Introduction

In 1837 John Deere patented the steel plow that cut through native prairie grasses and converted them to farms, first in the United States and then in distant lands. This plow, more than any other invention, symbolized the human ability literally to turn nature on its head. The steel plow became the foundation for modern agriculture. As the plows and the machines that pulled them got bigger, more and more land could be farmed by fewer people. Every increase in scale and intensity, however, increased environmental impacts as well. Over time it has become apparent that agricultural practices, more than any other single factor, have determined the state of the global environment.

But that picture may be changing. Though the John Deere name is synonymous with mechanized agriculture, the company has started venturing into the realm of sustainable agriculture. John Deere recently entered into a joint venture with a Brazilian agricultural company. This company held land that was producing primarily through cultivation techniques that eliminate tillage. The strategy of this partner is to buy degraded pasture and rebuild the soil to fully productive land for the cultivation of such crops as soybeans. Seeds are planted without turning the soil and organic matter is left on the surface. Such practices reduce soil degradation, erosion, and the use of fertilizers and pesticides, while increasing the soil's retention of water and other agricultural inputs added during production. The system is based on crop sequencing (growing two or three crops in the same year) as well as three-year crop rotations. The ground is planted with grass to build organic matter. Other improvements include keeping marginal lands out of production; areas that are not appropriate for farming are terraced and planted to trees. Perhaps even more interesting, the workers on the farm have an equity position in the company based on their length of employment and productivity. This is the new face of agriculture, and a few corporations like John Deere and its partners are beginning to invest in it. But it will take a long time to become the global norm.

One of the great contradictions of our time is that we know more about and are better able to save spaces and species than ever before. But we are losing both species and their habitats faster than ever, and more often than not the cause is agriculture.

Parks and protected areas, comprising about 5 percent of the land on the planet, have long been recognized as cornerstones of effective efforts to save biodiversity and ecosystems. Yet most species on the planet today live where people are trying to make a living. In general, most parks and protected areas were created to protect geologic formations and areas of striking beauty or cultural value, not biodiversity.

In any event, it is difficult to imagine how the size of parks and protected areas can be effectively maintained—much less increased in area—in the current and foreseeable political climate. Many protected areas are systematically attacked from all sides. Around the world, legal and illegal invasions of such areas are undertaken by oil and gas companies, miners, loggers, and others looking for resources that can be exploited. In addition, about half of the world's current protected areas are surrounded by agriculturalists, many of whom see protected areas as their next fields. The net effect of such actions is to reduce the value of such areas for biodiversity conservation. Even if the areas currently under protection can be maintained, recent research suggests that some 30 to 50 percent of species within them will disappear because their populations are too small to survive over the long run on the protected land available.

By contrast to the land under formal protection, about half of the habitable land on Earth is used for agriculture and livestock production. Because of this enormous scale, agriculture represents both a significant threat and an opportunity to protect biodiversity. One strategy for saving biodiversity is to help producers become more sustainable and productive so they can stay where they are, instead of expanding into pristine areas, while at the same time accommodating more biodiversity on their lands. Agriculturalists are the managers of global lands. They shape the face of the Earth (Tilman et al. 2002).

The environmental costs of agricultural practices (referred to as environmental externalities, ecological footprints, subsidies from nature, or passing environmental costs on to future generations) are usually not measured. When producers are not required to cover the true costs, they pass them on to society. For example, most current agricultural practices reduce the ability of ecosystems to provide goods and services. Clearing natural habitat and soil erosion both reduce carbon sequestered in the environment. This loss of organic matter in the soil reduces the ability of soil to absorb and retain water. Such practices not only increase overall environmental degradation downstream, they also increase the amount of external inputs (especially fertilizer) required to maintain productivity. Not only can more sustainable agricultural practices reduce these impacts, but they can also make agriculture a central part of the environmental restoration process.

The goal for sustainable agriculture must be to insure that society benefits not only from the production of food and fiber but also from the maintenance or restoration of ecosystem services such as watershed protection, healthy soil and the biodiveristy that depends on both. Globally, land cleared for agriculture is rarely allowed to return to a "natural" state. There are some exceptions in the eastern United States and Europe, but in general, once converted, land is used in one form or another by humans often until virtually nothing will grow there. At that point it may be abandoned, but it will never regain the biological diversity that it once had. The extent of environmental degradation caused by agriculture can still be seen near archeological sites in Central America and Southeast Asia that are a thousand years old. To restore such degraded land to productivity and reestablish other ecosystem services might be possible, but only at great expense.

Sustainable agriculture requires that ranchers and farmers alike be rewarded for producing food, fiber, *and* ecosystem services (Tilman et al. 2002). Globally, the main obstacle to this approach is that current subsidies support unsustainable production systems in one part of the world and make them necessary for survival in the rest. However, if a portion of these subsidies were used to pay for the production or maintenance of ecosystem services, they could increase overall agricultural production, profitability, and viability in the short, medium, and long term.

Current Agricultural Production

Agricultural production has modified the natural landscape more than any other human activity. The land dedicated to agricultural production continues to grow (see Table I.1). Globally, agricultural land use has increased at a rate of approximately 13 million hectares per year for the past thirty years. Much of this expansion has come at the expense of forests (except in North America and Europe). Producers are whittling away at natural habitat on the margins of agricultural areas. Because roads, infrastructure, and urban expansion often come at the expense of agricultural land as well, agricultural expansion into new areas is even more rapid than suggested by these figures, which reflect only net growth.

Table I.1 Global Land Area by Use, 2000
(in billions of hectares)

	1961	1970	1980	1990	2000
Total agricultural area	4.41	4.50	4.72	4.91	4.97
Total arable land	1.27	1.30	1.33	1.38	1.36
Total permanent pasture	3.14	3.21	3.29	3.41	3.48
Total forest and woodlands[1]	4.37	4.33	4.30	4.32	4.17
Nonarable and nonpermanent crops	11.70	11.65	11.60	11.54	11.56

Source: FAO 2002.
[1] Data for 1996.

There are several factors that determine the overall damage from agricultural production as well as the strategies to address it. Most agricultural commodity production is for basic foodstuffs, and most products are consumed within the country that produced them. Some 90 percent of all arable land is planted to annual crops, which cause more damage than perennials. Because annual crop production methods tend to exhaust the soil in which the crops are grown, producers must continually convert natural habitat to agricultural uses. As soil loses its fertility, land is used for a succession of different crops with fewer and fewer nutritional requirements. This can be visualized as farming down the nutrient chain.

Many think of capital-intensive, high-input production systems when they think of industrial agricultural commodities, and they think that these systems are somehow a distinct category of farm from those that put food on our table. In truth most high-input, intensive production systems are used to produce food crops that are destined primarily for the food industry and that feed most people on the planet.

Of course, agricultural crops are also used to manufacture nonfood products. These include fiber crops such as cotton, hemp, sisal, jute, flax, and wood pulp. Tobacco is also a major nonfood crop. In addition, plantation-grown natural rubber is indispensable in the manufacture of a number of key industrial products. The area of production devoted to these agricultural crops, however, is only a small fraction of that devoted to food crops.

In Search of the "Ideal" Agriculture

Many environmentalists do not believe that conventional farming can be improved sufficiently to reduce its damaging effects to acceptable levels. They would rather see agricultural producers revert to less intensive forms of low- or no-input agriculture that were common a century ago. These systems of production relied on a mix of crops, trees, livestock, and ground cover, and on crop rotations rather than more intensive monocrop production. Through their diversity, such systems offered more protection against pests and the weather. Nutrients were recycled within the system and through livestock. Production was more labor intensive. Such systems of production, it is said, produced less environmental degradation and were more sustainable than today's intensive, highly specialized agricultural production systems.

Such agricultural production systems have ancient roots. China's Yellow River (Huang He) Valley and Iraq's Tigris-Euphrates floodplains have been farmed more or less continuously for more than 7,000 years. Similar farming systems have been deployed or developed independently in Asia, Europe, and the Americas for 2,000 to 3,000 years. It is clear that some agricultural production systems can be operated over centuries or longer.

Nonetheless, there are several flaws in this "idealization" of less intensive farming, at least as it is often portrayed. Historically (and even in many areas where such farming is still being practiced today), the evidence is not conclusive that it was or is less hard on the land than many current practices. Some of these less intensive farming systems have failed, and often population densities have pushed cultivation levels beyond what is sustainable. There is ample evidence that parts of the Andes, Mesoamerica, North Africa, the Middle East, Europe, South and Southeast Asia, New England and even the Great Plains (to name but a few) were overfarmed to the point of degradation or collapse using "traditional" forms of agricultural production. Even today some of the most "traditional" production systems are found in rural areas with the most severe malnutrition and famine, as well as some of the most severe environmental degradation.

Most importantly, the Earth is currently home to over 6 billion people. Supporting them all by low-intensity cropping—depending solely on recycling organic matter and using crop rotation with legumes—would require doubling or tripling the area currently cultivated. This land would have to come from somewhere—and would most likely mean the elimination of most if not all tropical rainforests and the conversion of a large part of tropical and subtropical grasslands too. Lower-intensity agricultural practices are very labor-intensive, so such reversion would also require the return of a substantial share of the labor force to farming (Smil 2000). These are hardly acceptable alternatives.

During the last forty years global population nearly doubled. Contrary to many predictions, as the population has increased, global food production increased to feed most people. In fact, global per capita agricultural production increased 25 percent, while the amount of land needed to produce this additional food increased by only 10 percent. Table I.2 shows that, with the exception of wheat, the increases in consumption of major food crops are significantly larger than the increase in lands devoted to producing these crops. Where there have been famines, they have been caused by politics and human policies. Moreover, they need never have happened. While that may give little consolation to those who starve, it should give guidance to those who want to prevent famine in the future. Life expectancy has risen dramatically; China, for example, has risen to 69 years from 35 years in the 1950s (Chen and Ge 1995). The world prices of nearly every staple foodstuff are, in inflation-adjusted terms, lower than a generation ago. Most are at their lowest level for any time for which there are records.

Table I.2 Feeding a Hungry World

Crop	Contribution to Total Food Demand (%)	Change in Demand 1974 – 1994 (%)	Change in Area of Production 1974 - 1994 (%)
Rice	30	71	52
Wheat	18	97	96
Corn (maize)	13	115	72
Cassava	12	40	17
Potatoes	5	115	25
Sorghum	4	54	18
Bananas	4	47	14
Sweet potato	4	37	20
Food legumes	3	32	13
Barley	3	79	22
Plantains	2	29	-13
Millet	2	28	12

Source: FAO and CGIAR as cited in *The Washington Post,* 1995.

This apparent bounty is due in large part to the "green revolution" in agriculture. Since 1900 the world's cultivated area increased by about one-third, but because of a more than fourfold increase in productivity, total production has increased almost sixfold. A major portion of this gain can be attributed to selective breeding programs and to an 80-fold increase in external energy inputs, mostly in the form of fossil fuels (Smil 2000). This energy is used for machinery, fuel, and fertilizer and pesticide production. Energy, machinery, and agricultural chemicals have been substituted for labor. Other gains have come from reduced storage losses and increased food distribution to a wider range of consumers over more of the year.

On the other hand, it is clear that the Earth's current population cannot be supported in the American lifestyle, in which an estimated 40 percent of food is thrown away. The issue of feeding the world is not one of overpopulation, but rather a fundamentally different one of overconsumption. Such waste has an undeniable impact on the biosphere through the use of natural, material resources that are required to produce what is wasted.

The current answer to feeding the world is large-scale, high-input, monoculture (monocropping) agricultural production systems, which have existed for only 50 to 100 years. The environmental problems caused by such production systems perpetuate and intensify earlier agricultural impacts. The most damage is caused by habitat conversion (and the corresponding loss of biodiversity and ecosystem functions), soil erosion and degradation, and pollution (from fertilizer and pesticides). These impacts are not new. They result from the expansion of agriculture into natural habitats, shortened or eliminated fallow cycles, adoption of double and even triple cropping schemes, introduction of faster maturing and higher yielding varieties, and use of heavy machinery that causes soil compaction. In addition, the consolidation of smaller farms into huge operations, the salinization of soil resulting from improper irrigation practices, the use of agrochemicals, the inefficient use of larger quantities of water, and the consequent creation of more effluents from farming systems also contribute to increasing levels of environmental degradation.

These negative impacts raise serious questions about the long-term sustainability of high-input, intensive agriculture. The increasing dependence on globally limited supplies of fossil fuels is not sustainable. Continuous intensive monocropping may be productive and profitable in the short term, but as it is possible only through the application of increasing amounts of synthetic chemical fertilizers and pesticides, it is not sustainable over time. It is in no small part responsible for the modern form of "shifting cultivation" that results in the moving agricultural frontiers that are found around the world.

And of course this list of threats posed by intensive agriculture does not account for the growing tendency of farmers to turn to genetically modified organisms (GMOs) and the latest round of biotech inputs to increase productivity on ever-less-fertile land. These too may pose severe threats to biodiversity and to agriculture itself through the creation of noxious pests, weeds or more importantly the mutation or loss of beneficial soil microorganisms.

Around the world today, agriculture is practiced by a wide range of producers. Whether farmers sell 100 percent of their product to markets or are primarily subsistence-oriented (producing food for their families and selling surplus into local markets) they all have the potential to cause environmental damage. As producers become more dependent on markets to meet their own wants and needs, they produce what their circumstances will allow them to, to obtain the highest returns with the fewest risks. Initially this means selling surplus subsistence production. Over time, however, it means planting cash crops within less intensive production systems. Eventually, even this focus can shift as producers move to intensive monocropping systems, with subsistence crops marginalized into gardens. In many areas of the world there is still considerable local market demand for subsistence crops, but even in these markets what is valued can shift over time. For example, in Africa, production is shifting from such traditional crops as sorghum, millet, and cassava to rice, corn (maize), and wheat.

Despite all the problems with intensive industrial agriculture, it is equally clear that low-input cultivation systems, as they were practiced in the past, cannot meet the current food and industrial needs that people around the world have come to expect from agriculture. Somewhere between these two extremes are systems of production that are more sustainable and productive and that make better use of fewer resources than either the less input intensive or more intensive systems that currently dominate global agricultural production.

Any use of natural resources has impacts. The problem at this time is that producers have no incentives to reduce their negative impacts. If anything, because there are no disincentives to reduce environmental impacts, producers have every reason to ignore them. The question for societies is which impacts are acceptable, and how to discourage the practices that lead to unacceptable impacts.

The Organization of this Book

This book identifies and explores the main threats that key agricultural commodities pose to the environment as well as the overall global trends that shape those threats. It then identifies new practices as well as tried-and-true ones that can increase production while minimizing environmental costs. Many who analyze the environmental impacts of agriculture focus on trade policies that affect specific agricultural commodities traded internationally. There are two problems with this approach. First, most agricultural products are consumed in the producing country and not traded across borders, even in a processed form. Second, the main environmental impacts are on the ground; they relate to production practices, not trade. Trade and trade policies are one way to approach the problem but only if they can be focused in such a way as to reduce the production impacts of commodities that are not by and large traded internationally.

This book takes the position that working with farmers directly to identify or co-develop better management practices (BMPs) may be far more effective in the short term and may provide better information to inform subsequent trade and policy strategies. While some BMPs may be encouraged by government or even international trading partners, most probably will not. In the end, the protection of endangered species and habitats with high conservation value is often essentially a local or regional issue that involves subsistence farmers or producers connected to local markets rather than international ones.

Another issue that receives considerable attention among those interested in agriculture, poverty, and the environment is who causes the most environmental damage. A common assumption is that large-scale, capital-intensive, high-input commercial farms have more negative impacts than small farmers who are trying to scrape together a living by producing food for their families and selling surplus locally. In fact, both are to blame. An increasing body of evidence suggests that smaller, more marginal producers may actually cause the bulk of environmental damage in both developing and developed countries. This damage can result from farming marginal land, not having efficient equipment (or the money to buy it), or not having good information about better practices.

This book does not attempt to answer the question of whether large-scale, high-input; low-input; or subsistence agriculture causes most environmental damage. Rather, the focus is to identify which practices are more environmentally destructive and whether better practices exist to reduce or avoid those impacts altogether for any of these systems of production. The focus is on primary production directly rather than on the processing of the primary products, except where processing occurs largely on farm. Likewise, the focus is not on value-added processing through intensive feedlot systems such as those for cattle, chicken, or pigs. Such operations are more similar to factories than to farms and should be subject to the same pollution controls as other factories.

The twenty-one crops that are the focus of this volume include: bananas, beef, cashews, cassava, cocoa, coffee, corn (maize), cotton, oil palm, oranges, plantation-grown wood pulp, rice, rubber, salmon and shrimp from aquaculture, sorghum, soybeans, sugarcane, tea, tobacco, and wheat. These crops occupy most of the land used for agriculture in the world (see Table I.3). In addition, they represent a mix of temperate and tropical crops, annual and perennial crops, food and nonfood crops, meat and vegetable crops, and crops that are primarily traded internationally as well as those that are consumed primarily in the country of origin.

Table I.3 Global Area Planted to Crops Discussed on this Report, 1961-2000
(in millions of hectares)

	1961	1970	1980	1990	2000	Percentage Change 1961-2000
Bananas	2.03	2.71	2.78	3.38	4.1	90.1
Beef	3,144.74	3,211.45	3,287.88	3,409.64	3,459.8	10.0
Cashews	0.52	0.86	0.88	1.06	2.7	280.8
Cassava	9.63	11.62	13.60	15.20	16.8	74.5
Cocoa	4.10	4.06	4.42	5.38	7.5	82.9
Coffee	9.76	8.88	10.04	11.30	10.6	8.6
Corn	105.58	113.13	125.69	131.32	138.7	31.4
Cotton	31.86	34.16	34.32	32.97	32.7	2.6
Oil palm	3.62	3.27	4.28	6.08	9.7	168.0
Oranges	1.21	1.60	2.22	3.15	3.6	197.5
Rice	115.50	133.10	144.54	146.93	154.1	33.4
Rubber	3.88	4.62	5.41	6.65	7.7	98.5
Salmon	NA	NA	NA	NA	NA	NA
Shrimp	0.05^{+}	0.15^{+}	0.25^{+}	0.9^{+}	1.8	3500
Sorghum	46.01	49.41	44.09	41.55	42.0	-8.7
Soybeans	23.82	29.52	50.65	57.13	74.1	211.1
Sugarcane	8.91	11.11	13.29	17.08	19.6	120.0
Tea	1.37	1.69	2.37	2.26	2.3	67.9
Tobacco	3.40	3.77	3.90	4.65	4.2	23.5
Wheat	204.21	208.02	237.19	231.28	213.7	4.6
Wood Pulp	#	#	#	#	10	#

Source: FAO 2002
Note: $^{+}$ Estimated by author based on FAO production data.
# indicates data not available.

A number of significant crops are not discussed in this book. In many cases, the excluded crops are those whose area of production is in decline, or ones that are not deemed as globally significant as another crop that is included. Some of the more obvious tradeoffs were the inclusion of wheat instead of barley, rye, or oats; sorghum instead of millet; cassava instead of sweet potato; soybeans and oil palm instead of peanuts (groundnuts), sunflowers, canola (rapeseed), olives, or coconuts; and sugarcane instead of sugar beets.

Some of the omitted crops are very important locally. This is the case with such crops as potatoes, grapes, apples, horticulture crops, cut flowers, or sugar beets. The assumption, however, is that the issues and lessons that are raised through the discussion of the crops that are included are transferable to most of the others. And, while no blueprints for sustainability are included, the larger purpose of this work is to help the reader understand how to think about agricultural production and the environment.

The discussion for each crop chapter follows the same outline. Each chapter begins with "Fast Facts" that summarize important comparable information for each crop, including maps of production area. These facts include: the total area in and volume of production, the average and total value of production, the main producing and consuming countries, the percent of production exported, the species name(s), and the main environmental impacts as well as the potential to reduce those impacts.

In addition, each chapter presents (to the extent possible) comparable information about each crop. The discussion starts with an introduction to and history of each crop as well as an overview of the main producing and consuming countries. The main systems of production are described for each crop as well as any processing of the crop that occurs within the area of production. A section is included about the current substitutes for each crop and the impact of substitutes on markets. Market-chain analyses are included for each crop to the extent possible, but because this information is rarely in print, it is not complete. Market trends are also identified and analyzed but these, too, should not be considered definitive, as this is the stuff of crystal balls and is, as a result, rather incomplete. Finally, the major environmental impacts are discussed and strategies for addressing them are identified.

Much of the production and trade data in this book are based on statistics from the Food and Agriculture Organization of the United Nations (FAO). These data are generally the best available but are considered by many to underestimate both total production and area in production. In addition, a wide range of figures from different sources are used to illustrate different issues raised in different chapters and some of this data is contradictory. Every attempt has been made to reconcile these numbers, but it has not always been possible.

Price data, too, have been difficult to obtain and more difficult to verify and standardize. In general, prices have been indexed to 1990 U.S. dollar values. World producer prices for individual commodities were calculated by transforming FAO producer price data into world averages. Such data are reported as individual commodity prices per country. A group of countries that represent world production was chosen, taking into consideration the available data. The world producer price for each commodity is calculated from a simple arithmetic average of the chosen representative countries' producer prices.

Libraries are full of information about agriculture in general and about these crops in particular. Furthermore, the world is full of farmers who produce them and who can supply valuable information and strong opinions. In short there is neither a dearth of information nor opinions about these commodities and how they are produced. There is also considerable information (a vast quantity of publications, research, data, and analyses) focused specifically on describing or proposing how to reduce the environmental damage from producing each crop. This volume draws on all of these sources, including my own personal experience with large and small producers in both the developing and the developed world. Though every attempt has been made to make the crop chapters complete, inevitably there are gaps. Some issues are harder to address for most of the commodities in question. For example, little work has been undertaken to assess the cumulative environmental impact of any single crop in a specific place over time, much less the comparative impacts of crops that produce products that are readily substituted for each other. Even less has been done to evaluate the global impacts of a specific crop or to identify the likely environmental impacts of global trends within an industry. This book offers insights of a different scale and focus and suggests how more comprehensive work on future trends could help those interested in the environment and agriculture to better understand issues of economic, social, and environmental viability.

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