Editor's Introduction

Modern agriculture is a complex, multi-faceted activity, global in scale and increasingly dependent on advanced technology. Yet for all that, the fundamental principle of agriculture is exactly the same today as it was ten thousand and more years in the past and will remain for years into the future. At its most basic, the raison *d'être* of agriculture is to produce food. It does not matter how well the agricultural producers themselves understood the biochemical and biophysical aspects of photosynthesis and energy transport. Agriculture boils down to the simple act of putting a seed into fertile soil and reaping the fruits of the plant that grew from that seed. It is simplicity itself... in principle. As the saying goes, however, the devil is in the details.

Agriculture is one of the oldest social exercises of the human race. Many consider that agriculture is what made human civilization possible. Our hunter-gatherer forbearers undoubtedly saw that the wild plants they collected for food produced new plants where seeds from those plants had fallen to the ground. It would have been a natural step to intentionally collect the seeds and put them into the ground on purpose. As wandering peoples, they would have found those new food plants ready and waiting for them when they returned to that same location. After that would have come the realization that roaming about the countryside in a wide-ranging search to find edible plants was no longer necessary. They could instead remain in one location and the edible plants would in effect come to them as they grew in place. At that point, some nomadic hunter-gatherers became settled in a specific area, and thus agriculture began. Those who farm vegetable crops today, more than ten thousand years later, carry out exactly the same function as did their ancient ancestors.

The hunter-gatherer tradition didn't die out with the emergence of crop agriculture, though. The same process that resulted in the domestication of certain plants would also have pointed the way to the domestication of certain animals. Just as plants could be made to grow in the areas where the people settled, some migrating animals could be prevented from wandering and made to remain where the people lived. This marks the beginning of animal husbandry, the second primary aspect of agriculture that persists into the present day and beyond.

From these beginnings—both of immeasurable value to the human race—arose the multi-millennia long traditions of agriculture. This simplified description of how agriculture got its start understates the innately complex nature of agriculture. As a practice, agriculture represents the most intimate relationship the human species has with the planet it calls home. Agriculture depends on the favorable interplay of every aspect of the natural environment of Earth, from the functional structure of the soil below the surface, to the behavior of the farthest reaches of the atmosphere, and everything in between. It is worth keeping in mind that agriculture, despite its grounding in the soil, sky, and water of the planet, agriculture is an artificial construct. Despite its organic nature and basis in the natural rhythms of the plants and animals, agriculture is a sort of parasite. To exist at all, agriculture must maintain a symbiotic relationship with the planet's total ecology in order to coexist and integrate itself as a functioning component of the larger natural environment.

Earth's great cycles and seasonal changes establish an effective self-balancing steady state subject to the laws that govern the physical world. The climate of the planet goes through cycles of seasonal change. The water cycle describes the continuous movement of water on Earth, rising as water vapor from the oceans and condensing back into liquid and solid forms to fall as precipitation, and then making its way back to the oceans to start the cycle once more. The carbon-oxygen cycle describes how carbon and oxygen are in a constant state of motion, as atmospheric gases are changed into carbohydrates through photosynthesis and back again into gases as the end products of respiration and energy transport in living things. Gasses are also captured as carbonate minerals which are, in their turn, broken down to their component parts in the complex chemical environment that is Earth. Predator and prey species exist in cycles of life and death within the natural environment. Earth and the environment it supports is a huge, complex and dynamic system. The human endeavor of agriculture impacts the cycles and rhythms that make up this complex milieu, inserting new segments into each natural cycle as it draws inputs from each one and delivers outputs back to each one.

Lands that have been domesticated for agricultural uses have always coexisted with lands that are conserved to be wild. One unavoidable consequence of this is that predatory animals in the natural environment have an interest in the descendants of the prey animals that were domesticated thousands of years ago. This quite naturally brings some agriculturalists into conflict with their wild neighbors. In the first quarter of the twentieth century, for example, the gray wolf population in the wilds of Yellowstone National Park was eradicated, primarily to placate ranchers who claimed the wolves were killing their livestock. The reintroduction of gray wolves to Yellowstone National Park in 1995 was met with resistance from local ranchers who feared the wolves would soon be killing their livestock as they roamed outside of the boundaries of the park. As observation has amply revealed, the removal of those apex predators did severe harm to every aspect of the natural environment of the park, including its geography, because it disrupted the natural order. Their reintroduction initiated a trophic cascade that has restored some of that balance and gone some way toward mending the damage, while predation by gray wolves outside of the park boundaries has not been observed, although other wild predators such as cougars, coyotes, and grizzly bears can and do prey on livestock.

Plant crops are also not immune to competition with the wild. A huge part growing crops of any sort is keeping the wild at bay. Weeds are anathema to plant crops. They can take up a significant amount of the water and soil nutrients needed for the proper growth of the desired crop plants. Agricultural operations meant to enhance crop production such as irrigation and fertilization, extensive soil preparation, and field maintenance carry large costs and demand careful attention to assure their proper application as well as appropriate conservation of resources, even before considerations related to pest and weed control. A whole new set of costs and cautions are involved in the constant battle to eliminate undesirable weeds from the desirable crop plant. Other threats to crops include funguses, viruses, bacterial infections, insects, birds, and animals, forcing the farmer to fight the battle on several fronts at the same time. Physical deterrents, pesticides, and herbicides to counter these intruders add huge costs for farmers. Such is the nature of the artifice of agriculture in the milieu of the natural environment.

As much as the natural environment impacts how agriculture functions, it is equally true that agriculture affects the natural environment. Since agriculture is by nature an activity by and for the support of humans, any consideration of how agriculture affects the natural environment has to begin with an examination of how the human population affects the natural environment. In that long ago time when agriculture was first evolving, it would have noted that the seeds grew best when they were planted in cleared soils where they didn't have competition. Land areas could be cleared to make plots of ground where plantings could be concentrated. That meant that the yield—grains, seeds, fruits, nuts, leaves, shoots, stems, tubers—from those plants could be recovered with much less effort than wild harvesting. Now that humans could produce amounts of food that exceeded their basic needs, they could trade the excess food for material goods and services. In this way, agriculture became the foundation for commerce and the driving force for the establishing of villages, towns, and eventually cities, nations, and civilizations. All of these human establishments, from small cleared plots of land to sprawling cities, have one thing in common: the conversion of the corresponding and ancillary land areas, such as roads, from their natural state. This effectively removes those areas from the natural environment, reducing the area of the natural environment, fragmenting the layout of the natural environment, and drastically altering the role of those areas in natural cycles. Rainfall that had for millions of years percolated through soil to replenish underground aquifers, for example, is instead directed as surface run-off by the impermeable surfaces and artificial channels in the terrain modern man's environment of paved roads, buildings, airports, parking lots, and industrial complexes.

As agriculture became a more efficient means to feed ourselves and there was more food available, there was a simultaneous increase in the human population. As the population increased, the need for food from the practice of agriculture also increased. Greater need for more agricultural production means there is a concurrent the need for more lands devoted to agriculture, again to the detriment of the natural environment and the wild. Modern agriculture must address this problem by working to develop methods of producing more food in the same amount of space without depleting resources or ruining the long-term viability of the soil. Agricultural practices that eliminate the wild and convert it to agricultural land by clear-cutting or slash-and-burn techniques are no longer viable, although they are still widely practiced. In the Amazon basin, for example, huge tracts of ancient forests there are being clear-cut and converted to agricultural crop land and cattle pasture. Research has shown that the soil structure in those areas will not support these agricultural activities reliably in the long term. The soils that have been cleared are now exposed to erosive forces of wind and tropical rains without benefit of the protective cover that kept them in place. Flooding and desertification inevitably follow such practices, yet the clearing continues at an estimated twenty thousand hectares (fifty thousand acres) per day. Species extinctions, which occur at a normal background rate of between one and five species per year, are estimated to be occurring at an actual rate of between one thousand and ten thousand times the normal background rate as a direct result of agricultural and other human activities in 2018. Some may be tempted write the losses off as having no commercial use, but it is worth remembering that each and every one of the species, both plant and animal, that the human race relies on for its food was once also just a wild species with no perceived value.

Reliance on a relatively small number of species has created a type of farming known as monoculture, wherein the majority of agricultural activities are based on just a single species on the local or individual farm level or on just a small number of species at a regional level. Monoculture is a natural consequence of human nature. Once a given species—whether soybeans or Holstein cows or bananas—shows a desirable return on the investment of effort and expenditure required to bring it to market, it will be used by more and more farmers in an area. At some point, unless new species or genetic variants of those species are brought in to displace them, every farmer will end up raising those same species over a very large area. Husbandry would be geared only to obtaining better individual Holstein cows and more productive soybean plants within the same genetic variety. This is a normal practice in modern agriculture, and produces equitable results in terms of herd improvement and crop yields. But it is a practice that also opens the door for some very serious problems.

Individuals of the same species are all susceptible to the same diseases and abnormal genetic conditions. Without genetic variability within a species, entire populations can be wiped out by a single disease. This is true of both domestic and wild populations. The *Brucellosis* bacterium, for example, will affect every animal in a herd of the same species, whether it is a herd of dairy cattle or a herd of wild deer. The *Fusarium* virus that affects any plant of a particular plant species like tomatoes can infect every plant in a crop of that species. In 2018, corn crops in North America have been deemed unusable for animal and human food due to the presence of unacceptable amounts of the compound deoxynivelenol (also known as vomitoxin) that they contain. That compound is produced by a mold that flourished during warm, moist fall weather of that year.

Nowhere is the danger of monoculture more apparent than in crops in which every plant is genetically identical, a clone of some corresponding parent plant. This is a danger that the commercial banana industry knows all too well. First introduced to the United States at the Chicago World's Fair at the end of the nineteenth century, bananas quickly became the most popular fruit in the country. Huge plantations of banana trees were established in tropical countries, leading to the so-called "banana republics," to provide enough bananas to meet the consumer demand. Every tree in those plantations was the clone of a banana species known as the *Gros Michel* (French for Big Mike). A fungal infestation struck, and due to the extreme monoculture of the plantations, every single tree was susceptible to the fungus and the entire species was wiped out. A new variety was found that could be grown to replace the *Gros Michel* banana, known as the Cavendish banana. The Cavendish is smaller than and not as sweet as the *Gros Michel*, but it was resistant to the fungus that eradicated the *Gros Michel*. The Cavendish is the variety currently sold in grocery stores around the world. The story of *Gros Michel* is set to repeat itself once again, however, as banana plantations relied on extreme monoculture for rapid production, and the Cavendish variety now faces eradication due to its susceptibility to a different fungus species. That fungus has already infested and destroyed banana plantations in several parts of the world. Researchers are scrambling to find a new variety of banana that can be an acceptable replacement for the Cavendish banana. While some comb through tropical forests and fruit markets in the hope of finding a suitable type of banana, others, are pursuing another avenue available to modern agriculture: gene modification.

Gene modification, practiced since the earliest days of agriculture and animal husbandry, has, until quite recently, relied on the traditional practices of plant cross-breeding and of animal husbandry. Plants that exhibited desirable traits such as large, robust seed heads in comparison to others of the same species would either be grown preferentially or used to transfer the desirable traits to other individuals by cross-pollination. This type of modification took successive generations and might require many years to produce a variety that reliably exhibited the desirable traits. In animal husbandry, the same principles applied, and successive generations of animals were selectively bred to have specific breed characteristics. This type of breeding continues to the point at which genetic lines would "breed true." For example, all dogs can interbreed to produce "mutt" offspring, yet German shepherd dogs produce German shepherd puppies, poodles produce poodle puppies, and so on. It is interesting top note that all modern dogs are believed to have arisen through the likely domestication of wild wolves more than forty thousand years ago (the age of the oldest known domestic dog remains). Domestic dogs are interfertile with wolves like those roaming Yellowstone National Park, a fact that underscores the ancient link between modern agriculture and the natural environment.

In modern agriculture, genetic modification generally refers to the direct manipulation of the DNA molecule by scientific methods. In this process, a specific segment of a DNA molecule called a gene can be activated, deactivated, inserted, or removed to produce a genetic variant having an innate property that the organism would not normally have. It is a controversial practice, but one with great economic and social potential. One example was the so-called Flavr Savr tomato, a variety modified to deactivate the gene that controlled the ripening of the fruit. The goal was to produce a tomato that would ripen very slowly when grown to maturity, enabling it to resist bruising and damage during harvesting and shipping. The Flavr Savr could be harvested while still very green and hard and then allowed to ripen slowly in storage or as they sat on store shelves. Unfortunately, the Flavr Savr tomato failed because it could not ripen reliably to the state that consumers desired and it lacked the flavor of a properly ripened tomato. More successful examples of genetically modified species are found in corn and soybeans. Genetic modification of corn produced the 'Bt' corn varieties that are resistant to insect infestations. Other modified varieties of corn are given the 'ss' designation, indicating they are supersweet varieties that have higher levels of sugar content and sweetness compared unmodified varieties of sweet corn. Soybeans are a crop that is sensitive to the presence of weeds, and yields are significantly affected by the presence of weeds in soybean fields. For soybean growers, the herbicide of choice is Monsanto's Round-Up product. Unfortunately, Round-Up is a post-emergence herbicide that must be applied after weeds have begun to grow, and soybean germination is also occurring. Glyphosate, the active ingredient in Round-Up, does not discriminate between weeds and soybeans. This made its use in weed-infested soybean fields problematic. To get around this, genetic modification was used to produce so-called Round-Up Ready soybean varieties that are resistant to glyphosate and are not be killed off by the herbicide. The result has been strong, viable soybean production.

The controversy regarding genetically-modified organisms (GMOs) like Round-Up Ready soybeans is rooted in understanding what happens when GMOs cross-pollinate with traditional plant species. That is a sound concern, but it has been subsequently blown out of proportion by talk of "Frankenfoods" and other such fears. A related and more realistic concern is the genetic modification of animal species. Because humans and other animals consume the flesh of food animals, there is a real potential for the transfer of potentially harmful proteins called prions to the consumer. This is an effect that has actually been observed in domestic animals that have been fed with waste animals proteins as part of their usual feed regimen. Accordingly, there are many controls in place to limit the introduction of GMOs into the consumer market or to improve labeling requirements so that consumers can make more informed choices.

Increasingly, modern agriculture depends on advanced and highly technological equipment. Digital control of agricultural equipment operations is a particularly broad field of application in modern agriculture. A modern tractor or combine, for example, is not much like the tractors and combines of a mere twenty or so years ago. While a tractor remains essentially a powerhouse on wheels and combines recover ripened grain in the same way that they always have, these machines are now controlled through highly sophisticated electronics. Before these advances, land preparation, seeding, drilling, harvesting, and other operations depended solely on the skill of the human operator. The operator's goal was to manipulate the machines as efficiently as possible to produce straight rows with no overlap or broadened spaces between them, thus minimizing operating costs. Nowadays, machinery movement across fields, speed, seeding rate, fertilizer application, and all of the other aspects of machine control that were once the province of the human operator can now be completely controlled electronically and governed by guidance from GPS satellites. A human operator is only needed for the handling of random events, and can just sit back in the comfort of the climate-controlled cab and enjoy the ride.

Technology has made its way into essentially every aspect of modern agriculture, as more and more farm operations become fully automated. Every aspect of the feeding, hygiene, and milking of the dairy herd animals is carried out by computer-controlled automation in some large dairy farm operations. Similar automation is in place in many other large commercial operations such as sheep, pig, chicken, goat and turkey farms. Drones can monitor crops and help determine which fields need specific amendments or irrigation. A human presence is there essentially only to monitor the operations and to ensure that the systems are functioning as they are intended to function. It is a far cry from the days when one rose before the sun to milk a few cows by hand and gather eggs from a dozen chickens. It is an even farther cry from those long ago days when people followed herds of wild animals and gathered what wild plants would provide. But even though the methods have changed so much, the basic principles of agriculture have not. As they always have and always will, farmers do agriculture within the natural environment of Earth, to produce the food that feeds the world.

—Richard M. Renneboog, MSc

Contributor's List

Ronju Ahammad
Craig W. Allin
Richard W. Arnseth
Michael P. Auerbach
Alexandra M. Avila
Clara B.
Anita Baker-Blocker
Melissa A. Barton
Hannah Bement
Cynthia A. Bily
Tyler Biscontini
Rachel Leah Blumenthal
Sarah Boslaugh
Judith J Bradshaw-Rouse
Alan Brown
Michael A. Buratovich, PhD
Scott F. Burns
William E. Burns
Mary E. Carey
Robert E. Carver
Diana M. Casey
Zhiqiang Chen
Sneed B. Collard
David R. Coyle
Mark S. Coyne
Charles R. Crumly
William A. Dando
Peter L. deFur
Rene M. Descartes
Gordon Neal Diem
John P. DiVincenzo
Sally Driscoll
Maria Droujkova
Corinne Elliott
Jessica O. Ellison
Jack B. Evett
Jim Fowler
Lenela Glass-Godwin
José F. González–Maya
Nancy M. Gordon
D. R. Gossett
Gina Hagler
Angela Harmon
Jasper L. Harris
Peter B. Heller
Thomas E. Hemmerly
Virginia L. Hodges
Robert M. Hordon
Jason A. Hubbart
Lawrence E. Hurd
Mary Hurd
Micah L Issitt, BS
Jerome A. Jackson, PhD
Domingo M. Jariel Jr., PhD
Kamal J. K. Gandhi
Karen N. Kähler
Jamie Michael Kass
Diann S. Kiesel
Michael M. Kimberley
Robert T. Klose
Denise Knotwell
James Knotwell
Grove Koger
Dawn A. Laney, MS
Eugene Larson
Jeffrey Larson
Kari L. Lavalli
M. Lee
J. Lipman-Boon
Robert Lovely
Spencer G. Lucas
Nancy Farm Männikkö
Erika Marín-Spiotta
Jordan M. Marshall, PhD
Michael W. Mayfield
Laurence W. Mazzeno
John S. Mecham
Nathan H. Meleen
Roman J. Miller
Jacqueline E. Mohan
Thomas C. Moon
David C. Morley
M. Marian Mustoe, PhD
Bryan Ness
Oghenekome U. Onokpise
George R. Plitnik
Eduardo Ponce
P. S. Ramsey
C. Nicholas Raphael
C. Mervyn Rasmussen
Alexis S. Reed
Gregory J. Retallack
Mariana Rhoades
James L. Robinson, PhD
Lindsay Rohland
Krishna Roka
Carol A. Rolf, JD
Julia A. Rosenthal, BA
Lisa Jo Rudy
Panagiotis D. Scarlatos
Elizabeth D. Schafer, PhD
Martha A. Sherwood, PhD
John F. Shroder Jr.
Sanford S. Singer
Robert A. Sinnott
Amy Sisson
Elizabeth Slocum
Adam B. Smith
Philip A. Smith
Kymberley A. Snarr
Richard S. Spira
Dion Stewart
Toby Stewart
Bruce L. Stinchcomb
Frederick M. Surowiec
Janine Ungvarsky
Krishna Prasad Vadrevu
Megan E. Watson
Christine Watts, PhD
Jeffrey Wielgus
George Wrisley
Lisa A. Wroble
Robin L. Wulffson
Ming Y. Zheng

A

Agriculture & Agricultural Land

—Ming Y. Zheng

FIELDS OF STUDY

Agronomy; Environmental Studies; Soil Mechanics.

PRINCIPAL TERMS

carbon cycle: processes through which carbon atoms circulate among Earth's atmosphere, terrestrial biosphere, oceans, and sediments—including fossil fuels

climate change: a statistically significant variation in either the mean state of the climate or its variability

energy-intensive agriculture: a method of farming that involves working on a large scale, utilizing significant resources, energy, and mechanization; often also referred to as industrialized agriculture

greenhouse effect: phenomenon in which certain gases in a planet's atmosphere trap heat that would otherwise escape into outer space, thereby increasing the planet's surface temperature

SUMMARY

Agriculture is a practice that utilizes the intimate structure of the soil for the purposeful growth of animal and vegetable crops. The methods used in agriculture have significant effects on the nature of the soils being used, requiring that methods must also be utilized that maintain the long-term health and viability of those soils. This has not always been the case, and remediation of agricultural lands that have been mismanaged is difficult.

BACKGROUND

Modern, large-scale agriculture has led to increased greenhouse gas (GHG) emissions, primarily resulting from high energy inputs, land clearing, soil degradation, and overgrazing by livestock. The massive conversion of forests into farms has reduced the land's capacity to function as a carbon sink. As a result, more GHGs are emitted into the atmosphere, contributing to global warming and climate change.

There is now a consensus that the mean temperature of Earth will increase by an average of 2.0° to 5.8° Celsius in the twenty-first century. Some environmental models, taking into account likely changes in vegetation cover, predict an even higher rise of 8° Celsius during the century. The resulting elevated temperatures (even at the lower end of the estimates) will have significant effects on Earth's biosphere, including human life. Many factors are associated with this predicted temperature rise, but agriculture is among the major contributors.

DIRECT IMPACTS ON CLIMATE CHANGE

Agricultural activity is a significant source of greenhouse gases (GHGs). GHG levels are affected by land clearing, high energy inputs, soil degradation, and intensive animal husbandry. Based on current estimates, agriculture contributes to 25 percent of the world's carbon dioxide (CO_2) emissions, 60 percent of methane gas emissions, and 80 percent of nitrous oxide emissions. Agriculture's high energy input results primarily from manufacturing chemical fertilizers, herbicides, and pesticides; operating farm machinery; irrigating farmland using pumps and other machines; and transporting products over long distances. Collectively, these activities account for more than 90 percent of the total energy expenditure in agriculture.

The burning of fossil fuels releases CO_2 into the atmosphere. The CO_2 concentration in the atmosphere has increased from 277 parts per million to 382 parts per million since the beginning of the Industrial Revolution in the mid-eighteenth century. Industrialized agriculture is believed to have contributed to 25 percent of that increase.

Overuse of fertilizers, in addition to energy inputs in fertilizer manufacturing, contributes significantly to climate change. More than half of all synthetic fertilizers applied to the soil either end up in local waterways or emit to the atmosphere. A portion of the excess nitrogen fertilizers in the soil is converted into nitrous oxide, which is 296 times more potent than CO_2 in trapping heat and which has a long atmospheric lifetime of 114 years. Each year, nitrous oxide emissions alone account for the equivalent of 1.9 billion metric tons of CO_2 emissions.

China has the largest agricultural output of any country. Image by Anna Frodesiak [CC0].

The second greatest GHG emission by agriculture is methane, released in small amounts by rice paddies and in much larger amounts by livestock. As the demand for meat increases, more livestock are raised and are fed higher-protein diets. Both the number of livestock and their protein-rich diets increase the amount of methane they emit. Methane gas is fourteen times more potent than CO_2 in trapping heat. Its concentration has almost tripled since the Industrial Revolution, from 600 parts per billion to 1,728 parts per billion.

INDIRECT IMPACTS ON CLIMATE CHANGE

Agriculture also contributes indirectly to climate change. Clearing trees and other natural stands to make land suitable for agricultural uses removes important carbon sinks, so less carbon is returned to the terrestrial biosphere and more CO_2 finds its way into the atmosphere, where it contributes to climate change.

The effect of land clearing on climate change is evident from the consequences of the destruction of tropical rain forests. For instance, large areas in Brazil have been cleared to facilitate soybean production. This clearing disrupts the local water cycle, which in turn alters Brazil's climate. In rain forests, water circulates as a result of evaporation, which greatly increases humidity. Natural tree stands act to buffer extremes of heat, cold, and drought. When the trees are removed, the buffer disappears. Moreover, the amount of water vapor in the air decreases, causing shifts in rainfall patterns, moisture levels, air temperature, and weather patterns generally.

The conversion of forests into agricultural lands has significantly altered Earth's vegetation cover. Such changes in the land surface affect Earth's albedo—that is, the proportion of incident radiation reflected by the planet's surface. Changes in the albedo in turn can affect the surface energy budget, which affects local, regional, and global climates. Changes in vegetation also produce changes in the global atmospheric concentration of CO_2. Agricultural landscape ranks among the lowest in carbon sequestration. Thus, as more land is devoted to agricultural uses, more of Earth's carbon is converted to CO_2 and emitted to the atmosphere, contributing to global warming.

CLIMATE CHANGE & AGRICULTURE

Potential climate changes associated with elevated GHGs and an altered surface energy budget include an increased incidence of heat waves, severe storms, and floods, as well as elevated sea levels. Some 30 percent of the agricultural lands worldwide could be affected by these changes. Global warming alone is projected to have considerable effects on agriculture.

A warming of 2° Celsius or more could reduce global food supplies and aggravate world hunger. The impact on crop yields will vary considerably across different agricultural regions. Warm regions, such as tropics and subtropics, will be threatened by climate change, while cooler regions, mainly in temperate or higher latitudes, may benefit from warming.

Global climate change may have significant effects upon livestock systems as well. First, the productivity and quality of rangelands may be adversely affected. This in turn will affect the quality and productivity of livestock. Second, higher grain prices resulting from the disruption of crop production will lead to higher costs for livestock products. Third, increased severity and frequency of storms may intensify soil erosion and decrease the productivity of rangelands. Fourth, global warming could result in changes in the distribution and severity of livestock diseases and parasites, which may threaten the health of animals, especially those in intensively managed livestock systems.

POSSIBLE SOLUTIONS

Unlike any other industrial GHG emitters, agriculture has the potential to change from being one of the largest GHG sources to being a net carbon sink, reversing its role in climate change. Several practical measures can be taken to mitigate the climate change caused by intensive agriculture. These include the reduced and more efficient use of chemical fertilizers, protection of soil, improvement of paddy rice production, and reduction of demand for meat.

Precision farming can reduce the need for chemical fertilizers. In precision farming, fertilizers and other agrochemicals are applied based on crops' needs, in precise amounts and on a carefully managed schedule. The reduced application of these chemicals not only cuts GHG emissions but also alleviates other environmental problems such as water pollution and eutrophication of waterways.

As a result of intensive farming, agricultural soils have some of the lowest carbon contents of all land types. If these soils can be modified to absorb more of Earth's carbon, the result will be a net reduction in atmospheric carbon. Low soil carbon content can be reversed through a number of measures, including planting cover crops, fallowing, and engaging in conservation tillage. These practices will increase the amount of organic matter (and thus the carbon content) in the soil. They will also reduce soil erosion and surface runoff, thereby reducing the need for chemical fertilizers. Collectively, these measures can turn agricultural soils into carbon sinks, changing the nature of their impact on climate change.

To reduce methane emissions from rice production, better cultivation techniques will need to be adapted. For example, rather than continuously flooding rice paddies, farmers could supply water to the paddies only when it is needed during the growing season and keep the paddies dry during the nongrowing season. Such measures could reduce methane emission from rice fields significantly.

Livestock raising is the second largest source of GHGs in agriculture. The most efficient way to cut methane emission due to livestock is simply to reduce the number of farm animals. As an ever-increasing demand for meat and dairy products drives increasing animal husbandry, one effective approach to cut methane emission is to reduce the demand for meat, especially in developed countries where consumers have tremendous buying power. Reduced meat and dairy consumption would go a long way toward curbing methane emissions.

CONTEXT

Agriculture and climate change are interlocked processes, in that each exerts effects on the other in a complex fashion. Climate changes, especially shifts in precipitation and temperature, are widely believed to have significant effects on agriculture, because these two factors determine the carrying capacity of any ecosystem. At the same time, modern agriculture is a major contributing factor to global warming, as altered land cover and the emission of CO_2, methane gas, and nitrous oxide from intensive farming increase the GHG content of the atmosphere. However, it remains possible to transform industrialized agriculture, using techniques that could render it more sustainable and mitigate its effects upon global and local climates.

Further Reading

Bazzaz, Fakhri, and Wim Sombroek, eds. *Global Climate Change and Agricultural Production: Direct and Indirect Effects of Changing Hydrological, Pedological, and Plant Physiological Processes.* New York: Wiley, 1996. Assesses the effects of global climate change on the agricultural production of crops and livestock. Covers issues such as the CO_2 fertilization effect, the adverse effects of elevated levels of ultraviolet-B (UVB) radiation and ozone on plant growth and productivity, and the environmental effects of livestock.

Marland, Gregg, et al. "The Climatic Impacts of Land Surface Change and Carbon Management, and the Implications for Climate-Change Mitigation Policy." *Climate Policy* 3 (2003): 149–157. Reviews evidence on how changes in land use and altered vegetation cover affect surface energy budget in addition to GHG emission, which in turn affects local, regional, and global climate.

Palo, Matti, and Heidi Vanhanen, eds. *World Forests from deforestation to Transition?* Boston: Kluwer Academic, 2000. Addresses global and subnational issues concerning the world's forests, societies, and environment from an independent and nonpolitical point of view. Emphasizes the importance of developing a scientific understanding of the interconnectedness between forests, human activity, and the environment, and of the consequences of environmental change for societies' development and growth.

Paustian, Keith, et al. *Agriculture's Role in Greenhouse Gas Mitigation.* Arlington, Va.: Pew Center on Global Climate Change, 2006. Well-researched and clearly written paper. Offers reasonable measures and reachable goals for mitigating GHG emission by agriculture.

Agriculture & Animal Husbandry in the Ancient World

—Rene M. Descartes

FIELDS OF STUDY

Anthropology; Archaeology; History.

PRINCIPAL TERMS

husbandry: the breeding and interbreeding of animals for the maintenance and improvement of existing breed stocks

irrigation: the natural and artificial or forced application of water to agricultural crops, typically to counteract a scarcity of natural rainfall

SUMMARY

Modern agriculture is the current state of development in a process that is believed to have begun approximately 10,000 years ago when human societies in all different parts of the world began to cultivate plants and domesticate various animal species. The degree of technological sophistication of the time determined the nature of agricultural processes, just as it does in the present day. However, the fundamental principles of agriculture and animal husbandry are exactly the same in the present day as they were a hundred centuries in the past.

INTRODUCTION

Plant cultivation and controlled stock breeding served to increase human population densities and resulted in the emergence of urbanism, occupational specialization, social stratification, writing, and long-distance trade. Agriculture also necessitated the development of metallurgy, engineering, astronomy, and mathematics and transformed both religious and political systems as humans altered the environment through deforestation, terracing, and irrigation.

Archaeological evidence that attends humankind's great transformation from hunter-gatherer to agriculturalist includes pollen samples, vegetal remains, and animal bones. Art, writing, agricultural artifacts, and topographical modifications provide information on early farming systems.

Although the precise mechanism that led to domestication remains unknown, models proposed to explain the transition from hunting and foraging to incipient agriculture emphasize climatic change, population growth, and accidental domestication. The domestication process began independently in the Near East, Mexico, sub-Saharan Africa, eastern North America, South America, and eastern Asia. From these regions, techniques, cultigens, and animals diffused throughout the world.