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Global crop production and the efficacy of crop protection – current situation and future trends

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Abstract

Actual and potential crop losses of eight major food and cash crops have been estimated by evaluating data from literature and field experiments. Total losses were calculated from yield reductions due to pathogens, animal pests and weeds on a regional, continental and global level. Since 1965, worldwide production of most crops has increased considerably. Simultaneously, crop losses in wheat, potatoes, barley and rice increased by 4 to 10 percent, in maize, soybean, cotton and coffee losses remained unchanged or slightly decreased. The efficacy of crop protection practices was calculated as the percentage of potential losses prevented by control. The efficacy is highest in cotton (55 percent), it reaches only 34 to 38 percent in the food crops rice, wheat and maize. The variability among cropping areas is high: In Western Europe, 61 percent of potential crop losses is prevented, in North America and Oceania 44, in all other regions 38 percent. Due to the small share of Western Europe in worldwide production of 8 percent, the efficacy of actual crop protection worldwide is only 40 percent.

In view of population growth and rising food demand crop production has to be increased substantially. As potential loss rates often increase with attainable yields high productivity largely depends on effective crop protection management. Scenarios for the production of food crops by the year 2025 in developed and in developing countries are given. Recent and future developments in crop protection can contribute to establish sustainability in agriculture and to preserve natural resources. However, although effective control methods have been developed for most biotic yield constraints, the use of crop protection products is regulated by economic considerations rather than by food demand.

Introduction

Poverty-related environmental pressures, agricultural practices, consumption patterns and policies contribute to the actual problems of agriculture and food supply (Alexandratos, 1995). Actual agricultural production is characterized by high-input systems with high productivity and surplus production in developed countries, and by low-input systems, production deficits and malnourishment in many developing countries. Production of food and feed is limited due to limitations in natural resources such as arable land, water, soil fertility, inherent (genetic) productivity of crops, etc., in the ability of man to maintain or replenish these resources, and in shortcomings of protecting crops against biotic and abiotic constraints.

In general, agricultural systems are not ‘natural’, undisturbed ecosystems, and the inherent control mechanisms are often not sufficient to safeguard high crop productivity. Farmers have to cope with the competition of other organisms which are favored by the uniformity and repeated cultivation of susceptible crops endangering productivity. In order to promote crop growth and yield farmers have to protect plants against pests, organisms damaging crops grown for human consumption.

The ultimate purpose of crop protection is not the elimination of pests, but to minimize crop losses to an economically acceptable level. The efficacy of actual crop protection measures, differing from region to region, has been calculated from actual and potential losses due to diseases, animal pests and weeds using a 'no loss scenario' and a 'no control scenario' for the eight most important food and cash crops rice, wheat, barley, maize, potatoes, soybean, cotton and coffee. The development of production and crop losses since 1965 have been used for estimating production data for 2025 necessary to meet the growing food demand. The implications on crop protection, demands and management, will be outlined.

Estimation of potential and actual losses in 1991–93, by crop, and by region

In a world with high population growth the assessment of the potential and the actual performance of pest control practices is essential. Actual and potential losses to pests in eight economically important crops, estimated for 1988–90 by summarizing data from about 15,700 literature references and 3,700 field trials (Oerke et al., 1994), are updated for 1991–93. On a regional and global scale loss rates are estimated to calculate the significance and contribution of pest control in crop production. Data sources and methodology have been described previously (Oerke et al., 1994). Actual yields reported by FAO and actual yield loss rates estimated from literature resulted in the attainable yields ('no loss scenario'). Attainable yields minus potential losses gave the yields of the 'no control scenario'. Potential losses were estimated from literature and experimental field data using the control/no-control approach. Total loss rates (lr_t) were calculated from the loss rates for diseases (lr_D), animal pests (lr_A), and weeds (lr_W), respectively, according to the formula: $lr_t[\%] = 100 - [(100 - lr_D)(100 - lr_A)(100 - lr_W)/10^4]$. The yield effect or efficacy of actual crop protection practices has been calculated as percentage of potential losses prevented by control measures: EF = (potential loss rate − actual loss rate)/potential loss rate ∗ 100.

The potential loss rate due to pathogens, animal pests and weeds among the crops investigated is highest in cotton and rice, crops primarily grown in tropic and subtropic areas favoring the incidence and severity of pests. Without any control, worldwide 82 percent of the attainable rice harvest would be lost, mostly to weeds and animal pests, however, the importance of diseases is increasing. Mechanical, biological and chemical control measures reduce losses to an actual rate of about 50 percent (Figure 1). In wheat, the most important cereal crop next to rice which is grown especially under temperate conditions and in the subtropics, potential losses are considerably lower, the importance of animal pests is relative small. The potential loss rate worldwide totals 52 percent of the attainable production. Actual losses are at 34 percent. Similar to rice, the control of weeds is more effective than the control of pathogens and animal pests.

Among the dicotyledonous crops investigated potatoes are most important for food production in many areas. Potential losses worldwide are estimated to be as high as 73 percent (Figure 2). All pest groups are of similar importance. Actual crop losses reach 40 percent as diseases like potato late blight and viruses as well as insect pests like Colorado beetle and potato tuber moth are widespread and often difficult to control.

Considering the different cultivation situations in important growing areas, losses in three regions differing in crop productivity are summarized in Figure 3. In Western Europe, with temperate climate and high productivity, potential losses account for 57 percent of the attainable production, namely of wheat, barley, maize and potatoes. Losses to pathogens are high due to high intensity of cultivation. Effective control of all pest groups reduces losses to an actual rate of 21 percent. In North America and Oceania where cultivation of some crops is characterized by large-scale production at lower intensity, potential losses of the eight crops investigated average 56 percent. Although herbicide applications are common the use of fungicides and insecticides is widely restricted to some high-value crops and areas of intensive cropping. At 32 percent actual losses are higher than in Western Europe. In all other parts of the world, potential losses are high at 72 percent although intensity of cultivation is often low. Climatic conditions favoring the epidemic development of pests in the tropics and subtropics and the cultivation of crops susceptible to pests like cotton, rice and coffee result in high potential losses which are reduced actually to about 45 percent of the attainable yield.

The efficacy of pest control on crop yields is highest in cash crops like cotton and coffee (Table 1). On a global scale, 56 and 46 percent, respectively, of the potential losses are prevented in these crops whereas in food crops often grown for subsistence without governmental support, only 36 to 38 percent are prevented. However, regional variation is higher than the differences among crops. Differences among regions are high especially in food crops whereas variation is smaller in cash crops. In Western Europe, efficacy of crop protection in 1988–90 was higher than 60 percent (Table 2). In North America and Oceania about 43

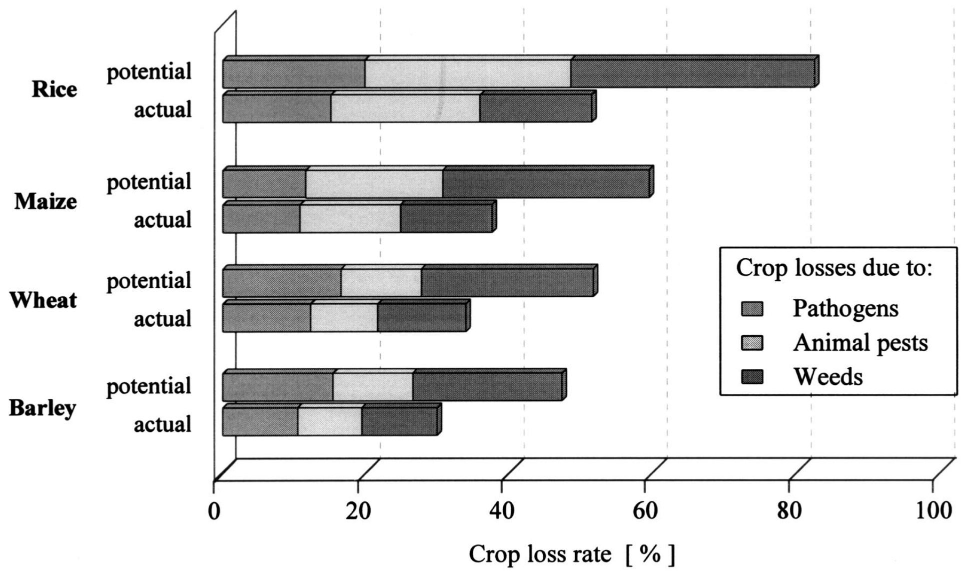

Figure 1. Potential and actual crop losses due to pathogens, animal pests, and weeds in monocotyledonous crops, in 1991–93.

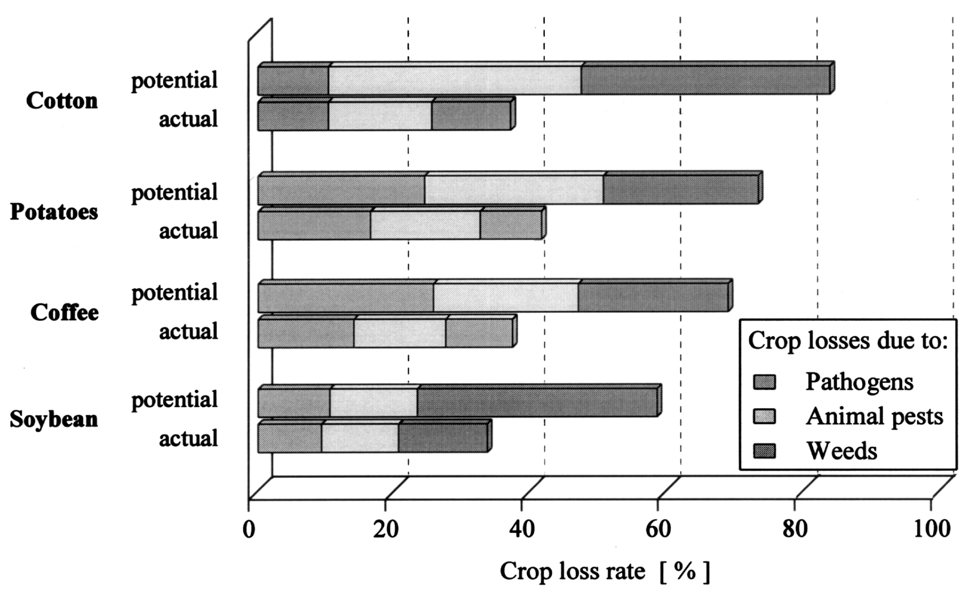

Figure 2. Potential and actual crop losses due to pathogens, animal pests, and weeds in dicotyledonous crops, in 1991–93.

percent, in all other regions 37 percent of potential losses have been prevented. Especially in large parts of Africa, South Asia and Latin America disease control is rare and often would not be cost-effective because of low productivity of cultivation.

Worldwide, disease control reduces the potential losses by 23 percent. The yield limiting potentials of animal pests and weeds are reduced more efficiently by 31 and 55 percent, respectively (Table 2). Weed control manages an average efficacy of more than 50 percent because control may be either chemical, mechanical or by hand. The maxima for efficacy of more than 70 percent of potential losses prevented clearly demonstrate the potential of modern crop protection. How-

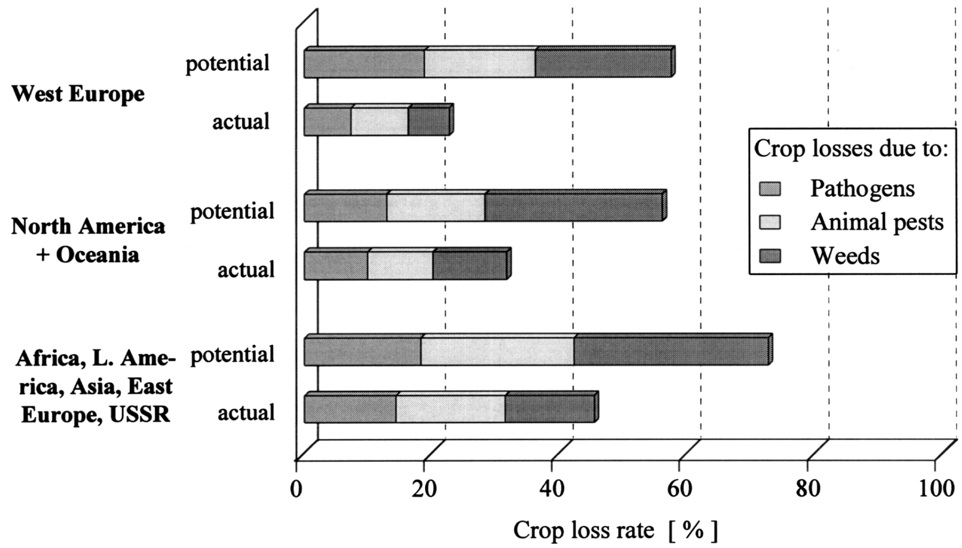

Figure 3. Potential and actual crop losses due to pathogens, animal pests, and weeds in eight major food and cash crops, in 1991–93, by region.

Table 1. Efficacy of crop protection practiced in 1991–93 on crop yields, by crop (worldwide averages, and minima and maxima in regions)

Crop	Potential loss rate [%]	Efficacy of crop protection [%]		
		Worldwide average	Minimum	Maximum
Cotton	83.8	56	24	66
Rice	82.4	38	18	73
Potatoes	73.4	43	11	64
Coffee	69.0	46	20	57
Maize	59.3	36	11	69
Soybean	58.6	43	30	60
Wheat	51.6	35	11	68
Barley	47.2	37	10	70

ever, modern crop management often is confined to regions with high productivity of agriculture which is closely related to the prosperity of national economies.

Trends in production and losses since 1965

Comparing crop production and actual losses to pests for 1991–93 to data from 1965, when Cramer (1967) estimated crop losses for more than 60 crops using similar methodology, the differences between regions and crops, respectively, are evident (Table 3). Worldwide, production of food and cash crops increased considerably, however, crop losses increased not only in absolute but also in relative terms. In West Europe, intensive (chemical) crop protection almost prevented a rise of losses despite increasing potential losses due to reductions in crop rotations, increased fertilizer use and the use of high-yielding varieties often susceptible to pests. Considering the variability of estimates, loss rates for grain crops increased only slightly and decreased slightly in high-value crops. In North America and Oceania, with higher loss rates in grain crops, the trends are very similar. In contrast, crop losses in most other cropping areas increased, in some crops considerably.

In many developing countries the high loss rates of 1965 have increased further because production has been raised by the use of high-yielding varieties, fertilizer use and a rise in cropping intensity, all factors reducing the ability of crops to withstand competition from pests. Yields per unit of area were often low in 1965 and actual available levels have been raised to a lesser extent than attainable yields. The high damage potential of pathogens, animal pests and weeds can be controlled only by an adequate intensification of crop protection, i.e. the use of varieties resistant/tolerant to pests, crop rotation, mechanical, biological and chemical control. The high potential of actual crop protection methods is demonstrated under intensive farming in industrialized countries and in cash crops. However, the transfer of methods from one region to another is often not feasible.

Figure 4 depicts the relationship between attainable yield and potential losses. In 205 wheat trials in

Table 2. Efficacy of crop protection practiced in 1991–93 on crop yields, by region, and by pest group

Region	Potential loss rate	Efficacy [%]	Pest group	Potential loss rate	Efficacy [%]
West Europe	57%	61	Pathogens	17.5%	23
North America and Oceania	56%	43	Animal pests	22.7%	31
Rest of world	73%	37	Weeds	29.6%	55
World, total	69%	40			

Table 3. Production and actual losses due to pests in major food crops (rice, wheat and maize) and cash crops (cotton), in 1965 and 1991–93, respectively

Crop(s)	Region	1965		1991–93	
		Production [million t]	Cross losses [%]	Production [million t]	Crop losses [%]
Wheat, rice and maize	World	746.8	36	1,578.3	42
	West Europe	30.3	14	105.4	18
	North America + Oceania	169.8	28	318.9	32
	Rest of world	546.7	39	1,154.0	46
Cotton	World	37.0	34	53.9	37
	West Europe	0.3	29	1.0	27
	North America + Oceania	10.5	33	10.6	31
	Rest of world	24.0	34	42.4	39

Germany between 1985 and 1990, losses to diseases increased not only in absolute terms but also in relative terms, from 11 percent with an attainable yield of 4 t/ha to 20 percent with 11 t/ha. The same applies to the damaging effect of weeds in rice, demonstrated by the yield response of rice in 312 field trials in Japan. Potential loss rates increased from 29 to 35 percent, from 1.2 to 3.5 t/ha in absolute terms. The epidemic spread of and crop damage by pathogens and animal pests is favored by short rotation, lush biomass production, plant tissue with high water content and rich in nutrients as well as by micro-climatic changes. Simultaneously, the competitiveness of crops for water, nutrients and light and their ability to compensate for small physiological disorders are reduced in intensive farming systems. Therefore, the use of high-yielding varieties and fertilizers as well as irrigation not only increase crop productivity but also the dependence on crop protection management.

Population growth and food demand

The world's grain production increased from 640 $\cdot 10^6$ t in 1934–8 to 1,740$\cdot 10^6$ t in 1988 due to increases in the area under cultivation, improvements in cultivars and management practices including irrigation, more effective pest control and mechanization, and improved plant nutrition. Per capita dietary energy supplies in developing countries rose by 27 percent from 1961–63 to 1987–89 (Mitchell and Ingco, 1993). However, there are concerns for the future of agriculture because production is either insufficient – in many developing countries – or is perceived to be unsustainable (Loomis and Connor, 1992). Actual agricultural production is characterized by surplus production in many developed countries, especially Western Europe, and production deficits in many developing countries, this applies primarily to Sub-Saharan Africa. Chronic malnutrition affects some 800$\cdot 10^6$ people, 20 percent of the population of the developing countries, as many as 37 percent in Sub-Saharan Africa and still more in some individual countries (Alexandratos, 1995).

World population continues to grow. Estimates on future population growth vary, sometimes considerably, depending on the factors included for the calculations. They should consider factors related to the economic and social development in different regions: distribution of poverty and welfare; access to education, especially for women, and labour; political and

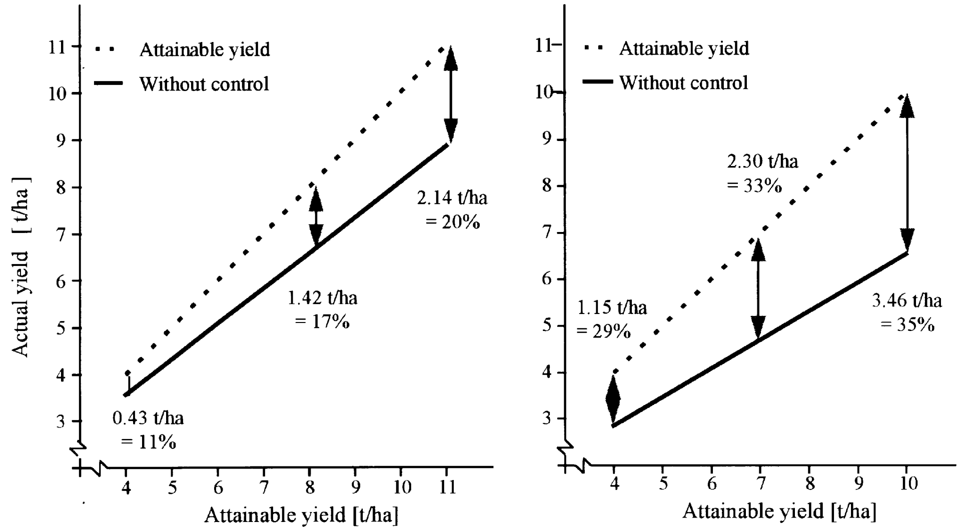

Figure 4. Relationship between attainable yield and susceptibility of crops to losses to pests: results from 207 fungicide trials in wheat in Germany (left) and 314 herbicide trials in rice in Japan, in 1985–90.

social efforts to reduce population growth; availability of food, etc. Population is expected to increase from $5.3 \cdot 10^9$ in 1990 to 7 to $7.2 \cdot 10^9$ in 2010, and to 8.2 to $8.5 \cdot 10^9$ in 2025, more than 90 percent will be in developing countries (Figure 5, modified from McCalla, 1994). The population in Asia will nearly double to over $4{,}000 \cdot 10^6$, while that in sub-Saharan Africa will more than triple. In developed countries, growth rate will be only small, in Europe nearly zero. In 1985, 75 percent of the world's population lived in developing countries, this figure will rise to 83 percent by 2025. The number of malnourished will rise to over $1{,}000 \cdot 10^6$.

In addition to population growth, income growth also increases the demand for food. Even with modest income growth in developing countries, the demand for food in 2025 will be more than double current levels (McCalla, 1994). Further, urbanization, in conjunction with income growth, will cause the character of diets to shift from roots and tubers and lower quality staple grains to higher quality cereals, such as rice and wheat, livestock products, and vegetables. More animal protein can be produced only by high input of feed: two kilograms of grain for producing 1 kg of poultry, 4 kg for 1 kg of pork, 7 kg for 1 kg of beef.

Concerned about future food supply of the growing population, the FAO has published the report 'World Agriculture: Towards 2010' (Alexandratos, 1995). Its major statements are: The land in crop production in developing countries (excluding China) will rise by about $90 \cdot 10^6$ ha to some $850 \cdot 10^6$ ha; the intensity of land use (land cropped and harvested in a year) will rise from 79 to 85 percent. Irrigation has to be increased by $23 \cdot 10^6$ ha or 19 percent in a net sense, i.e. on top of the expansion needed to offset losses of irrigated land due to salinization. Fertilizer use in the developing countries will rise from 62 kg/ha of harvested area (about one-half the average of developed countries) by 3.8 percent p.a. to some 110 kg/ha. As regional differences remain high (11 kg/ha in sub-Saharan Africa to 90 kg/ha in Near East/North Africa) a doubling by 2010 would still be nutrient mining in some areas, in others it would mean excessive use.

Considering a projection till the year 2025, arable land should grow by about $95 \cdot 10^6$ ha, developed countries having a share of only $4 \cdot 10^6$ ha (Table 4). The contribution of increasing land in production to meet the increasing food demand was calculated similar to Alexandratos (1995) estimating a contribution of 15 percent for the longer period till 2025 instead of 22 percent for the period till 2010. As the most productive soils have been farmed first, potential yields from new lands are generally low, and disproportionately larger additional area is required to satisfy food needs, it is a rather optimistic scenario. However, because of the population growth, on a global level, the arable land per caput will decline by 24 percent from currently 2,500 m^2. More important, the arable land per caput will decrease in developing countries, which are already today short in land, more rapidly than in developed

Figure 5. Actual distribution of world population, by region, and projection for population growth until 2025.

Table 4. Changes in arable land and arable land per caput from 1975 to 1990 and trends to 2025 necessary to meet food demand [estimated from data from FAO (1992), McCalla (1994), and Alexandratos (1995)]

Region	Development 1975 to 1990		Projection 1990 to 2025	
	Arable land	Land per caput	Arable land	Land per caput
World	0.22% p.a. (43 M ha)[1]	−1.50% p.a. (1990 = 2,549 m²)[2]	0.23% p.a. (≈95 M ha)	−0.75% p.a. (2025 = 1,959 m²)
Developing countries	0.37% p.a. (38 M ha)	−1.70% p.a. (1990 = 1,730 m²)	0.35% p.a. (≈90 M ha)	−0.85% p.a. (2025 = 1,283 m²)
Developed countries	0.05% p.a. (5 M ha)	−0.70% p.a. (1990 = 5,196 m²)	0.02% p.a. (≈4 M ha)	−0.35% p.a. (2025 = 4,596 m²)

[1] change in absolute terms [million ha].
[2] arable land per caput in absolute terms [m^2/caput] in 1990 and 2025, respectively.

countries. In East Asia, for example, only 600 to 625 m^2 can be used for food production per caput in 2025.

Increasing productivity in many developing countries is already putting stress on the natural resources – in some countries as much land is lost to erosion and salinization as is brought into production through irrigation or area expansion. During the next 30 years degradation of soils due to deforestation, overgrazing and mismanagement of arable land is estimated to affect some $1.2 \cdot 10^9$ ha of land worldwide, of which about $450 \cdot 10^6$ ha are in Asia (McCalla, 1994). At present, 5 percent of arable land has been lost due to incorrect use, as much as 9 percent in Asia, and only 1 percent in Oceania (Netherlands Scientific Council for Government Policy, 1995). According to the United Nations Environment Program (UNEP) 60 percent of the 3.3 10^9 ha of arable land are at risk to desertification, especially in South Asia, East Africa and the Andes. Constant farmers' pressure on land with poor land-use, caused by high rates of population increase, makes it probable that much of the soil degradation will be permanent. The annual rate of deforestation till 2010 is estimated at $4.2 \cdot 10^6$ ha, or 0.25 percent p.a. of the total forest area (Alexandratos, 1995). If trends for changing forest land into arable land continue – in the period 1980–90 arable land increased by $32 \cdot 10^6$ ha while forest area decreased by $150 \cdot 10^6$ ha – at least $240 \cdot 10^6$ ha of forest will have disappeared by the year 2025.

While yields of some cereals have doubled in the last thirty years, yields of most other developing country crops – such as maize, cassava, sorghum, millet, beans, and edible legumes – have shown less rapid increases. The doubling of basic food products necessary to meet food demand is impossible without increased research and development efforts. Worldwide experimental trials indicate that for rice genetic improvement possible by conventional breeding methods has been largely exhausted. Biotechnology represents an attractive approach to attain dramatic increases in rice productivity by expanding the genetic base of rice germplasm (Ford et al., 1994). However, despite enormous progress in basic biotechnologies the impact on food production is much slower than predicted earlier (McCalla, 1994). Till 2010, growth rate of world agricultural production at 1.8 percent p.a. will be lower compared to the 3.0 percent p.a. in the 1960s, 2.3 percent p.a. in the 1970s and 2.0 percent p.a. in the period 1980–92 (Alexandratos, 1995).

World per caput supplies of food for direct human consumption are today some 18 percent above the level 30 years ago. But the development has been uneven and unstable, and the situation in sub-Saharan Africa is worse than 30 or 20 years ago. In parallel, continuous population growth has meant that the absolute number concerned worldwide has fallen only modestly and remains high at some $800 \cdot 10^6$ persons (Alexandratos, 1995). Per caput production of cereals has grown from 302 kg in 1969–71 to a maximum of 342 kg in 1984–86. Since then it declined to 326 kg in 1990–92 and it is likely that the worldwide average may not grow further and it would still be 326 kg in 2010. In developing countries it will grow from 216 kg in 1988/90 to 229 kg in 2010 (actual consumption in developed countries: 635 kg per caput). Per caput food supplies in the developing countries will con-tinue to grow, from nearly 2,500 calories to just over 2,700 calories by the year 2010. Progress will be made in Near East/North Africa, East Asia and Latin America/Caribbean regions, however, chronic malnutrition is likely to be widespread in South Asia and sub-Saharan Africa with 37 percent of the population affected. Net imports of cereals from developed countries will increase from $90 \cdot 10^6$ tons to about $160 \cdot 10^6$ tons by the year 2010.

The FAO report is not representative as the development in the PR China is largely excluded. Currently, China has to nurture one fifth of human population at just 7 percent of arable cropland. During the last 45 years arable land per caput was halved to 820 m^2, one third of the world average. China is losing nearly 10^6 hectares or 1 percent of its cropland per year to industrialization and will probably follow a path similar to that Japan, South Korea and Taiwan underwent earlier by halving the grain area from 1950 to 1990. Due to a decrease in cropping area and changes in diets, the PR China will probably import more grain by 2025 than world trade totaled in the 1990s (Brown and Kane, 1994). In 1995, China's grain deficit was $16 \cdot 10^6$ t and it will increase probably to $370 \cdot 10^6$ t in 2030. As actual yields of rice and wheat are high, further yield increases will be difficult. The use of fertilizers is already high, and – according to the rule of decreasing marginal returns – the rate of yield increases has declined in the last years.

According to R. Thompson, Winrock International Institute for Agricultural Development, Morrilton, AK, (pers. comm.) the PR China has managed a high rise in productivity in the 1980's, nevertheless it will become a regular importer of grain and soybean in the future. In other countries, especially in Southeast Asia, changes in human diets – vegetables, fresh fruits and animal protein will replace small grains and traditional vegetarian foods because of rise in incomes – will endanger food supply. In South America there is the highest potential of cultivating areas and the success of Chile in the last decades demonstrates the potential of productivity rise.

Actually, world grain stocks are at all time lows and the '95 harvests in the PR China, the former USSR and North America have been lower than in the previous years. According to FAO Director General Diouf, grain production per caput will decrease in 49 out of 68 low-income developing countries (FAO, 1995). In 28 out of 40 Sub-Saharan countries grain supply per caput will decrease and world stocks for food may fall below the reserve level (17 percent of annual consumption). A 3 to 4 percent increase of grain production is necessary in 1995 to meet the food demand in 1995/96 and to prevent an aggravation of the insufficient food supplies. In the long run, an annual 2 percent or more increase in global production is required. Two to three times more food have to be produced by high productivity farming systems in order to prevent environmental disasters due to exploitation of natural ecosystems.

Crop production and future challenges for pest management

As McCalla (1994) stated, there is widespread agreement on the needs to increase food production due to population growth. Nevertheless there is little agreement on the possibilities and ways to generate the supply in order to meet the demand. The FAO (Alexandratos, 1995) assumes that in developing countries increases of yields per unit of area have to produce 66 percent of the rise in productivity by the year 2010 (Table 5). About 20 percent of production raise should result from an expansion of arable land, and 12 percent from increasing cropping intensity.

IRRI has estimated that annual rice production must increase from $460 \cdot 10^6$ t in 1987, to $560 \cdot 10^6$ t by the year 2000 and $760 \cdot 10^6$ t by the year 2020, in order to keep up with increasing population (IRRI, 1988). A scenario for 2025 has been worked out to calculate the contribution of yield increases to production raise in rice and wheat necessary to provide similar per-caput supplies as in 1991–93 (see below): Production for 2025 was calculated from actual production and population growth given in Figure 5. Considering the FAO projections until 2010 (Table 5) the contribution of yield increases to production growth was estimated to vary between 50 to 80 percent: North America 50 percent, Latin America, former USSR, Africa and Oceania 60 percent, East Asia, Near East, Southeast Asia, and South Asia 70, 75, 80, and 85 percent, respectively. Compared to the FAO data, these figures are slightly higher considering the longer time period and the finiteness of land resources. Yield projections for rice and wheat yields in 2025 were calculated from production growth rate and contribution of yield increases, region by region (Figure 6 and 7, bottom).

Figure 6 summarizes the actual and attainable rice production by region (top, percentages indicate actual production relative to attainable production), and yields for 1991–93 and 2025 (bottom, percentages indicate compound growth rate) by region, necessary to provide the same production per caput as in 1991–93. Within 30 years rice yields in many developing countries have to be increased by 40 to 90 percent (up to 92 percent in South Asia), the only exception will be East Asia with 22 percent, a rate similar to that of developed countries. More important, yields in regions with widespread upland or rainfed lowland rice production like the Near East and South Asia have to rise to an average of 4 to 6 t/ha. As indicated in the map for actual production loss rates due to pests are high in these areas and improved crop protection may play a major role in increasing rice yields.

For wheat, yield increases until 2025 have to be only in the range of 0 to 24 percent in developed countries, a target easy to accomplish (Figure 7). In South Asia, Africa, the Near East and Latin America, however, yields have to be raised by 40 to 92 percent (1 to more than 2 t/ha). Considering the often irregular water supply and poor soil fertility in these regions the task is enormous. As high cropping intensity is related to increased potential loss rates to pests, high productivity can only be accomplished by adequately improving crop protection.

The figures for yield increases given above for East and Southeast Asia and parts of Latin America have to be considered as minimal requirements because food demand is estimated to increase more than population due to income rises, and projections on land use for the PR China are doubtful. The same applies for developed countries where domestic demand increases slowly, nevertheless, the demand for grain export to developing countries will increase considerably from $90 \cdot 10^6$ t in 1990 to more than $280 \cdot 10^6$ t by the year 2025.

The scenario has calculated the demand ignoring the great differences in the potential of the regions. What will really happen? Extrapolating current trends productivity will continue to increase at higher rates in Europe, North America and East Asia than in less developed countries. Especially in regions with actual low yield levels production has to be increased considerably. Regarding the development during the last three decades and the situation of national economies the future tasks for agriculture in Africa, the Near East and South Asia are enormous: Within three decades yields have to be raised by 70 to 90 percent, while yield increases in the period 1970 to 1990 were only 10 to 60 percent in most of these countries. Irrespective of increases in fertilizer use and progresses in plant breeding or crop protection to reduce the high actual losses, the food demand in 2025 may exceed the capacity of soils and the availability of water in some of these regions.

To be sufficient, agricultural systems will need to be increasingly intensive and thus increasingly dependent on external sources. Modern farming systems are sustainable (at different levels) as long as there is energy and inputs for their maintenance. Their weakness is not low sustainability but dependence on inputs, low autonomy (Loomis and Connor, 1992). External inputs and sophisticated technology are essential

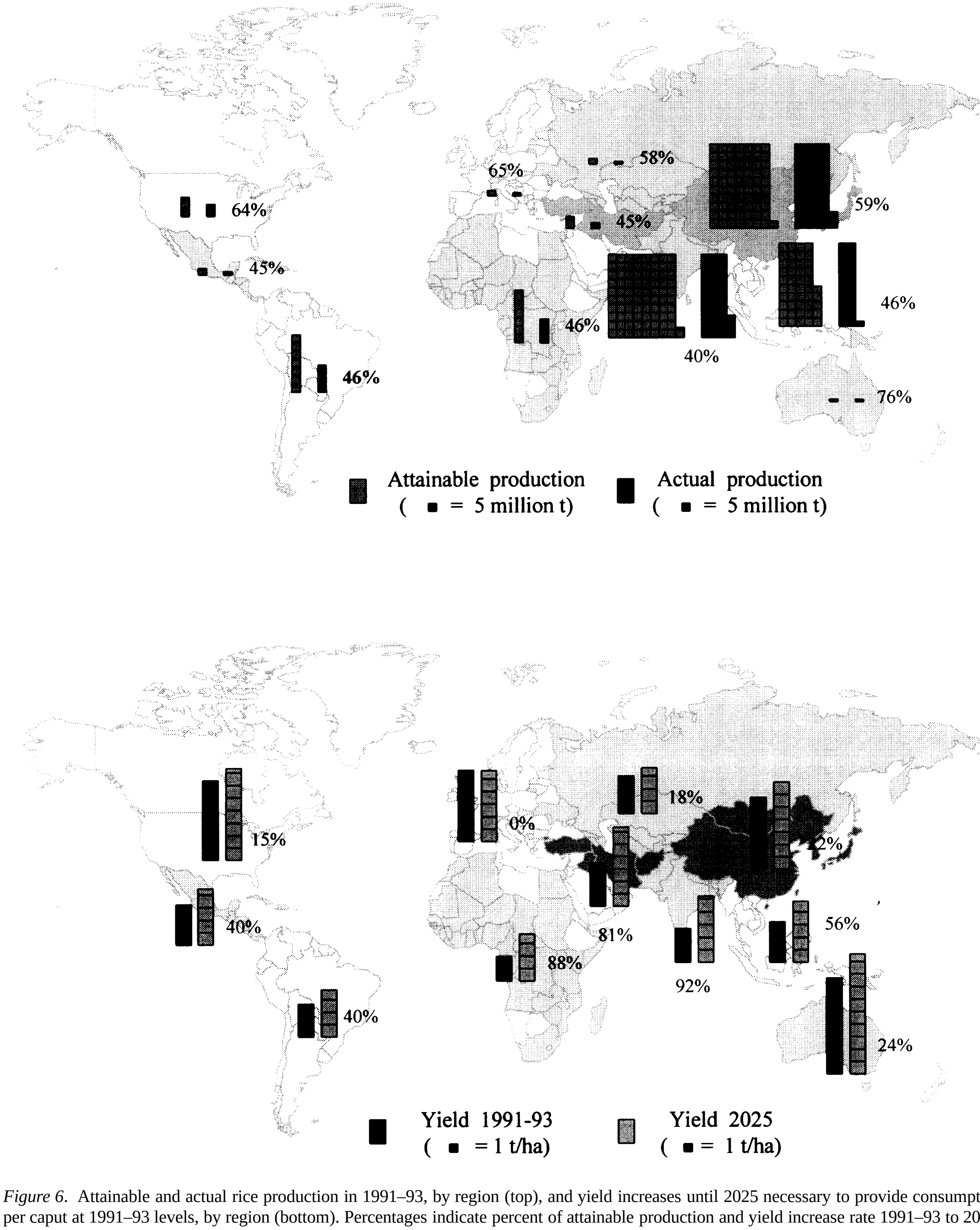

Figure 6. Attainable and actual rice production in 1991–93, by region (top), and yield increases until 2025 necessary to provide consumption per caput at 1991–93 levels, by region (bottom). Percentages indicate percent of attainable production and yield increase rate 1991–93 to 2025, respectively.

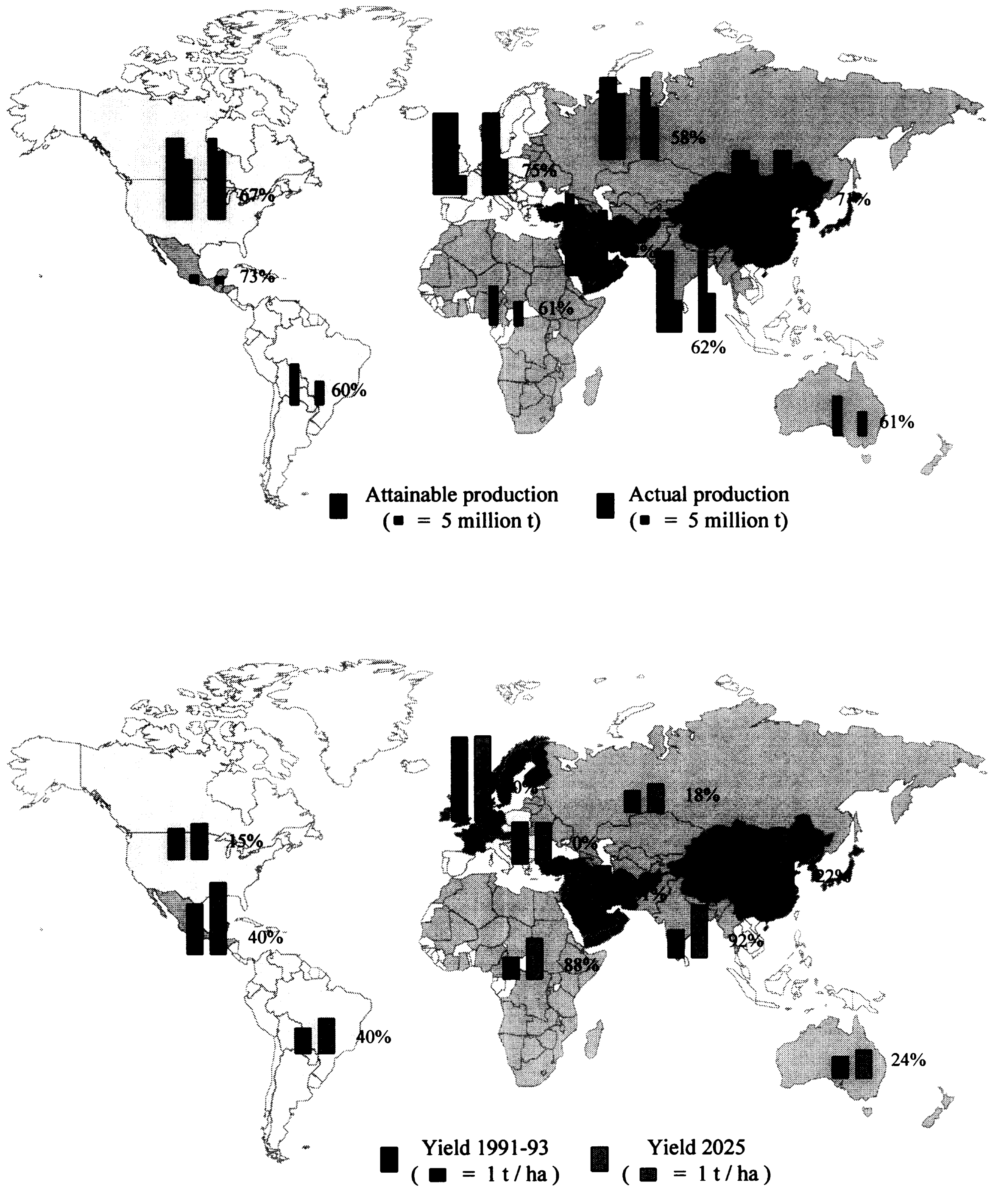

Figure 7. Attainable and actual wheat production in 1991–93, by region (top), and yield increases until 2025 necessary to provide consumption per caput at 1991–93 levels, by region (bottom). Percentages indicate percent of attainable production and yield increase rate 1991–93 to 2025, respectively.

Table 5. Sources of growth in crop production in developing countries, excluding China [in percent] (modified from Alexandratos, 1995)

	1970 to 1990 yield increases	1988/90 to 2010 contribution of increases in:		
		Yield	Arable land	Cropping intensity
Developing countries	69	66	22	12
Sub-Saharan Africa	53	53	30	17
Near East/North Africa	73	71	9	20
East Asia	59	61	32	7
South Asia	82	82	4	14
Latin America	52	53	28	19

in agriculture. Furthermore, with high productivity, agriculture can be restricted to the safest and most suitable land, a high portion of land can be left to natural habitats. Chemically-assisted agriculture actually helps to preserve a diversity of species by conserving the amount of land necessary to sustain agricultural production. Every 0.1 percent of yearly yield increase in the period 2010 to 2025 'substitutes' for about $25{\cdot}10^6$ hectares of rainfed cropland (Feder and Keck, 1994). Intensive farming systems are lower-input and more sustainable per unit food supply than extensive ones. Organic farming as performed world-wide in the 1940s has not been adequate for food supply for a world population only half the present size.

Crop protection – chemical, mechanical, and biological – based on modern technologies and applied by responsible and well-trained farmers has the potential to increase crop productivity considerably in many regions. In some countries, however, the ecological and social conditions often interfere with effective control strategies and prevent improvements in areas suffering from high losses and where small improvements would already have a high impact on yield levels. Regarding the availability of natural resources like soil, water and nutrients, pest control has also the potential to preserve these finite resources and to optimize their use for food production. Therefore, an intensification of crop protection seems appropriate for many developing countries. Increasing the intensity does not mean *per se* rising the amount of pesticides applied, but it includes the use of varieties resistant to pests and adapted to local conditions, the organization or improvement of extension services educating and training farmers, the development of integrated pest management strategies for major crops, the availability of modern control agents right in time, and the development of new, environmentally friendly compounds for the control of major pests in tropical and subtropical crops. Due to the development of new chemical groups the biological activity of pesticides has been improved and the application rates per ha can be reduced. This trend is likely to continue.

The decision to take action for control or not also depends on economic considerations. The use of selective herbicides, insecticides or systemic fungicides can only be cost-effective preventing losses in crops with high productivity due to adequate water and nutrient supply. Water is the most important yield-limiting factor and restrictions will increase. Today, agricultural production is limited by water supply in 20 countries, in the next 10 years 15 other countries will add to them (Bonte-Friedheim, pers. comm.). Next to water, genetic yield potential and adaptation, crop losses due to pathogens, animal pests, and weeds are major yield constraints. Certainly losses to pests can never be eliminated, nor, considering the ecological function of many organisms as well as economic reasons, should they be reduced to zero. However, given a sound economical background for agriculture, a high proportion of actual losses may be used as potential resources for future production. The reduction of crop losses has an absolute priority in view of the increasing human population.

The means for feeding the human population exist including such obvious measures as increasing food production and reducing crop losses to pests. But they also include measures that will involve politics much more than they involve productivity (Costle, 1979). Scenario studies using long-term projections often neglect the finiteness of natural resources extrapolating current linear trends. However, neither the extent to which resources have been actually exploited, nor the reserves which can be used for sustainable agriculture in the future are known exactly. Furthermore, predictions have to consider actual and future interrelations among factors affecting agricultural productivity. Modern agriculture is all too complex as to be identified as a single concept involving uniform application of knowledge, machines and agrochemicals. Diversity of farming practices is related to soils, climates, access to markets and technology, and cultural influences differing greatly between regions.

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