or close to 200 bushels/acre. This means that only 150 m^2 of wheat would be necessary to cover the caloric need of one person for a full year. For further visualizing it may be helpful to remark that in climates where crops could be grown the year round, only 500 x 600 km^2 would suffice to cover the caloric need of the whole population of the world.

Of course, there are many areas in the world that for all practical purposes cannot be reclaimed for growing crops. And on areas that can be reclaimed, crops cannot be grown during part of the year because temperature are too high or too low. And within the growing season their growth rate may be considerably reduced by lack of water. If the latter is the case, plants prevent their dessication by closing the so called stomata, the openings in the epidermis of the leaves by which the CO_2 diffuses out of the surrounding air to the photosynthesis sites. Thus water shortage blocks photosynthesis and growth. There is no evidence at all, that there are miracle crops which need less water for maintaining their production than common water-efficient agricultural crops and could therefore be used for exploiting much more efficiently the semi-deserts of the world.

Taking all these factors into account, the potential production of any region can be estimated and from these the potential production of countries, continents and the world as a whole. For the continent of Africa, the potential production varies from zero in the Sahara desert to 2500 g m^{-2} wheat equivalents for some regions in equatorial Africa where crops can be grown the whole year round. But even in the most favourable regions only a little over half of the soil surface is suitable to reclaim at all. Nevertheless, when all potential productions are taken together the total appears to be sufficient to cover to caloric needs of 10 billion people which is 30 times the present population of 0.3 billion in Africa. For the world as a whole, the situation is not much different, but their are, especially in Asia, countries and regions which operate much closer to their potential.

Material inputs

By and large there seems to be an almost unlimited potential to grow sufficient food for an increasing world population and to set also considerable areas aside for agrification of the resource base of the chemical industry and for energy plantations. In spite of this the situation at present such that hardly enough food can be grown for the present population of the world. The reason of this apparent discriptance is that the food situation is not so much determined by the ultimate capacity to grow food but rather by the rate at which the food production can be increased compared with the rate of increase of the population and of their level of aspiration. This rate of increase of food production is lagging behind dangerously because the better soils are already in use for a long time and new areas can in general only be reclaimed at large costs by using advanced technology. But even then they yield only a fraction of the potential due to lack of plant nutrients like phosphate and nitrogen. This lack of plant nutrients is also the main reason that much of the land which is for some time in cultivation yields only little above 50 g m^{-2} so that up to 3000 m^2 of a grain crop is needed to cover the caloric needs of one person for a year. And the fertilizers that are needed to augment the fertility of the land are again a product of advanced technology.

In other words, to improve the food situation either machinery has to be used to extent the surface under cultivation or fertilizers to increase the yield per unit surface and the problem with both is that they are expensive in countries with a primitive infrastructure and require considerable knowledge and a well developed economy for their use. But far too many farmers are still trapped in the vicious circle of the poor that increased cash-flow is needed to increase production and increased production is needed to increase cash-flow.

These indispensable material inputs and quite some others that are not mentioned here require fossile energy for their manufacture, transport and use and especially in the developed countries this amounts to so much that agriculture could perhaps as well be defined as the human activity that transforms unedible fossile energy into edible energy by means of the sun. For instance, a potato crop in the Netherlands may yield about 4 kg m^{-2} or 12 K Joule per m^2, but its production requires 4 K Joule of fossile energy. Of these 4 MJ roughly 1/3 is incorporated in the fertilizer and another sizable portion is of course used to operate all the labour saving machinery.

Energy farming

Nevertheless the energy balance on the farm is positive. But in spite of this, the potato cannot be used as a feedstock to produce liquid fuel, because the manufacture of alcohols out of starch requires so much energy especially in the process of destillation that the overall balance ends up negative. This is otherwise in some tropical areas where sugar cane can be grown. Not only is the potential and actual production rate of this crop considerably higher, but after extraction of the sugar juice, the remaining stems can be used to underfire the distillation process. Moreover, the farmers that grow sugarcane are often so badly paid, that they use hardly any fuel consuming machinery. Even then the net production per hectare is only sufficient to drive a car over 30.000 km, so that vast areas of land are necessary to sustain a motorized society. In some countries, there is much land available for the cultivation of sugarcane and exists at the same time such a large difference in wealth between the urban and the rural population that the rich may drive cars on gasohol produced by the poor in the sweat of their face. A complete other prospect in the use of by-products like molasse for the production of fuel. This may be worthwhile if these by-products cannot be used more advantageous as food for animals. Market stabilisation by maintaining as capacity for fuel production at hand may be also worth considering for commodities like sugar and coconut with a volatile market. Energy-efficiency considerations play then a much less prominent role.

In more temperate regions, cellulose producing crops like trees and hemp are the most promising as an energy crop because they can be used for heating and underfiring without much further processing. But also then large surfaces are needed. For instance a small wood fired electricity generator of 100 M Watt output would need a surface of 10 x 40 km^2 of excellent growing short rotation trees. This means that an area larger than the whole of the Netherlands would be needed to cover only the electricity needs of this country. The area needs would still several times larger if the trees would be grown on marginal land as they usually are.

With fast growing crops, individual farmers would need only about 2 hectare to cover their energy needs around the house. In this way the high taxes on energy could be evaded. But even then, it appears that at least in the Netherlands for the time being more money can be made by growing normal agricultural crops and buying the energy in a more convenient form.

In developing countries, not only the agricultural crops grow much slower because of lack of plant nutrient, but also the trees, so that in spite of the much smaller use of energy also about 2 hectare of forest is necessary to cover the fuel needs of a family. Such areas are still available in quite a number of rural areas. But the costs of transport of wood is so large, that the area need is again prohibitive for continuing use of this fuel base in urban areas. And since the world as a whole is rapidly urbanizing, it is not difficult to predict a continuing relative decrease of wood as a fuel source.

Further agrification

The considerable use of energy in modern agricultural production has been used as an argument to produce directly food from fossile energy as single cell protein. In that case not only energy is used for the manufacture process, but also as a feedstock. Energy wise this is therefore advantageous only if natural gasses could be used, which would be flared away otherwise at the oil fields. Single cell proteins would need also considerable and expensive processing before they could be sold for human consumption. As an animal food it would have to compete against the much cheaper concentrates that are by-products of the human food processing industry and against roughage that is often grown on grazing land that is anyhow unsuitable for arable production.

There are also the recurrent proposals of growing algae. However, to do this on a large scale capital investments are needed in the order of those needed for high priced out of season greenhouse crops. And since the potential growth rate of algae is not higher than of greenhouse crops it is not worth considering, even leaving the pest and disease problems that arise with growing them in a water-substrate alone.

Not only the food processing industries, but also the textile and paper industries and the chemical and pharmaceutical industries use large quantities of agricultural products. Apart from special products as rubber, quinine and fibers, the main raw materials are cellulose, starch, and sugars. The cellulose is mainly a forest product. In principle this is a renewable resource, but in practice too much of the forests are raped. The production of the other raw materials and plant fibers occurs by means of cultivation of agricultural crops and thus competes directly with the production of food.

This can hardly be seen as a problem in the Western industrialized countries, because agriculture struggles there with the problem of saturated markets for many of its products and could use very much another use than food for their products. Unfortunately prices are such that further agrification can only be envisaged when the energy prices are going to increase considerably.

For many developing countries it could be reasoned that on the long run, the production potential is also so large compared to the projected need for food that over and above this need any national and international demand for industrial feedstocks could be met. As had been said, however, in the short run not the ultimate capacity to produce agricultural products is limiting, but the rate at which the production can be expanded. And then the increased growth of industrial feedstocks or for that matter any other product for the international market, could very well lead to such an increase in food prices that the urban poor are bound to suffer. The growth of more commercial crops may be a mixed blessing in rural areas as well because it is not sure at all that money made in this way, if any, is sufficiently spent on food that is not grown anymore for home use. On the contrary, in many developing countries the growth of food is a burden for the woman and the growth of commercial crops a privilege of the men and for them there are many other tempting products to buy than food for the family.