Crop Science: Progress and Prospects

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Preface

This book contains 20 invited chapters written by renowned scientists from throughout the world, that resulted from the Third International Crop Science Congress held in Hamburg, 17–22 August 2000. After the Congress, the papers were adapted to meet the requirements for a stimulating textbook for advanced students or young professionals. The topics around the theme of the Congress, 'Meeting Future Human Needs', are crucial to crop scientists worldwide. The challenges raised in each chapter clearly show the tasks ahead for crop scientists interested in meeting the demands for food of a growing population in a sustainable way.

The subject matter presented in this book is organized into five general parts that correspond to the four programme themes of the Congress. The first provides an overview of the growing needs of humankind and stresses the constraints imposed by scarce natural resources and the actual genetic potential of crop plants. Part 2 focuses on biotic and abiotic stress in crops and cropping systems. The analysis of the stress situation from the molecular to the system level offers new insights that are a prerequisite for innovative approaches in agronomy and plant breeding. However, agricultural land use is not only the core activity for the production of food, but also a driving force for the diversity and stability of agro-ecosystems. Part 3 explains why regional differences in gene populations as well as biological diversity in agricultural ecosystems are crucial traits for sustainable production systems, while the potential of new technologies is developed in Part 4. Cropping systems can be designed for specific requirements on a more rational basis with the use of decision support systems. Biotechnology offers great opportunities for changing crops for the future. Finally, the book contains the Declaration of Hamburg, expressing the concern of crop scientists about the role of science and society in meeting the demands of future human needs, while a contribution from FAO analyses world agricultural trends from an ethical perspective.

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Foreword

Through the achievements made in crop science and production technology over the last decades, agriculture is now able to feed the majority of the world's population better than in the past. However, there is an increasing concern that the present knowledge, resources and technologies will not be adequate to meet the demands, once there are 8 billion people on this planet by about 2020. Challenges are to feed and to fulfil the needs of a growing population in a sustainable way. This requires a better and more comprehensive insight into ecologically sound crop production processes, especially in fragile environments and resource-poor countries. Furthermore, there is a need to integrate the newly acquired knowledge in the field of gene and information technology in the development of future crops and cropping systems.

Strengthening agricultural research and education at national and international levels is a prerequisite to fulfilling future human needs. There is a need for crop scientists worldwide to rethink their responsibility towards the global needs for food, rural development, and human health and well-being at the one side and the conservation and efficient use of scarce resources at the other. Crop science deals with problems that are consumer related, such as food quality and safety, but at the same time with sustainable use of land, water and genetic resources. The scope is from the gene to the field and from the crop to food and health.

It was a great honour to organize the Third International Crop Science Congress in Europe. The European Society for Agronomy (ESA) in cooperation with the German Societies for Agronomy and for Plant Breeding took the formal responsibilities. Many individuals contributed to the success of this Congress with participants from over 100 countries. The core group of the Programme Committee made an utmost effort to invite outstanding scientists in the various fields to enrich the scientific quality of the programme. The proceedings cover the plenary and keynote papers of four themes: food security and safety, biotic and abiotic stresses, diversity in agroecosystems and future crops and cropping systems. It is highly appreciated that these papers could be published in a way that the proceedings may serve as a textbook for advanced students and young professionals in crop science.

Hartmut Stützel
President ESA 1998–2000

Hubert Spiertz
President ICSC – 2000

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Food Security? We Are Losing Ground Fast!

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Introduction

‘Food security’ is a complex concept. It implies ‘physical and economic access to balanced diets and safe drinking water to all people at all times’ (Swaminathan, 1986). This means that ample food is grown, processed and transported, and that everyone has either money to buy food or grow it. This chapter cannot but deal with the ‘land’ subset of food security issues, and with how ‘land’ relates to food production and to income generation. In particular, this chapter discusses the impacts of land degradation on national food self-sufficiency and household food security. It will first discuss the trends in total cultivated land area and in the quality of the cultivated land, and then translate them as consequences for food production and income generation.

About 60% of the world’s land surface is suitable for grazing, half of which can also be used for arable cropping in a sustainable manner (3.4×10^9 ha). Nations are endowed with good land to very different degrees. The area of land suitable for cropping but still unused is still very significant in southern Africa and the Americas, but suitable unused land is already scarce in Asia and East Africa. Yet, the growing population, particularly in Asia, and the changing diets will lead to a much higher food demand in 2020. Moreover, most population growth will be in urban areas (FAO, 2000). This means that: (i) food production globally should double in the next 20 years; (ii) trade and reduction of urban poverty should make food accessible to the entire urban population; and (iii) farmers on degraded land should acquire new means of generating income and hence achieving food security.

In earlier analyses based on data from the 1960s, some scientists underlined that the global carrying capacity was very large and could meet any

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demand for food (Penning de Vries and Rabbinge, 1997), while others stressed that many poor countries continue to have insufficient income to generate that demand (IFPRI, 1994), or are more conservative about possibilities (Alexandratos, 1995). But new information shows that widespread land degradation seriously threatens global food security, even if money is available, as it lowers the food production and carrying capacity, and moreover reduces the capacity of resource-poor farmers to generate income. Implications for crop science are discussed.

Trends in the Area of Land Cultivated

Irreversible degradation

To produce the food an average human being consumes, 0.05–0.5 ha of land is required. But agricultural land can become degraded completely and irreversibly by various processes, including soil erosion, nutrient mining, salinization and pollution. Among the immediate causes are agricultural practices, such as cultivation without manure or fertilizer, overgrazing and deforestation, and often abetted by an unfavourable climate. Unfavourable socio-economic conditions determine that farmers often cannot avoid such practices. On the basis of a review of more than 80 case studies with data from the 1980s, Scherr (1999) estimated that 16% of all agricultural land in developing countries (total 0.85×10^9 ha) is seriously degraded, meaning that crops can no longer be grown profitably and that restoration is economically impossible. She derived the global average annual loss for the past five decades to be 0.3–1.0% ($5\text{–}8 \times 10^6$ ha) of arable land, and calculated the global loss of agricultural productivity due to the cumulated degradation as high as 5–9%. The rate of loss of productive land is increasing (ADB, 1997). Scherr expects that degradation will force an additional 0.15–0.36×10^9 ha out of production by 2020. This is as much as 10–20% of all land currently cultivated. For an estimate of the future impact of degradation, the conservative and global average of 0.5% loss of agricultural land per year is applied.

Infrastructure

Building of roads and infrastructure often occurs at the expense of cultivated land. A significant portion of land suitable for agriculture is already covered by roads, houses, industries, golf courses and other recreational facilities. In OECD (Organization for Economic Cooperation and Development) countries, the fraction is 10% or more, and in developing countries generally 5% or less, but it generally covers the very best soils (Young, 1998). City encroachment on agricultural land increases the pressure on the remaining land.

Housing, roads and other infrastructures require in the order of 0.025 ha per capita (Young, 1998). This fraction is also rising: the annual loss of agricultural land in China is estimated at 0.5% (Xu, 1994). Also, in OECD countries suburbanization continues, and Evans (2000) cites the same relative rate (equal to 8×10^6 ha year^{-1}) for a global average, and stresses its importance. Compensation by urban agriculture is modest. For extrapolation into the future, the value of 0.1% annual loss is used, similar to the 40-year average.

Acquiring new land

Approximately 1.5×10^9 ha of land is currently cultivated, and another 1.7×10^9 ha is used for grazing and forestry (FAO, 2000). Even though we are losing land area in some regions, more is brought under cultivation elsewhere, and the total area of cultivated land continues to increase in Africa, but is almost stable in Asia (Fig. 1.1). Scherr (1999) and Young (1998) estimated that only an equivalent of 10–30% of currently cropped land is actually still available. Since land resources and populations are very unevenly spread, this implies that resource-poor farmers in some countries are already cultivating marginal lands, the exploitation of which cannot be sustainable: they can extract a living from the soil, but degrade it completely within 5–20 years in many cases. The overall 'degrade and pollute now, pay later' attitude towards environmental problems should therefore change quickly (ADB, 1997). Young (1998) calculated that some countries, including Bangladesh and Pakistan, with 50% or more of the poor population

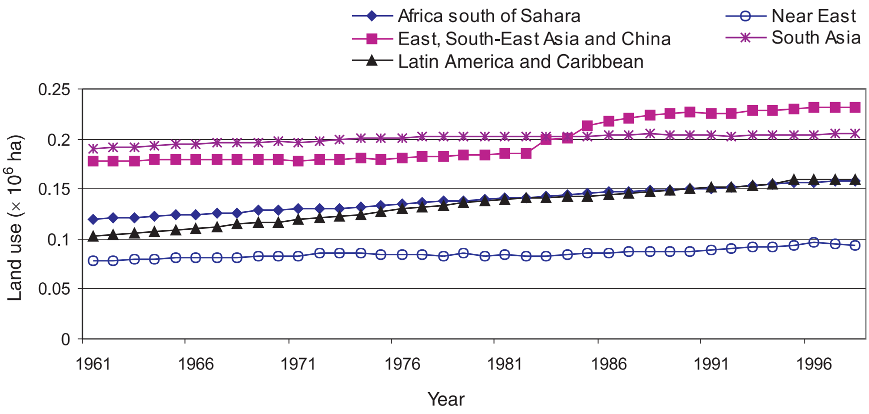

Fig. 1.1. Developments in land use globally, in sub-Saharan Africa (AFR), Middle East and North Africa (MENA), South Asia (SA), South-East and East Asia and the Pacific (EAP), and South plus Central America (LAC), in 10^6 ha (FAO, 2000).

involved in agriculture, have a negative land balance already. It is therefore expected that the cultivated area in Asia will start to contract.

Non-food crops

Some arable land is used for non-food crops. FAO data show that this fraction amounts to approximately 30% (sum of total arable area minus all food crops), and includes tree plantations for timber and paper (10%, Evans, 2000), crops for fibre, flowers and pharmaceuticals. The coarse data show that this percentage became smaller in past decades at the global level (FAO, 2000), and nearly halved in Asia and also, surprisingly, in Africa. While this trend may reverse in the future, expansion of non-food crops does not appear to threaten food production capacity. On the contrary, it provides more income to strengthen food security.

Energy crops

Crops used for energy generation but without any contribution to food production deserve separate attention. The global need for energy is huge, and since oil reserves are dwindling and the Kyoto protocol urges countries to reduce their net output of the greenhouse gas CO_2, energy plantations could theoretically provide a solution. Consumption of non-metabolic energy varies from 20×10^9 J per capita year^{-1} (traditional living in Africa) to 225×10^9 and more (OECD countries). Rapid growth in energy consumption is expected in many developing countries. Energy crops (such as willow coppice) in sustainable plantation systems in Europe yield $5–15 \times 10^3$ kg ha^{-1} year^{-1} of combustible dry matter, or $70–210 \times 10^9$ J ha^{-1} year^{-1}. In the humid tropics with fertilizer the figure may be double, but poor soils in a sub-humid climate yield less. These data imply that if all energy for human use (heating, transport, cooking, etc.) were generated by energy crops, every individual would need 0.2–2.0 ha of plantation. Minimum land area for green energy is clearly an order of magnitude larger than minimum area for food and infrastructure. This could make energy crops clear competitors with food crops for land area. Fortunately, energy crops are not attractive financially: cost per unit of electricity generated from biomass in Europe would be three times as much as electricity from coal (but nearly the same when externalities and an existing subsidy are included; Meuleman and Turkenburg, 1997). Moreover, economy of scale requires this technology to be applied at a large scale ($>1 \times 10^5$ ha), bringing the option to grow energy crops beyond the choice of individual farmers. Rising energy prices could invite large-scale energy crops in areas with a large demand for electricity, insufficient hydropower, and a low capacity to generate income through other crops. Such a development would resemble the use of crops to substitute oil through sugar and alcohol. Although technically this worked well in Brazil and elsewhere, the process has a high minimum throughput and brings a low return to investment. It is therefore expected that energy crops will not provide significant competition to food crops in the next 20–40 years.

The balance: a flight forward

Approximately 1.5×10^9 ha of land is cropped, mainly with food crops (FAO, 2000). Even though we are losing land in parts of many countries, more is brought under cultivation, and the total area of cultivated land is increasing slowly. However, more productive land may have been irreversibly lost in the past 10^4 years than is currently being cropped (Rozanov and colleagues, cited in Scherr, 1999). Ponting (1991) points at the decline of major civilizations, e.g. the Sumerians in southern Mesopotamia, among others, due to unsustainable land and water management. Humanity appears to be slowly consuming the natural resource of 'land'. Even though this process has been ongoing for millennia, it cannot continue much longer since most land and water reserves are nearly fully engaged.

The next 20 years

Extrapolation of the data by Scherr (1999, Table 5), where the category 'severe degradation' corresponds with loss of productive capacity and about two-thirds of all degraded land is 'severely degraded', we find that in Africa 28–35% of the land that was suitable for agriculture in the 1960s will be out of production by 2020 and in Asia 19–26% – the same as the average for the entire world. Judicious practices, including better crops and proper use of fertilizers and water, could stop degradation, and reverse it. Unfortunately, the socio-economic environment in many developing countries (unfavourable prices, markets, land tenure) often still provides insufficient inducement for adoption of these practices (Craswell, 2000). When these conditions do not improve, land degradation will remove 10–20% of land currently cultivated out of production by 2020. Building and infrastructures will remove another 5%. Provided that the area with non-food crops (including energy) does not expand, then 15–25% of the agricultural land will go out of food production between 1990 and 2020. In practice, severely degraded land can no longer be replaced fully by 'new' land on which agriculture could be sustainable. The unequal distribution of good soils and opportunities for non-farm income will force some countries to reach the limit soon, or they have reached it already and use unsuitable land (Young, 1998). Signs that this is happening include land use conflicts around conservation areas, low farm income on the recently acquired lands, rising national imports and accelerated degradation. Particularly when legislation around natural resources remains underdeveloped and land tenure is not arranged, much suffering by resource-poor land users is to be expected.

Figure 1.2 summarizes the developments in land area in five key regions of the world: sub-Saharan Africa (AFR), Latin and Central America (LAC), Middle East and North Africa (MENA), South Asia (SA), and South-East and East Asia (EAP). The figure shows land degraded, land in use and suitable land, all relative to the total area 'suitable for agriculture' before human impact started. We see that in all regions, land for agriculture is progressively consumed, and that the reserves of suitable land are getting smaller. In MENA and SA, land is already being used on which agriculture is unlikely to develop in a sustainable manner, and this fraction is growing. The data for these figures are calculated with the overall averages of rates of change mentioned before, while for the year 2020, a scenario of continued degradation was chosen. The implications for global carrying capacity are not easy to compute, as it relates also to climate and availability of irrigation water. However, very roughly, a loss in land area is proportional to the loss in potential food production.

Large countries can enhance production on their best lands and maintain self-sufficiency. Many (57) developing countries, however, are small and half of them already experience high (0.16–0.30 ha per capita) or very high land pressure (<0.15), so that conserving farmland quality must be a strategic food security concern (Scherr, 1999).

Trends in the Quality of Cultivated Land

Land loses value for agricultural production if it is not adequately managed. Degradation refers to removal of nutrients (soil mining) or soil and nutrients (erosion), salinization and compaction. Nutrient depletion occurs when crops are harvested and nutrients are not returned to the field, or replaced by manure or fertilizers. This can lead to acidification and is common on poor soils in areas with marginal agriculture. The most destructive process, erosion, occurs on sloping land when rain hits soil when it is vulnerable after tillage (Turkelboom, 1999), or from building infrastructures (Enters, 2000). It removes soil with nutrients from slopes and deposits it in valleys, where the sediments may enhance agriculture or silt up waterways and reservoirs. Salinization occurs when salt, brought by water to the surface, is not flushed down or out regularly. Land in several large irrigation schemes suffers seriously from salinization.

Light and moderate soil degradation affects agriculture in three ways (Fig. 1.3): (i) it reduces maximum crop yield (by affecting the water holding capacity of the soils for rainfed cultivation); (ii) it lowers actual yields if little fertilizer is used (weaker input use efficiency, less profit, increasing weeds); and (iii) it increases the risk of crop failure. These factors make production

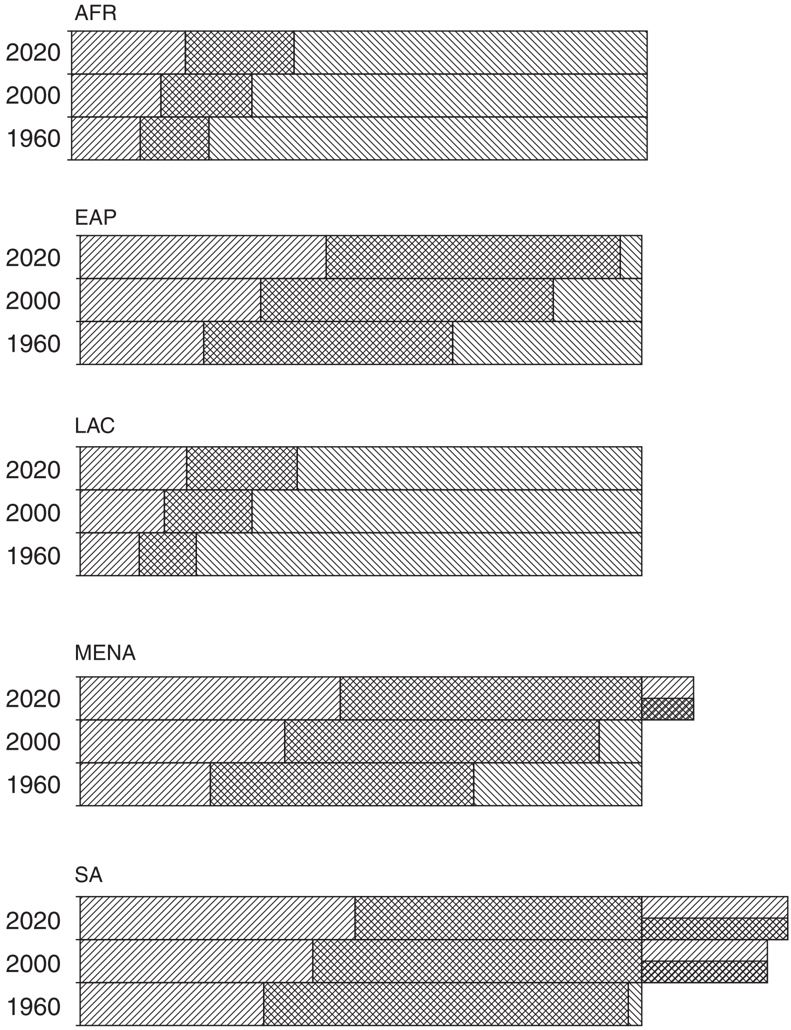

Fig. 1.2. The fraction of land suitable for sustainable agriculture that is still available (right), the land currently in use for arable and permanent crops (centre), and the area degraded to an extent that is not cultivable and recovery is uneconomical (left) is shown for all regions. The lower set of bars indicates the situation in 1960, the middle set the current situation (2000), and the upper set the situation for 2020 for a medium scenario of development described in the text. The bar is split when more land is 'used' than is 'available' for sustainable agriculture. See p. 6 for abbreviations.

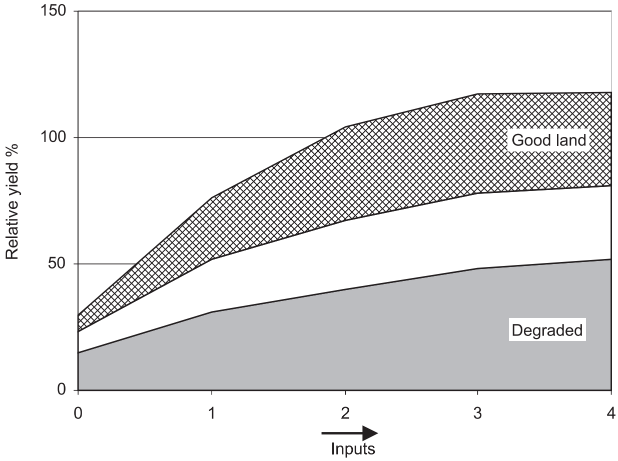

Fig. 1.3. Two hypothetical sets of curves of crop yield in rainfed conditions as a function of the level of inputs (labour, water, fertilizer, crop protection). The set on degraded land shows lower maximum yields, reduced input efficiency and higher risk.

costs higher (Scherr, 2001), generation of income more difficult, and investment in agriculture less attractive. Indirectly, land degradation tends to decrease rural household food security.

While it is impossible to be precise about the extent and rate of loss of soil quality due to the multitude of processes and causes, the shortage of specific data, and the sometimes localized appearance of the problems, a brief overview will show that the global community is suffering large physical and economic losses.

Global

The publication of the Global Assessment of Land Degradation (GLASOD) made it possible to provide an estimate of the extent of human-induced soil degradation (Oldeman *et al.*, 1991), and it is still the main study that underlies many analyses. One of these suggests an aggregate global loss of 11.9–13.4% in productivity due to human-induced degradation since the mid-1940s (Crosson, 1995); 22% of the area suitable for agriculture is damaged, and the average global cumulative loss of potential productivity is 5–9% (Oldeman, 1994).

Degradation brings huge losses in the production capacity of the land resource. For example, the total annual cost of erosion from agriculture in the USA only is about US$44 × 10^9, about US$250 per hectare of cropland

and pasture. On a global scale, annual displacement of 75×10^9 t soil causes a $\$4 \times 10^{11}$ reduction in value of the global natural resource (Eswaran *et al.*, 2001) – even considering important off-site effects. Continued nutrient depletion undermines the long-term sustainability of vast areas of land. Gruhn and Goletti (1998) estimated that by 2020, the annual global net nutrient removal will reach more than 350×10^9 kg. Global inorganic fertilizer production in 2001 is only 157×10^9 kg. The projected 2020 supply of fertilizer falls short of covering the gap, let alone restoring the already lowered level of soil nutrients.

Africa

Overall yield reduction caused by past soil erosion in Africa is estimated to be 9%, and if the current rates continue, it will amount to 16.5% by 2020 (Bridges and Oldeman, 2001). This is based, among others, on Lal (1995) who suggests a yield reduction of 2–5% for each mm of lost soil (apart from its value as sediment). Agricultural productivity in sub-Saharan Africa derives its value of 7% directly from nutrient depletion of its soils (Drechsel and Penning de Vries, 2001). Human-induced desertification is experienced on 33% of the global land surface and affects more than 10^9 persons, half of whom live in Africa (Beinroth *et al.*, 2001). Half of the rainfed lands in Africa experience at least a 10% loss in productive potential, and irreversible productivity losses of at least 20% due to erosion occur in large parts of 11 countries (Dregne, 1990). GLASOD estimated cropland productivity loss to be 25% (Oldeman *et al.*, 1991). The gross discounted future loss from degradation varied from under 1% to 18%, and the gross discounted cumulative loss (which assumed a continued process of degradation over time) for five countries ranged from under 1% to 36% to 44% of the annual gross domestic product (AGDP) (Scherr, 2001).

Asia

The expert survey, Assessment of Soil Degradation in South and South-East Asia (ASSOD), found ‘moderate’ (or worse) impacts of soil degradation on 10% of all lands, and that serious fertility decline or salinization affected at least 15% of arable land (van Lynden and Oldeman, 1997). The annual cost of soil degradation in South Asia was estimated to be US$$9.8–11.0 \times 10^9$, the equivalent of 7% of aggregate AGDP. In South Asia, annual loss in productivity is estimated at 36×10^9 kg cereal equivalent valued at US$5400 million by water erosion and US$1800 million due to wind erosion (Beinroth *et al.*, 2001).

Uncoupling production and consumption

Degradation is also related to the trend of uncoupling food producers and consumers. This started long ago and is accelerating because farmers have become specialists who sell all or most of their produce and buy other food items. Urban populations grow rapidly: nearly all population growth of 2 billion persons in the next decades will be in cities, particularly in Asia (FAO, 2000), and (inter)national food trade will continue to grow. Trade is positive in that it provides consumers with a larger diversity and minimal cost. But trade also gives rise to the ecological problem of incomplete recycling of crop nutrients (Miwa, 1990). Large quantities of crop nutrients are mined from rural soils and transported in processed and unprocessed food items to cities or feedlots. For Bangkok, which already gives much attention to a clean environment, Faerge *et al.* (2001) found that while the annual influx of N in food is 19.4×10^6 kg, and 1.8×10^6 kg of P, only 7% (N) and 10% (P) is recycled to agriculture. The remainder accumulates in land and water, pollutes canals and rivers and leads to health problems, or is burned or denitrified. Such a low degree of recycling is common among large cities. Cities in OECD countries avoid health problems by waste burning and dumping, but also do not comply with the ecological requirement of recycling. The magnitude of the problem in developing countries is not yet evident, but it ought to be addressed now that we are on the verge of a strong growth in size and numbers (ADB, 1997). Since nutrients are not returned to the region of origin, and in many degraded lands not fully replaced by fertilizers (as their use is not warranted due to low produce price), an imbalance is created between urban and rural areas, internationally. Due to export, production capacity declines and the value of the land as a provider of non-marketable ecosystem services, on gross average double that of marketed services (Constanza *et al.*, 1997), is reduced.

Food security

Loss of soil quality is of particular importance for household food security in marginal areas, because acquiring a fair income becomes more and more difficult when degradation progresses. Whenever land is without clear tenure, people do not invest, even if other conditions are favourable. This and other issues should be addressed at political levels. But there is insufficient awareness and urgency because degradation is, by political standards, a slow process and its effects are postponed because of compensation in various ways (new land, extra fertilizer use, etc.). National food security is not threatened by degradation of land quality, as food can be bought from other countries, but food self-sufficiency is vulnerable.

Counteracting Losses of Natural Resources

Reports and documents about degradation are not clear in their definitions. This leads to uncertainty and variability. For example, a large multi-institutional study (WRI, 2000) reports that two-thirds of agricultural land is degraded; Scherr (1999) mentioned 38%. Yet it is clear that the problem is urgent, and that many of the actions recommended are beyond soil and crop science. Scherr (1999) concluded that:

> Degradation appears not to threaten aggregate global food supply by 2020, though world commodity prices and malnutrition may rise. . . . The area of soil degradation is extensive, and the effects of soil degradation on food consumption by the rural poor, agricultural markets and, in some cases, national wealth are significant. ... Active policy intervention will be needed to avert the consequences of soil degradation and harness land improvements to broader development efforts.

Pagiola (2001) adds that:

> Widespread land degradation not only affects agricultural production and watershed-scale natural resources, but may also have global environmental impacts. Terrestrial ecosystems are an important carbon sink, and declining above- and belowground biomass due to degradation can reduce this sink. Land degradation may also reduce biodiversity by forcing farmers to clear additional land or reducing native vegetation in agricultural areas.

In an optimistic view, Greenland *et al.* (1998) state that with the political will, and the necessary commitment to education and research, lowered food security could be prevented. Our analyses add that loss and degradation of agricultural land seriously reduce the options of many nations for food self-sufficiency, and cause many farmers to learn new skills and to try to earn an off-farm income. Degradation of agricultural lands makes farm products more expensive, or eliminates any profit and forces many farmers to leave their income-generating farming.

Implications for Crop Science

The challenge is to increase both farm productivity and sustainability. However, the related requirements are sometimes conflicting at the physiological, agronomic and economic levels, so that an exclusive focus on one aspect will not yield the optimum solution.

Land degradation would be less if more biomass were returned to the land or if more roots were left after the harvest. This would help to maintain, or even increase, the level of soil organic matter. In addition, this would increase C-sequestration. Perennial plants are more suitable to build up root mass than annual crops, and prevent and suppress erosion better. A larger root biomass may be achieved with new varieties that recycle more nutrients from leaves and stems to roots shortly before the harvest (IRRI, 1991). The requirement for more biomass and nutrients (returned) in root systems is contrary to the search for the maximum yield.

Land degradation invites crop scientists to address more production processes under severe stress conditions, such as drought, nutrient shortage and salinity. This includes eco-physiological research and identification of non-food crop species that do better under stress. Grasslands are still less exploited, and research is welcome on how to use and manage them better for food production.

National food self-sufficiency would be enhanced if the productivity of food crops on good land were greater. This warrants research on further yield increases. But household food security on rural and marginal land (hundreds of millions of hectares) will be unaffected if poor lands do not generate more income.

Applying chemical fertilizer to the land can prevent nutrient depletion. In many countries there is a significant resistance to chemical fertilizer. In the long run, this is a threat to food security. This may be overcome by better practices and by example. Introduction of N-fixation for new crops could be interesting, but it probably still remains in the distant future and will only be really helpful if poor farmers have economic access and do not resist genetically modified organisms (GMOs).

Lastly, much more attention is required to recycling between production and consumption sites, even though this will increase cost. One problem is that low value waste, which is very variable, is often contaminated, and has to be upgraded and transported over significant distances to poor farmers. (Peri)-urban farmers might provide an option, but processing closer to the rural farm could also help.

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