Site productivity, the key to crop productivity

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Introduction

A large part of the world's population still invests the greater part of its energy into cultivating fields and pastures to cover its basic needs, namely acquiring and processing food. In contrast, inhabitants of industrial nations spend the greater part of their life with gathering and managing information. Food in these countries is taken as given and is available 24 hours a day and at all times of the year, offering a big selection. Acquiring food, this basic need of mankind, takes only several minutes of daily life. Due to the (wrong?) assumption that food will also be unlimitedly available in the future, agriculture is loosing its significance in the public eye, both in industrial countries and internationally.

The fact is that agriculture, including the affiliated sectors, is the biggest employer world-wide. At the moment, one billion farmers are producing food for six billion people. Although the challenges to produce improved quality food in increasing quantities for an ever growing population without burdening the environment are given, the investments into international agricultural and ecological research are decreasing.

Especially in development co-operation the opinion is widely spread that there is enough knowledge in the agricultural and ecological sectors available. It just needs to be processed more efficiently, preferably in team work, to overcome problems such as over-use of resources, low crop yields and insufficient marketing structures. Surely it is undeniable that sciences bring forth many detailed data, the meaning of which is perhaps not always analysed in depth. But it is also undeniable that we

are still far away from understanding ecosystems. Even the basically simply organised agro-ecosystems are largely eluding an ecosystem analysis. Without understanding the qualitative effects of anthropogenic influences and their quantification it will hardly be possible to assess the bearing capacity of individual ecosystems. But this is an indispensable precondition for an ever repeated demand for sustainable use of our (cultural) landscape in the various ecozones of our planet.

Man as architect or the derangement of man

Talking about agricultural research means talking about man. That in many ways most highly developed vertebrate which has now been existing in its present form since about 50 000 years. Threatened by disease and hunger and surrounded by enemies man was limited to a small number of individuals at first and his effect on the environment was only regional. Today, man has developed into the maker of biospheres, changing ecosystems permanently. Man is the only organism who managed to dominate all other species.

Economic growth and its associated energy consumption, and also the increasing demand for food are changing the landscape and have since been destroying uncountable plant and animal species. This “derangement” of man probably started about 12 000 years ago. At that time man realised that hunting and gathering were not enough to safeguard his livelihood and he began to cultivate land. He began planting certain plants and domesticating animals. Goats and sheep became domestic animals, the wolf was tamed, later on cattle and the horse. One could also call this period the first "green revolution". Natural ecosystems – mostly forests – were cleared to make room for man's fields and settlements. This process is still continuing to the present day. Every day it irreversibly destroys several species. Depending on the basis of calculation the losses are between 3 and 130 species a day (Wilson 1992). Already Plato (427 – 347 BC) reported about the consequences of deforestation in the Mediterranean region, *"Once, when*

forests still covered the mountains of Attika the earth took up water and kept it, so the soaked-up mass could slowly run through the heights and fill the sources; but now the fat and soft earth has been washed out and only the skinny frame of the land remains – like the skeleton of a sick body."

In the past centuries, western cultures have made great progress in gaining scientific power over nature. Now, a great deal is taking its revenge, as we can see with the environmental pollution and destruction. Our era is characterised by increasing technology and by the use of synthetic chemical compounds which contaminate soil and water. Both resources are becoming noticeably scarce. Furthermore, consumption of fossil fuels are polluting the atmosphere. Everybody is aware of the enlargement of the ozone hole, the increasing loss of that UV-absorbing ozone shield which in evolution once permitted the transfer of life from water to the land. The expected global warming will be the first world-wide damage resulting from man's intervention into the earth's energy household (Metzner 1999).

Since a long time now man's actions and the related effects have not been restricted to only local influence. Our daily behaviour here in Europe influences the lives (survival) of for example people on the islands of the South Pacific (rising of the ocean level resulting from melting of the polar caps through climate warming). We are still far away from understanding the system Earth, but are continuously changing the system without knowing what our actions will result in.

The threat to man by his own kind

Today man is only threatened by his own kind. A continuously growing population ought to think about the question, whether it can procure the necessary resources to feed itself in the long run. Considering only the physical supply, many more people could probably be supported than predicted. But it is also a question of living quality. In industrial countries

the term prosperity has gained importance and is connected to a certain living standard which has not much relevance to living quality in an environment worth living in. One thing is certain. The quickly growing population, at the moment about 1.5 % per annum, will continue to have an impact on the environment, probably much quicker and more lasting than it has already done till today.

From 1830 to 1930, the population grew from one billion to two billion people, i.e. this process took one hundred years, still. The third billion came within 30 years (1930-1960), the fourth billion needed only 15 years (1960-1975). Later on it took only one decade each time to add another billion. Satisfying the increasing demand for food and renewable raw materials will continue the claiming of new forest land.

According to the International Food Policy Research Institute (IFPRI 1999) in Washington, the world's farmers will have to produce 40% more cereals in the year 2020 to meet the food demand, which would be about 2.5 billion tons. Most of this increase shall be achieved by increasing the area productivity. Only a mere fifth (7.4 %) shall be produced by increasing the land area under production, meaning an additional 51 million hectares.

Whether we are able to avoid an increase of arable land and produce the required extra food on land already in use by increasing the productivity will depend largely on the question whether and by how much we will be able to increase the site productivity. A precondition for sustainable production increase would be that each site is used according to what it can bear. It is more than obvious that this is the only way at the moment to prevent a continued destruction of natural ecosystems.

Apart from cereals also the demand for roots and tubers (plus 37 %) and for meat (plus 58%) will increase till 2020. This is not only a result of an increased population but also of urbanisation, especially in southern countries, and the corresponding change of living standard and food preferences. The predicted increase in urban population will go from 1.7

billion in 1995 to 3.4 billion in 2020, meaning that 52% of the population of developing countries will live in urban areas.

The increasing demand for meat products in southern countries calls for special attention. This consumption behaviour represents a change in living situation due to urbanisation and an increase in income. Nevertheless, the per capita demand for cereals and meat in developing countries will still be far behind that of industrial countries. In the year 2020 a person from a developing country will still be consuming less than half of what a person in an industrial country consumes in cereals.

Due to an increasing demand for meat the demand for feed stuffs will also increase. Especially the importance of maize for feed purposes will increase, greatly affecting agriculture and research. According to present predictions, the demand for maize in 2020 will be significantly higher in southern countries than for wheat and rice. About 60% of the demand for maize will be used for animal feeding. In the past 20 years about 40% of the total cereal consumption was used for feeding purposes. Decreasing our meat consumption today could already mean that we might return large areas back to nature or avoid that new areas are taken under the plough, resp.

The challenge of the future

The ecological capacity of the earth is increasingly getting under pressure due to the increasing population (especially in the next decades), due to economic procedures and due to the way we think. Even 200 years after publishing the "Essay on the principle of population as it affects the future improvement of society" by the priest Thomas Robert Malthus (1798) the topic of world-wide food security is still very up to date, but not on the agenda of the well-to-do societies of today. Food security does not only mean supplying enough food but also considers next to availability the quality of the food and the accessibility

for every one. One increasingly scarce food – clean drinking water – needs special attention.

Despite the presently sufficient food production, about 700 million people are still suffering from hunger because they do not have the money to buy the necessary food. This problem will become more pressing due to the fact that it is exactly the poorest societies and countries who will have the biggest population growth rates (2.8 compared to 1.5 % of the world average). In fact those countries which are characterised by low employment rates and low wages (compared to food prices) and which can hardly develop purchasing power.

While the number of individuals demanding food is growing, the resources needed to produce the food are decreasing. In the year 2000 six billion people are sharing 1.5 billion hectares of arable land, which corresponds to 2500 m^2 per person. In 1975 it was still 3200 m^2 per person. If we consider the biologically productive area (about 8.3 billion hectares) of the earth, the population density amounts to 72 persons per km^2. The biologically productive area is continuously degrading. Over-use and non-sustainable agriculture result in deforestation, savannification, desertification and salinisation, contamination of soils and wind and water erosion. *Deforestation* clears the land for agricultural use, settlements, roads and industry. If the deforestation continues unrestrained the area of the tropical forests will be reduced from 1.6 billion ha today to 1.3 billion ha in 2020. As a result flora and fauna species will disappear permanently but also the local and global water household will be strongly influenced. Furthermore, the new areas gained through deforestation are often lost again due to man-induced spreading of savannah and desert and due to degraded arable land caused by salinisation and soil displacement. The acquisition of new or compensation of lost arable land is thus still taking place at the forests' expense.

The anthropogenic-induced savannification is often a result of fire wood use. Forests are an important ecological and economic resource. Only

by using this resource, so freely provided by the nature, could purchasing power and thus civilisations develop. Whether it is possible to keep or improve these better living conditions (civilisations) will depend on the intensity and extent of the future use of this resource.

In many African countries south of the Sahara about 90% of the energy needed is covered by wood. Even with stagnating wood consumption per person, the daily wood demand will be much higher than the regrowth in the whole Sahel, due to population growth (Timberlake, 1985). Over-use inevitably leads to environmental degradation and this in turn increases the social and economic marginalisation of a population, a mechanism which feeds on itself and is often described as a “circulus vitiosus”.

Not seldom the affected population reacts upon such constraints with migration to other regions or urban centres. Africa is the continent anticipated to be urbanised the fastest. Based on the total, the share of urban population was 28% in 1980 and will probably reach 54% by 2020 (WBGU 1996). This rather uncontrolled urbanisation process is more a result of impoverishment than of development, meaning that homes are left due to emergency situations and not voluntarily. Parallel to state internal migration, international migration is also increasing. Today, an estimated 70 million people, mainly from southern countries, are working in foreign countries. Each year the number of those migrating is increasing (at present about one million), a similar number is applying for political asylum (DSW 1994).

Cities are forced to expand at the expense of forests and arable land to be able to take up the immigrants. In the wake of this process, important food, water and energy resources are destroyed. Everywhere near such accumulating centres there are large waste disposal sites to be found which again serve as a living basis for many people. As it is usually not a controlled disposal of waste material, frequently groundwater and drinking water, air and soil are contaminated. Having to find food, energy sources and housing in cities, it seems that man is forced to strain the

environment beyond its limits thus robbing himself of his own essential basis for living.

Due to non-adapted land use practices there are, year by year, enormous erosion incidences, strengthened by wind and water. Surface soil displacement is estimated at 24 tons annually world-wide (Nair & Swaminathan 1997). While soil degradation proceeds rapidly – according to DSW (1994) 11% of the productive soil surface, an area as large as China and India together, have lost their fertility to a large extent between 1950 and 1994 – the soil genesis takes time, often hundreds or thousands of years. The loss of soil which serves as source of site, water and nutrients for plants leads to an endangering of the basis for human food production. Thus, the conservation or rehabilitation of arable land is a major precondition for food security world-wide. Environmental protection, food security and poverty reduction are a complex network. Therefore, an adapted agricultural production, adjusted to the carrying capacity of the environment should be promoted, i.e. adapted to the location, environmentally friendly and thus sustainable cropping methods.

Man is making himself dependent on some few species

The internationally oriented agricultural research, led by the Consultative Group on International Agricultural Research (CGIAR) with its world-wide 16 agricultural research centres, but also the industrial research including seed producing companies concentrate mainly on so-called commodities, i.e. selected agricultural crops (e.g. cereals, rape seed, soybean, cotton). It is only recently that we are fully realising that a crop plant has to grow and thrive in a field within an agro-ecosystem tied into a landscape, that successful production depends on infrastructure and functioning markets as well as on man himself, too.

About 500 years ago with the beginning of globalisation in agriculture and the shipping of crop plants to other continents, there was a big

demand for "new" plant species. As late as in 1787 the British government sent out their ship “Bounty” (note the fitting name) to the South Pacific to collect and take breadfruit trees (*Artocarpus altilis*) to the Caribbean for better food supply there. Even though the first attempt failed with the mutiny on the Bounty the second attempt was a success. Even the name “breadfruit tree” as given by the Europeans upon its discovery, ought to make one think. It is a tree adapted to tropical conditions which today in a semi-domesticated form already delivers 6 tons of dry matter rich in starch per ha and year (Bowers, 1981), a fruit that equals any other starch plant in nutritional value.

Despite the superiority of the breadfruit tree on tropical sites, the future will probably see an increased tropical area planted with maize as a starch source. But especially in the tropics with its heavy rainfalls a permanent cover of the soil is necessary to avoid erosion and nutrient losses. Maize as an annual crop cannot provide this soil protection. Therefore, it would be important for these locations to use trees like the breadfruit as starch sources which additionally, in contrast to maize, make permanent use of the all-season high radiation.

Today, only three crops, rice, wheat and maize, deliver 60% of our protein and food energy. Twenty-one annual crops cover 65% of the world’s arable land. As we have seen with the example of maize, this concentrating process is progressing and, in the case of maize, even more so in future when its demand as feed stuff increases. Increased maize cropping will cause increased soil degradation, especially in the tropics and subtropics where maize is not a well-adapted crop.

One reason for the fact that a decreasing number of crop species are sharing the world's arable land (almost a fifth of the biologically active area of the world) is surely that research funds are being concentrated on projects that promise high market shares and thus profit in as short a time as possible. On the other hand, this led to an accumulation of scientific knowledge over the past decades, so the chances for reaching the set goals are the best there. Thus the gap between well and less

intensely researched crops widens, resulting in an increasing neglect of the latter.

Example rice

Rice is a good example to show that research is mainly crop oriented and less ecosystem oriented. Without doubt rice is a central food and energy source for more than 2 billion people, especially in Asia. The ability of rice to grow in water logged soils has resulted in various and long-term stable agro-ecosystems, several hundred years old. The yield potential of modern irrigation rice varieties is about 10 tons per ha. The world's average yield is 3.8 t ha^{-1} (FAO 1998). The average for Africa is only 2.2 t ha^{-1}. The International Rice Research Institute (IRRI) in the Philippines has been doing research since 1990 to increase the yield potential of rice. To achieve this, plant types with low tillering, strong stalks, thick and erect leaves, intensive root system and an increased yield index are bred. Considering the present yield potentials of rice and the actual yields on the field, one may ask why more should be invested into increasing the yield potential instead of trying to harvest the existing yield potentials first.

Since a few years IRRI is also doing research on functional foods. The aim is to increase the β-carotene content of the endosperm with the help of genetic engineering and, thus, to improve the nutritive value of the rice. For this purpose the first step was to transfer a gene (phytoene synthase gene) from *Narcissus pseudonarcissus* into rice. The much discussed nutritive deficiencies of the South Asian population, especially vitamin A and iron deficiencies, are perhaps a result of the increasing focus on rice as food in the past 30 years. In traditional rice cropping systems one can today still observe women and children collecting fish and crustaceans from the rice fields, so to speak as a by-product of their usual harvest. Only the change of production with high fertiliser applications (e.g. China uses 240 kg N ha^{-1} per year on average together with pesticide application) has led to a loss of these animal protein and mineral sources.

Trying to place a great deal of nutritive value into one crop contradicts the use of a diversified menu composed of cereals, fruits, vegetables etc. Or do we want to exclusively live off rice in the future? Furthermore, such a research direction poses the danger that we will become even more dependent on only some few crops. The question to ask is whether we need such a transformed rice plant. Here, perhaps, progress might be the realisation not to do all that is feasible. Furthermore, it is proven that investing into education and raising the status of women as well as into better food access can prevent the consumption of wrong diets far more effectively.

Site productivity, the key to crop productivity

A modernisation of agriculture based on bio/gene technology with the corresponding agricultural technology is no general solution for providing food security. Rather, it is to be assumed that the yields would only increase in well endowed areas, as was the case with the "green revolution". By using high yielding varieties (rice, wheat) in combination with mineral fertilisers and pesticides, at the same time making use of tractors, harvesting machines and irrigation, the "green revolution" effected immense yield increases, especially in regions with traditional irrigation. About 2 billion farmers who have to make their living off marginal lands were passed by without a trace of this "revolution". A development strategy based on high yielding varieties, agro-chemicals and agro-technology, as again discussed due to the possibilities of biotechnology, strengthens the economic imbalance at the expense of those households who live off less endowed land. But it is precisely these peasant families, often living at a mere survival level, who work the marginal lands, without considering any ecological correlations when farming the hillsides or fishing in mangroves. This results in an ever increasing intensity with which terrestrial and marine ecosystems are being over-used or completely destroyed. The consequences are boundless erosion and loss of biological diversity. Furthermore, erosion increases the sediments carried by rivers, causing flooding in other

places and endorsing destruction of coastal ecosystems The latter is intensified when the mangrove forests which function as a natural sediment filter are cut. In many places this change of ecosystems means the loss of its living basis for the local population. This results in a migration into areas with still intact ecosystems which in turn are being over-used without considering their regeneration ability. It is a terminal process which must be halted.

We should no longer be satisfied with a mere increase in yield numbers as the criterion for successful agricultural research and productivity increase. Therefore, the sciences represented in international-oriented agricultural research ought to dismiss their higher goal of increasing yields for single crops. Agro-ecosystems are part of the landscape and must be understood as such. It is not enough to focus on intensification and maintenance of crop production in order to protect the remaining ecosystems. As the calculations of IFPRI (1999) based on FAO data show, the increase of cereal yields has slowed down continuously since the end of the 60's. In South East Asia the rice yields have even stagnated in the past decade despite the use of high yielding varieties, fertilisation and plant protection. Since the pressure on the available land is increasing, it is also increasingly urgent to obtain continuously stable yields in a region. The emphasis here is on continuously stable and not on maximal yield. In future, we must give our attention to the site performance in its complexity rather than to the yield performance of a crop. The aim cannot be (yet?) to breed a "15 ton rice" when we cannot exhaust even half of the presently available genetic potential of 10 tons ha^{-1} because the site’s conditions are being neglected. Just as a technically highly developed car needs a good road to unfold its performance, a well bred crop needs a well-prepared site. A co-operation between ecological research and agricultural research can greatly contribute to maintain or, better still, improve the natural production potential of an agro-ecosystem. Only through this method can natural ecosystems be protected for a fairly long time against direct access by man.

Semi-natural, balanced systems (without erosion) which are both productive and aesthetic should be striven for. Our constructive energy must be released in the creation of sustainable multifunctional agro-ecosystems. Man and a variety of species must find their place in such a formed landscape and not just survive but also *live*. Thoughts and actions which are exclusively focused on yield performance will ultimately lead to an industrial-like agricultural production, which will result in agricultural deserts, i.e. cleared, ecologically impoverished landscapes where man does not feel comfortable any longer. The environmental effects of industrial-like agricultural production are well known from Europe. We cannot afford to under-use but still less to over-use arable land knowing that there are only limited biologically productive areas on our earth available and that the world population is steadily increasing. Over-use will ultimately lead to the loss of arable land and, thus, natural ecosystems will have to be taken into production for compensation.

Man, as an increasingly active architect of the system has the task to predict the effects resulting from change and to form man's actions in such a way as to be in harmony with the physical and biotic environment. Otherwise, he will run risk of causing his own failure.

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