SYSTEMS THEORY APPLIED TO AGRICULTURE AND THE FOOD CHAIN

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Understanding and Managing Changes in Agriculture

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PRODUCTIVITY AND SUSTAINABILITY

Agriculture has to be productive and sustainable (TAC/CGIAR, 1989). From the ecological viewpoint, this implies that renewable resources are maintained, non-renewable resources are used with foresight and the intrinsic value of the natural environment is recognized, and from the socio-economic viewpoint that farm families make a decent living and that increasing and changing demands for agricultural products are satisfied at affordable prices. These are each reasonable goals and boundary conditions, but together they constitute a world in which conflicting productivity and sustainability demands have to be satisfied at the same time and thus form a continuing source of political debate. The outcome of this debate depends on ideological and political views, socio-economic conditions, technical possibilities and past performance.

For most of the history of mankind, the possibilities of increasing agricultural production by increasing the production per hectare have been very limited, so that increase in demand was in general met by expanding the area under cultivation. In some situations, sustainable farming systems were developed. Examples are shifting cultivation in tropical forests and rainfed bunded rice in Asia. However, in most situations productivity demands overruled sustainability demands, so that soil resources were over-exploited. This is witnessed by the vast areas of once good agricultural land that have been lost or damaged by wind and water erosion, exhaustion or salination. Well-known ex-

amples are the bare hills in the Mediterranean region, the saline soils in the Middle East, the mining for nutrients of the commons in Western Europe and the destructive dust storms in the 1930s in the USA.

THE FIRST GREEN REVOLUTION

This disastrous development came to an end in the industrialized Western world during and shortly after World War II. At that time the linear rate of yield increase per unit area soared in terms of wheat equivalents from an average of about $2\,kg\,ha^{-1}\,year^{-1}$ to more than $50\,kg\,ha^{-1}\,year^{-1}$ (de Wit *et al.*, 1987; de Wit, in press), while the rate of growth of the population declined. This 'first green revolution' was characterized by innovative combinations of old and some new techniques, such as the use of more sturdy varieties with shorter straw, better water management and timeliness made possible by soil amelioration and mechanization, improved soil fertility by the use of inorganic fertilizers, and better control of weeds, pests and diseases through the use of biocides.

At the same time, the growth of the population slowed down, but large discrepancies between supply and demand were kept under control by an increased use of luxury products, like meat, vegetables and flowers, and by taking land out of production in marginal regions. When everything else failed, overproduction was accepted against prices with a social function and subsequently dumped on the world market. Such price subsidies were made possible because of the rapid decline of the number of people working in agriculture due to mechanization. This is in sharp contrast to the past when the agricultural sector was a dominant sector of the economy and was not only used as a source of agricultural products but also of labour and capital to develop other sectors of the economy.

This increased production per unit area and per man required an increased use of external inputs from the industrialized sector of the economy, and large-scale reconstruction and reallocation of land in regions with agricultural perspectives. This has led to irreversible changes in the landscape that affected diversity of the environment and quality of natural resources. At the same time the social and environmental fabric was jeopardized by marginalization in agriculturally poorly endowed regions. These developments also reflected

conflicts between productivity and sustainability, but now conflicts arise out of affluence and the lopsided use of technical means, no longer out of poverty and lack of technical possibilities.

EFFICIENCY OF RESOURCE USE

Referring to the so-called law of diminishing returns, it is often taken for granted that the large increase in yield that has been witnessed required a much more than proportional increase of means of production. Accordingly, when yields per hectare are related to, for instance, nitrogen use per hectare, in the course of time one would expect a decreasing return. However, it appears (de Wit, in press) that at present at the high end of the yield range the efficiency of nitrogen use is the same as at the low end, so that any sign of diminishing returns is absent.

The reason for this apparent contradiction is that the law of diminishing returns only holds when increasing amounts of a certain production factor are used under otherwise the same conditions. However, a feature of intensification of production is that it is not the improvement of one growing factor that is decisive, but the improvement of a number of them. This leads to positive interactions that imply that the total effect of the measures that are taken is larger than the sum of the effects of each of them separately. Liebscher (1895) acknowledged this in the last century by formulating his so-called law of the optimum that states that a production factor contributes the more to production, the closer the other production factors are to their optima. The law reflects the fact that the agricultural production process in low-yielding situations, where many limiting and partly unknown factors interact, is not very well understood and therefore difficult to manage, whereas in high-yielding situations it implies better control so that inputs may be better timed and adjusted to demand. Of course, this does not exclude the possibility that some inputs are so cheap that there is little incentive for the farmer to economize on their use, so that more of them are used than is necessary to reach the production goal. A recent analysis (de Wit, in press) confirmed this law of the optimum: no production resource has to be utilized less efficiently upon the approach of optimal growing conditions and many are used more efficiently. Therefore, where it is profitable to use an input mix, it is more profitable to use each of the inputs of this mix at

optimum intensity. Yield increases are thus determined in an autonomous process that is fuelled by public and private research, extension and marketing. System analysis and simulation studies (Buringh, *et al.*, 1979) have shown that in many regions of the industrialized Western world there exists still a considerable yield gap between what farmers actually produce and could potentially produce. This makes any optimum a moving target for the farmer.

DIVERGING DEVELOPMENTS

Any market-oriented policy that seeks to adjust agricultural demand and supply by downward adjustments of prices has to come to grips with this phenomenon of autonomous yield increases. It is true that the supply will be reduced by marginalizing those regions that are less suitable for agriculture. However, at the same time yields continue to increase in regions where agriculture is considered profitable.

This autonomous increase of yields is on average about 1·5 per cent per annum in the European Community (EC) (Meester and Strijker, 1985) and, since land that is abandoned has a below average yield, it is necessary to take at least 2 per cent of the land out of regular production each year to compensate for the yield increase on the land that stays in production. Until the year 2000 this would amount to at least 20 per cent of the agricultural land or about 15×10^6 ha in the EC alone. This is equal to the surface of all the agricultural land in Great Britain. Such marginalization of agriculturally less-endowed regions is not a new phenomenon but has been going on for quite some time in the industrialized world, as witnessed by the vast tracts of abandoned land in, for instance, France and the eastern USA.

It is sometimes suggested that the internal demand for agricultural products within the EC should be increased by replacing imported concentrates by local products. This would compensate for a production increase of about 4 years (de Wit *et al.*, 1987). However, any additional import restrictions at the borders of the EC are internationally unacceptable. There are also attempts to increase the demand by agro-industrialization, for instance the production of ethanol for cars, pulp for paper and vegetable oils for lubrication. However, the production of ethanol requires huge subsidies whereas the energy balance of the process is either not or barely positive. The cultivation of fibre crops for pulp production is technically feasible but is unlikely

to be able to compete with imports for a long time to come. Most attractive may be the cultivation of oil crops for the production of biodegradable lubricants to replace environmentally unacceptable mineral oils (Slettenhaar, 1989). If one could succeed in capturing every year an additional 2 per cent of this market of 5×10^6 t year^{-1}, this would account for 10^5 ha year^{-1}, but this is less than 10 per cent of the land that was calculated to go out of regular production every year. Such figures illustrate the magnitude of the problem.

Well and less-endowed agricultural regions are geographically unevenly distributed within the EC (de Wit, 1988). Therefore any policy of price liberalization will come to a deadlock unless the more prosperous countries and regions, out of proper self-interest, are willing to support the less-endowed regions in creating development possibilities that aim at a social and economic structure that can replace the agricultural structure to a large extent. Where this is not feasible, social programmes should be supported that enable the younger part of the population to move to more promising regions and the older part to fade away in some grace. This requires more authority, leadership and money in the EC, but without this the common market in agricultural products is put at risk by any market-oriented policy. Such a partition into regions where agricultural production continues to increase and those where agriculture disappears as an important source of income has divergent consequences for the sustainability of agriculture.

Land that is taken out of regular production in the less-endowed regions will in some cases be used for ranching, forestry and the establishment of nature reserves. The profitability of such land uses is so small that much of the land will be left to run wild. Such extensification could be considered a positive development but for the fact that the environmental and social fabric formed by traditional farming systems is destroyed in the process. Hence, there may be valid reasons to put the brake on such destruction by supporting agriculture in regions that are marginalized. However, conserving a way of life in which 30 per cent of the population is supposed to make a living in agriculture is in the long run not only very expensive but also unacceptable to the population as a whole.

Support of agricultural development in potentially suitable regions of new member states is something else and may be necessary for political reasons. However, this requires that in other suitable regions land is taken out of production for other purposes such as, for

instance, the strengthening of the ecological infrastructure. Such developments would occur at the expense of efficient resource use, but this may be very well worth it.

Pollution prevention is best served by concentrating farming in the most favourable regions. The need for energy, fertilizers and biocides per unit product is then the lowest. This relieves the overall burden on the environment; even so, environmental standards continue to be threatened locally because of the increased use of resources per unit area in regions where agriculture continues to be practised. Also, smaller farmers are caught between falling prices for their products and an increasing general level of prosperity. Hence, the number of farmers in well-endowed regions continues to decrease and the size of the farms continues to increase and with this their level of mechanization and automation.

PROBLEMS OF SUSTAINABILITY

Merciless exploitation of comparative advantages results in regional specialization and narrowing of crop rotation. Especially in combination with heavy mechanization, this threatens sustainability. Fields are then barren for too large a part of the year and subject to loss of soil structure and to unacceptable rates of nitrogen leaching and of wind and water erosion. Another problem of specialization is the development of pests, diseases and weeds that are difficult to control. Therefore much of the crop husbandry research is directed towards widening of the crop rotation and the development of soil cultivation practices and machinery that conserve the structure of the soil and the reintroduction of cover crops.

As summarized elsewhere (de Wit, in press), high-yielding crops may be more susceptible than low-yielding crops to obligatory parasitic pests and diseases, like aphids, mildew and rusts, mainly as a result of higher nitrogen concentrations in the attacked tissues. This promotes insurance spraying, i.e. spraying without first establishing the risk of damage to the crop. Integrated pest management methods have been developed to reduce such high use of biocides. These rely on varieties with a broad resistance, observation-driven chemical and biological control systems, avoidance of over-fertilization with nitrogen and other cultural practices. With such methods the average number of spray applications to wheat crops is

kept at 2·5 in the Netherlands, compared to 8·5 in the UK and 7 in the northwest of the FRG (Rabbinge, 1987). On the other hand, it has been found that higher-yielding crops may be less susceptible to non-obligatory parasitic diseases like septoria, fusaria and verticillium and to nematodes. Fast-growing crops are also better able to suppress weeds than low-yielding crops, so that herbicides are less needed under high-yielding conditions at later stages of growth. This is contrary to the widely held belief that high-yielding crops require in general more biocides for their protection.

Corrected for inflation the price of nitrogen is at an all-time low in the EC in spite of the large increase of the price of energy in the 1970s. This has promoted considerable wastage, especially in animal husbandry. An environmental tax at least to double the price of inorganic nitrogen from the factory has been suggested (e.g. German Council of Experts for Environmental Problems, Rat Umweltfragen, 1985) to reduce such wastage. To obtain some idea about the long-term effects of such a tax, a comparison may be made with the tax on gasoline; in countries with high taxes on gasoline, small, energy-efficient cars have been developed that do the job of transporting the driver and his occasional passenger just as well as the big, gas-guzzling cars in countries with low gasoline taxes. The proceeds of such a tax could be guided into an EC fund for structural improvements in the less-endowed regions of the Community (de Wit, 1988). If need be, the tax burden on the farmers in well-endowed regions, who use most of the nitrogen, could be compensated for by price support within the framework of the Common Agricultural Policy. The costs are then passed on to the consumer, like costs associated with structural differences that supposedly make European agriculture more costly than agriculture in some other economic blocks. That is the price that has to be paid if one wants to maintain a viable agriculture in the European Community and to meet long overdue environmental standards.

A practically unavoidable consequence of greater uniformity is increased genetic erosion. By means of gene banks and conservation *in situ* attempts are being made to slow down this process, hopefully to such an extent that the rate of genetic impoverishment is counterbalanced by the increased ability for gene manipulation. There may be some comfort in the thought that any random sample of plants may already contain most of the individual genes in the plant kingdom albeit not in the combination that would induce desirable characters.

THE SECOND GREEN REVOLUTION

Of course there are far too many poor people in developing countries, but in contrast to disheartening expectations at the end of World War II, the medical doctor did not steam ahead of the agriculturalist. The Law of Malthus has not finally been proved to be true but agricultural production has kept abreast of the strongly increasing demand for food. Despite an almost three-fold increase in Third World population since 1945, global food shortages have been averted and famines have been reduced in both frequency and size. This required an increase in production of over 3 per cent per annum. The demand for food will continue to increase at least at these rates in the coming decades because of a continuing increase in population and income.

Roughly two-thirds of the increase of production was achieved by increasing yields per unit area and the other third by extending the surface under cultivation during the last 40 years, but regional differences cover the whole range from zero increase in yields to zero area expansion. There are still large areas that could be reclaimed in some parts of Africa and of South America, but in many regions of Asia most of the land that is suitable for some form of agriculture is already in use.

The Rockefeller and Ford Foundations were aware of this at an early stage (Baum, 1986) and founded at the beginning of the 1960s the International Rice Research Institute (IRRI) with the objective of transferring the yield-increasing techniques that were developed in the Western world to the cultivation of rice in Asia. This transfer appeared not too difficult and the results were readily adopted in regions where farmers were guided by some extension and attractive terms of trade.

Famous examples are the unprecedented yield increases in the Punjab and on Java. On the latter island, the yields of sawah rice increased only at a rate of about 2·5 kg ha^{-1} $year^{-1}$ before 1968, so that it was necessary to import increasing quantities of rice for the increasing population. Since then, yields have increased at a rate of 125 kg ha^{-1} $year^{-1}$ (de Wit *et al.*, 1987), so that the growth of the population has been overtaken. The average yield increases over the whole of Asia were so large that the godowns filled up with rice and the prices went down. This solved the problem of hunger due to physical scarcity, but problems of hunger due to poverty and problems of equity remained.

The possibilities for increasing production are still so large that well-endowed regions are likely to be able to meet demands at relatively low prices in the coming decades in most countries of Asia (Buringh *et al.*, 1979). As in the developed world, this will marginalize less-endowed regions because their terms of trades will become less favourable. Scarcity of funds and the lack of political power of the population of marginal regions makes it very unlikely that the transfer of money that will be needed to reverse such marginalization processes will occur in the foreseeable future. Most farmers in these regions are thus condemned to subsistence and to exploitation of natural resources to satisfy immediate needs or to moving elsewhere. Agricultural research which is particularly directed towards improvement of least endowed regions may open up new possibilities in some situations. However, in many cases its results are more readily applied in regions that are better off. The comparative advantage of these least endowed regions is then not increased and their marginalization continues.

Seed stock, industrial fertilizers and biocides can be traded in small amounts, so that, in areas where application of new techniques is attractive, the smaller enterprises will eventually follow the larger ones. However, this is of little or no consolation to the smallest farmers. In spite of increasing yields, they cannot maintain their aspired level of income because they are caught between falling prices for their products and an increasing general level of prosperity with the consequence that they become impoverished. Experience in the Western world and in Japan shows that this is an unavoidable process unless one accepts permanent and increasing income transfers from the other sectors of the economy to the agricultural sector. However, this would drain scarce resources that are so badly needed to create more diversified regional economies with job opportunities outside the agricultural sector for small farmers and landless labourers.

MORE SUSTAINABILITY PROBLEMS

This second green revolution manifested itself only 20 years after the first green revolution and is therefore a striking example of a rapid transfer of techniques. This did not come about without problems.

For instance, pests and diseases can develop easily to epidemic proportions in the tropics because first principles of crop rotation are

violated by growing the same species side by side during the whole year in various stages of development and by cultivating crops in mixtures instead of in rotation. Change of crops and of seasons then ceases to form a natural control on epidemic developments. Blanket spraying, however, may give rise to more problems than are solved because resistances develop and natural enemies are decimated. An example is the epidemic increase of brown planthoppers on Java in the middle of the 1970s that for some years caused a set back in the rate of increase of rice yields.

Even more so than in temperate climates it is therefore necessary to develop integrated methods to control pests, diseases and weeds, but this draws heavily on the infrastructure for research, teaching and extension. Therefore, epidemics and adverse consequences of their control may very well remain a serious problem for some time to come, and with it a risk of calamities during manufacture, transport and use of biocides.

In contrast to biocides, minerals and nitrogen occur in the natural environment but this is no excuse to waste them. However, inspired by many bad examples in the developed world, injudicious methods of fertilizer use have been promulgated and are now in wide use. For instance, the uptake of nitrogen fertilizer by irrigated or rainfed rice is often considerably less than 20 per cent of the amount that is applied (van Keulen, 1977). Better methods of application would enable an increase in this recovery to 50 per cent or even more. Such improvements of efficiency would make the use of fertilizer attractive in many more regions than at present and reduce the adverse environmental impact of over-fertilization in other regions.

There are many irrigated areas in Asia but these are often subjected to aging and inappropriate management. Sometimes the upper parts of the watersheds are reclaimed or deforested in such ways that soil erosion rapidly silts up reservoirs and channels. In other cases, there is lack of drainage, so that lower lying parts of the irrigation systems become saline. It is also disheartening that the importance of a proper social, economic and administrative infrastructure is often underestimated, so that many projects that were technically promising turned out to be failures. These problems apply far less to rainfed cultivation of rice as practised in many regions of South-East Asia. This may very well be one of the most sustainable farming systems that has been developed.

URBAN BIASES

The situation in South America is in sharp contrast to that in Asia. This continent is sparingly populated and has potential for increased production both by more intensive use of the land that is already in production and by reclaiming more land with due concern for the maintenance of indispensable tropical rainforest reserves. The coexistence of these vast underutilized resources for production and large numbers of poor small farmers is evidence of the geographic and socio-economic inaccessibility of this land. The commercial farm sector controls most of the better endowed but underutilized land resources, while the large peasant sector often occupies and overuses marginal lands (FAO, 1988). Problems of soil degradation and deforestation originate from inappropriate agricultural policies that perpetuate this limited access of small farmers to land and provide tax shelters for labour-extensive development of new areas where extensive systems of arable cropping and cattle ranching are not sustainable.

The key to improvement should have two levers: land reform should make it possible for the small farmer to expand onto agricultural land that is at present controlled by the large absentee landowners and agricultural policy reforms should make it attractive to intensify such utilization so that further degradation by overexploitation comes to an end. These are revolutionary changes that go against the immediate interests of the powerful urban middle class in many South American countries.

Such urban biases (Lipton, 1977) have led to a policy of neglect of the rural population in Africa. Dump prices on the world market, low exchange rates, lopsided trade policies and taxes, price control and subsidies promoted food imports, kept food prices low and thus discouraged food production. This enabled the maintenance of low wages in urban areas, so that investments in urban regions were favoured at the expense of those in rural areas.

This policy of disregard of rural development is running into a dead end for several reasons: there are less surpluses available against dump prices, industrial products of developing countries are often not attractive for the spoiled Western consumer, foreign debts are surging, local currencies are devaluing and imports have to be curbed. These changes make it more attractive to bring local agricultural products to the urban markets, to invest in the development of rural regions and

to use fertilizers and other external means of production. This would enable farmers again to grow more of the food where the mouths are. Such renewed urban–rural linkages are essential for a more sustainable and equitable development. It requires a policy that is geared towards strengthening of the infrastructure of roads and markets, of agro-industrial activities in both urban and rural regions, and of agricultural research, teaching and extension.

A THIRD GREEN REVOLUTION?

In spite of the present dismal situation in most of Africa, there are regions with considerable potential, for instance the extended savanna regions, in which growing seasons of about half a year are characterized by a good level of rainfall and radiation and by relatively warm days and cold nights. Soils may be chemically poor but they respond very well to the use of fertilizer and are easy to cultivate. A number of these regions are suitable for the development of productive family farms that are also viable in the long run. To compete successfully with life and work in urban regions it would also be necessary to improve the productivity of labour and to mitigate the drudgery of farming. However, the soils are vulnerable to erosion, so that amelioration measures to control surface run-off are needed and farming systems have to be developed that keep the soil as much as possible covered with crops and mulches. Agricultural systems as developed in the Western world pose far too many risks of erosion. They require also large imports in the form of machines, spare parts and fuel and generate too little employment to be socially attractive.

However, a number of African countries are mainly in the humid lowlands that are covered with tropical rainforests. In some circumstances, part of their demands could be met by expansion of agricultural land use at the expense of natural forests, but in others it would be preferable to save these forests and to meet increasing demands for food on existing agricultural land. Since demand is at least going to double in the coming 25 years, this would require that the yields on the land that is already in agricultural use have to increase at a rate of about $50\,kg\,ha^{-1}\,year^{-1}$. These are as high as green revolution yield increases in the Western world and Asia, but they have to be achieved under far less favourable agro-ecological and socio-economic circumstances. Because of the limited potential for

irrigation and the necessity of erosion control, attempts are made to meet such increasing needs by the development of techniques that build upon traditional systems of shifting cultivation. Systems are then visualized in which fallow periods are shortened by growing annuals and woody perennials in combination and green mulches are used to keep the soil covered. Even biotechnology is not able to create green miracles. Hence, none of these systems are likely to meet increasing needs without an increase in the use of external inputs comparable with those of the first and second green revolutions. This would require a third green revolution, but this is not sufficiently acknowledged because too often the efficiency of traditional subsistence systems is underestimated and the carrying capacity of natural resources is overestimated.

The Sahel may serve as an example. The pastoralists exploit the excellent pastures in the north of the Sahel at the border of the Sahara during the short rainy season by a yearly transhumance and survive the rest of the year in the south of the Sahel, where little feed but sufficient drinking water is available during the dry season. This herding system is labour intensive, but measured by off-take per unit surface area is the most productive system that can be visualized under such agro-ecological circumstances (Breman, 1982). Any attempts to improve production by the introduction of other techniques would fail without the introduction of external production resources. This holds also for a better integration of transhumance in the north with arable farming in the south if this were socially acceptable to begin with.

SOIL VERSUS OIL

About half of the soils on earth may be considered suitable for some form of agriculture. Half of this half is already in use and the other half requires either large efforts to reclaim it, or is very fragile or occupied with ecosystems such as tropical forests that are worth conserving. The only way to avoid a rape of the earth and at the same time to meet the needs of an increasing world population is by the use of intensified agricultural systems that produce increasing amounts of food on land that is already reclaimed and by making use of fossil fuels for the manufacture and use of the external inputs that are needed. By doing so the use of one unrenewable resource is substituted by the use of another.

The wisdom of such a substitution depends on the relative scarcity of soil and oil and the possibilities for substitution (TAC/CGIAR, 1989). Although it is possible to grow valuable crops in water culture on bare rocks, soils are an irreplaceable constituent of natural ecosystems and without them it is practically impossible to maintain agricultural systems for the production of the bulk of food and feed. The proven and surmised reserves of fossil oil are about 100 times the present annual use, whereas huge amounts of fossil energy are available in the form of natural gas, coal, tarsands and others. Unfortunately, their indiscriminate use leads to an increase in the carbon dioxide (CO_2) concentration of the air the adverse effects of which are considered to outweigh the beneficial effects. There are, however, substitutes in the form of solar and wind energy, and nuclear energy out of fission and, possibly, fusion that contribute far less to CO_2 production. Bio-energy recycles the CO_2 but its use is nevertheless counterproductive, because it requires agricultural exploitation of large areas of land.

Obviously, the way we continue to live is not sustainable in the long run, but in the meantime society is likely to be better served by forms of agriculture that save soil at the expense of oil than the other way round.

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