IMPACT OF GLOBAL CHANGE ON AGRICULTURE

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Summary

Agriculture and environment are intimately and reciprocally related. This relationship can be explained by reference to the carbon cycle, the human modification of which has resulted in the provision of food and fuel energy, wealth generation, and a range of environmental problems. The converse aspect of the relationship between agriculture, environment, and people means that the environmental, socioeconomic, and technological developments have had, and will continue to have, repercussions for agriculture. Soil erosion, desertification, and the impairment of water quality can, in extreme cases, result in the abandonment of agricultural land; even in cases of slight to moderate degradation, productivity and carrying capacity will decline.

Agriculture plays a pivotal role in the people-environment relationship, and as such it comprises both the generator and recipient of stimuli for change. In a temporal context, agriculture can unequivocally be described as a major agent of global change; since its inception 10 000 years ago, agriculture has been a direct cause of change in the biosphere.

Agriculture is a technology that represents a fundamental bond between people and environment.

The inception and dissemination of agriculture, which created unparalleled environmental and cultural change, is herein reviewed. Agriculture will continue to cause environmental change at scales from the local to the global; the major driving force will be population change. Global change will also influence the extent and characteristics of agricultural systems. The likely roles of environmental change, notably climatic change and deteriorating soil and water quality, of socioeconomic developments, such as the spatial pattern of population growth and globalization, and the impact of new technologies, e.g., biotechnology and information technology, are analyzed.

Biotechnology involves the harnessing of organisms, or components of organisms such as genes, to undertake specific tasks; agriculture itself is thus a form of biotechnology. It has many applications in agriculture and is a significant tool for intensification. As with all technologies, it has its drawbacks and its advantages. The latter, combined with its capacity for wealth generation, will ensure that biotechnology will constitute a major force in world agriculture and thus a major agent of environmental change. In terms of scientific advances, biotechnology is likely to have the most profound effects on agriculture. The advent of genetic engineering in particular must be considered as a major agent of both agricultural and environmental change in the early twenty-first century.

1. Agriculture and Environment

Agriculture is a technology that represents a fundamental bond between people and environment. There is a reciprocal relationship among all three. This relationship has existed since early humans began active hunting, to replace scavenging, and collecting; it intensified as permanent arable and pastoral farming developed between eight millennia and ten millennia ago in centers of innovation, e.g., the Near East, the Yangtze basin, central Mexico, and the northern Andes. Essentially, agriculture manipulates biotic and abiotic resources to produce food energy and useful substances such as hides and fiber; specific plants and animals are selected for certain qualities and they are husbanded using the resources of soil, water, and climate.

The nature of agricultural systems has varied temporally and those of today are equally heterogeneous. Such vicissitudes occur on two counts: first, the biotic and abiotic resources vary considerably on a spatial basis and the latter, especially, determine the limits within which agriculture can be practiced; second, the level and intensity of technology varies. The world is characterized by an extraordinary array of agricultural systems ranging from traditional, low-energy-input subsistent systems to industrialized high-energy-input monoculture. This variation can be emotive. On the one hand, it is a testament to human ingenuity and its derivation of support for some 6×10^9 people that has transformed a substantial proportion of the Earth's wildscapes into landscapes. On the other hand, the variety and extent of agricultural systems bears witness to the vast modification that humanity has wrought on the biosphere and begs the question as to whether ecosystem services, such as biogeochemical regulation (this is essential for climatic regulation), can be adequately maintained. This is especially relevant to the global biogeochemical cycle of carbon that is discussed below.

Agriculture has been responsible for more environmental change than any other technology. As it has expanded and intensified, through "need" and "greed," i.e. to sustain and promote population growth through the provision of food and to provide commodities for barter and trade in the process of wealth generation, agriculture has caused a wide range of environmental problems. Of these, the loss of biodiversity is perhaps the most significant because of its irreversibility. Soil erosion, desertification, and the impairment of water quality through cultural eutrophication, waterlogging, and salinization are all initiated or accelerated through injudicious agricultural practices.

Indeed, the availability and quality of water may become one of the most limiting factors to agricultural productivity in the future (see *Quantity and Quality of Water for Agriculture*).

Agriculture has also had a major impact on humanity, notably through the process of development with which it is intimately associated. It is linked with population growth and wealth generation; where surpluses are produced people have been freed from food production. This, in turn, has contributed to trade, industrialization, technological endeavor, and service provision through its facilitation of division of labor.

The converse aspect of the relationship between agriculture, environment, and people means that the environmental, socioeconomic, and technological developments have had, and will continue to have, repercussions for agriculture. Soil erosion, desertification, and the impairment of water quality can, in extreme cases, result in the abandonment of agricultural land; even in cases of slight to moderate degradation, productivity and carrying capacity will decline. Thus agriculture becomes self defeating, a problem which is more common in poorer nations than in richer nations; the former have fewer safeguards, often little research on effective conservation measures, and limited access to technology. There is also much speculation as to the likely impact of global warming on the world's agricultural systems.

The Intergovernmental Panel on Climate Change (IPCC) and the UK Meteorological Office has suggested, on the basis of wide-reaching evidence, that global warming caused by anthropogenic activities is occurring. It is estimated that global temperatures rose by about 0.6 ºC during the last century, a trend that will most likely accelerate through the twenty-first century. Agriculture, through its part in altering the character of the biosphere and its consumption of fossil fuels, has played a significant role in global warming (see *The Impact of Agriculture on Global Change*). How global warming will affect agricultural systems is debatable; for some nations there will be advantages and for others there will be problems.

Included in the many socioeconomic factors that will continue to influence agriculture are population change, trade relationships (part of the globalization process), and rising standards of living. None of these factors operate uniformly on a global basis but the repercussions may be global. For example, population growth, which it is estimated by government agencies to range from about 30% to 90% by 2050, will occur mostly in the developing countries of tropical and subtropical regions.

The pressure on agricultural systems in these nations will increase substantially, and at the same time there will be pressures to increase the productivity of agricultural goods for export. Where standards of living are increasing, as in newly industrializing nations such as China and those of Southeast Asia, changing food demands, and especially increasing consumption of meat and dairy products, will cause agricultural systems to change in response to consumer choice, i.e. market forces. Forces that are external to a nation will also influence agricultural systems. The demand for flowers and high quality vegetables, such as asparagus and *mange tout*, and rising demands for beef in Europe and North America, have resulted in the increased production of these commodities in some developing countries. In some cases the production of goods for export takes precedence over the production of staple foods, which are sometimes provided through food aid.

Inevitably, in the electronic and scientific world at the turn of the millennium, information technology and scientific developments have had significant impacts on agriculture. Information technology can facilitate the efficient use of resources through improved land-use practices. Of particular importance are knowledge-based systems (computers) and remote sensing; data from these can be combined in Geographical Information Systems (GISs). Knowledge-based systems can be used to control irrigation systems and to determine the quantity and location for artificial fertilizer treatments and applications of crop protection chemicals, i.e. they can be used to determine best management practices. Remote sensing from aerial photographs and satellite imagery can provide information on parameters such as soil type, soil moisture, the state of crop health, and real and potential crop yield. GISs can also be used for environmental management related to agriculture; for example areas subject to risk of soil erosion and desertification can be identified and agricultural practices adapted accordingly.

In terms of scientific advances, biotechnology is likely to have the most profound effects on agriculture. The advent of genetic engineering in particular must be considered as a major agent of both agricultural and environmental change in the early twenty-first century. The ability to manipulate whole organisms is the *fundamentum relationis* of agriculture; genetic engineering is the capacity to alter the genetic makeup of plants and animals to foster the expression of desired traits. Genetic engineering has applications in medicine and environmental remediation, but its main and most controversial application to date has been in agriculture. The possibilities of engineering traits such as herbicide, drought and salinity tolerance, pesticidal properties, and so on, are exciting; all could increase productivity substantially. However, there are as many potential disadvantages as there are advantages. Genetic engineering could produce just as many environmental threats as it presents opportunities for conservation. It could also have repercussions for human health and, like most technologies, it is not available equitably.

The issues introduced here, which relate environment, agriculture, and people, are elaborated below following an examination of agriculture's role in the global biogeochemical cycle of carbon.

1.2. Agriculture and its Role in the Global Carbon Cycle

As this volume illustrates, agriculture is a multifaceted activity with many definitions. It is, however, rarely defined in relation to its role in the global carbon cycle despite the fact that the fundamental objective of agriculture is the production of carbon-rich substances. Thus agriculture can also be defined as a carbon processing system or a means whereby humankind, for its sustenance, success, and wealth generation appropriates carbon within the biosphere.

Through the process of photosynthesis, crop plants combine water and carbon dioxide with energy from solar radiation, to produce carbohydrates. These substances are used by the crop with other nutrients to produce all the chemicals necessary for their metabolic processes, for their structural parts, and for respiration and reproduction, e.g., cellulose, proteins, amino acids, and so on. This reflects the direct role of agricultural systems in the global carbon cycle. The intensity of this role will vary enormously from one type of agricultural system to another. Where there is little modification of natural ecosystems and little input of fossil-fuel energy, the degree of manipulation of carbon capture is low, as occurs in those rangelands where nomadic pastoralism is prevalent. In contrast, the industrialized, often monocultural, agricultural systems of Western Europe and North America represent intense manipulation of carbon capture. The relatively high volume of "useful" (usually edible) carbon generated in these systems is made possible through the use of fossil fuels.

Mechanization, crop protection and animal health chemicals, and artificial fertilizer are all products of fossil-fuel use; consequently the carbon fixed in ancient biospheres is subsidizing the current production of useful/edible carbon. In particular, these products are used to modify the environment through improving the capacity of the agricultural system to capture carbon, and to enhance planting and harvesting. This environmental improvement also includes the reduction of competitors for carbon, e.g., insect pests, weeds.

Despite this manipulation of carbon, agricultural systems rarely "fix" more carbon than the natural ecosystems they replaced. This has implications for the global carbon cycle on three counts. First, the carbon from the biomass is released as natural vegetation communities, especially forests and woodlands, are modified or replaced. Second, the organic matter of the soil is subject to accelerated decomposition, so this aspect of carbon storage is also reduced. Third, the removal of a natural vegetation cover diminishes the capacity of an area of land to absorb and store carbon. Overall, there is a net flux of carbon from the biosphere to the atmosphere.

Thus, through its direct and indirect impact on the global carbon cycle, agriculture causes a release of carbon (as carbon dioxide) from the biosphere to the atmosphere and so contributes to global climatic change. Moreover, through the loss of biodiversity it impairs the capacity of the biosphere to absorb carbon. It is also apparent that disruption to the global carbon cycle has intensified as technological innovation in agriculture has increased in sophistication. The pitting of carbon (fossil fuels, biomass carbon) to acquire carbon (food and fiber) is at the very crux of agriculture. On the one hand, it is successful insofar as it supports about 6×10^9 people worldwide, but on the other hand, it is a major contributor to global environmental change which will have repercussions for agriculture in the twenty-first century (see *The Overall Impact of Agriculture on the Biosphere and the Atmosphere*). This interplay between agriculture and the global carbon cycle conceptualizes and epitomizes the reciprocal relationship between agriculture and environment, including global environmental change.

2. Agriculture and Global Change: A Reciprocal Relationship

There has been a reciprocal relationship between global change and agriculture since the inception of the latter. Indeed, global environmental change as the last ice sheet of the Pleistocene retreated 12 000 years ago to 10 000 years ago probably contributed to the development of agriculture through the impact of climate on biospheric resources. The inception and spread of agriculture was a major turning point in the people-environment relationship because it marked the exertion of increasing control by humankind over the environment. Agriculture thus occupies a central place in the people-environment relationship as illustrated in Figure 1. It has not only prompted, and benefited from, scientific and technological innovations that, in turn, have empowered society's manipulation of the environment, but it has underpinned political power and military might. Moreover, it has facilitated developments that have also transformed people-environment relationships. Such developments include the advent of metallurgy, world exploration, and the Industrial Revolution.

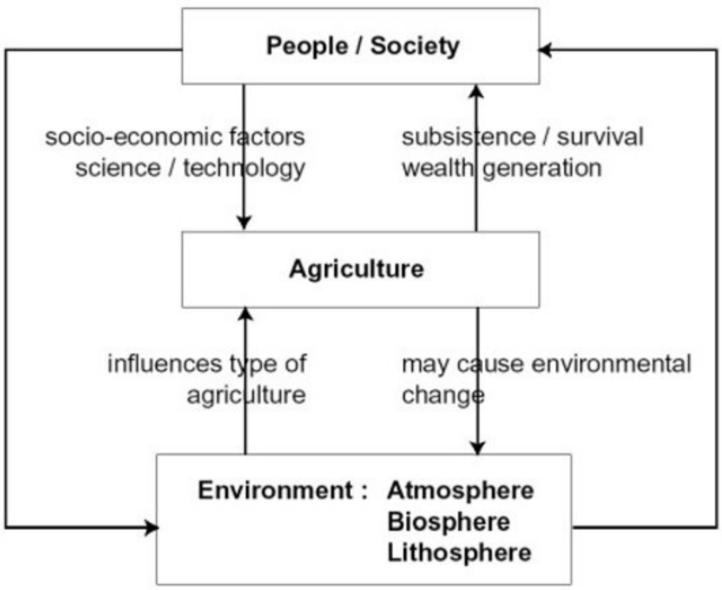

Figure 1.The primary relationship between agriculture, people, and environment

These advances have manifested in various forms globally but they have all influenced agricultural systems profoundly. Metallurgy produced new and efficacious tools for manipulating the environment, and world exploration resulted in an exchange of crops and animals between the Old and New Worlds. The Industrial Revolution grew out of agricultural innovation and the adoption of coal as a source of energy to replace wood. Its success was made possible because of a reliable food supply within Britain and Europe along with imports from colonies and former colonies. Population growth surged and elicited positive feedback in agricultural systems at home and abroad. This had a major impact on the environment; the period 1650 to 1950 witnessed a massive alteration of the biosphere with widespread deforestation and loss of biodiversity. The relationship between agriculture and global change is thus not only reciprocal but also dynamic.

2.4. The Past: The Inception of Agriculture and Its Spread

The first domestication of plants and animals occurred between 10 000 years ago and 5000 years ago. It is generally considered that the earliest agriculture was developed by sophisticated hunter-gatherer communities in the Near East (see *History of Agriculture*). Here, sheep, cattle, goats, and pigs were domesticated 8000 years ago to 9500 years ago. Wheat, barley, oats, rye, and various legumes were also domesticated in the same region at about the same time. Modern varieties of these animals and crops still underpin global agricultural systems today, indicating the momentous nature of the activities of palaeolithic and neolithic communities as the last interglacial opened. However, archaeological excavations in the middle Yangtze River of China have yielded remains of domesticated rice about 11 000 years old; this indicates that domestication was occurring a little earlier than in the Near East and that once again the target species was a grass from which rice was domesticated. Two other centers of domestication have also been recognized: in Central America (Mesoamerica) maize, another grass, was domesticated between 8000 years ago and 4500 years ago; in the Northern Andes (Peru) potato was domesticated about 5000 years ago (see *Domestication and the Development of Plant Cultivars*).

From these places, and other centers of origin, domesticates spread as pastoralism and arable agriculture were adopted in peripheral regions. For example, it took 5000 years for agriculture to spread through Europe to its northern and western peripheries. Agriculture also spread to the East into western Asia and south into Africa. The paleoecological record of lakes, peats, and archaeological sites attests to its impact. In Europe, for example, the spread of agriculture brought about the transformation of natural ecosystems into agricultural systems; domesticates replaced wild species. The pattern was repeated in Mesoamerica and in China. Thus began an episode of biodiversity loss that is unprecedented in the geological record (see *Complementary Conservation of Biodiversity and Plant and Animal Gene Banks*). Humans had begun to transform the biosphere.

What remains enigmatic, however, is why domestication occurred. What were the stimuli that prompted this shift in lifestyle and altered the people-environment so significantly (see *History of Agriculture*)? Probably both cultural and environmental factors conspired to enforce a change in social organization. Climatic change, and associated ecological change, was occurring which would have influenced the plant and animal resource base of hunter-gatherers and may have caused scarcity. Similarly, population increase and/or the desire to produce a surplus food supply for power, trade, and barter would have prompted innovation. Whatever the reasons, environmental and cultural change assumed new directions; the technology of agriculture became the linchpin in the people-environment relationship (see *Domestication and Development of Plant Cultivars* and *Forests and Grasslands as Cradles for Agriculture*).

The division of labor facilitated by agriculture allowed new resources to be exploited and the exploitation of existing resources to be increased and improved. These, in turn, led to additional cultural and environmental changes throughout prehistory and history. Many civilizations rose and fell on the basis of their ability to provide and control food supplies, a situation that was also linked to their capacity to avoid environmental degradation. However, another important stage in the relationship between agriculture and global change began in the 1500s.

Land links with Central Asia and China were established, and maritime links between the Old and New Worlds were forged. Intercontinental exchanges of people, wealth, flora and fauna, animal and crop complexes occurred for the first time on a large scale and with relative rapidity. This period could be described as the initiation of globalization, of which agricultural goods and practices were a major component. For example, the introduction of European agricultural practices into the New World, and later into Australia and New Zealand, set in train an unprecedented loss of natural ecosystems, especially forests, which were replaced by croplands.

The area of the latter more than tripled between 1700 and 1920. Growing demands from an increasing European population, which was also urbanizing, intensified demand from the colonies; this, in turn, brought about land-cover change and a massive shift to agriculture at the expense of natural ecosystems. Such trends reinforce the significance of population increase and wealth generation as primary forces in environmental change globally with agriculture as the chief mechanism (see *Food and Agriculture and the Use of Natural Resources*).

Other factors also played a role in this environmental change either through direct or indirect impacts on agriculture. For example, the invention of machines, such as the combine harvester (first produced in the US in 1838), the stripper harvester, and milking machines increased agricultural productivity and facilitated intensification. Similarly, the development of refrigerated ships encouraged sheep and cattle ranching in Australia and New Zealand by providing the wherewithal for the export of meat to Europe. These and many other innovations between 1700 and 1900 enhanced the capacity of agriculture for environmental change while the growth of markets in Europe, which was also benefiting from the wealth generated by industrialization, provided incentive.

Yet more innovations in the early twentieth century, notably the capacity to produce artificial nitrate fertilizers through the Haber Bosch process and the production of crop protection chemicals, allowed agriculture in developed economies to intensify further, i.e. to industrialize. This increasing control on productivity was encouraged by protectionist policies to safeguard food supplies in nations, such as the UK, which had found themselves vulnerable in times of war.

Two world wars have thus had a significant impact on global agriculture. Protectionism and industrialization have consequently played a part in environmental change, notably through the impact of artificial nitrate fertilizers, i.e. cultural eutrophication and crop protection chemicals. Such impacts cannot be described as truly global, though in the case of artificial nitrates there is a measurable impact on the global nitrogen cycle, but they are nevertheless widespread and significant.

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Biographical Sketch

Antoinette M. Mannion, Ph.D., graduated from the University of Liverpool, UK, in 1972 with a B.Sc. Hons.; postgraduate work was undertaken at the University of Bristol, UK; 24 years were spent at the University of Reading, UK, as lecturer and then senior lecturer in Geography, with specialist interests in biogeography, environmental change, and agriculture. She has authored six books and numerous journal articles.