



# FOOD, FEED, AND FIBER

Food outputs from the world's agroecosystems have more than kept pace with global population growth and as of 1997 provided, on average, 24 percent more food per person than in 1961, in spite of the 89 percent growth in population that occurred over the same period.<sup>8</sup> Despite the impacts of global economic shocks induced by the oil crises of the mid 1970s and early 1980s, improvements in agricultural productivity have seen food prices drop by around 40 percent in real terms (see *Figure 8*). This represents a significant improvement in human welfare, particularly for poor consumers, who spend a large share of their income on food, as well as for those farming households able to take advantage of new production technologies. But despite these major achievements, the full benefits of more and cheaper food are still beyond the reach of the estimated 790 million of the world's poorest people who are chronically undernourished (FAO 1999a:29).

## Global Production Patterns

An important factor in determining the likely impacts of food, feed, and fiber production on the condition of agroecosystems is the amount of land occupied by different crop and animal production systems. The cultivation of some crops, such as cassava, when poorly managed, can expose soil to water erosion

and rapidly exhaust soil fertility. Other systems, such as soybean, if properly managed, can help fix nitrogen in the soil and provide ground protecting cover. Large amounts of pesticide and fertilizers are often applied to potatoes and other vegetables.

Figure 8

## Global Index of Food per Capita and Food Prices



Source: Food per Capita: FAOSTAT 1999; Food Prices, 1959–80: IMF 1987; 1980–98: IMF 1998.

Table 7

**Regional Distribution of Crops by Area Harvested, 1995–97 Average**

Region	Cereals	Maize	Rice	Wheat	Fiber Crops	Fruits	Oil Crops	Pulses	Roots and Tubers	Sugar Crops	Other	Total	Percentage of Total Crop Harvested Area
													(Mha)
North America	82.5	29.6	1.2	36.9	0.1	1.3	40.5	2.0	0.7	1.0	2.2	130.3	11.0
Latin America and the Caribbean	50.3	29.1	6.5	9.3	0.3	6.6	27.1	8.7	4.3	8.5	10.3	116.2	9.8
Europe	63.8	11.1	0.4	26.7	0.1	7.3	13.8	2.6	3.7	3.0	5.0	99.3	8.4
Former Soviet Union	92.1	2.7	0.5	47.6	0.3	3.0	10.5	2.7	6.3	2.5	2.3	119.8	10.1
West Asia/North Africa	42.5	1.9	1.4	25.5	0.0	4.2	6.3	4.1	0.8	0.9	5.3	64.1	5.4
Sub-Saharan Africa	80.2	24.6	6.7	2.9	0.4	7.2	22.4	13.7	17.0	1.2	12.9	154.8	13.0
East Asia	96.9	24.4	35.3	30.1	0.4	9.4	26.5	3.5	10.3	1.9	16.7	165.6	14.0
South Asia	130.3	8.1	57.8	37.2	1.5	4.4	42.6	26.7	2.1	5.3	11.6	224.6	18.9
Southeast Asia	49.5	8.4	40.5	0.1	0.8	3.2	16.1	3.0	4.1	2.1	12.1	90.8	7.7
Oceania	15.9	0.1	0.1	10.2	0.0	0.4	1.7	2.1	0.3	0.5	0.4	21.2	1.8
World	704.0	139.9	150.6	226.5	3.9	47.0	207.6	69.2	49.5	26.8	78.8	1,186.8	100.0

Source: Compiled from FAOSTAT 1999.

And, globally, chicken and pig production are becoming increasingly industrial in scale, often giving rise to significant local pollution problems.

At a local level, the structure of production and its evolution over time are closely related to the level of agricultural commercialization. As communities become more actively involved with markets, farm production becomes less focused on self-sufficiency and increasingly on producing those commodities for which the land, the farmer, or the community has some economic comparative advantage. Thus, trading opportunities lead to increasingly divergent patterns of production and consumption at the local level. In such cases, farm households are more interested in the monetary value, rather than the nutritional value of local food and fiber production. For these reasons the food, feed, and fiber indicators presented here include a variety of area, yield, dietary energy, and monetary measures.

### CROP DISTRIBUTION

Some 704 million hectares, almost 60 percent of the world's cropland, is dedicated to the production of cereals. Only in Latin America, with some 43 percent of cereals, does that share fall below half of all harvested land (see Table 7). Wheat, rice, and maize are the dominant cereals, occupying 32, 21, and 20 percent of cereal crop area, respectively. The irrigated and mixed humid and subhumid agroecosystems of Asia contain a staggering 89 percent of the world's harvested rice area. Wheat areas are more broadly spread across temperate and subtropical rainfed and irrigated systems, with the Former Soviet Union, South Asia, and North America accounting for over half the

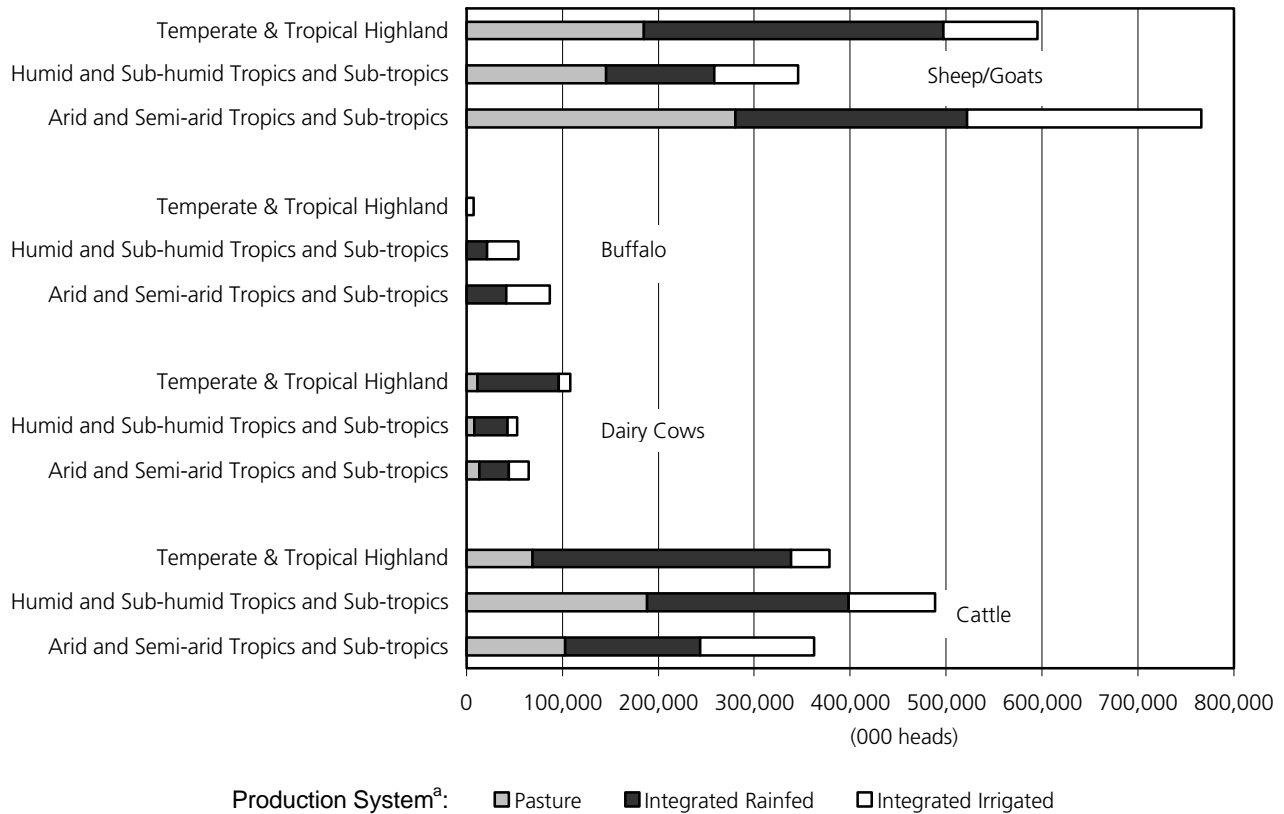
global total. Maize is even more widely distributed partly because of its broader agroecological adaptability and partly because of its ubiquitous use as an animal feed source. Latin America, North America, Sub-Saharan Africa, and East Asia all harvest between 24 and 30 Mha of maize per year. Although on average, about 66 percent of global maize production is used for animal feed, the developed-country average is around 76 percent and the developing around 56 percent (CIMMYT 1999:62).

The 208 Mha of oil crops, of which soybean occupies some 67 Mha, represents the second most common crop group. In addition to their oil content, these are important sources of high-quality protein animal feed. About 80 percent of processed soybean (the cake left following the removal of oil for human consumption) can be used as animal feed. Cereals and oil crops occupy about 77 percent of the area of the world's croplands. The remainder of cropland is occupied by pulses (5.8 percent), roots and tubers (4.1 percent), fruits (4.0 percent), sugar crops (2.2 percent), and other (6.5 percent).

Agriculture produces more than food. Crops producing fiber (such as cotton, flax, sisal), medicines, dyes, chemicals, and other non food industrial raw materials account for nearly 7 percent of harvested crop area. Some food crops are grown primarily for fuel (such as ethanol) but more woody biofuels are being planted. Currently available agricultural statistics exclude most of the world's production of trees, shrubs, and palms grown on farms for woodfuel, construction material, and raw materials for household artsanry or local processing.

Figure 9

### Distribution of Ruminant Livestock by Production Systems<sup>a,b</sup> and Agroclimatic Regions<sup>c</sup>, 1992-94 average



**Source:** IFPRI calculation based on FAO world livestock production systems (Seré and Steinfeld 1996).

**Notes:** (a) Pasture—more than 90 percent of feed comes from grassland, forages, and purchased feeds; Integrated Rainfed—more than 10 percent of the dry matter feed comes from crops, by-products, or stubble; Integrated Irrigated—same as Integrated Rainfed plus more than 10 percent of the value of non-livestock farm production is from irrigated land. (b) excludes confined (“landless”) animal production estimated at 66,231 thousand heads for cattle and 9,931 thousand heads for sheep and goats. (c) Agroclimatic regions were based on FAO’s agroecological zones project (FAO 1982).

### LIVESTOCK DISTRIBUTION

The global ruminant-livestock population includes approximately 1,225 million head of beef cattle, 227 million head of dairy cattle, 148 million head of buffalo, and 1,708 million head of sheep and goats. Latin America supports the largest beef cattle population of approximately 350 million head (26 percent), and West Asia/North Africa (WANA) the smallest with 8 million head (under 1 percent), while over 96 percent of the world’s buffaloes are in Asia, which also has the largest share of the sheep and goat population (30 percent). By production system (see Figure 9), cattle are fairly uniformly spread across major agroclimatic zones, with a slightly higher share in the tropical and subtropical humid and subhumid areas (39 percent). Dairy cattle are predominantly found in temperate and highland ar-

ean (48 percent), while sheep and goats predominate in tropical and subtropical arid and semiarid ecosystems (45 percent). Integrated rainfed crop-livestock systems dominate in the production of beef cattle (50 percent), dairy cattle (66 percent), and sheep and goats (39 percent). However, for Sub-Saharan Africa and Latin America, pastures are dominant for cattle (67 percent and 50 percent of animals respectively) (Seré and Steinfeld 1996).

Over the past 30 years, livestock production has approximately tripled compared to a doubling of crop output (Pinstrup-Andersen et al. 1999). The most recent surge in demand for meat and milk, particularly in developing countries, has given rise to what has been dubbed the “Livestock Revolution” (see Box 2).

## Box 2

**Livestock Revolution**

There is increasing evidence of a substantial livestock revolution taking place, particularly in the developing world. Unlike the Green Revolution, this change is driven by significant increases in demand for meat products—particularly poultry and pig meat—and milk, which in turn are translating into growing demand for feed grains and high-protein meal. This rapid growth should offer greater income opportunities and improved nutrition, particularly to the poor, but will likely pose additional environmental and human health problems.

Over the period 1982-94, the global demand for meat grew by 2.9 percent per year, but this change comprised a growth rate of 1 percent for developed countries and 5.4 percent for developing countries. Within some specific meat categories, developing-country growth rates were even higher—pork 6.2 percent per year, poultry 7.6 percent per year, and milk at 3.1 percent per year. By 1993, there were about 878 million head of pigs and some 13 billion chickens globally. About 36 percent of the pig population was in the developed countries and of the 64 percent in the developing world, 44 percent was in China alone with the next largest region, Latin America, having 9 percent. In the case of chicken, the overall developed/developing-country share of 35/65 percent is spread much more evenly across regions.

Both pig and poultry operations in developing countries are likely following the same type of intensive landless production prevalent in developed countries and are directly importing the necessary technologies to operate industrial-scale pig and poultry operations near urban centers. As we show in the box on *Cheaper Chicken, More Pollution*, even in the United States where environmental regulation enforcement powers are established and applied, such concentrated industrial-scale installations can lead to significant local pollution and health hazards. Other health risks, particularly in developing countries, could arise through animal-borne diseases, such as avian flu and salmonella, microbial contamina-

tion from unsafe handling of foods, and a build-up of pesticides and antibiotics in the food chain through production practices.

The growth in meat demand also implies an additional demand for feed cereals (especially maize), oil crop cake, and other crop residues, such as those from cassava and sugar processing. Analysis by the International Food Policy Research Institute (IFPRI) suggests that under pessimistic future scenarios this demand would increase real maize prices by around 20 percent by the year 2020, to about the same price levels that prevailed in the early 1980s.

From the perspective of the poor, the livestock revolution offers many opportunities. The rural poor and the landless, especially women, could get a higher share of their income from livestock than better-off rural people (with the main exceptions found in areas with large-scale ranching, such as parts of Latin America). Furthermore, livestock provides the poor with fertilizer, draft power from cattle and buffalo, and in some areas fuel, along with other opportunities to diversify income. Livestock products also benefit the poor by alleviating the protein and micronutrient deficiencies prevalent in developing countries. Increased consumption of even small additional amounts of meat and milk can provide the same level of nutrients, protein, and calories to the poor that a large and diverse amount of vegetables and cereals could provide. Such synergies could also promote the broader scale adoption of integrated crop-livestock systems, which with proper management can be highly sustainable production systems for smallholders in developing countries.

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*Source:* Adapted from Delgado, C., M. Rosegrant, H. Steinfeld, S. Ehui, C. Courbois. "Livestock to 2020: The Next Food Revolution." Food, Agriculture, and the Environment Division Discussion Paper No. 28. Washington, D.C.: IFPRI.

## **Input Intensity of Agricultural Production Systems**

Although there are a relatively limited number of globally important agricultural commodities—some 30 commodities supply more than 90 percent of the world's calorie consumption—the ways in which those commodities are produced varies significantly (FAO 1998:14). Furthermore, the specific mix of inputs and production technology applied has a direct bearing on the long-term capacity of agroecosystems to deliver agricultural and environmental goods and services. Production systems can be characterized by the extent to which they rely on the following: polyculture versus monoculture; traditional versus modern

varieties; inorganic fertilizers versus recycling of crop residues and manures; pesticides versus biotic control; rainfall versus the supplemental application of water; and hand labor versus machinery. Seeds and water are considered separately in subsequent sections; so here we focus on indicators of labor, fertilizer, machinery, and pesticides (summarized at a regional level in Table 8).

### **AGRICULTURAL LABOR**

The labor input-intensity measure is defined as agricultural labor per hectare of cropland.<sup>9</sup> Across all global agroecosystems the average labor utilization is 0.85 person per hectare (pph), but varies widely according to labor scarcity (wage rates), pro-

Table 8

**Input Intensity Indicators, 1995–97 Average**

Region	Agricultural Labor (person per hectare)	Tractors <sup>b</sup> (hectare per tractor)	Inorganic Fertilizer <sup>a</sup>				Irrigated Share of Cropland (percent)
			N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Total	
North America	0.02	41	57.1	21.6	23.1	101.8	9.8
Latin America and the Caribbean	0.28	102	26.7	18.3	17.1	62.1	11.3
Europe	0.15	14	89.7	32.2	36.5	158.4	12.5
Former Soviet Union	0.11	102	14.0	4.5	2.3	20.8	9.3
West Asia/North Africa	0.45	60	39.7	18.1	3.3	61.1	26.4
Sub-Saharan Africa	0.98	622	6.1	3.4	2.1	11.6	3.7
East Asia	3.58	47	130.7	51.1	83.2	265.0	38.7
South Asia	1.57	123	62.9	19.3	6.6	88.8	38.0
Southeast Asia	1.47	232	50.2	16.6	17.0	83.8	17.4
Oceania	0.05	138	17.7	25.5	6.8	50.0	5.2
World	0.85	57	53.2	21.0	15.5	89.7	17.5

**Source:** Compiled from FAOSTAT 1999.

**Notes:** Labor, fertilizer, pesticide, and tractor inputs are expressed based on hectares of cropland (annual plus permanent crops). (a) Includes only commercial inorganic fertilizers: Nitrogen (N), phosphorus (P<sub>2</sub>O<sub>5</sub>) and potassium (K<sub>2</sub>O). (b) Tractors are defined here as all wheel and crawler tractors (excluding garden tractors) used in agriculture.

duction structure, production technologies, energy and machinery costs, and so on. Thus, in land-abundant, high-income countries with extensive animal production, such as the United States and Australia, the average labor input intensity across all agroecosystems is around 0.01 pph and 0.02 pph respectively. In (agricultural) land scarce, low-income regions having irrigated and mixed irrigated/rainfed crop-based agroecosystems, such as East Asia, labor inputs average about 3.6 pph. Across the Asian agroecosystems the average labor input always exceeds 1.4 pph (see Map 6 and Table 8).

### TRACTORS

One indicator of the nature of production systems is the extent to which agricultural machinery, specifically tractors, are used. Tractors offer labor-saving increases in productivity where labor is scarce (relatively costly) and perform a range of traction and transport functions that might be uneconomic manually. They are, however, expensive to purchase and maintain, are more suited to flatter lands, and their overuse can lead to soil-management problems, such as compaction and other changes in physical properties.

As a global average there are about 57 hectares of cropland per tractor. In the highly commercialized agriculture of Europe and North America, where high labor costs prevail, there are about 14 and 41 hectares per tractor, respectively. In Asia, characterized by lower incomes, high population density, and much smaller land holdings, there are approximately 47, 123, and 232 hectares per tractor respectively in East Asia, South Asia,

and Southeast Asia (see Map 7 and Table 8). Sub-Saharan Africa averages around 600 hectare per tractor. These averages need to be treated with caution as there is no differentiation by tractor type or quality—for example, by horse-power rating.

### INORGANIC FERTILIZERS

An important input-intensity indicator is the extent to which inorganic (mineral) fertilizers are applied. In many agroecosystems, nutrients extracted by crops and pastures are replenished, to varying degrees, by the application of inorganic fertilizers containing nitrogen (N), phosphorus (P<sub>2</sub>O<sub>5</sub>), and potassium (K<sub>2</sub>O). Too little replenishment, from inorganic or organic sources, leads to long-term nutrient depletion that can exhaust the inherent soil fertility. Excess or mistimed fertilizer application can cause nutrient runoff or leaching and consequent soil and water pollution problems. The most commonly observed consequences of such pollution are the eutrophication of water bodies, and the damage to other forms of aquatic life and downstream water uses caused by algal blooms.

Global fertilizer consumption stands at about 128 million tons per year (1997) and has been in general decline since 1989, although the surge in cereal production from 1995 to 1997 reversed this downward trend, at least temporarily (FAOSTAT 1999). It is estimated that about 55 percent of fertilizers are applied to cereals, 12 percent to oil crops, 11 percent to pasture and hay, about 6 percent to roots and tubers, and about 5 percent to fruit and vegetables (Harris 1998:19). Nutrient application rates are important indicators of both the potential for

Table 9

**World Pesticide Consumption, 1983–98**

Region	Value <sup>a</sup>			1998 Value per ha of Cropland <sup>b</sup>	Share 1998	Compound Growth Rate <sup>a</sup>		1992 Pesticide Share <sup>a</sup>			
	1983	1993	1998			1983-93	1993-98	Herbicides	Insecticides	Fungicides	Other
	<i>(US\$ millions)</i>			<i>(\$ per ha)</i>	<i>(percent)</i>	<i>(percent per year)</i>					
North America	3,991	7,377	8,980	40	26	6.3	4	66	22	8	5
Latin America	1,258	2,307	3,000	19	9	6.3	5.4	47	29	19	4
Western Europe	5,847	7,173	9,000	102	26	2.1	4.6	43	18	30	9
Eastern Europe	2,898	2,571	3,190	14	9	-1.2	4.4	38	39	18	5
Africa/Mideast	942	1,258	1,610	5	5	2.9	5.1				
Asia/Oceania	5,572	6,814	8,370	16	25	3	4.4				
Japan		3,545						31	34	33	2
Far East		2,600						31	48	14	7
Total	20,507	27,500	34,150	23	100	3	4.4	45	29	19	6

**Source:** (a) Yudelman et al. 1998:10. (b) IFPRI calculation based on Yudelman et al. 1998:10 and FAOSTAT 1999.

yield enhancement as well as for nutrient mining or leaching. A recent global survey of fertilizer usage found that vegetables as a group have the highest fertilization rates, some 242 kilograms per hectare (kg/ha), followed by sugar crops (216 kg/ha), and roots and tubers (212 kg/ha). Cereals and oilseed, the dominant crops by area and by the total volume of applied fertilizer, receive about 102 kg/ha and 85 kg/ha respectively (IFDC/IFA/FAO 1997 cited in Harris 1998:5).

At the individual crop level, the average application rate of fertilizers for banana, at 479 kg/ha, far outstrips the next most fertilized crops: sugar beet (254 kg/ha), citrus (252 kg/ha), potato (243 kg/ha), vegetables (242 kg/ha), and palm oil (242 kg/ha). The fertilization practices of such crops clearly have potential to cause pollution damage. Among cereals, maize is the most fertilized at 136 kg/ha, while wheat and rice receive 116 kg/ha and 112 kg/ha, respectively. However, there are wide variations. The average fertilizer application rate for wheat varies from just under 20 kg/ha in Myanmar and Nepal to more than 300 kg/ha in Japan (IFDC/IFA/FAO 1997 cited in Harris 1998:5-8).

As shown in Table 8 and Map 8, aggregate fertilizer use (average NPK applied per hectare of cropland)—the selected fertilizer intensity indicator—varies from around 265 kg/ha in East Asia, through 102 and 158 kg/ha applied in North America and Europe respectively, to a low of around 12 kg/ha in Sub-Saharan Africa (FAOSTAT 1999).

Although increasing nutrient supply is recognized as an essential step in raising agricultural productivity in Sub-Saharan Africa, there is much debate about the most appropriate strategies for achieving this. For both technical and economic reasons, the use of inorganic fertilizer alone is generally seen as inappropriate. Technical reasons include the need for enhanced soil organic matter content as a precondition for the effective-

ness of inorganic fertilizers. Economically, the credit institutions and fertilizer markets accessible to poor producers are often absent or not well developed. Preferred nutrient management approaches include increased use of organic fertilizers such as green and animal manures and crop residues, and other practices that maintain and improve not only fertility but also water-holding capacity and organic-matter content. To achieve the productivity levels necessary to meet the rapidly growing food demands of Sub-Saharan Africa will most likely require a hybrid form of nutrient management, emphasizing strategic use of both organic and mineral fertilizers.

Fertilizer input alone is not a sufficient indicator of the long-term productive capacity of soil. Over time, it is the balance of net nutrient inputs and outflows through crop harvesting, soil erosion, leaching and so on, that are more important. Soil nutrient balances are considered further in the Soil Resource Condition section.

## PESTICIDES

A central strategy in improving agricultural output is to limit losses from the effects of pests and diseases and from weed competition. Since the mid 1900s, the approach to crop protection has relied increasingly on the use of pesticides (defined here to include insecticides, nematocides, fungicides, and herbicides). Data on pesticide use at a regional and global level is limited. Data on its intended and unintended impacts are even more scarce and often controversial.

Global estimates suggest that while current losses in wheat through the impacts of pests, diseases, and weeds are around 33 percent they might rise to 52 percent without the use of control measures. Maize losses could also potentially increase by approximately 20 percent, from 39 to 60 percent, and rice losses could increase 30 percent, from 52 to 83 percent (Oerke et al.

1994 cited in Gregory et al. 1999:235). If such estimates are even broadly correct, the negative impacts of reduced pest control effectiveness on farmer incomes and consumer prices would be extremely significant. Certainly, pesticide use has risen and continues to increase dramatically (see Table 9), indicating that farmers find pesticides cost-effective from a production perspective, particularly where alternative forms of crop protection are labor intensive and labor costs are high.

Other economic and social dimensions of pesticide use cause widespread environmental and human health concerns and have raised questions about its scientific rationale. Environmental concerns focus on the toxicity of many pesticides to biological species other than those directly targeted, such as soil microorganisms, insects, plants, fish, mammals, and birds, that might not only be beneficial to agriculture or other human economic activities, but that are part of a biodiversity valued by society for recreational, cultural, ethical or other reasons. Although regulations in many countries have promoted the development of more-specific, less toxic, and more rapidly decomposing pesticides, many of the more damaging pesticides are still marketed in countries where regulations are more lax. Human health concerns include the effects of ingesting chemical residues contained in foods, but also the ill-effects on farm workers of pesticide handling and application, particularly in countries where safety standards are not well established, understood, or enforced (Antle and Pingali 1994; Crissman et al. 1994).

Part of the scientific debate on crop protection relates to the ability of pests, weeds, and viruses to develop pesticide resistance. This results in a constant need to develop new pesticide products (or pest resistant plant varieties) to keep one step ahead of biological adaptation. This cycle, dubbed the “pesticide treadmill,” has led to biological adaptations resistant to most commercially available pesticides. One global estimate suggests that around 1,000 major agricultural pests (insects, mites, plants, and seeds) are now immune to pesticides (Brown et al. 1999:124), including some 394 insects and mites, 71 weeds, and 160 plant species in the United States alone (The Heinz Center 1999:26). Because of such problems, Yudelman (1998:13) estimates, despite a 10-fold increase in both the amount and toxicity of pesticides in the United States between the 1940s and 1990s, that the share of crops lost to pests actually rose from 30 to 37 percent. Other research has found that economic levels of pesticide application are often much lower than those adopted by farmers. Because pesticide costs are often a relatively small share of total production costs, farmers prefer to overapply pesticide than risk severe crop losses.

Pesticides, however, are not the only means to counter crop loss from pests and diseases. Integrated pest management (IPM) techniques, for example, apply ecological science to enable biological suppression that can often keep pest populations below damaging levels, save pesticide and application costs,

and in some cases enhance yields. In the Yunnan Province in southern China, IPM techniques for controlling *rice blast* have been rapidly adopted. In 2000, 42,500 hectares of rice fields were being grown using IPM, while 10 other provinces are reportedly experimenting with the approach (Mew 2000). In Vietnam, IPM techniques are reportedly applied by 92 percent of the Mekong Delta’s 2.3 million farm households, and insecticide applications have fallen from an average of 3.4 per farmer per season to just one (IRRI 2000). In Indonesia, a survey of 2,000 farmers trained in and applying IPM techniques found that rice yields had increased by an average of 0.5 tons per hectare and the number of pesticide applications had fallen from 2.9 to 1.1 per season. Furthermore, rice fields under IPM were being recolonized by plant and animal species previously suppressed by pesticide use (van de Fliert 1993; reported in Reijntjes et al. 1999).

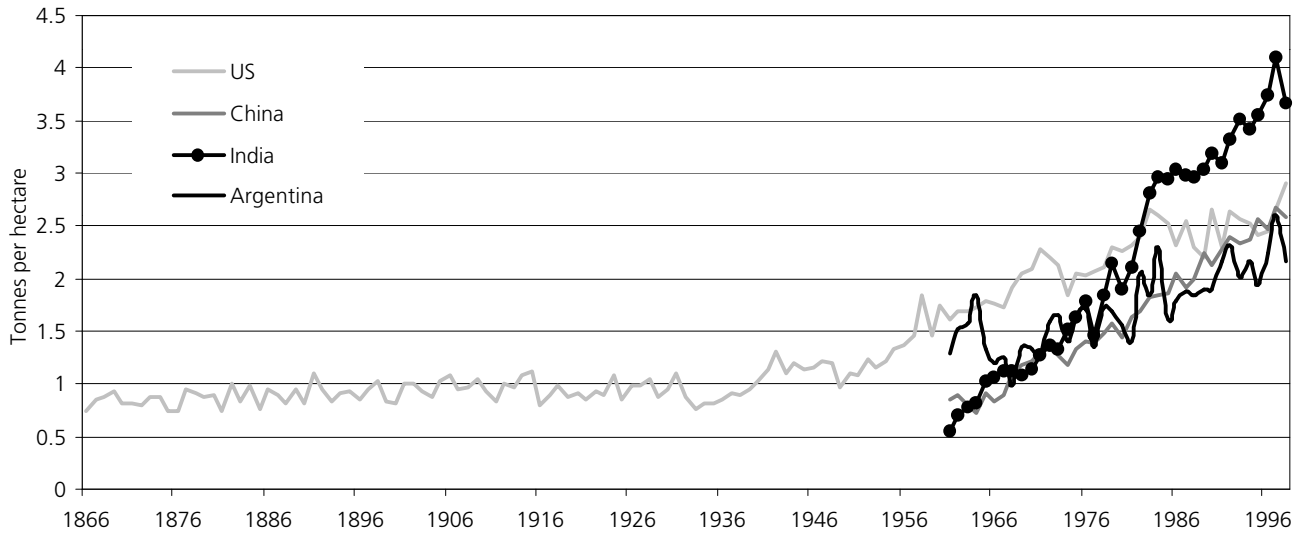
IPM is not just a developing country, small scale approach. In the United States there have been considerable advances during the 1990s in developing and promoting IPM methods. This has resulted in significantly positive trends in IPM adoption by large-scale, commercial producers, particularly of cotton and potatoes (Fernandez-Cornejo and Jans 1999).

## Status and Trends in Yields and Production Capacity

An important measure of the current capacity of agroecosystems to produce food is the quantity of crop or animal output they can produce per unit of land or per animal—their yield. To some degree, the agroecological characteristics of the domain in which an agroecosystem is located determine this capacity. For example, the biomass production potential of the warm humid tropics is considerably greater than that of the dry semiarid subtropics. But the potential for crop loss through pest and disease is also greater in the tropics, and higher temperatures and rainfall tend to leach and otherwise deplete soil nutrients more rapidly. Within the broad production potential boundaries defined by such agroecological conditions, the specific production practices and inputs applied determine yield levels.

As populations and markets have grown and agricultural expansion possibilities have declined, it has been necessary to intensify production. Many of the major scientific breakthroughs in developing high yielding crop varieties that respond to more intensive cultivation took place during the last two thirds of the twentieth century (see Figure 10). The intensification process has kept aggregate production growing faster than population and, thus, has increased the per capita availability of food over time. But there is also substantial evidence that intensification pressures in both low- and high-external input production systems can bring about significant environmental problems: soil erosion from hillside production, soil salinization in irrigated

Figure 10

**Growth in Wheat Yields**

Source: Compiled from FAOSTAT 1999; USDA-NASS 1999.

areas, and water pollution from nutrient and pesticide residues, among others. Although slowing down intensification might reduce such environmental externalities on existing agricultural land, proportionally greater amounts of land would be required to meet existing and future food needs. Strategic options to address this problem include policies to foster moderation of population growth rates, more agricultural research, and the development of environmental conservation practices.

The focus of much current agricultural research and development effort is on improving the productivity of agriculture in ways that are more environmentally benign. These so-called “win-win” options should provide simultaneous improvements in both agricultural and environmental goods and services.

At present, the highest yields for practically all commodities that are not exclusively tropical and subtropical are attained either in North America or Europe (see Table 10). Of note, however, are the high average rice yield levels in the irrigated agroecosystems of East Asia, primarily China, at 6.2 tons per hectare. These are only slightly below the highest regional average of 6.6 tons per hectare for North America, but in East Asia these irrigated rice ecosystems occupy approximately 35 million hectares compared to only 1.2 million in North America. Almost without exception the lowest average regional yield levels are found in Sub-Saharan Africa for both crops and livestock. Yields are about average for livestock products for Latin America and the Caribbean (LAC), despite the dominance of the livestock sector, possibly reflecting the much greater emphasis on extensive grazing systems in that region. There are also stark contrasts between the milk yields of Oceania, Europe, and North America, ranging from 2,200 to 7,200 kg per

animal per year, and those of Sub-Saharan Africa and Southeast Asia, at 152 and 163 kg per animal per year, respectively. This regional variability results from differences in climate, herd genetics, levels of specialization, and investments, among others.

The growth rate of cereal yields declined between 1975-85 and 1985-95 in 7 regions that account for approximately 80 percent of global production<sup>10</sup> (see Table 11). Globally, cereal area has been in gradual decline (but less than yield increases, so production has grown), and both area and yields of oil crops have seen continued growth in both periods. Of particular note is the sustained production growth in Sub-Saharan Africa of roots and tubers that globally show little to no growth over the past decade. Analyzing changing production in this way provides useful insights into the relative emphasis of area expansion versus intensification of production and, hence, on the likely nature of environmental consequences of change.

One current concern is that the recently observed slowdown in the growth of cereal yields (Pingali and Heisey 1999) will compromise agriculture’s capacity to feed the additional 1.5 billion people expected over the next 20 years, especially since per capita grain consumption also continues to rise. Some fear that this situation reflects stagnation in scientific progress, natural resource degradation, and growing pest resistance. But there is evidence that market factors also drive the trends. Declining commodity prices have caused farmers to make yield-reducing adjustments in input use. Increased attention has been paid to quality enhancement, protein content, grain size and shape, taste, processing qualities, sometimes at the expense of yield. Rising profitability of crops such as soybean and canola has led

Table 10

**Yields of Selected Commodities by Region, 1995–97 Average**

	North America	Latin America and the Caribbean	Europe	Former Soviet Union	West Asia/North Africa	Sub-Saharan Africa	East Asia	South Asia	Southeast Asia	Oceania	World
Yields of Crop Products						<i>(Mt/Ha)</i>					
Cereals	4.5	2.6	4.5	1.4	2.0	1.1	4.8	2.2	3.1	2.0	2.9
Maize	7.6	2.5	5.8	2.9	4.4	1.4	4.8	1.6	2.3	6.5	4.0
Wheat	2.4	2.4	4.7	1.5	1.9	1.6	3.8	2.4	0.9	1.9	2.6
Rice	6.6	3.2	6.1	2.3	5.8	1.6	6.2	2.8	3.3	7.4	3.8
Sorghum	4.1	2.8	4.9	1.0	1.6	0.8	3.9	0.8	1.5	2.1	1.4
Millet	1.5	1.2	1.5	0.7	0.8	0.6	2.0	0.8	0.7	1.1	0.7
Potatoes	35.8	13.7	22.9	11.3	19.7	8.5	14.3	15.3	13.1	33.4	16.0
Cassava	–	12.0	–	–	–	8.2	15.5	21.8	12.1	11.1	9.9
Dry Beans	1.8	0.6	0.9	1.4	1.3	0.7	1.1	0.4	0.9	0.7	0.7
Soybeans	2.5	2.2	2.9	0.6	1.8	0.8	1.7	1.0	1.2	1.8	2.1
Groundnuts	2.8	1.7	1.2	1.7	2.4	0.8	2.7	1.1	1.3	1.7	1.3
Sugar Beets	45.4	65.2	48.7	17.9	34.7	–	26.7	26.3	–	–	35.1
Sugar Cane	75.4	62.7	62.7	–	99.6	54.1	63.4	63.1	60.6	86.9	63.2
Seed Cotton	1.8	1.4	2.8	2.0	2.7	0.9	2.8	1.0	0.7	3.4	1.6
Yields of Animal Products						<i>(Kg/Animal)</i>					
Beef and Veal	308	192	248	162	143	139	166	106	169	208	199
Milk	7,158	967	2,185	2,055	238	152	543	630	163	3,644	931
Pigmeat	83	71	84	76	71	46	76	35	59	59	76

Source: Compiled from FAOSTAT 1999.

Table 11

**Crop Area and Yield Trends**

Region	Cereals				Oil Crops				Roots and Tubers			
	75–85		85–95		75–85		85–95		75–85		85–95	
	Area	Yield	Area	Yield	Area	Yield	Area	Yield	Area	Yield	Area	Yield
<i>(percentage annual growth rate)</i>												
North America	0.25	1.77	-1.02	1.20	0.55	1.27	1.69	0.87	0.21	1.30	0.81	1.29
Latin America and the Caribbean	0.17	3.01	-1.05	2.26	1.84	2.87	0.27	3.37	-0.48	0.73	-0.30	0.70
Europe	-0.20	3.00	-1.15	0.33	5.54	-0.43	1.84	0.05	-2.47	0.86	-3.13	-0.28
Former Soviet Union	-1.05	0.87	-1.47	-0.96	0.06	0.20	0.13	-1.14	-0.93	-0.25	0.09	-0.92
East Asia	-0.98	4.73	-0.10	1.89	2.33	3.37	1.21	1.79	-1.05	1.18	0.66	1.11
South Asia	0.39	2.38	-0.24	3.06	3.00	3.80	2.03	4.30	0.67	1.78	1.11	1.76
Southeast Asia	1.17	3.74	0.71	1.78	0.80	0.31	2.75	0.03	0.78	1.04	0.24	0.08
West Asia/North Africa	0.22	1.13	0.74	1.87	0.99	1.21	0.87	0.52	2.74	2.25	1.65	1.56
Sub-Saharan Africa	0.52	0.26	2.49	-0.65	1.87	2.38	3.04	3.05	2.35	1.25	4.02	1.71
Oceania	3.50	0.91	-1.92	1.50	2.68	0.71	1.34	0.16	0.88	0.91	0.40	1.18
World	-0.15	1.84	-0.29	1.16	1.67	2.17	1.71	1.83	0.10	0.47	1.13	0.02

Source: IFPRI calculation based on FAOSTAT 1999.

Table 12

**Value of Agricultural Production by Region, 1995–97 Average**

Region	Cereals	Roots and Tubers	Fibers	Fruits	Oil Crops	Pulses	Sugar	Livestock	Other	Total	Share of World Value
	<i>(millions of 1989-91 dollars)</i>										<i>(percent)</i>
North America	47,880	2,829	5,483	8,807	19,782	1,461	1,370	86,611	11,180	185,404	14.0
Latin America and the Caribbean	17,874	4,209	1,837	16,983	12,542	3,068	9,066	63,167	11,823	140,570	10.6
Europe	37,480	9,263	784	21,363	9,980	1,644	5,043	117,386	18,194	221,136	16.7
Former Soviet Union	17,532	7,922	2,407	3,789	1,975	835	1,513	42,045	5,086	83,103	6.3
West Asia/ North Africa	11,653	1,730	2,232	10,738	2,405	1,955	1,111	21,812	16,242	69,878	5.3
Sub-Saharan Africa	11,891	11,762	1,788	6,367	5,003	2,529	1,065	19,640	8,720	68,767	5.2
East Asia	74,368	15,444	7,011	14,034	12,876	1,738	1,924	110,353	61,564	299,313	22.6
South Asia	48,142	3,295	6,281	9,030	10,601	9,964	5,635	40,863	20,243	154,055	11.6
Southeast Asia	28,097	3,187	260	5,453	7,691	1,410	2,124	15,183	9,664	73,070	5.5
Oceania	4,341	366	589	1,150	564	689	672	17,971	924	27,266	2.1
World	299,259	60,007	28,673	97,713	83,419	25,294	29,524	535,031	163,641	1,322,561	100.0

**Source:** IFPRI calculation based on FAOSTAT 1999 and FAO 1997a.

**Note:** The total value of agricultural production was formed by weighting 134 primary crop and 23 primary livestock commodities quantities by their respective international agricultural prices for the period 1989-91.

to some displacement of cereals from the most productive farm-lands. And economic problems have depressed yields in the Former Soviet Union, a major cereal producing region.

### The Value of Outputs

Agriculture represents around 2, 9, and 23 percent of the total gross domestic product (GDP) of high, middle, and low-income countries respectively. In many of the poorest countries, it often represents 40 to 60 percent of total GDP.<sup>11</sup> Although agriculture represents a mere 1-3 percent of national GDP in the temperate, subhumid, and humid high-income countries of Western Europe and North America, the agricultural GDP of these countries represents about 78 percent of the global total (World Bank 2000:188). Furthermore, there is much evidence that the conventional measure of agriculture's share of total GDP significantly underestimates its true contribution. For example, while the Philippines, Argentina, and the United States were recorded as having agricultural GDP's that comprise 21, 11, and 1 percent of total GDP, respectively, studies have shown that the total "agribusiness" value of agriculture including manufacturing and post-harvesting services comprises 71, 39, and 14 percent of the total GDP in those countries (Bathrick 1998:10).

### VALUE OF AGRICULTURAL PRODUCTION

The global and regional value of agricultural outputs are summarized in Table 12 by major commodity group. The total value of output from the world's agroecosystems is \$1.3 trillion per year (IFPRI calculation based on commodity prices in 1989-91 international dollars (FAO 1997a), and average production from 1995-97 (FAOSTAT 1999)). Crops represent 60 percent and livestock 40 percent of this value. Within crops, cereals dominate (38 percent), and together with fruits (12 percent) and oil crops (11 percent) provide over 60 percent of total crop value.

### VALUE PER HECTARE

A comparable indicator of the monetary value of agroecosystem production is the value of output per unit of land.<sup>12</sup> However, the output value is sensitive to the choice of land variable: agricultural land, cropland, or harvested area (see Table 13 and Map 9). Globally, the value of crops per hectare of total cropland is \$521 per hectare, while expressing the same total value per unit of harvested land yield is \$662 per hectare. Areas with the highest shares of irrigated land, and hence higher cropping intensities, show higher values per unit area of cropland. By all these measures, the intensely cultivated rainfed and irrigated systems of East Asia are most productive. The clear distinction between potential returns to investment in crops versus extensive livestock is revealed in the value of livestock per unit of pasture land. The extensive livestock systems of Sub-Saharan Africa and Oceania exhibit low values per hectare of pasture,

Table 13

**Value of Agricultural Production per Hectare, 1995–97 Average**

Region	Total Value <sup>a</sup> of Output per Hectare of		Value of Crops per Hectare of		Value of Livestock per Hectare of Pasture
	Agricultural Land <sup>b</sup>	Cropland	Cropland	Harvested Area	
			<i>(1989-91 dollars per hectare)</i>		
North America	370	824	439	756	328
Latin America and the Caribbean	180	878	482	663	103
Europe	1,026	1,636	766	1,042	1,462
Former Soviet Union	145	375	185	341	123
West Asia/North Africa	193	744	511	747	81
Sub-Saharan Africa	69	400	285	316	24
East Asia	438	2,067	1,304	1,139	203
South Asia	582	724	531	503	831
Southeast Asia	674	810	642	637	866
Oceania	56	492	167	436	41
World	266	876	521	662	156

**Source:** IFPRI calculation based on FAOSTAT 1999 and FAO 1997a.

**Notes:** (a) The total value of agricultural output was formed by weighting 134 primary crop and 23 primary livestock commodity quantities by their respective international agricultural prices for the 1989-91 period. (b) Agricultural land is the sum of cropland and permanent pasture.

Table 14

**Food Nutrition, Human Populations, and Agricultural Employment by Region, 1995–97 Average**

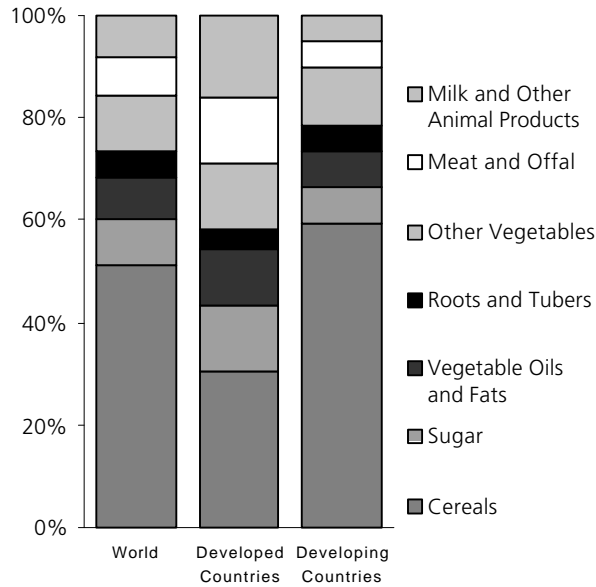
Region	Amounts Supplied by Agriculture <sup>a</sup>						Population			Labor Force		Total Population
	Calories		Fat		Protein		Agri-cultural	Rural	Urban	Total	Agri-culture	
	<i>(calories/ capital/ day: DES)<sup>b</sup></i>	<i>(share of total DES)<sup>b</sup></i>	<i>(grams/ capital/ day)</i>	<i>(share of total fat)</i>	<i>(grams/ capital/ day)</i>	<i>(share of total protein)</i>	<i>(millions of people)</i>					
North America	3,569	(99.2)	139.5	(99.3)	105.4	(95.7)	7.6	70.7	228.8	153.2	3.7	299.5
Latin America and the Caribbean	2,746	(99.4)	76.1	(99.2)	68.9	(96.4)	111.7	127.9	360.0	203.0	44.5	487.8
Europe	3,232	(99.0)	132.2	(99.3)	93.4	(94.8)	41.9	133.8	383.5	245.1	20.1	517.3
Former Soviet Union	2,776	(99.2)	73.3	(99.2)	79.9	(95.8)	49.7	92.9	198.9	146.8	23.5	291.8
West Asia/ North Africa	3,008	(99.5)	72.8	(99.3)	79.5	(97.4)	104.8	137.3	213.5	126.1	41.9	350.8
Sub-Saharan Africa	2,221	(99.4)	47.1	(99.0)	51.8	(95.9)	365.9	397.3	183.8	258.1	167.1	581.1
East Asia	2,783	(98.0)	68.1	(97.8)	69.6	(90.2)	871.6	895.6	539.8	839.2	517.8	1,435.4
South Asia	2,400	(99.6)	43.8	(99.5)	56.3	(98.3)	729.5	933.2	339.8	551.3	334.0	1,273.0
Southeast Asia	2,594	(98.4)	48.8	(97.4)	55.0	(88.6)	252.4	320.9	167.3	238.8	132.6	488.2
Oceania	2,940	(99.0)	112.5	(99.1)	89.1	(94.7)	5.3	8.6	20.3	13.6	2.5	28.9
World	2,732	(99.0)	70.3	(98.6)	69.3	(94.1)	2,540.4	3,118.2	2,635.6	2,775.1	1,287.8	5,753.7
<i>Percent of total population</i>							44.2	54.2	45.8	48.2	22.4	100.0

**Source:** Compiled from FAOSTAT 1999.

**Notes:** (a) Values exclude fish and other aquatic products. Values include livestock sources under both intensive and extensive (grasslands) grazing systems. (b) DES: Dietary Energy Supply.

Figure 11

**Share of Major Food Groups in Total Dietary Energy Supply**



Source: FAO 1996:25.

but because of the higher proportion of confined animal production (or the limited amount of pasture) and a higher consumption of pig and poultry meat, Europe, South Asia, and Southeast Asia show markedly higher returns by this measure.

**NUTRITIONAL VALUE**

The overriding purpose of agriculture is to provide an adequate and stable supply of food. Thus, a primary measure of the social value of agroecosystem outputs is their adequacy in satisfying human nutritional needs in terms of calories, proteins, fats, vitamins, and other micronutrients. The nutritional indicators adopted here are the per capita calories, fats, and proteins derived from agricultural sources. We use the per capita calorie indicator (also called the per capita Dietary Energy Supply, DES) as the primary indicator amongst these. As shown in Table 14, the global average DES supplied by agriculture is some 2,732 kilocalories per day (kcal/day), representing 99 percent of the total DES. In terms of protein, agriculture provides 69.3 grams per person, representing 94 percent of total protein intake (fish and other aquatic products make up most of the balance).

North America, Europe, and West Asia/North Africa enjoy the highest levels of DES, with over 3,000 kcal/day respectively. The lowest levels are found in Sub-Saharan Africa, South Asia, and Southeast Asia, with 2,200–2,600 kcal/day respectively. The regional disparities are even more marked in the case of proteins derived from agriculture, where North Americans con-

sume twice as much as Sub-Saharan Africans, 105 compared with 52 gram per day. Overall, the developed countries with 24 percent of the population consume 29 percent of the global DES, 34 percent of the global protein supply, and 43 percent of the global fat supply (FAO 1996:19). Actual per caput energy requirements vary by region because of systematic differences in body weights, metabolic rates, and human activity levels. Requirements for developing countries are typically around 2,100–2,200 kcal per day (FAO 1996:53).

Although, on the average, daily calorie requirements are exceeded by the DES in each region, per capita DES is broadly distributed about its mean value, highlighting that there are many people with inadequate food supply. In Sub-Saharan Africa, a staggering 33 percent of the population are undernourished, a significantly higher proportion than in Asia and Pacific, the next malnourished regions, although absolute numbers in Asia and Pacific are substantially higher (FAO 1999a:29). Although global food supply could provide adequate nutrition for the entire global population, a number of political and socioeconomic factors, including the limited capacity of the world’s poor to purchase sufficient food, hamper progress to achieving these objectives.

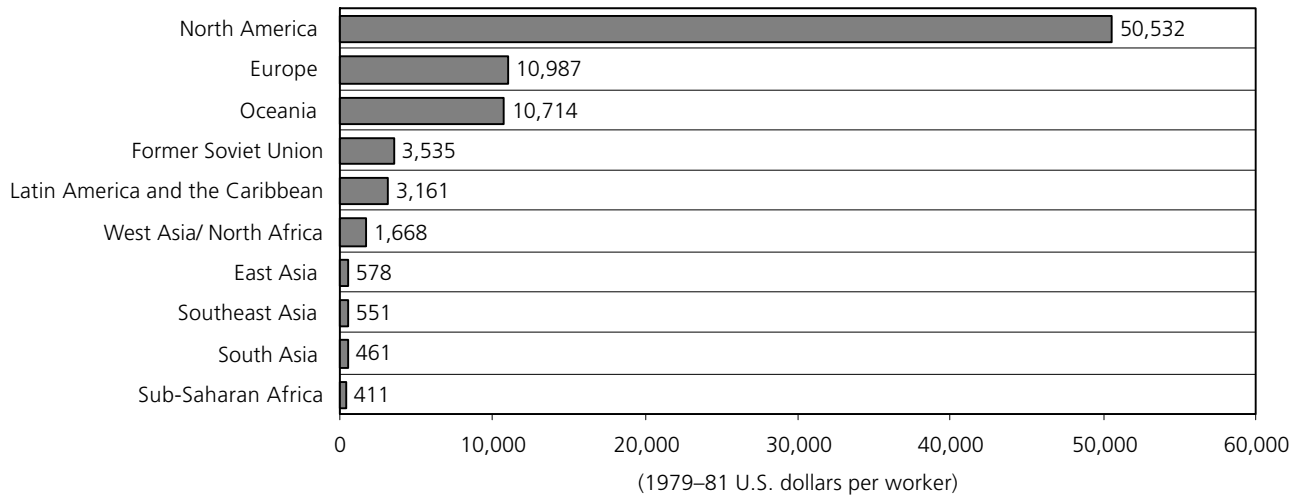
Vegetable products contribute around 84 percent to overall DES (71 percent developed, 90 percent developing) (FAO 1996:23). This is mainly comprised of cereals, sugar, and vegetable oils and fats (see Figure 11). Trends reveal a significant increase in the importance of animal products, meat, milk, and eggs, in the developing world (see Box 2), as well as a general decline in the consumption of roots and tubers (with the notable exception of Sub-Saharan Africa where roots and tubers contribute 21 percent to DES (FAO 1996:25)).

**EMPLOYMENT AND INCOME**

For rural households and communities—the majority of the world’s population—agricultural labor represents the dominant, sometimes only, source of livelihood. In 1996, about 3.1 billion people (54 percent of global population) were living in rural areas, and of these about 2.5 billion were estimated to be living in agriculture dependent households (see Table 14). FAO estimates the agricultural labor force at 1.3 billion people (22 percent of the total population and 46.4 percent of the total labor force), but the proportions are highly variable. North America has only 2.4 percent of its labor force directly engaged in agriculture, while East, South, and Southeast Asia as well as Sub-Saharan Africa have between 55 and 65 percent.

In recognition of agriculture’s importance as an income source for rural households, we have selected the annual value of agricultural production per agricultural worker as a proxy for the relative income potential of agricultural workers across the world’s agroecosystems. The value of production per worker includes purchased inputs and other farm operating costs as well

Figure 12

**Value of Production per Agricultural Worker, 1995-97 Average**

**Source:** IFPRI calculation based on World Bank 2000 and FAOSTAT 1999.

as labor. Globally, the value-added from agricultural production per member of the agricultural labor force is \$1,027 per year (1989-91 U.S. dollars). The income measure is much higher in regions having both high overall productivity and low labor inputs (*see Figure 12*). North America's income proxy of around \$50,000 per worker per year is over 4 times greater than that of Europe. This figure contrasts starkly with the value of \$411 (barely 1 dollar a day) per worker per year in Sub-Saharan Africa. The South Asia, Southeast Asia, and East Asia income proxies of \$461, \$551 and \$578, respectively, are 12 to 40 percent higher but still low in absolute terms. The progression nearly triples with West Asia/North Africa posting \$1,668 and Latin America and the Caribbean \$3,161 per worker per year.

These figures need careful interpretation. Although absolute levels of value-added per worker are much higher in North America, much of the production value is derived from the greater use of capital and purchased inputs. Thus, the indicator value is not adjusted for the economic returns attributable to other production inputs, or for variations in the quality of labor. Another refinement would be to adjust values to reflect the purchasing power of a dollar across different regions. The actual incomes of most farmers in North America and Western Europe, in common with those in many countries around the world, are low in relation to other economic sectors, and are declining (USDA 2000). However, farmers in developing countries seldom receive income-enhancing transfers and subsidies commonly available to farmers in most industrialized countries.

### Enhancing the Capacity of Agroecosystems to Produce Food, Feed, and Fiber

Despite past successes, affordably feeding the current world population, and the more than 70 million people per year by which that population will continue to grow over the next 20 years, remains a formidable challenge. Area expansion options are limited, soil and water resources in agricultural areas are often already stressed, pesticide resistance is increasing, and growth in yields seems more difficult to achieve. Increasing agricultural productivity remains, therefore, a central agroecosystem development goal, but one in which the calculus of productivity is more broadly defined to encompass the use of physical and biological resource stocks and human health impacts.

The strategic cornerstones of enhanced productivity are likely to be the following: increasing genetic potential of crops and livestock; reducing biotic losses associated with pests, pathogens, and weeds; extending the range of abiotic adaptability (for example, by increasing salt and drought tolerance); and increasing the efficiency of natural resource use.

Both conventional breeding and biotechnology-based innovations will improve the yield potential of crops and livestock. Long-term productivity losses and environmental stresses caused by conventional intensification can also be eased by better crop selection and crop rotations, and by soil, fertilizer, pesticide, and water management practices that conserve soil and water, enhance soil fertility, and disrupt the development of pests, diseases, and pesticide resistance. IPM, an approach that combines biological and cultural control of pests with reduced and judicious use of pesticides, has proved extremely effective but

is knowledge intensive. IPM is finding increasing favor with both commercial and smallholder farmers alike where specialist support is on hand to help adapt IPM practices to the constantly evolving field situation. However, because the use of pesticides will likely continue to grow in the foreseeable future, there is still a pressing need that they become increasingly target-specific and more rapidly and safely degraded. In developing countries, in particular, there is also a need to strengthen regulatory and enforcement mechanisms governing pesticide import, production and use, and to improve the training and protection of agricultural workers exposed to pesticides.

A common need underlying all of these strategies is that for improved knowledge. Ultimately this calls for continued investment in agricultural and natural resource research that can help design more productive and more environmentally beneficial farming systems and production technologies.

### Summary of Indicators and Data

At the global level, the indicators of food production levels and trends appear satisfactory. Compared to gloomy predictions of the world food situation by the end of the millennium, they could even be viewed as measures of considerable success. And despite slowing yield growth rates and increasing pesticide resistance, current expectations are that food production capacity can be kept in line with the growing demand in the global market (Pinstrup-Andersen et al. 1999).

There are, nevertheless, many underlying causes for concern. Perhaps the most telling are the enormous regional disparities that exist among the indicators of yield, nutrition, value, and income potential. These indicators are particularly troublesome since it is precisely in the areas of lowest productivity,

such as Sub-Saharan Africa, and of highest land degradation pressure such as much of Asia, Sub-Saharan Africa, and Central America, that the biggest advances in agricultural productivity need to be made. These areas have some of the highest population growth rates, and for the foreseeable future, they will continue to rely on national, and often local, sources to meet their food requirements.<sup>13</sup> Despite the growth and increasing liberalization of world trade, food imports today meet an average of only 10 percent of local food needs (McCalla 1999). Although trade expansion is likely, poverty is so widespread, foreign exchange so limited, and transport and marketing networks so poor in many of these countries, that purchasing imported food might not be an option for many.

At a regional and global scale of inquiry it is difficult to interpret available evidence in an integrated way, since there is so little information on actual land use patterns and practices. For example, little data exists on the application of organic nutrients and, when available, such data can be difficult to standardize among the different organic nutrient sources. Thus, although we have more (production, value, population) and less (technology, nutrients, pesticide, irrigation) reliable and complete sources of data, they are insufficient to determine how, say, nutrient, water, and pesticide inputs are likely to be combined by region, agroecosystem zone, and production system. Only by working at the appropriate scale and with spatial data that allow these pieces of information to be properly integrated—an explicit goal of the proposed Millennium Ecosystems Assessment—will it be feasible to better interpret the relationships between the capacity of agroecosystems to produce food versus their capacity to produce environmental goods and services.