

Reading 8

Cropping Systems and Practices

The patterns of different cropping systems are highly variable—as diverse as are the crops themselves and the climates, habitats, levels of mechanization, and human customs under which crop production is undertaken. Depending on the part of the world, certain considerations will weigh more heavily than others. In one place primitive methods are appropriate, in another the system is highly mechanized; in some areas, growth factors are paramount, and in others economic realities are of greater concern. Before reviewing specific cropping systems, let us consider whether there are any general principles underlying the often complex ways in which crops are grown and harvested. Certainly cropping practices enjoy historical continuity; they must exhibit adaptations to ecological realities in order to remain viable.

Primitive harvesting undoubtedly consisted of little more than casual collecting of wild seeds, fruits, and other plant products. The hunting of game supported nomadic tribesmen, but was incidental in increasingly sedentary societies on the highroad toward civilization. Sedentary tribes came to rely chiefly upon the nearby abundance of food that domestication and cropping provided. Thus since the earliest days of agriculture 2 general “cropping systems” have been in operation: one centering on grazing and browsing animals (the animals harvest the vegetation, and people, secondarily, the milk and meat a system still basic in some parts of the world, such as East Africa where it is practiced by the Masai), and the direct harvest by people of the crops they sow and tend (though sharing some of their produce with livestock). The latter system forms the basis for most of today’s agriculture and horticulture.

Box 1—Sobering Observations

This chapter opens with some generalizations about cropping systems, provides some perspective on modern practices, and ends with a review of “agribusiness”—a capitalistic society’s response to modern needs. But in some circles, the claim that American agriculture is the envy of the world, a grand accomplishment, is met with only muted applause.

Indeed, some people suggest that intensive agriculture means “paying for oil with soil”—that is, that soil contamination, soil deterioration, and loss of soil to erosion are the consequences of the system’s incessant demands. Here’s what the editor of *Garden* (vol. 1, no. 3, July/Aug. 1977) offers as an aside to an article by Wendell Berry entitled “Let ‘em Eat the Future.” It epitomizes this rising concern:

Species impoverishment is inherent in conventional agriculture. Out of the quarter-million extant species of flowering plants and the 2,000-odd species that have ever been used in agriculture, agribusiness deals with only a dozen or so, resulting in vast and dangerous monocultures, all taking up the same nutrients and the same amounts of water and subject to the same diseases. This sinister state of affairs we call American know-how.

Nor is American agriculture’s extravagant use of energy exemplary. Obviously, it would not be possible, worldwide, to expend the 750 liters of fuel per hectare (about 80 gallons per acre) used for growing corn in the United States. Measured in terms of input of energy versus output, this is slovenly husbandry, far less efficient than that of the uneducated New Guinea tribesman, and not even close to “sustained yield”!

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Forages for livestock are discussed in Chapter 20. The rumen or “second stomach” of cattle enables them to digest cellulosic materials indigestible by people and carnivores. The rumen is populated by a flora of microorganisms called flagellates, which symbiotically make possible the digestion of forages and fodders useless to other animals.

Grasses and legumes are the major products used for livestock feed, and various management procedures conforming to climate, soil, and other environmental considerations are followed. Grazing is an especially effective way of utilizing “secondary” land, which is too steep, rocky, dry, or otherwise unsuitable for economical growing of direct harvest crops. Even today the system of grazing varies from merely turning out half-domesticated livestock onto open range, to cultivating pastures that are as meticulously organized for maximum production as is any agricultural pursuit (with appropriate combinations of grasses and legumes, properly fertilized, irrigated, and otherwise managed). Open range herding is really not very different in principle than was the taking of wild game, whereas advanced animal husbandry is systematized to yield as much as 400 kilograms or more of high quality beef to the hectare annually. In practice, of course, livestock raising is usually combined with direct crop production; in primitive societies the pigs may be allowed to root in the garden on occasion, whereas in technically advanced operations the grain, hay, and silage may be delivered to the livestock.

A cropping system must relate to the climate or biome (Fig. 1) in a general way. Mean annual temperature and mean annual precipitation are major determinants of climate. Notice in Fig. 1 that certain types of natural vegetation result from the interaction of temperature and rainfall, and these in turn are indicative of the cropping practices suited to the region. We will see in this chapter that swidden (slash-and-burn) and plantation agriculture are especially suitable for tropical forest habitat, diversified farming for the deciduous forest and moist grasslands, ranching and dry land cropping for the drier grasslands, irrigation agriculture for the deserts, tree cropping for the coniferous forests, and grazing for the alpine or arctic meadows.

Whatever the cropping systems that evolved in each of these dissimilar habitats, undoubtedly each underwent long evolution by trial and error, and depended upon domestications made from the wild there or nearby.

During such long evolutionary periods even climate may change (as almost surely it seems to have done in northern Africa), leading to still newer cropping innovations. Or people may impose change on older cropping systems, as occurred with the development of the Mexican wheats by Norman Borlaug of the International Center for Improvement of Maize and Wheat (CIMMYT) in Mexico and of the new rice cultivars by the International Rice Research Institute (IRRI) in the Philippines. Such new cultivars usually call for greater human control of the environment (such as implementation with fertilizer), and the growing season is likely to be different than that for traditional cultivars (and thus upsetting to established habits). Although

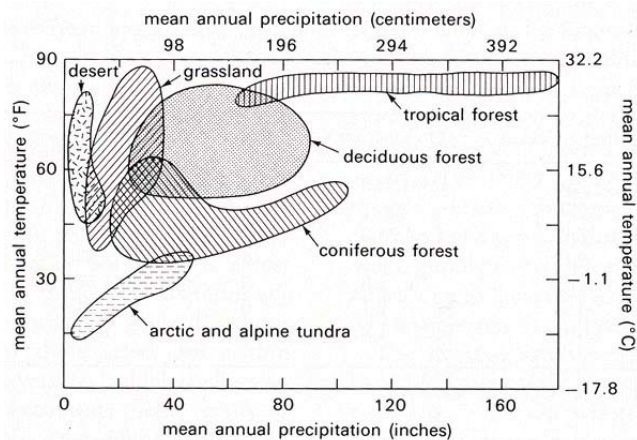


Fig. 1. Six biomes of the world ecosystem characterized by mean annual temperature and precipitation. [Courtesy National Science Foundation; from *Science* 175:47, 1972, copyright © 1972 by the American Association for the Advancement of Science.]

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changes like these seem trivial on the surface, the influence can be profound on delicately balanced economic and political systems geared to other considerations. For example, the new cultivar may favor well-to-do and knowledgeable growers (who are able to finance the purchase of fertilizer and to use it intelligently) over peasant farmers (who may have to sacrifice their independence as landholders for economic reasons, with consequent, and possibly widespread, political dissatisfaction).

On the whole, the ecosystems (the ecological relationships between all elements of the environment) of the tropics are more complex and more diverse, and allow for many more alternative paths of energy flow, than those of temperate and boreal climates. A tropical ecosystem is therefore usually more resilient than a nontropical one, and able to absorb more abuse with quicker recovery if the deviation is not too drastic. By the same token, monoculture is a greater departure from the norm in the tropics than it is in temperate climates, and pests are more numerous. Lateritic tropical soils, naturally deficient in organic matter, withstand the drastic imposition of cultivation poorly. Conversely, of course, the ecosystems of colder, harsher environments are less complex, contain fewer species (in larger populations), and show less stability and resistance to the impact of a cropping system imposed upon it.

Any cropping system implies some manipulation of the ecosystem. This ranges from merely taking care not to exhaust a resource completely (as do the Australian Bushmen and the people of remote tribes in Africa and South America), to nearly complete environmental control, in which moisture, fertility, pests, and even temperature are carefully managed (as in the intensive growing of strawberries and fresh vegetables in California, in which even the soil is sterilized before planting).

Considering the relative richness of tropical ecosystems, it is perhaps inevitable that tropical cropping would have gravitated more toward multiple species than has the agriculture of such climates as the United States and Europe, taking advantage of the greater abundance of ecological niches. Simpler systems are appropriate to the harsher environments of temperate climates, more rigidly controlled by technological means (examples of such systems being the extensive monoculture of corn, wheat, annual cotton, and so on). Attempts to impose a simplified cropping system on tropical habitats (say, the plantation system, which will be discussed), have, on the whole, not met with persistent success, and today there seems to be a trend toward smaller, individual plantings supplemented by multicrop door yard gardens.

Yet it is impossible to dispute the productivity of cropping systems that utilize the maximum density of highly selected individual plants, even though such a system may be naturally unstable and require close technological supervision. Notice in Table 1, in which designation of pesticide usage indicates intensive cropping, that total yields per unit of land area are greatly favored by this highly technical approach. However, it must be recognized that such intensive cropping, if it is to be effective, is heavily dependent on outside resources—capital (which provides the many forms of labor saving equipment), energy (especially electricity and gasoline to power machinery), and knowledge (the technological background gained from an advanced educational system, as well as a familiarity with such supplementary aids as pesticides).

Simplification of the ecosystem by means of monoculture presents a constantly changing pattern. Advantage is taken of new regulative practices to improve yields and especially the efficiency of human labor. Production at a 1920 rate on even the finest Corn Belt soils would be unremunerative today. At that time, plowing was done with a single moldboard plow pulled by a mule or a span of horses, the farmer handling the plow. Readying the seedbed and planting were

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similarly tedious. With open-pollinated corn or any other crop, seed for the next planting was usually from a previous harvest on the farm; even under ideal conditions such strains were incapable of yields half that of modern hybrids. Weed control was solely by tillage, and required additional passes over the field, which were very costly in labor (and doubtless caused some damage to crop roots). Because of the need for row space along which a horse could pass, plant populations per acre were considerably lower than at present. Harvest required much hand labor, field shocking, and multiple gathering or threshing operations.

Yet, this was a beginning for mechanized monoculture. In America farming has gradually evolved into the highly mechanized systems discussed later in this chapter. Multiplow tractor drawn equipment has replaced the independent moldboard plow, and, with some models, one pass completes seedbed preparation, planting, fertilizing and pesticide application. Herbicides eliminate the need for subsequent weed-control cultivation. Large plant populations in narrow rows are harvested by a field combine, and on-the-farm cribs with grain-on-the-cob are mostly a thing of the past. Yields per acre have increased fourfold, and yields per hour of human labor have increased tenfold. As we will see, the end is not insight, as more and more environmental variables are brought under control.

Most efficient, in terms of low input per unit of yield, would be “primitive” forms of gardening, still practiced in such remote locations as New Guinea, parts of central Africa, and the Amazon basin. In these regions all ecological niches are utilized, and the result is a mixed planting that looks quite untidy to someone from the temperate zone who is accustomed to neatly kept fields. In taking maximum advantage of sunlight, space, and the generally abundant rainfall, growers in these areas use a thin canopy of trees as a crop overstory, which shelters an understory of bush and herbaceous plants, many of which avail themselves of underground space, too, thereby yielding comestible rootcrops and tubers as well as the fruits and greens found above the ground. Such a cropping system is quite balanced, and requires minimum maintenance once it is established. The shade and crop competition help restrain weeds, and regrowth occurs rapidly to compensate for portions harvested. Moderate attention to weeding and the maintenance of improvised fences to keep pigs or other livestock out (until appropriate occasions when they might undertake harvest for themselves) are the chief demands upon the custodians.

Tropical systems utilize vegetatively propagated crops much more than do temperate systems. Most root and tree crops are propagated by division or from cuttings, and even herbaceous plants, if not perennial in the tropical climate, are more conveniently started from vegetative slips rather than from seed. Quite the opposite is true for temperate zone agriculture, especially where agriculture is based primarily upon grains and legumes massively planted by mechanized means.

Table 1. Areas and nations ranked in order of pesticide usage per acre and in order of yields of major crops.

Area or nation	Pesticide use			Yields		
	ml/ha	oz/acre	Rank	kg/ha	lb/acre	Rank
Japan	11,250	154.0	1	5,482	4,890	1
Europe	1,950	26.7	2	3,430	3,060	2
United States	1,557	21.3	3	2,600	2,320	3
Latin America	227	3.1	4	1,973	1,760	4
Oceania	205	2.8	5	1,569	1,400	5
India	153	2.1	6	818	730	7
Africa	131	1.8	7	1,211	1,080	6

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Diversified subsistence gardens in the tropics may continue to be productive for a number of years in favorable locations. Less diversified plantings exhaust soil fertility within a few years, and must be reestablished on “virgin” ground elsewhere—the so-called shifting agriculture, also called the slash-and-burn, or swidden, system of cropping. A forest that has been felled and burned for manioc or maize is a typical example. Once the protective canopy of trees is destroyed, ecological change is rapid and drastic; soil fertility is quickly exhausted, and sun loving weeds and other pests often become impossible to control. Although conservative of inputs, the swidden system is extravagant of land use, and suited only to lightly populated regions, which are now quickly vanishing from the face of the earth. When population pressure necessitates continuous cropping of the same soil and the use of seeded plants to increase the yield, problems quickly arise in the tropics. Many lateritic soils become hard as brick and unusable when subjected to cultivation for a long period.

The greatest advancements in tropical cropping have not come in the dense rainforest regions, however, but in habitats where rainy and “dry” seasons alternate. Apparently the contrasting ecological regimens that result provide a rich range of habitat, well suited to origination and domestication of special crops and cropping systems. It appears that many crops (especially the starchy root crops) originated in climates of this sort, where the monotony of rainforest is interrupted by a dry season that opens new opportunities.

Intensive cropping is quite demanding, and best confined to good soil and level land. A crop of some 5 metric tons of grain per hectare will deplete the land of about 100 kilograms of nitrogen, 20 kilograms of phosphorus, 25 kilograms of potassium, 21 kilograms of magnesium, and 9 kilograms of sulfur. If crop fields are to remain productive for intensive use, it is clear that nutrients must be replaced continuously, and to do so in adequate amounts is possible only in those parts of the world where fertilizer is readily available. Although in some places food needs could no longer be met were cropping systems to be limited to the “natural” methods characteristic of subsistence agriculture, it appears that intensive cropping can be continuous if measures are undertaken to replace nutrients, and if the organic content of the soil is maintained at adequate levels through the incorporation of plant residues. Admittedly, however, intensive cropping is too recent a practice to provide the experience (which can only be gained in many decades) necessary for making an evaluation of the permanence of the system, unlike some other cropping systems that have been carried on in certain areas since the dawn of civilization (such as the paddy farming in parts of the Orient (see Fig. 2) or the terrace agriculture and irrigation



Fig. 2. Rice growing in Southeast Asia is more intensive than it may seem. Although taking advantage of abundant, inexpensive labor, it increasingly uses highly bred cultivars, fertilizers, and pest controls. Here, in Burma, flooding the paddies necessitates hand transplanting from the nurseries, but the trade off in weed control is worthwhile under prevailing circumstances. [Courtesy Food and Agricultural Organization of the United Nations.]

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systems of the Near East and the South American Andes).

It is quite evident that in many parts of the world misuse of the land has caused the destruction of civilizations that once existed there. The tendency of lateritic soils to become unworkable when exposed to cultivation has been mentioned. Perhaps an even more significant cause of soil depletion is erosion in hilly country, and on overgrazed or overbrowsed lands (like those on which feral goats range in the Near East and Oceania). Sardis, in southern Turkey, is an example of a once wealthy community now virtually abandoned. Lands of the eastern Mediterranean, now denuded and bare (and unfit for any cropping unless accorded expensive renovation), were once covered with magnificent forests (such as the cedars of Lebanon). Although soils respond differently in susceptibility to erosion, depending upon such factors as cultivation, slope, rainfall, and so on, a study in Puerto Rico shows how serious erosion can be: nearly 48 metric tons per hectare of Pandura sandy loam exposed by clean cultivation were lost in a single simulated storm. If a cropping system is to be enduring, soil protection must certainly be afforded. Unfortunately, scant attention is given to soil conservation in many parts of the world, especially in some of the remote areas whose inhabitants have little if any modern agricultural knowledge and where more primitive cropping practices prevail.

THE MODERN CONTEXT

In general, crop producers aspire to the greatest possible yield commensurate with reasonable cost. The balance struck varies with location and occasion. In relatively prosperous parts of the world where population pressure is not yet excessive, as in the United States, the cost of labor is generally the prime consideration, more important than total production and even yields. It is not economical to farm those types of land, those kinds of crops, or those inconvenient locations that require extra hours of human labor for limited additional production. In other, more crowded parts of the world, such as the heavily populated Orient, labor is far less important than is total production. There each square foot of productive land will be farmed, even at the expense of many hours of tedious hand labor. Given aids to increase growth, such as fertilizer, yields per hectare may be greater than under highly mechanized, massive farming in America, where detailed attention to the land is not practiced because it is too costly.

Goals and methods will continue to change, depending upon economic conditions of the future and upon the ability of people to limit the size of the world population. The day is already at hand when American agriculture is more concerned with increasing production rather than managing the surpluses that had plagued the agricultural economy for some decades. In Japan, where trained labor is becoming more costly, a trend toward greater mechanization in agriculture can be expected. The cultural system best adapted to any given part of the world depends largely upon the human ecology of the place.

One thing can be foreseen: there will come a time when a ceiling on production is imposed beyond which it is impossible to go, practically. No matter how rich the soil is made, and no matter how well the crops are tended, space, sunlight, and crop potentiality will limit further increase. Maximum possible yields will have been achieved, because the crops will have been grown on the richest possible soil under the most suitable conditions obtainable. Somewhat before this ceiling is reached, the law of diminishing returns will have made impractical further increments of possible increase. The cost of practices needed for this last measure of return will be impossible to justify. Most of the world, however, is a long way from reaching such a ceiling, and the increased use of fertilizers alone should greatly extend the world's capacity to produce crops. Fortunately, this

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gives civilization some margin of time to institute population control and to reduce rapidly mounting demands on natural resources. It is sobering to note that even with all the improved cultural practices developed since World War II, and the consequent increased yields, the world is no better fed today than it was decades ago.

The quality of production must be assessed, too. How long can the United States, for example, continue to enjoy a basic meat diet, an extravagant source of protein in terms of the resources needed to produce it? Will not the time come when a much greater part of our dietary protein must be gained directly from plants? And what cropping practice, what type of fertilization, will yield suitable chemical quality in each foodstuff, even if at the expense of some yield? Cropping practices of the future must take this into consideration. Moreover, people will have to determine not only the best means of growing a crop, but which kind of crop best fits the economic situation of the moment.

Complicated interrelations are involved in agricultural policy decisions. Should such crops as soybean, which is relatively low in yield but high in protein, be grown in preference to crops that are higher in yield but lower in protein, such as grains and root crops? What about select sugarcanes, in which the yield of dry substance is powerfully increased at the expense of nitrogen content? What combination of such crops provides the best balance? Maximum use is made of photosynthesis with the sugarcanes, but certainly the protein is deficient. Broad cultural systems under maximum population pressure will have to provide a daily intake of about 2500 kilocalories. The ratio of protein to carbohydrates plus fat should ideally be about 1 to 11. Rice is one staple crop that matches good yield with this protein quality. Various analyses made to evaluate such factors as yield, protein content, and utilization of straw show that rice is capable of sustaining 25% more persons per unit of area than wheat. One can hypothesize sustaining even greater populations by using a high-yielding sugar to ferment proteinaceous yeast. Of course some help will come from the sea; for some time there has been talk of "farming" the marine plants of the continental shelves. Let us hope, however, that people learn to regulate their numbers before turning to yeast and algae just to stay alive. The world will not be a happy place in which to live if it becomes necessary to sustain upwards of 20,000 persons per square mile, though this is theoretically possible with good crop land.

As we enter the latter decades of the 20th century, resource problems become serious in the face of exploding world populations. It is apparent that exploitation of fossil fuels cannot continue indefinitely at the prodigious rate to which we have become accustomed. At best, the cost of energy will be increasingly dear, and fuels will become progressively difficult to obtain. The implications for mechanized cropping are profound. Perhaps the world will find it necessary gradually to shift back toward the ancient systems, based upon a current sunlight budget (that is, at its simplest something like the New Guinea tribesmen's way of life, mentioned previously).

Already the advanced agricultural countries are at a point of no return, with an insufficient land base remaining to nurture the livestock that would be necessary for a return to animal power instead of petroleum-fueled machines. Food shortages would certainly result, even in areas of present surplus, were horses, mules, bullocks, and similar draft animals, all needing food and space perhaps amounting to as much as 1/3 of the land they work, to be substituted for machines powered by fossil fuels.

The cost of fertilizer will be continuously increasing, particularly for nitrogen compounds heretofore produced in processes involving relatively inexpensive petroleum inputs. Therefore, greater and greater emphasis will no doubt be given to nitrifying systems, such as are presently

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found in naturally evolved symbioses in rice paddies, and to the use of *Rhizobium*-nodulated legumes in crop rotations.

It may also become necessary to introduce a new type of cropping, that of biomass production. This, at its simplest, involves maximum growth of vegetation (whether native plants, weeds, or crops) to trap energy from sunlight. The biomass so produced might be used in any of several ways: for direct consumption by ruminants, for fermentation to derive such products as alcohol, for chemical manipulation into useful compounds, for fuel, and so on. As this is written, biomass production is still an ill defined and incompletely investigated area, but it will doubtless involve many of the cropping systems mentioned in this chapter. Already there has been some talk of coppicing—that is, cutting all trees and woody vegetation on a piece of land and then harvesting the stump sprouts periodically. Biomass production by this method would probably be only about one tenth as productive as natural biomass production by a mature forest at its height of productivity. (The coastal coniferous forests of the Pacific Northwest, among the lushest in the world, are estimated to produce 4000 metric tons of biomass per hectare annually; deciduous woodlands east of the Mississippi may yield 400–500 metric tons per hectare.)

Still another problem that is increasing worldwide is the shortage of fuel wood. Heretofore this has been a matter of only local importance, but now it has dire implications for cropping systems. In many parts of the world, virtually all available woody materials are harvested and salvaged from wood and field, effectively barring the land and preventing the regeneration of forests (Fig. 3). Ecosystems are seriously degraded. Nepal provides an example of this: with increasing population, once forested lands have been cleared farther and farther up the mountain slopes to make room for terraced crops. Fuel wood, the only source of fuel other than dried cattle dung, thus becomes more and more remote, so that a day's journey by foot may be required to fetch a bundle of fagots that once could be gathered just beyond the doorway. Denuded land erodes in spite of diligent terracing, and much fertile soil ends up in the river valleys of India. In a similar fashion, the caatinga forests of dry northeastern Brazil have been overharvested to provide fuel for sustaining the electric utilities in the larger coastal cities. And East African savannah forests have



Fig. 3. Throughout the world, many of the last remaining forests are being exhausted, as here in timber-poor eastern Algeria. Denuded forest land will erode, and, especially in marginal climates, it is unlikely that the forests will regenerate. [Courtesy Food and Agricultural Organization of the United Nations.]

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been cut both for fuel and for grazing land making a countryside naturally well suited to tree crops overtaxed and unproductive. Such demands for fuel wood cause drastic disturbance, in the sense of diverting much land from its best ecological use (or its proper cropping system).

TECHNIQUES

In the general discussion so far we have alluded to a number of situations and practices of rather fundamental importance. Some can be traced back to the beginnings of agriculture, and are world-wide today. Let's examine them more closely, keeping in mind that people are rather flexible, omnivorous animals that can adapt to a wide range of situations. They can, for example, interrupt the food chain at almost any level, to consume the more energy efficient vegetable products in place of the more costly animal products, a practice generally followed under stringent circumstances. Also, people can substitute high yielding carbohydrate crops (such as sugarcane and cereals) for proteinaceous crops (mostly legumes, which must sacrifice some energy for nitrogen metabolism to make protein).

Possessing a degree of thoughtfulness, people may make their choices in light of what they expect the future to bring. At present, uneducated peasants are being offered improved "green revolution" crops, which, however, must be fertilized and otherwise given extraordinary care in order for them to fulfill their potential. It is no wonder that the simple farmer often chooses a lower risk system, one that evolved locally over a long period of time, utilizing low yielding but trustworthy crops and practices with which he is thoroughly familiar. The alternative would be to become a "vassal" of the more complicated system, neither well understood by him nor financially feasible (unless he is unusually wealthy). In the tropics, especially, social rather than technological factors are often more important in determining the nature of the agroecosystem.

Obviously, any cropping system is limited by the broad parameters that define the ecology of the area—temperature, length of growing season, adequacy of rainfall, soil quality, topography, and so on. Seldom are all natural conditions favorable, but innovative people have learned to overcome many deficiencies. This is especially true under heavy population pressure, when land is scarce and costly and highly productive agriculture is needed. Various inputs can be provided to help optimize photosynthetic potential. Thus the intensive agriculturists of Japan will alleviate nutrient limitations by fertilization, reduce pest losses by various techniques (including the generous use of pesticides), forestall drought through irrigation, and so on.

In contrast to the intensive agriculture of advanced economies is subsistence agriculture—small scale, self sufficient production usually employing heterogeneous germplasm (landrace strains rather than select cultivars), and utilizing little in the way of modern inputs (such as chemical fertilizers, pesticides, and machinery). Subsistence agriculture has been ubiquitous since time immemorial, and it still provides sustenance for half the world's population. One cannot deny its appropriateness for many cultures, and one must recognize its virtues under less sophisticated circumstances. Subsistence agriculture is in actuality a finely tuned, steady state means of food production that has evolved through trial and error over a long period. Of course it yields little in the way of cash crops with which to barter for manufactured items, which today are often considered necessities; but neither is it dependent upon uncontrollable and unintelligible inputs from the outside world. It cannot sustain the large populations that intensive agriculture can, but should technology falter or civilization wane (as may be the case during revolution, with drastic exhaustion of a sustaining resource, or when a natural disaster occurs), it can be the more reliable way of life (Fig. 4).

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Each age has had its advanced cropping systems appropriate to the times, in the search for more abundance and relief from laborious tasks. Among the practices that have been utilized in many places in many different cropping systems are land manipulations, crop introductions and selections, intercropping and multiple cropping, fertilization, and crop protection.

Land Manipulations

Since the earliest days of crop production, people have reshaped the terrain in order to irrigate, to provide better drainage, and to conserve the soil. Only recently has it become apparent that raised beds or fields (such as the chinampas of Central America) were not a pre-Columbian rarity in the lowlands, but commonplace. These provided suitably drained and aerated soil in lowland places that would otherwise be sodden. When one flies the earth in a modern aircraft, it becomes apparent that terracing—the making of contoured banks or ridges on slopes to make them cultivable—is practically ubiquitous. Terraces conserve water and soil in all parts of the world (Fig. 5). Likewise land has been engineered for irrigation since the earliest days of farming, a fact well demonstrated by archaeological evidence from the Near East, the Andes, and East Asia. Mostly this was done by creating gently sloping sluiceways for gravitational movement of water. Terracing and irrigation have together been especially important in creation of tropical rice paddies, which sustain much of the world's population (Fig. 6).

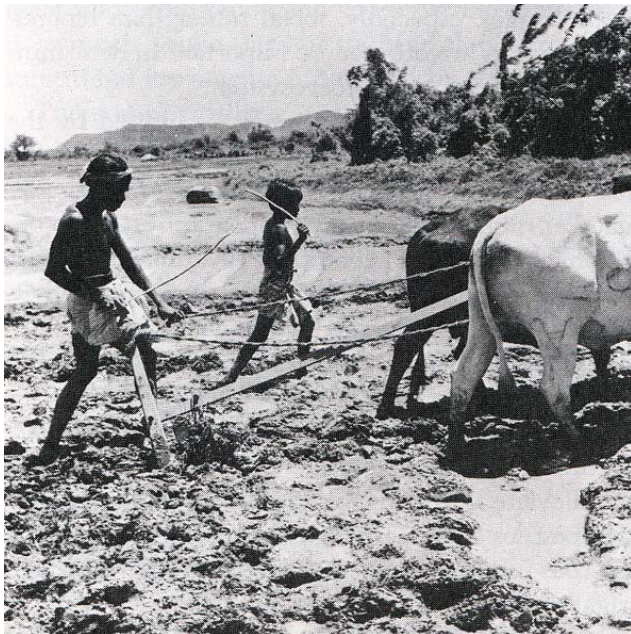


Fig. 4. Traditional subsistence agriculture, such as here in Sri Lanka, utilizes few outside inputs, and sacrifices some net output to the use of draft animal power (in place of complicated, often undependable motorized equipment). As energy resources per capita diminish, will this be the prime methodology of the future? Courtesy Food and Agricultural Organization of the United Nations.]



Fig. 5. Land terraced by hand to conserve the thin soil in an area of subsistence farming of mountainous Java. [Courtesy Food and Agricultural Organization of the United Nations.]

Crop Introductions and Selections

Ancient people purposefully selected and introduced plants in order to achieve their domestication. Species suited to the locality were chosen, and within each species selective pressure was brought to bear upon various advantageous traits (such as greater productivity, longer bearing season, preferred size and shape, and so on). As we have noted, conditions dictated that, in general, annual crops adapted to a short growing season became the mainstays of temperate cropping, while perennial, everbearing crops were more often chosen for tropical environments, where carry over and storage are more difficult.

Intercropping and Multiple Cropping

Intercropping, whereby different crops are interplanted, is characteristic of subsistence agriculture. The practice has much to recommend it, because it spreads the risk of a crop failure or devastation by insects or disease over 2 or more crops. Its disadvantage is the inconvenience it causes by making it impossible to obtain the efficiencies of scale that can be enjoyed with a single crop. Intercropping (often termed mixed cropping, multiple cropping, or polyculture) is being more frequently recommended for tropical regions, where the trend is away from large plantations and toward individual holdings. Double cropping (or triple cropping, in some instances) refers to successive croppings within the same year. This is appropriate for fertile land in a climate with a lengthy growing season, for it increases the productivity of the land proportionally. Often, however, repeated cropping is thwarted by marginal growing conditions, seasonal changes, a build up of pests, nutrient exhaustion, or other difficulties.

The increase in productivity that came with flood control in the Nile Valley, which eliminated the “wasted” time when the fields were under water, will be discussed later in the chapter. Double and triple cropping is now possible on these fertile lands, although only time will tell whether ecological change—most likely involving fertility loss and pest build up—will exact its toll. It is interesting that depictions in the tombs of ancient Egypt indicate that seed was planted just before the flood season, so that a silt top-dressing (as well as abundant soil moisture) was immediately present for crop encouragement as the waters receded. New methodologies, such as the use of fertilizers, can doubtless be taught to the Egyptian farmer, but it remains to be seen whether the economics of the age old natural system can be profitably substituted for.

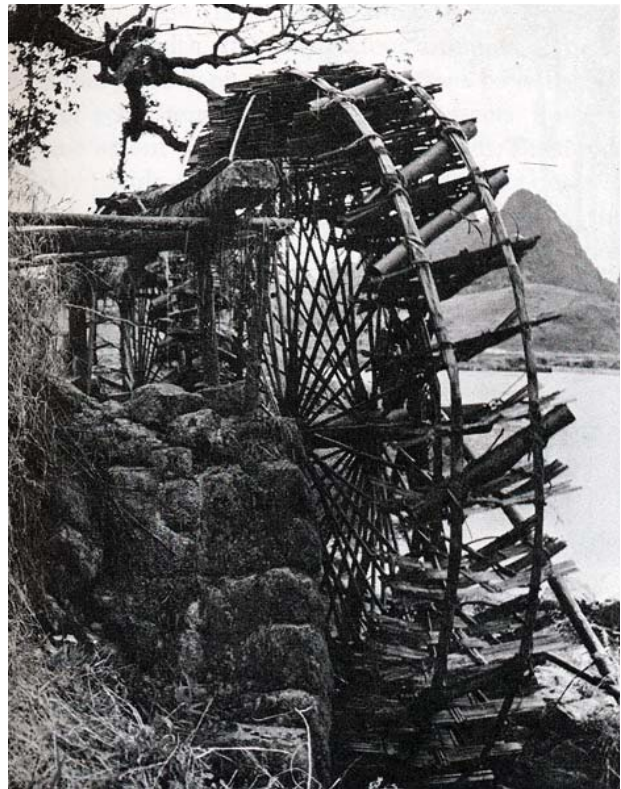


Fig. 6. A water lift ingeniously constructed with split bamboo, for irrigating rice paddies in China. The vanes of the wheel are activated by the current, and the bamboo scoops carry water to the trough at the top. [Courtesy Food and Agricultural Organization of the United Nations.]

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Fertilization

Since ancient times it has been realized that adding nutrients to the soil is a valuable cropping practice (Fig. 7). Manures, guano, and (especially in tropical environments) composted vegetation have been extensively used over the ages. Perhaps second only to a lack of moisture, a lack of nutrients imposes a serious limitation on the photosynthetic potential of a crop plant. The technically advanced agriculture of today takes advantage of soil and tissue tests to zero in on nutrient needs. The nutrients are generally supplied from economical synthetic sources, in proper balance, and in easily handled formulations. Incautious fertilization, however, can induce disturbances and imbalances, cause changes in pH (which, in turn, can affect micronutrient availability), and introduce unwanted elements (such as cadmium or other heavy metals).

Crop Protection

People, of course, are not the only consumers of their crops. Especially troublesome competitive consumers are arthropods (primarily insects) and pathogenic microorganisms, but even vertebrate animals often feast on cultivated fields. Weeds, too, are a major problem, competing with crop plants for space and nutrients. Crop predation is especially acute under tropical conditions, and many agriculturists believe that it is more the cause for the deterioration of productivity often seen on farmland in the tropics than is soil depletion. The principal tactics for controlling pests have been the selection of resistant cultivars, the utilization of cultural controls (such as rotational cropping, cultivation, timing of planting, and fallowing), and the institution of biological controls (introducing predators or competitors of the pests). Only recently has the application of pesticides become commonplace, and only in advanced agricultural economies.

At first, almost miraculous results were achieved with the use of pesticides, with small quantities of “novel” molecules sufficing to fell weeds and insects often quite selectively. But all is not well on the pesticide front these days. In addition to newly found hazards to health, the tremendous amounts of pesticides that have been used in some areas have tended to alter ecosystems. Especially with insects, but also to some extent with pathogens and weeds, resistance quickly builds up in the pest so that heavier doses of more toxic chemicals are called for. Eventually the cropping system becomes overly dependent upon pesticides, which become less and less functional and more and more harmful to the environment. Cotton growing is a notorious case; the crop as generally cultivated in the United States requires innumerable treatments. With public sentiment turning against the extravagant use of pesticides, integrated pest management (IPM) is gaining favor. The idea, sensible in principle, is to utilize cultural and natural controls to the greatest extent practicable, reserving pesticides only for emergencies and especially devastating invasions.

Other Innovations

The trend toward mechanization has been un-



Fig. 7. The difference fertilization can make in crop yield, in Turkey. Wheat plants like the one on the left, which was heavily fertilized, will bear much more abundantly than those like the one on the right, which was underfertilized. [Courtesy Agency for International Development.]

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derway since the 1st draft animal was hitched to a plow to replace manual cultivation with a digging stick. The remarkable extent to which fossil fuel has been used to power the innumerable labor saving devices commonplace in advanced agricultural societies is commented upon later in this chapter. Similarly, human inventiveness has created irrigation systems far more effective than the gravity powered systems of old (Fig. 8). Hormonal chemicals, usually synthesized, can today regulate plant growth. Pheromones mimic insect sex attractants, luring harmful insects to poison or traps. Synthetic hormones that disrupt growth are used to prevent insects from fulfilling their normal reproductive cycles. No-till and mini-till systems have been developed, in which herbicides are used to control vegetative growth other than that of the planted crop.

SYSTEMS

There is no end to the schemes that might be employed for raising and harvesting a crop. But certain systems adapt better than others to certain circumstances. Although ill defined and with many variations, the following procedures cover most of the cropping methods people undertake to gain their livelihood from the land in all parts of the world.

Shifting Agriculture (swidden cropping)

Shifting agriculture is a slash-and-burn-and-abandon process employed mainly by primitive cultures in sparsely populated regions. The **milpa** of the American tropics and the **ladang** system of the Orient are examples. The storehouse for vegetational wealth in the tropics is lush topgrowth, not soil. Shifting agriculture endeavors to release these stores for down-to-earth cropping, making but temporary use of stubborn lateritic soils.

Forest trees are either girdled or felled. The dead vegetation is burned during the dry season (or sometimes left to decay and deteriorate through termite action). The resulting open ground is automatically fertilized with wood ashes. After only a few crops, fertility is typically exhausted. The clearing is then abandoned, and the process is repeated elsewhere. On unfavorable terrain, much soil is lost through erosion.

Cropping entails the planting of seed or, more commonly, vegetative parts as soon after burning as the soil softens with the onset of the rainy season. Under primitive circumstances, planting is done simply by dibbling holes in the soft soil with a planting stick and dropping in the seed or the

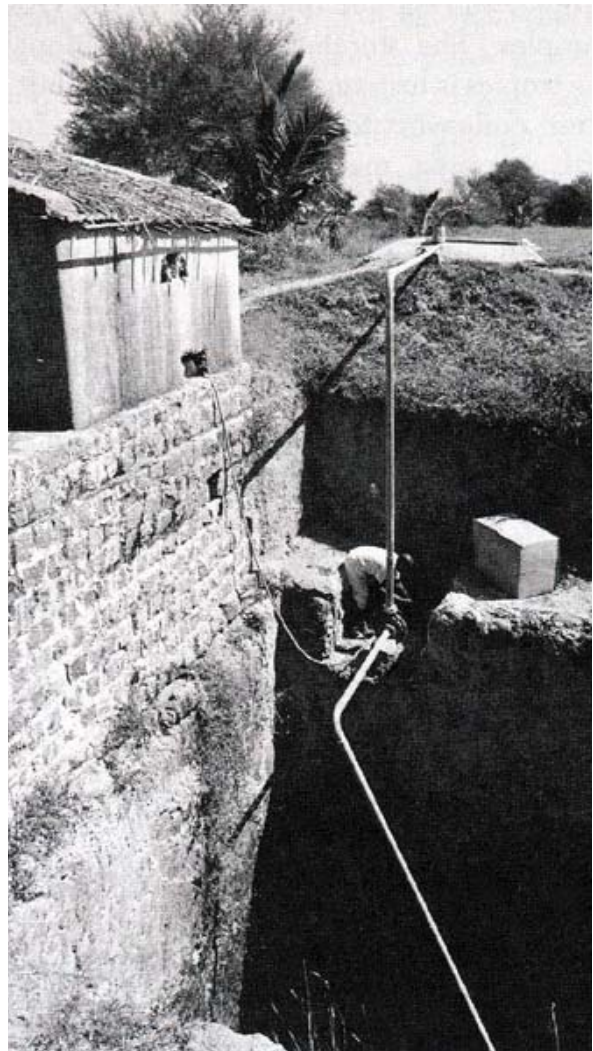


Fig. 8. Technology steps in, increasing yields through irrigation. Here, in Nalagonda, southern India, a well has been dug and a motorized pump has been installed, resulting in six fold increase in rice productivity. [Courtesy Agency for International Development.]

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vegetative part. Some weeds will volunteer in the crop, and hand pulling may be needed to aid the crop. Brush or grasses typically overrun the clearing within a very few years.

In a region as unpopulated as the Amazon Valley has been until recently, slash-and-burn agriculture was a superior system, all things considered. It provided a readily available and effective means of fertilization, from the ashes produced by burning. However, yields typically decrease by about 50% with each successive planting, although this could be ameliorated somewhat if the abundant natural vegetation were cut and composted, and then hoed into the soil. As development proceeds in tropical areas, some problems of nutrient deficiency can be corrected with complete fertilizers, but composting is still needed to conserve soil structure. As modern cropping methods have been introduced, trace element deficiencies, particularly of magnesium, have often proved a limiting factor.

Obviously, shifting agriculture makes extravagant use of land and is wasteful of trees. Societies depending upon it must either keep on the move or extend operations ever farther from the central city as nearby lands become exhausted. Frequent clearing of the same land degrades the vegetation into an unmanageable tangle of brush. Maybe this is why empires based upon shifting agriculture have not endured as well as those established on valley flood plains.

Tree Horticulture

Fruits, derived mainly from woody plants, are important crops. They were gathered from the wild by primitive people, and today they help to support the economies of many parts of the world. Tree crops, mostly fruits and nuts, are particularly suited to tropical cultural systems, and, as was noted earlier in this chapter, they allow for a more stable cropping system there than does swidden cropping. In addition to fruits, woody plants are grown for tea, maté, wax, rubber, quinine, and cork, often in plantations (which will be discussed subsequently). In temperate climates, orchards—counterpart to the tropical plantation—yield a variety of fruits and nuts and even such decorative materials as holly.

The tropical climate is generally better suited to tree growth than to the production of the annual crops that people living in temperate climates have come to regard as agricultural mainstays. The lateritic soils of the tropics become hard and refractive; powered equipment for cultivation is expensive and hard to procure and maintain; efficient means of mass handling and storage are generally lacking. But tree groves accompanied by family gardens support individual families and small villages well. They are enduring and harmonize with the tropical forest environment. Thus, as settlements become too mature for shifting agriculture, villagers turn to tending groves of coconut and other palm fruits, breadfruit, banana, citrus, avocado, and so on. This kind of tree horticulture is supplemented by diversified home garden patches (Table 2), and usually some domesticated animals are used to help keep down the prolific tropical growth and to supply manure for the plantings. Fishing and hunting often yield additional protein.

In some systems trees are cultivated as a source of fertilizer. The tops are constantly cut back to the trunk, the vegetation being used to fertilize cleared ground, usually by burning but sometimes by composting.

Plantation Agriculture

A successful agricultural method where large sections of land have been cleared is the **plantation system**, hallmark of tropical agriculture in many regions. A simple example might be the growing

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of plantains in Ghana. Locally selected cultivars are perpetuated by vegetative “suckers,” after felling of forest and burning of brush in the dry season. Reasonable attention is given to mulching, irrigation, propping of fruit bunches, intercropping with vegetables, spraying for disease and pests, timing of harvest, and so on. Only where an enlightened supervision practices sanitation, selection of disease free suckers, and fertilization, can a planting endure for many years and thereby avoid the swidden system of moving on to new ground after only a few seasons.

A good plantation combines the better features of shifting agriculture with those of horticulture. Under trained managers, often sent from agriculturally advanced parts of the world, plantations generally utilize the land efficiently (Fig. 9). The plantation system requires responsible management and the capital resources to supply the necessary machinery and facilities and to open up marketing opportunities. Although there is no doubt that many foreign controlled plantations have exploited native populations unfairly, it is regrettable that the rise of nationalism and anticolonialism has tended “to throw out the baby with the bath water.” The rubber plantations of Sumatra and Malaysia, the cacao plantations of Africa and Central America, the nutmeg orchards of Grenada, and the sugar and coffee plantations throughout the tropics probably represent the soundest ways of utilizing the land under prevailing circumstances. The native populations of these parts of the world often lack agricultural training and so must be supervised—a situation that must be changed if world food demands are to be met. There should be some means of combining social enlightenment with the efficiencies of large-scale operations, especially in the less developed tropical countries where small holdings are not well managed.

Table 2. Some of the many species typically cultivated in a dooryard garden in Central America (Yucatan).

Scientific name	Common name (English)
<i>Annona cherimola</i>	cherimoya
<i>Brosimum alicastrum</i>	breadnut
<i>Byrsonima crassifolia</i>	craboo
<i>Capsicum annuum</i>	chili
<i>Carica papaya</i>	papaya
<i>Citrus aurantiifolia</i>	lime
<i>C. aurantium</i>	sour orange
<i>C. reticulata</i>	mandarine orange
<i>C. sinensis</i>	sweet orange
<i>Cocos nucifera</i>	coconut
<i>Cordia dodecandra</i>	
<i>Diospyros digyna</i>	black sapote
<i>Mangifera indica</i>	mango
<i>Mentha piperita</i> var. <i>citrata</i>	bergamot mint
<i>Persea americana</i>	avocado
<i>Psidium guajava</i>	guava
<i>Sabal yapa</i>	guano palm
<i>Sechium edule</i>	chayote
<i>Tagetes erecta</i>	marigold



Fig. 9. A tea plantation in East Africa. Adequate capitalization, improved cultivars, and trained supervision combined to give high yields and economical production. [Courtesy Ivan Massar for World Bank.]

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Orcharding

Although the Orient and the tropics still rely a great deal upon backyard plantings of a few fruit trees, in technologically advanced countries commercial orcharding has evolved into a large scale specialization (Fig. 10). The blemished fruits typical of backyard plantings no longer find a market in the United States. Select varieties with proper keeping qualities, exact spray schedules, and harvesting standards, typical of professional orcharding, have taken their place. It is not unexpected that production centers have shifted to particularly favorable climates—in the United States mostly to the coastal Northwest and the Great Lakes region. Europe has seen similar specialization—for example, the heavy plantings of pears in the Rhone Valley, and of both apples and pears in the Po and other valleys of northern Italy. Southern Australia, South Africa, and southern Argentina also produce considerable fruit crops.

Eastern Asia is particularly well suited to fruit production, having climatic conditions equal to other fruit producing parts of the world, plus the blessing (for fruit production) of an unlimited labor supply. Skillful gardening rather than extensive agriculture has an ancient tradition in Asia. It is said that there are more than 500 species of native Chinese plants that produce edible fruits, of which at least 120 species are in cultivation. These include apple, pear, persimmon, jujube, peach, grape, mandarin orange, sweet orange, pineapple, banana, longans, and litchi nut. Peach cultivars, such as ‘Chinese Cling,’ renowned as a parent of the ‘Belle of Georgia’ and ‘Elberta’ cultivars, have come from China, and this area with its long history of civilization (during which many selections and adaptations were made) promises a wealth of untapped breeding potential still.

In the United States and Europe, apple, citrus, pear, peach, plum, apricot, cherry, pecan, walnut, and grape are among the principal orchard species. Throughout the tropics, coconut and banana are extremely important; and in special locations such as Hawaii, pineapple is a major crop. Lesser fruits grown in the tropics include mango, papaya, date, fig, avocado, olive, and pomegranate; in temperate climates, almond, persimmon, blueberry, chestnut and various bramble species.

Each type of orchard, each soil and climatic zone, demands its own cropping practices. In general, select planting stock is usually grown in a nursery through budding, grafting, and rooting of cuttings. Saplings are transplanted to the orchard, where they are spaced geometrically to accommodate eventual tree size and the equipment used to tend the orchard. In the United States, trees are generally spaced 6–14 meters (20–45 feet) apart, but the trend is toward high density plantings in new orchards. In Europe, where land space is at a premium, dwarfed “hedgerow” orcharding is very common, especially with apple and pear. There are obvious efficiencies in harvesting fruit that grows low enough to be reached from the ground or from a moving platform. In northern Europe, trees are often trained to wire trellises or are maintained as dwarfs either by pruning or by using size controlling rootstocks. In Italy and France, plantings range from spaced trees

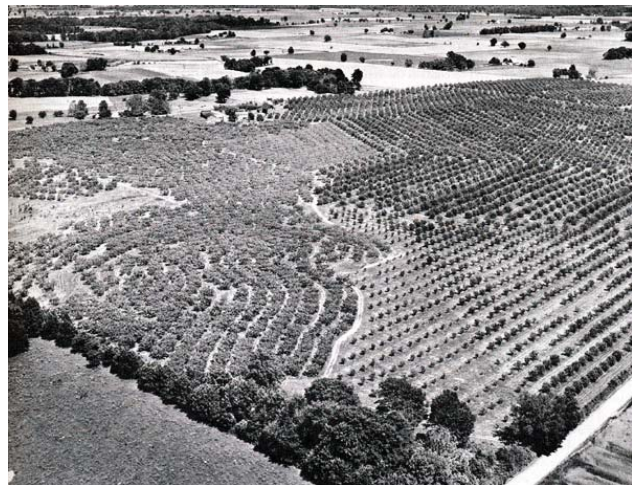


Fig. 10. A portion of land owned by the Dixie Orchard Company, Vincennes, Indiana. This large enterprise manages more than 400 hectares of apples and peaches. [Courtesy U.S. Soil Conservation Service.]

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to narrow “fruiting walls.” ‘Golden Delicious,’ an apple cultivar popular in the United States, responds well to hedgerow growing and is now extensively planted in Europe under this system.

Few orchard trees demand as fertile a soil as do annual crops, but, instead, thrive best in deep, well-drained locations. Their root system, much more extensive than that of annuals, is more continuously active but does not cross transfer nutrients well from one side of the plant to the other. Fruit orchards often do well on light soils, and tolerate wide ranges in pH. But they may be susceptible to shortages of minor elements.

Location is important; blossom loss from freezing can be prevented by planting orchard trees in equable climates leeward of bodies of water (which warm later in spring and cool more slowly in autumn, allowing late blooming and ripening), and on rises rather than in depressions (where cold air settles, causing frost).

Various soil-management schemes are practiced in the orchard, ranging from clean cultivation (particularly when the planting is young) to the maintenance of sod or legume covers to hold and build the soil. With modern herbicides, sod and weeds can be restrained without cultivation, resulting in less competition for water and fertilizer and the elimination of cultivation injury to surface feeder roots.

The modern orchard requires elaborate maintenance to produce fruit of marketable quality. As many as a dozen pesticide sprayings may be required during the growing season. Seasonal pruning is needed to regulate shape and to contain the trees for convenient harvesting and maximum fruit production. Fertilization (and irrigation, if required) must match local soil requirements.

Cultivars must be properly selected to insure pollination and fruit set (although this can be implemented with chemical sprays). Many fruits are self-sterile and must cross pollinate, sometimes with an entirely different cultivar. This entails appropriately spaced interplantings and, for some crops, introduction of pollinating insects (such as honeybees). Moreover, some fruits set well only in alternate years. Cross pollination is generally necessary for a good crop of apples; many pears, sweet cherries, and plums are likewise self-unfruitful. Peaches, nectarines, apricots, and sour cherries self pollinate adequately.

Growth-regulating materials have found great application in modern orcharding. In such temperate fruit crops as apples, pears, and peaches, **chemical thinning** is commonly practiced to adjust the crop load. This is necessary in order to control fruit size and to prevent alternate bearing and winter injury—problems that arise from overbearing. Chemical thinning materials may be either caustic substances (such as dinitro compounds) that burn off the blossoms or auxin derivatives (particularly naphthaleneacetic acid) that bring about embryo abortion. Auxins are also used to prevent premature fruit drop in the fall. In grape production, gibberellins have been used to induce seedlessness and particularly to increase fruit set and fruit size in seedless cultivars. The chemical SADH (succinic acid-2,2-dimethylhydrazide, also known as daminozide) has interesting effects—dwarfing, the induction of earlier production, intensified fruit color, and improved storage qualities.

Added to the orchardist’s tasks may be such things as nematode control and protection against freezing (as in citrus orchards in Florida), the proper timing of the harvest (in bananas, for keeping during shipment, and in rubber, for maximum yield), and perhaps above all the securing of seasonal hand labor for harvesting. Fruits that can be shaken from a tree to fall on nets or canvas without damage are increasingly being harvested mechanically (with padded devices that vibrate the tree or bush).

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Flood-plain Irrigation

Most remunerative of all cultural systems in the tropics and subtropics is flood plain cropping with irrigation, a system that had its beginnings in Mesopotamia, the Nile Valley, and Tehuacan. Flood-plain irrigation supports dense, sedentary populations along the Nile and throughout the Orient, where individual paddies are created by terracing and intensive land management. Practical skills and much hand labor are needed, with the result that, by and large, flood plain irrigation has been most successful where the people are peaceful, intelligent, and dexterous. The system has been singularly successful in Southeast Asia.

Irrigated Desert

Although stream borders in desert valleys have always been among the world's most productive agricultural locales, it remained for modern technology to make practicable the massive, intensive, highly remunerative farming seen today in such naturally unlikely spots as the interior valleys of California, southern Arizona, and the high plains from Colorado into Texas. Irrigation projects that transport water for many miles are the prime means for turning "worthless" desert into productive agricultural land. Well managed and scientifically irrigated holdings in California and Arizona can produce twice as much cotton as the famed cotton lands of the Southeast. The same is true with such forages as alfalfa, in comparison to yields in the Northeast with natural rainfall (and shorter growing season).

Where irrigation is not possible through diversion from streams, increased drilling capabilities and huge pumps enable well-capitalized farmers to draw groundwater from as much as 600 meters (nearly 2000 feet) below the surface (the water table, unfortunately, is thereby being lowered in many parts of the country at an alarming rate). **Trickle irrigation** in which water is dripped to the soil directly below the crop plants slowly and in precise quantities, is finding increasing approval as a practice that is more conservative of water than is flood irrigation or sprinkling. (Apparently, trickle irrigation also permits the use of somewhat more saline water, which is typically found in arid regions).

In arid regions, which are naturally inhospitable to people, irrigation permits very remunerative yields under highly technical and intensive farming methods. Some of the world's most specialized large scale agricultural operations have been established on level desert. Desert soils may not be as good as prairie soils, but their deficiencies can be compensated for by fertilization and proper irrigation. How involved these operations can become is exemplified by the efforts of the Kern County Land Company in California to trap seasonal runoff for underground storage, to be pumped out later for irrigation. Soil treatments that will maximize surface infiltration are assiduously sought, and ponding fields are built merely as insoak reservoirs to get mountain stream runoff into the water table. Almost no water runs "uselessly" to the sea any more in southern California.

Even the huge flow of the Nile is being appreciably drawn down for expanded irrigation of the deserts of lower Egypt, now that the Aswan High Dam is in operation. Expansion in food production more than sufficient to keep pace with the burgeoning Egyptian population has resulted, perhaps more because triple cropping (three crops per year on the same field) is possible now that the annual spring floods are controlled. There is a trade-off, however: the fertility value of the silt that was once deposited by the spring floods has been sacrificed, and commercial fertilizer must increasingly be used (and this mostly, by uneducated farmers not accustomed to fertilizer usage, in a system lacking the infrastructure for agricultural supplies or sophisticated marketing means).

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The huge outlays generally required for large-scale irrigation farming in the United States are reminiscent of the management practices of plantation agriculture in the tropics. Small, self-sufficient home farms are seldom seen. Many of the large land holdings are owned by absentees and managed by hired professionals. Even with private operations the “farmer” acts more like a “businessman” (not uncommonly commuting hither and yon in his private airplane) than the over-alled cultivator of the soil so dear to the American political ethic. These owners and managers are just as interested in credit, national money policies, the stock market, and the Washington political scene as are the executives of industrial corporations. In groups or associations they may even control marketing outlets and have connections overseas. This is probably but a foretaste of what most agriculture will be like eventually in advanced countries.

Diversified General Farming

The farming tradition familiar to Western civilization in temperate climates—the system of diversified general farming—embraces most of the temperate-zone crops, planted, where they are well adapted and economically remunerative, by the landholders themselves. This sort of cropping developed in climates where rainfall is sufficient to maintain forest vegetation. Until quite recently Europe and North America have been particularly dependent upon farming of what was formerly forest land. By and large a very flexible farming program is possible on land of this sort. Though the soils are not particularly fertile by nature, they are quite responsive to fertilization practices and proper handling. Much of the best cotton, soybean, corn, and dairy pasture lands, so important in the eastern United States, are of this type.

The colonist regarded the virgin temperate forest as somewhat inimical to his economic well-being. Trees were to be utilized, of course, for timber, fuel, furniture, and so on. But the forest seemed limitless, and the main task at hand was to cut down the trees and grub out the stumps, so that land could be cultivated and cropped. In North America even the Indians had made a few clearings in the forest, where they planted corn and other crops. Gradually the hand felling of trees and manual hoeing of soil, which were characteristic of the early Virginia colonies, changed to soil cultivation with moldboard plows drawn by oxen or horses, and then to today’s use of elaborate farm machinery. This evolution is at the heart of American economic progress, and will be discussed in more detail under “Mechanization.”

General farming allows great self sufficiency. New World colonists or European peasants could provide themselves with life’s chief essentials, and perhaps a bit extra for barter. It was a system that encouraged individualism, so dear to the American political image. Gradually farming of the humid temperate lands has given way to greater specialization, although diversification and crop rotation are not yet things of the past. Some once forested lands prove particularly suitable for vineyards or orchards—especially in equable climates near bodies of water, such as in western Michigan and from northern Ohio to upstate New York. Cotton was the basis of a one crop economy in the upper South a century ago, where, after a good many fields were nearly ruined, diversification eventually returned (tobacco, beans, peanuts, corn, small grains, orchards, hay, and forage). Once forested lands in Ohio and Indiana are today among the best in the Corn Belt, where corn is rotated with soybeans and occasionally with small grains or pasture. It is hard to imagine that the state of Ohio, once almost solid forest, has within a century and a half been transformed into a man-made “prairie” with scarcely a virgin stand of trees to be found anywhere in its tens-of-thousands of square miles.

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Prairie

The temperate prairies, the modern world's breadbasket, were among the last of the major vegetational complexes to be harnessed. The harsh, windy environment provided little in the way of fuel and shelter. Until sturdy, powered implements became available the plowing down of thick sod was a backbreaking chore. It is not surprising that, in the colonization of America, cultural systems patterned after those of the Old World carried settlement easily to the boundaries of the prairies, where migration paused until new techniques and attitudes (built around wheat cropping) could replace the diversified farming tradition long familiar in the East.

Prairie life breeds cooperation rather than individualism. The very nature of the environment calls for large acreages devoted to but one or a few well-adapted crops. Neighbors, though more distant, are also more cherished—the sole social outlet in a culturally barren environment. And the lifeline for existence itself is a tenuous road or railroad leading to the industrialized parts of the world, from which come the tools and supplies not locally obtainable. With an existence that is anything but self sufficient, being dependent upon distant markets, there is real concern about other parts of the world, and a cooperative rather than isolationist political outlook develops.

Modern transportation and powered equipment have completed destruction of the native prairie even more quickly, than the eastern forests were felled. Only small pieces of the original prairie remain, although it once covered hundreds of thousands of square miles in the United States, from Illinois to the Rocky Mountains and from Texas to Canada. Much of this has been replanted to domesticated grasses and legumes for hay and forage, and even more to such cultivated crops as wheat and grain sorghum. Unfortunately, at times prairie lands that were too dry for cropping have been stripped of their protective sod cover, causing a loss of soil to wind storms. Other prairie lands have been so overgrazed that grassland has become degraded to brush and desert.

Dryland Farming

The western reaches of grassland in the United States embrace the drier short grass prairie, where a system of alternating crop with fallow permits acceptable yields under minimum rainfall. Alternate strips, or fields, are sowed (usually to wheat) and left unplanted (but cultivated to control weeds). Such rain as does fall soaks into the fallow ground and is not dissipated by plant growth. Moisture “stored” in this fashion for 1 year is usually sufficient to sustain a crop the 2nd, after which the process is repeated. Dryland farming is a human adaptation to the severest part of the prairie environment, and requires a hardy breed of agriculturist to withstand the adversity of dry cycles for the prospect of bounty in relatively rainy ones. Soils are good, and dryland farming is increasingly giving way to irrigation as facilities become available.

Burning and Grazing

The natural vegetation in many parts of the world is grass, and its utilization for grazing (originally by wild animals, later by livestock) can support a moderately concentrated population. Where climate is seasonally too dry for forest or parkland, prairie persists, but even there it can be argued that periodic burning is required to keep brush and grass in balance. This is particularly true in tropical savannahs or in forest clearings, which are burned annually to prevent the incursion of trees. Often savannahs are burned merely to get rid of lignified old leafage, which is unpalatable to stock and contains little protein; the animals prefer tender new sprouts. Dispute is endless over whether such burning causes long-term deterioration, which is likely if burning is accompanied by overgrazing. But certainly burning is essential in some regions to prevent reversion to forest.

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Tough grasses that have invaded tropical clearings are often intentionally destroyed by controlled burning just as new growth starts; food reserves in underground parts are low then, and the grasses are easily weakened.

Browsing

Agriculturists considering various cropping practices might take a hint from wildlife species, among which browsing (the nibbling of woody vegetation as opposed to the grazing of herbaceous ground cover) is commonplace. In some respects the planting and maintenance of low growing shrubs and trees requires less effort and is more conservative of energy than is establishment and maintenance of pasture. Some tests have shown that a greater quantity of digestible protein is produced per hectare by browsing than by the grazing of forbs and grasses.

Goats and camels in particular are noteworthy browsers among domesticated livestock. Often they are simply turned loose to consume wild vegetation. With reasonable attention to husbandry, it should prove possible to combine the browsing of certain livestock species with some commercial yield (as of fruits or nuts, and perhaps a modicum of fuel wood) from shrubs and trees. Plantings of jojoba (*Simmondsia chinensis*) might be very productive in this respect. The species could be a source of agricultural income in arid climates where few other crops are adapted: controlled browsing might be combined with at least some remuneration from harvesting the seeds, which contain a valuable liquid wax.

Forest Management

Forests have only recently come to be regarded as crop rather than as natural bounty to be freely taken. With much of the world's virgin timber already cut, there is now concern not only for quantity but for quality also. Save for a few remaining wild parts of the world, such as the Amazon valley and the remote subarctic regions, forests are today more or less managed. In some cases their management is just as intensive as that of cultivated crops, and includes specialized techniques for planting and replanting as well as harvesting.

Compared to the systems used for annual crops, however, and even orchards, forest cropping systems are still in their developmental stages. Over most of the tropics and much of the temperate zone, management is minimal. Shifting agriculture continues, and in many places trees are cut for timber, pulp, and firewood much as they were by early settlers. But technically advanced societies have come to realize that forests are not unlimited. There is little hope that improved forestry practices will be imposed over most of the tropical woodlands in the near future; rather, high-grading (removal of only the best trees of the best species, leaving inferior types to reproduce) will continue, as will wanton deforestation for fuel and new



Fig. 11. Early-day logging in the United States (this in Shasta National Forest, California) with bullock teams. This mode of operation is still practiced in remote forest regions, such as the Gran Chaco of Paraguay, Tierra del Fuego in Argentina, and parts of Africa and Asia. [Courtesy U.S. Forest Service.]

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cropland. But more intelligent use of temperate forests is at hand, both with regard to their use as a source of raw materials and as an esthetic and recreational resource.

Forest management has many problems that are peculiar to it. Most obvious is the long time required for tree growth. Up to the present, forestry has depended upon old-growth timber, some of it thousands of years old. New growth generally takes 15 to 150 years to reach merchantable size for timber and significantly less time for pulp, depending upon the part of the world. It is apparent that any mistakes made in selecting new planting stock, or in getting it started, will be perpetuated for decades. Besides causing a loss of time, mistakes of this kind cannot be corrected without the additional cost of cutting useless stock and replanting again.

In many parts of the world, forestry relies for its seed mainly upon native trees. It is assumed that natural selection will have provided a suitable genotype for any given area. A specialized forest seed industry has now been developed, whereby seed from years of abundance is properly stored for use in leaner times. In most temperate countries where seedling culture is practical, a 5 to 7 year supply of seeds of commercially important forest trees is always on hand.

Ecological studies are identifying more clearly the environmental factors that favor individual forest species. The modern forester has some information on the silvicultural practices favoring pine, mixed conifers, hardwoods, and so on. Temperature, thermoperiodicity, light, moisture, and soil condition all interact to determine the suitability of a forest site. Of course, these are in turn affected by elevation, slope, and so on. Temperate-forest yields (stem-wood volume) are about 700 to 900 cubic meters per hectare per year (10,000 to 13,000 cubic feet per acre per year), the yield de-



Fig. 12. Modern yarding of logs with a helicopter in California. [Courtesy U.S. Forest Service.]

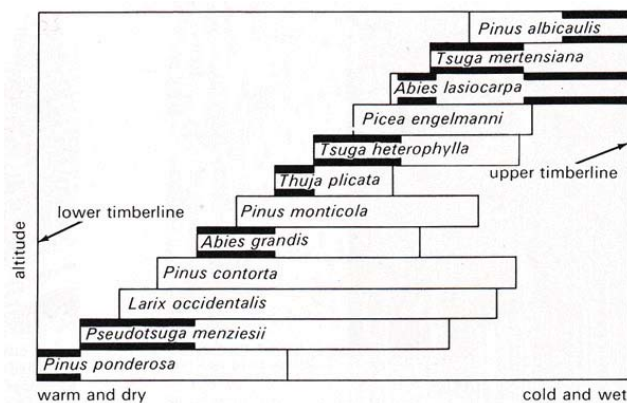


Fig. 13. The usual order in which coniferous trees are encountered with increasing altitude in eastern Washington and northern Idaho. The horizontal bars indicate the upper and lower limits of the species relative to the climatic gradient. The heavy lines indicate that portion of a species' altitudinal range in which it can maintain a self-reproducing population in the face of intense competition. [After R. Daubenmire, "Vegetation: Identification of Typal Communities," *Science* 151:291–298, 1966. Copyright © 1966 by the American Association for the Advancement of Science.]

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creasing with increasing dryness or elevation. Evergreen forest is more productive at elevations of 1500 meters (about 5000 feet) or higher or at latitudes north of about 45°. An example of the change in (and overlap of) dominant forest species as the environment alters is shown in Fig. 13. Ponderosa pine and Douglas-fir, for example, are adapted to the warmer and drier forest belts of the Pacific Northwest, and are gradually replaced by other species as the climate becomes colder and wetter with increasing elevation.

Armed with this sort of information, the forest managers can base their decisions on measurements rather than on guess work. Still, there are many aspects of tree growth about which little information has been gathered. Compared to annual crops, trees are peculiar in the tremendous amounts of energy-rich materials they are able to incorporate into their tissues. Just how might the trapped chemical elements be most efficiently replaced? Recirculation through leaf fall is very much related to temperature. Tests in the Great Smoky Mountains show that fallen leaves decompose only about 35% in the 1st year at 1500 meters (about 5000 feet) but 46% at 300 meters (about 1000 feet). In the tropics recirculation may take only a few weeks or months. Measurements of energy exchange for individual species and stands are very scanty. Whether one species can trap more energy than another or whether uneven-aged stands can trap more energy than even-aged stands is not known, nor are we certain how many times land can be clear-cut and still yield a vigorous new stand of high-quality timber. Forestry is still quite a way from attaining completely scientific cropping.

Although the ultimate aim in cropping forests is the same as with annual crops—profitable return on investment—the business outlook has to be adjusted to long term objectives. It is impossible to see 50 years into the future, which is the time needed in some areas to mature a new tree crop. A logical approach under these circumstances is to cut one-fiftieth of the holdings yearly; after 50 years the 1st parcel would be ready for harvesting again. This is the principle behind **sustained yield** (Fig. 14). It is also possible to manage forest made up of trees of diverse ages on a sustained-yield basis by cutting only a portion of the volume during each cutting cycle. In practice, 100% sustained yield may be difficult to achieve in any but the largest holdings, although it is a practicable ideal to strive for in temperate forest, in which there are essentially solid stands of one or a few species. In the tropics, where there is a tremendous diversity of species, ecological complications are more likely to occur. For one thing, tropical forests do not lend themselves to clear-cutting. Rather, selective cutting is necessary—one tree here, another there—in order to procure a uniform product for economical processing, handling, and marketing. However, in some tropical forests, notably in the lower Amazon valley, attention is now be-

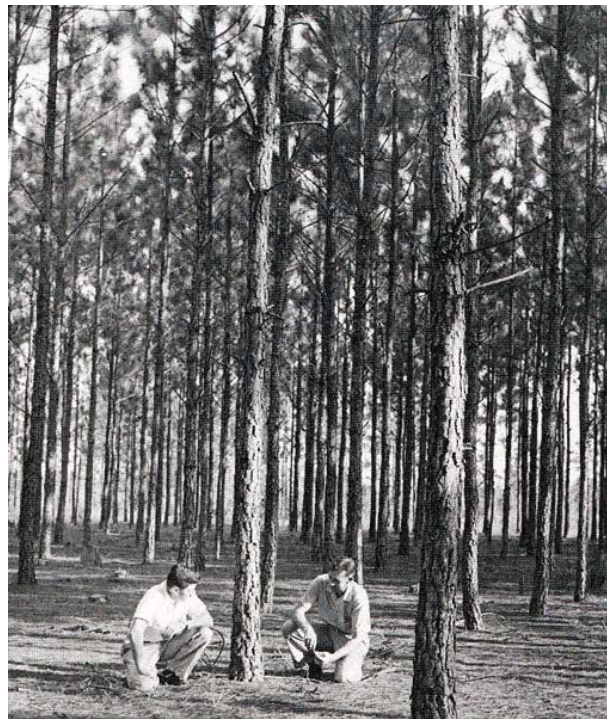


Fig. 14. A carefully managed pine planting, characteristic of sustained-yield operations in the southeastern United States. [Courtesy, U.S. Forest Service.]

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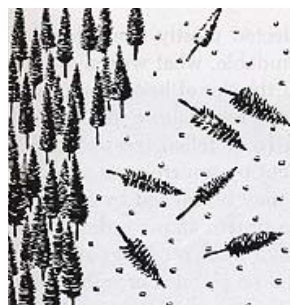
ing directed to harvesting all tree species for paper pulp.

In many temperate forests, clear-cutting of timber over extensive areas has given way to sequential harvesting in smaller blocks. This practice leaves adjacent stands of seed trees, which under favorable circumstances will recolonize, the cut area within a few years (Fig. 15). The size and treatment for cleared blocks vary with local conditions; whether woodland should be clear-cut or selectively cut involves such considerations as whether regenerating seedlings demand full sunlight or are of a type that prosper under partial shade, and whether slope is such as to cause significant soil erosion when all plant cover is removed. In areas where insufficient seed trees persist or are of types that do not recolonize naturally, replanting of the forest is necessary. The

Block Cutting



Trees like the Douglas-fir need full sunlight for proper growth. Also, their seeds are carried a good distance by the wind.



For these reasons the accepted way of harvesting Douglas-fir is to cut all marketable trees in a block of 100 acres or less. Ample standing timber is left between blocks.



Seeds blow in from the surrounding forest and new trees appear. The new stand is thinned periodically to provide growing space and to remove undesirable trees.



In about 40 years the 1st cut-over block is mature enough to provide seed for the neighboring block. After a few more decades the 1st block can be harvested again.

Seed-Tree Cutting



Southern pines also need sunlight, and their seeds are carried by the wind. Isolated trees are relatively windfirm.



It is therefore possible to remove all trees from a large area except for 4 or 5 per acre, which act as seed trees. These remain until the new seedlings are established.



When the seedlings have grown enough so that they are reasonably safe from fire—5 to 10 years—the seed trees can be removed in their turn.



After about 20 years the new stand of pine should be thinned to prevent crowding. Under favorable conditions the pines can be harvested 30 years after original cutting.

Fig. 15. Harvesting systems in forest management. [After St. Regis Paper Co.]

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courts in 1974–1975 in the “Monongahela decision,” ruled that a long-disregarded law, the Organic Act of 1897, compels selective harvests (bans clear-cutting) in the national forests of Appalachia. This was a question of considerable contention during the mid-1970s until a compromise bill was worked out and passed by Congress as the National Forest Act of 1976. The new law did provide for some management as even-aged stands, but in general tended to preserve the conservation thrust of the 1897 Organic Act.

Various degrees of success have been obtained in reforestation. Where huge areas have been devastated, such as in the Tillamook burn of Oregon in 1933, the least advantageous sites have regenerated poorly even after a period of more than 40 years. Neither direct seeding nor planting has been very successful in many parts of the burn, perhaps because soils exposed by the forest fire have been altered and eroded, and perhaps for other ecological causes.

Replanting cut-over forest is now commonplace, and in the future this practice will largely replace the hit-or-miss and time-consuming practice of natural regeneration. Tree cropping takes advantage of mechanization, too, although not to the same extent as in field cropping. Some seed is scattered by airplane and by helicopter, usually at the rate of about 0.5 kilogram per hectare (nearly 0.5 pound per acre) for Douglas-fir in the Northwest. Mechanically pulled devices are used for planting nursery seedlings on fairly level land with few rocks. In rough, rocky country, hand planting is still necessary, although expensive. Seedlings of Douglas-fir can be grown in the nursery for a penny or two each, but hand planting them in forest sites may cost as much as \$400 per hectare (more than \$160 per acre), quite a sizable investment.

Tree seed is still collected mostly from the wild. The difficulties are formidable, what with most pine and fir cones growing at the tips of branches 15 to 75 meters (about 50 to 250 feet) above the ground. Much seed is gathered from felled trees after logging. Sometimes cones cut by squirrels are appropriated; a bushel or more may be cached by a squirrel in one hideaway. Such a system allows little directed genetic selection (although weak seedlings are eliminated in the nursery) and no planned cross-breeding. Tree-breeding possibilities should be tremendous once suitable techniques are more widely developed.

The tree-seed industry is just beginning to come into its own. Cones of coniferous trees are oven-dried and tumbled to free the seed. A temperature of about 49°C (120°F) is best for some pines, whereas 32°C (90°F) is better for fir. Seed is dewinged by brushing or friction, and the residues are blown away. It is typically stored at subfreezing temperatures. At these low temperatures viability is retained for 5 to 10 years.

Most tree seeds must be cold-stratified for good germination. Seed planted into the nursery in autumn is cold-stratified naturally by winter weather. Seed for spring planting is typically soaked in water for most of a day and then held at temperatures slightly above freezing for a number of weeks. It will then germinate in 7 to 10 days. Nursery seedlings are tended in much the same way as orchard trees; they are watered, fertilized, weeded, and usually cultivated for 1 to 4 years (Fig. 16). In the southern United



Fig. 16. Slash pine seedbeds in Georgia. This nursery grows about 30 million seedlings per year. Increased selection of germ plasm has a tremendous impact upon eventual production. [Courtesy U.S. Forest Service.]

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States seedlings are sufficiently mature for field planting in 1 year.

Of course, direct seeding is much simpler and more economical than nursery operations. It is likely too, that the root system of a seedling sprouting in place is more adequate than one that has been transplanted once or twice. Direct seeding is generally the only practicable means of replanting large and inaccessible areas; it is also the only means of replanting species that do not transplant well, such as longleaf pine. The comparatively heavy seeds of hardwoods are often more successfully seeded directly than are those of softwoods (conifers). Potential loss is great with direct seeding. Birds and small mammals may eat the seed, and weeds may smother the seedling. Rodents are sometimes poisoned with treated grain prior to seeding. Where terrain permits the use of tillage equipment, seed is liable to be buried. Coatings are applied to the seed (pelleted seed) to repel animals, insects, and birds.

A helicopter or aircraft can seed as much as 1200 hectares (nearly 3000 acres) in a single day. Broadcast seeding from the ground, with hand or tractor-mounted seeders, is tedious but generally more precise and quite satisfactory for small tracts. Seeding from air or ground is more effective if the soil has been mechanically prepared beforehand to the extent that the terrain allows. Mechanized row drilling is even possible on favorable sites.

Large forest-products companies, today accounting for most of the pulp and lumber produced in the United States, are as elaborately organized as are the gigantic field-crop farms discussed earlier. Virtually all of the large lumber and plywood producers now use computers for linear programming in operations analysis to streamline their planning, production, and sales. Lumber itself may be graded electronically. Raw materials—logs—are thus more efficiently turned into wood products. Logs are no longer inexpensive; they must be fully utilized for profitable operations. The trend is to use all types of timber cut, and programming can indicate quickly whether a certain log of a certain type at a certain time should be used for lumber or plywood. Operations research may suggest that lower-grade logs are satisfactory for plywood sheeting, thus freeing higher-grade logs for premium sale for other uses; or that spruce can be substituted for white fir in interior plys, thus saving costs (largely because spruce has a shorter drying time than fir and because its use relieves a bottle neck at the kiln and speeds the product to market). Or it may take into account glue-spreading capacity and market demand to determine whether plywood should be 3-ply or 5-ply. Computerized predictions can be made for markets months and years ahead, to better adjust product mix to needs. One of these days, no doubt, the processing of forest products will be scientifically controlled from raw material to finished product, as in the processing of farm products. The small, inefficient forestry operation is already as obsolete as the small, inefficient farm.

MODERN CROPPING INNOVATIONS

Mechanization

Mechanization has brought significant new opportunities to plant cropping, especially for seeded crops in temperate climates. Mechanical harvesting is now widespread, and is employed not only for grains but for tree and bush fruits, root crops, leafy vegetables and even crops as perishable as ripe tomatoes. The efficiency in terms of human labor that mechanization brings is nowhere more evident than in North America, where today 1 farmer produces sufficient food for about 56 non-farming people—a situation in striking contrast to the nearly universal participation in farming found in primitive societies (and in the United States during the colonial period). Mechanization, the biological engineering that provides tailor-made cultivars, and all of the accouterments for crop

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care have not only had a quantitative effect but have on the whole improved quality as well.

The trend of industrialized societies is to use more capital and less labor. The pressure of labor costs encourages extensive and often rapid mechanization. Since it often proves impossible to hire efficient hand labor in the United States at any wage, much less low wages, it is no wonder that in 2 years the picking of canning tomatoes in California changed from 100% hand picking to 85% mechanized picking. Even though a picking machine may cost upwards of \$20,000 with its accessories, it still pays for itself in a reasonably short time.

The increase in number of certain farm machines in the 2 decades between 1940 and 1960 was phenomenal. There are now nearly a million corn-picking units in operation, most of them put into use since World War II. Sprinkler irrigation has risen 50 fold in the same interval, with only about 40,000 hectares (about 100,000 acres) irrigated in 1945 compared with more than 2 million hectares (more than 5 million acres) in 1965. Twelve million horses and mules gave way to 5 million tractors within 1 generation in the United States, and the trend is for tractors to get ever bigger and more powerful. Some units are essentially a self-propelled chassis with power take-offs to which special attachments are hitched for a wide variety of operations. There are cultivators that barely scuff the topsoil, others that chisel deep into the subsoil; rotary hoes that chop weeds, and tractors that pull up to a dozen plows; spray machines that arch over tall crops, and others that carry spray booms 30 meters wide.

Harvesting machines are able to determine the readiness of head lettuce for picking, to cut asparagus under photoelectric control, to shake tree fruit onto cushioned catchers, to vacuum-sweep pecan and tung fruits from the ground, to dig potatoes and sort the tubers while traveling at speeds of more than 3 kilometers per hour, to collect pineapples on conveyers that are many meters wide, and so on. A multitude of devices for separation, cleaning, and sorting of agricultural products minimize the drudgery of yesteryear. Many crops are prepared for harvest with chemical sprays to control ripeness and abscission. Indeed, it seems that some piece of equipment has been invented or adapted for almost every once-laborious agricultural operation. The situation is nicely summarized in Fig. 17.

The effects wrought by this mechanical revolution are truly astounding. The greater output per hour of human labor was accomplished by substituting tractors for horses and by putting into use about a million each of pickup balers, corn picker-shellers, and grain combines (Fig. 18). Cotton is now picked mechanically throughout most of the cotton belt. Airplanes are used to sow rice and to spread pesticides. There are mechanical tobacco harvesters, motors to lift hay and move grain. Machines limb, top, cut, and handle entire trees. Gadgets shake fruit and nuts from trees, prevent frost, grind and blend feeds, dry grain and hay. There is equipment to place just the right amount of fertilizer in just the right soil location, to spray the exact row width with herbicide, to meter seed exactly 12 rows at a pass. For a long time, metering was accomplished by slotted planter plates that accepted seed of a particular size and shape, thus necessitating uniform seed. Now plateless planters can utilize the more economical seed not standardized for size, and are less likely to crack the seed coats. Furrow openers can work through crop residues left on the soil surface to provide an organic soil mulch, with precise depth control even at a speed of 8 kilometers per hour. No wonder corn yields have risen from about 2.3 metric tons per hectare (about 34 bushels per acre) in 1945 to more than 6.7 metric tons per hectare (on well-run farms), with yields of over 13 metric tons per hectare (about 200 bushels per acre) in sight (Fig. 19). It took about 350 hours of human labor to produce some 7 metric tons of corn in 1800, only 34 hours by 1950, 3.5 hours in 1960, and less than 1 hour in 1966. Tobacco yields have doubled since 1945, wheat

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yields gone up 80%, and soybeans 30%. Today's agribusiness uses capital and brains to increase production and profit.

Such a degree of mechanization is possible only under a fortunate combination of industrial capacity, capital, and technical knowledge. It could hardly be operative today in much of Latin America, Africa, or the heavily populated parts of the Orient (where human labor is often much less expensive than machines). It is ironic that acceptance of agricultural innovation is greatest and fastest where agriculture is already profitable and progressive. It is most adaptable to large farms in sophisticated societies. Even within the United States it is more easily adapted to the prosperous farms of Iowa than to the hills of Appalachia (for a variety of reasons). The fruits of mechanization have been little enjoyed in most tropical countries, except to a small degree where plantation agriculture is practiced. Even today much of the world's crop land is tediously scratched by oxen pulling a forked log as a plow. But, as was noted early in this chapter, this may be the wave of the future what with high energy costs and petroleum shortages!

Agribusiness—the new system

In agriculturally advanced parts of the world, such as Japan, the United States, Canada, and parts of Europe, the simple farmer of yesteryear is fast becoming a manager of crop production, drawing upon chemistry, biology, engineering, economics, and many other disciplines. The modern farmer runs a rural "factory" producing proteins, fats, and carbohydrates. The modern farmer's goal is the same as that of any person in business—to maximize return. Thus in these parts of the world the trend in farm operations will be toward a high-yield system, drawing upon many technical resources. If soybeans are planted, they will be a select variety, for which a special fertilizer is compounded in keeping with

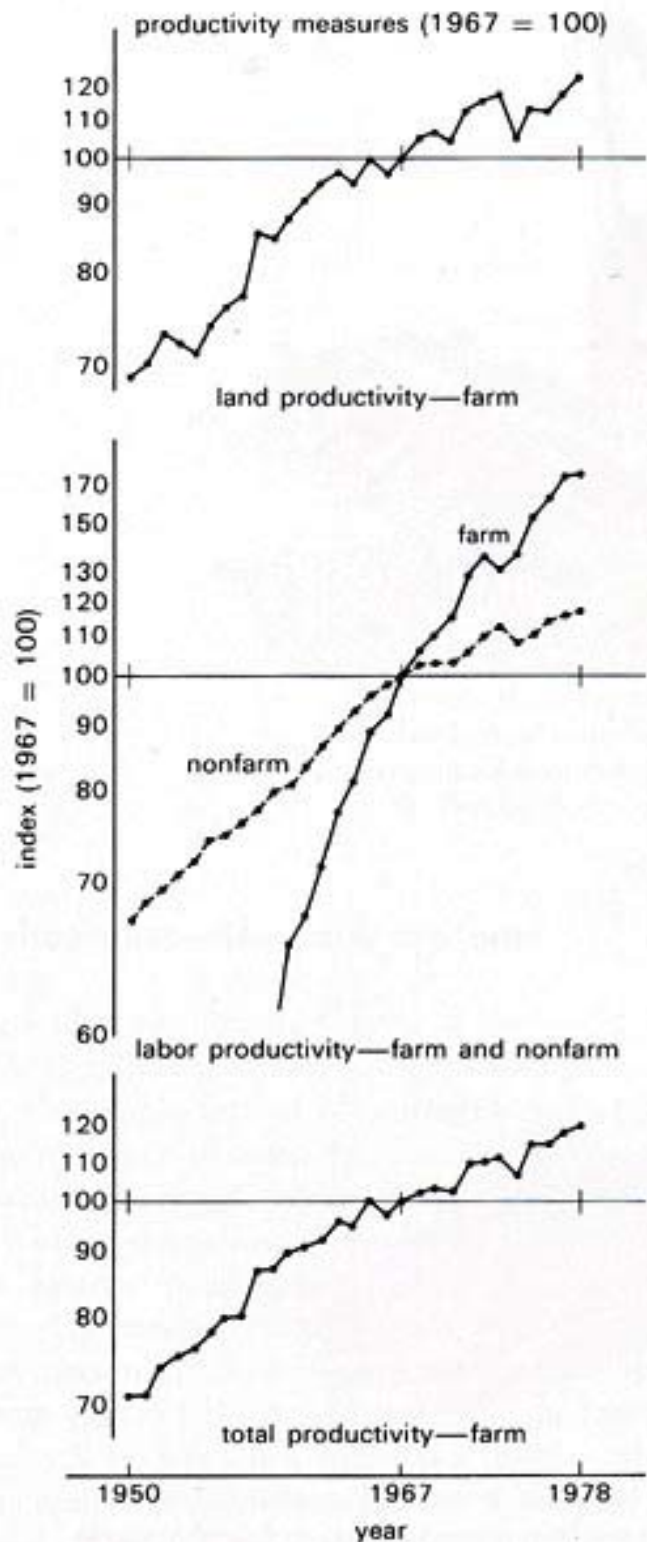


Fig. 17. Increases in the ability to produce in the United States during the last 3 decades have been achieved by fewer farm workers and more equipment. (Value for 1967 = 100.)

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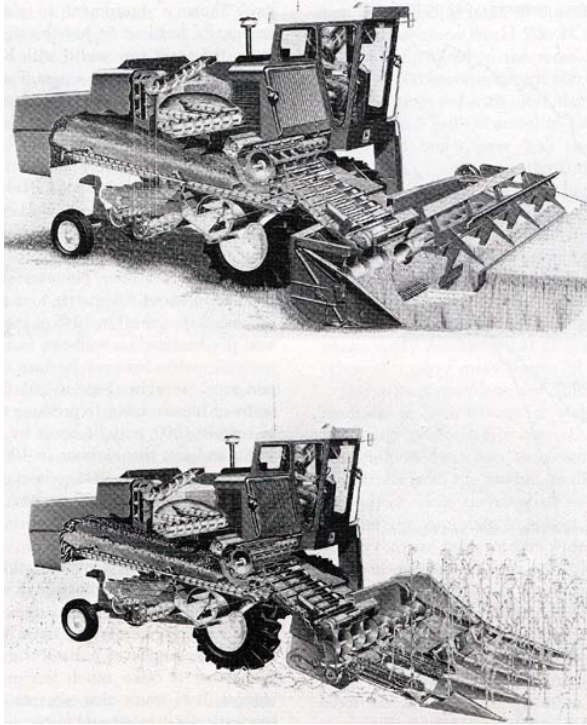


Fig. 18. Mechanized grain harvesting: The invention of the combine, a unitized mechanism for harvesting grain and freeing it of chaff and detritus, has had a tremendous impact on agriculture. A single machine substitutes for hand cutting, shocking, flailing (threshing), winnowing, and associated procedures of primitive agriculture. (top) In the self propelled wheat combine an adjustable reel holds grain bearing stalks against the basal cutter bar; the auger guides cut stems to a central beater and eventually to the rasp bar cylinder that rotates within the open grate concave (just above the front wheels). 90% of the grain separation occurs at the concave; the grain is abraded free from the seed head by the cylinder, and falls through open slots in the concave to conveyor belts below. Additional mechanisms in the upper rear part of the combine further agitate stems and chaff to retrieve remaining grain, the spent straw being issued from the rear of the machine. Screening mechanisms in the lower rear part

of the machine clean the grain further by siftings and air blasts before it is elevated to the grain tank (behind the operator). The clean grain can be unloaded through the unloading auger (behind the operator) directly into trucks drawn alongside the combine. (bottom) The corn combine, similar in principle, has a gathering mechanism designed to accommodate rows of corn. Ears are freed from stems by a snap bar mechanism (instead of cutting the whole stalk). The rasp bar cylinder and concave are designed to shell the corn from the cob. Grain is retrieved and cleaned as in the wheat combine. [Courtesy John Deere Co.]

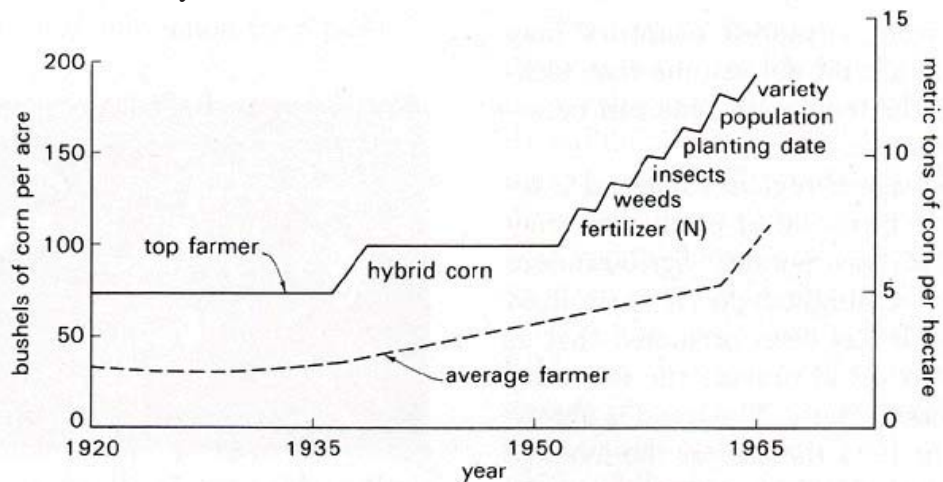


Fig. 19. Corn-yield trends in Illinois. By successively incorporating improved cultural practices in their cropping system, the most productive farmers achieve dramatic increases in yield in relatively short periods of time. They can be expected to adopt any technological improvement coming to their attention if it provides even small economic return or increased efficiency. [Courtesy J.W. Pendelton.]

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local soil needs (as determined by test). Pre-emergence weed control will be provided. Planting machinery will adjust spacing and row width for maximum utilization of sunlight. Chemical growth regulators may even control shape of the plants, prevent lodging, and defoliate plants before harvest. Irrigation will probably be used, perhaps automatically applied as soil moisture reaches a predetermined critical level. Pesticides will be accurately and efficiently applied at exactly the correct season (before diseases or insects get out of hand). All of these activities may very well have to be programmed by specialists who never work in the fields.

Specialized services make such systems click. Much of American agriculture is already beyond general servicing by a county agent, trying to cover all facets with demonstrations, tours, and bulletins. Experts in many fields are needed, operating as a team. Diverse inputs are demanded that must be correct, timely, and sophisticated. The system is concerned with the whole sequence of steps dealing with the organism from growth to distribution and marketing. The agribusiness manager must be aware of government programs, transportation problems, unionization and financial trends, as well as of new cultivars, cultural techniques, and pest hazards.

The less well-developed parts of the world cannot support such a sophisticated agribusiness, and in heavily populated lands mechanization to relieve labor (as opposed to increasing production) is hardly the answer. What many parts of Africa, Asia, and Latin America need at this stage are simple, practical agricultural techniques developed through local research, not involved investigations or computer controls. Agriculturists from advanced countries may provide guidance, but should not assume that techniques developed for the temperate zone can necessarily be applied elsewhere.

In agriculturally advanced regions the trend is toward fewer but larger farms. Most production may eventually come from incorporated agribusinesses rather than individual holdings too poorly capitalized to operate efficiently. It has been predicted that as few as 500,000 farmers could provide the necessary production for the United States. The trend is unmistakable: from 1954 to 1964 the size of the average farm increased from around 100 hectares (about 250 acres) to 144 hectares (about 356 acres), each farm representing an investment of hundreds of thousands of dollars. The number of farms decreased from 5 million to 3 million, of which 1.5 million provide 90% of the total output. During that decade 1.25 million farmers left the farm, and total farm acreage decreased about 3%; yet crop production increased remarkably. The farmers themselves now work less strenuously and put in fewer hours.

Agribusiness has immense social consequences. For example, migrant workers work seasonally and may be unemployed in the off-season, causing grave social problems. And what of the political consequences, as fewer and fewer votes come from the farm and more and more come from the city? Farm programs will no doubt change, and the interests of the non-farmer will be given greater consideration.

Present techniques and trends

Improvements in efficiency are eagerly sought in agriculturally advanced parts of the world. Amid the plethora of improvements in product and practice, several trends seem to be shaping up.

Minimum tillage is increasingly practiced, its usefulness varying from soil to soil and from crop to crop (Fig. 20). It is a marked departure from the traditional idea that fields are best thoroughly cultivated. Soil is better protected from erosion and is less compacted by machinery. Crop yield is usually equally as good as under conventional cultivation, yet with an economy of operation (at least one plowing or disking is avoided). Equipment now in use can prepare the soil,

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apply the fertilizer, and plant the seed in 1 pass over the field. Extreme examples of minimum tillage involve relatively little soil disturbance of any kind. For example, a sod blanket may be killed chemically, left as a mulch, and a row crop planted in slits cut into the dead sod (the no-till system).

Vegetables and small fruits can sometimes be grown with no postplanting tillage at all. Weeds are controlled entirely by herbicides. Solid plantings of course take much better advantage of space, since cultivating equipment need not pass between rows. With some crops this may facilitate harvesting, and certainly surface feeder roots are not physically disturbed. Furthermore, no buried weed seed is brought to the surface where it can sprout. Feasibility, of course, depends upon local conditions—for example, whether the soil is of a type that allows adequate water infiltration without cultivation. In any event, several root crops, including potatoes, have been grown in Britain without postplanting tillage. Yields of potatoes, parsnips, carrots, gooseberries, broad beans, and Brussels sprouts have all been close to or slightly better than yields where cultivation is practiced. The cost of herbicide treatment must be weighed against the cost of cultivation for a particular area.

Another trend is toward higher plant populations, to take maximum advantage of sunlight. Increased fertilization and irrigation are needed to accommodate the more densely planted fields. Dense plant populations often shade weeds and protect soil somewhat more adequately from erosion. In some crops nowadays seeds are even being oriented during planting so that leaf position (as in corn, which has leaves in a single plane) is crosswise, not overlapping and partly shading other plants in the row. Dense plantings are being used effectively with cotton, grain sorghum, sugar beets, soybeans, and corn just about as fast as new equipment to fit the narrower rows becomes available. The narrower rows may give an additional 20% yield if fertility and moisture are adequate.

Corn populations denser than 60,000 plants per hectare (about 24,000 plants per acre) are generally impractical; excessive crowding can cause lodging and undeveloped ears. Simple arithmetic shows that more symmetrical spacing is had with more closely spaced rows. On traditional 40 inch rows (the old standard, devised to accommodate the mule), the distance between seeds in the row must be about 15 to 18 centimeters (6 to 7 inches) to achieve a population of nearly 60,000 plants per hectare. But a 75 centimeter (30-inch) row allows about 20 to 23 centimeters (8 to 9 inches) between plants, with less crowding in the direction of the row. Perhaps even larger yields would be

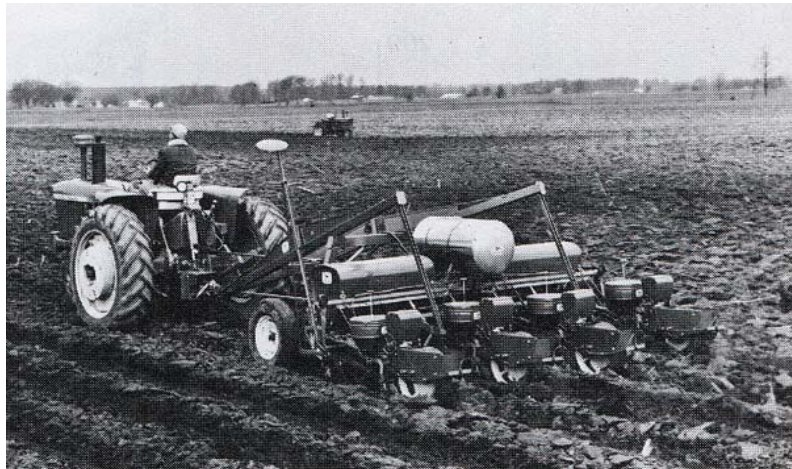


Fig. 20. “Minimum tillage” implies reduced soil cultivation and separate planting operations. Here wheeltrack planting creates two distinct soil zones, the row zone and the interrow zone. The row zone is smooth and firm, providing good soil to seed contact for fast germination. The interrow zone is left rough to catch and absorb rain faster and to reduce germination of weed seeds. The planting machine shown here is equipped with attachments for the application of dry fertilizer, insecticides, and liquid herbicides. [Courtesy John Deere Co.]

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obtained if approximately 40 centimeters (about 16 inches) were allowed between rows and plants, which would be possible if herbicides were made to substitute for cultivation.

Where cropland is abundant, and high yield with fewer plants is more important than yield per hectare, such as those areas in which planting limitations are in force, plant yield can often be increased by skip-row planting. A row or two of crop is sowed, then a row or two left fallow. The plants then receive light from the sides as well as from above, resulting in more photosynthesis and higher yields per plant. Even greater growth can sometimes be stimulated by placing reflecting boards in the vacant rows, which, like mirrors, direct more sunlight to the sides and bases of the plants.

There is increasing interest in **field processing** of many crops to avoid unnecessary haulage and storing. Preliminary treatment of hay crops in the field (“conditioning,” a partial chopping to facilitate drying) is increasingly practiced, as is automatic heat-drying of forage (often as mechanically formed pellets) before storage and marketing. Combines clean up grain in the field, casting straw and other residues back on the land. Corn is increasingly shelled in the field, too. Inexpensive procedures for oxygen-free storage of silage are being developed, as are simplified feed-lot operations.

The following are a few examples of present trends in the production of various crops.

Hay and forage

Field pelleting or wafering of hay and forages is increasing as more dependable and economical machinery becomes available. It is common in dry climates, as in the alfalfa fields of central California. Field conditioning of hay before baling is widespread everywhere. Improvements have been made too in mechanized bale handling and in gathering green chop (see Box 2).

Corn

The trend toward denser plant populations in corn production has already been mentioned. The distance between rows is increasingly being reduced from the conventional 40 inches (1 meter), and corn is increasingly being harvested with a 4-row corn-head on a combine, which can handle 350 liters (about 10 bushels) per minute. Field shelling is well accepted, now that drying systems and high-moisture storage facilities are more available.

Cotton

In cotton production, narrower rows and planting to assure an even stand without thinning are on the increase. Herbicidal weed control, chemical defoliation prior to picking, and machine harvesting are standard today in efficient cotton farming. Hybrid cotton is under development.

Vegetables

Typically, root crops such as beets and leaf crops such as lettuce are densely planted in rows and then thinned. Not only is machinery now available for automatic thinning, but techniques are being rapidly developed for properly metering seed during planting so that thinning is not necessary. Plastic or resinous mulches are often used to assure a better stand. Systems for mechanical harvesting are used in practically all vegetable crops.

In tomato fields it is now possible to fumigate the soil (with ethylene dibromide) and prefer-tilize with anhydrous ammonia at the same time. Raised beds are formed and planted, and a pre-emergence herbicide and starter fertilizer are drilled in by the same machine. Seeding is metered

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for a plant population as high as 124,000 plants per hectare (about 50,000 plants per acre). During growth, insecticide and fungicide sprays control insects, mites, and disease. A mechanical harvester cuts spreading tomato vines at root level, lifts them, and shakes the tomatoes into a bin. The old vine is discarded, while a small crew sorts out green tomatoes and tosses them back onto the field. The harvested fruit is handled in bulk for dispatch to processing facilities.

To some extent, high-value greenhouse crops are being fertilized with carbon dioxide, which

Box 2—Planning High TDN Yields for Livestock

The TDN (total digestible nutrients) available to livestock from feed and forage is the key to profitable animal husbandry in technically advanced lands. A high TDN yield is best gained from select cultivars, of course. Yet there are options, and systems must be chosen in view of such local conditions as moisture availability, length of growing season, soil type, slope, and so on. On good land that has been progressively cropped, 11 metric tons of TDN per hectare (about 5 tons of TDN per acre) can be obtained either from 56 metric tons of corn silage, 15 metric tons of corn, or 22 metric tons of alfalfa hay. Which route is best? Or if a meadow can be harvested for silage instead of for hay, to yield an additional 25% of TDN, does the added expense justify this choice?

On poorer lands, especially on slopes unsuited to cultivation, yields may amount to only a bit more than 3 metric tons of TDN per hectare (about 1.5 tons per acre). This type of land may be most efficiently exploited by letting livestock graze rather than by trying to produce the 18 metric tons of silage or 4.5 metric tons of grain needed to match this TDN yield. Cost of inputs (fertilizer and capitalization of technology) for high yields on poor land may be so great that intensive cropping may not be the most efficient use! Urging a highly responsive forage such as alfalfa (each metric ton of which removes about 50 kilograms of lime, 6 kilograms of phosphate, and 22 kilograms of potash from the soil) to maximum production on poor soil might require doubling of inputs for an increase of only 50% in output! Adding grass to alfalfa may reduce TDN yields, but may still be the wisest course for protection of soil on slopes.

Obviously, management is a vital factor. Proper timing of fertilization is important, not only to provide maximum yields when needed, but to control the botanical composition of the pasture. Choice of cultivar is significant. For example, white clover may prove to be better on a shallow soil (if moisture is not limiting) than deeper-rooted alfalfa or red clover, which are ordinarily more productive. Where moisture is insufficient for maximum corn yields, sorghum may be preferable, or, on stony hills perhaps tall fescue forage. In the southern United States, Coastal bermudagrass, which provides a high TDN yield on good soil, would be inferior to bahiagrass on poor land.

Maximum advantage is not taken of TDN opportunities if a pasture is undergrazed. Yet rotational grazing to allow recovery from overgrazing can increase TDN yields by 50%. If corn is harvested in the milk stage it may yield only two thirds as much energy as silage feed made from the same corn allowed to mature to the dent stage. Yet, delaying alfalfa harvest can impair nutritive quality so much that 50% additional feed grain may be required for equivalent animal weight gain. But too early (or too frequent) cutting of alfalfa can hurt the stand and increase the weeds!

Obviously, managing modern forage production intelligently requires no little technical knowledge. Profitable farming is not for the untrained.

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is vital for photosynthesis but is sometimes limiting to plant growth because it is in scant supply (only 0.07% or less is present in the air), as well as with optimal amounts of mineral nutrients.

CONCLUSION

Cropping systems vary with crop, time and location, and level of technology. They have evolved with the development of human society. This development can be considered to have proceeded in 3 stages. The 1st, the most primitive, consisted in **gathering from the wild**. This was the basis of pre-agricultural societies, and it is still practiced in many primitive parts of the world. Many of the plant products used in advanced countries are still gathered from the wild: chicle, Brazil nuts, blueberries, gum arabic, and occasionally rubber. The next stage, the **management of natural stands**, was the basis of early orcharding. Much of the world's forest and range land is still handled in this manner, as is the herding of livestock on open range. Finally, the most advanced stage, **cultivation**, involves management of the plant throughout its life cycle. It usually depends on the introduction of exotic species and complex techniques of soil manipulation, environmental control, and alteration of plant growth processes. The intensity of management varies greatly. The scale of operation ranges from extensive outdoor farming to concentrated cropping in small gardenlike areas. It extends to the artificial environments found in greenhouse production, and to the synthetic factory systems of the pharmaceutical and fermentation industries.

Box 3—Overtones to Advanced Agriculture

Cropping systems, in all of their manifestations, are profoundly disturbing to natural ecosystems—to habitats as they were before they were occupied by people. Some of the consequences of “progress” to human ecology are seldom taken into account. Involved overall is the ethical question of human concern for humankind. When the Third World proclaims its right to unlimited population increase (as it did at the Bucharest conference) and in the next breath accuses “developed” countries of irresponsibility should the masses not be adequately fed, confrontation is unavoidable. We are faced with the age old ethical dilemma of whether short term evil (inadequate sustenance) leading to long term good (population in balance) is justified, or whether short term good (assistance programs) leading to long term evil (mass misery) is preferable.

As the United States Congress debated the bill entitled The Self Reliant Development and International Food Assistance Reform Act of 1979, here's how New Directions (a nonprofit organization devoted to leadership in pressing world affairs), one of the instigators of the bill, sized up the situation. New Directions felt that the dependency of many poor nations obstructs their economic progress. “This is particularly true in the area of food. Our massive food aid program is growing every year, while agriculture in the Third World stagnates. American food dumped on Third World markets depresses the prices of local agricultural products to the point where many stop farming. At the same time, the increased demand for our farm products helps to drive up food prices for Americans” (New Directions, vol. 1, no. 2, April 1979).

G.K. Myrdal, in reviewing development projects undertaken in various parts of the world, had this to say about not taking human carrying capacity into consideration: “But seldom is provision made to hold populations at the new levels that land can support. In consequence, the land deteriorates, deserts spread or become barren, and a greater number of people end up worse off than they were before development of the area took place. One can question whether international development agencies should continue to play this losing game.”

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Outdoor cultivation systems usually start with some degree of land and soil preparation. In areas new to agriculture this may entail land clearing, adjusting land slope to prevent erosion and washouts, and the creation of irrigation and drainage systems. It usually entails adding soil amendments (such as lime and fertilizer) and making various physical changes in the soil to create conditions favorable to tender seedlings.

The procedures used to increase yield comprise a wide spectrum of processes to modify the plant environment and to control plant growth processes. Growth control can be achieved by such ancient techniques as training and pruning, grafting, and breeding, or by such modern methods as the application of growth-regulating materials. Regulation of plant physiology is limited only by the extent of our understanding of growth and development—the more complete our knowledge, the more sophisticated the control. It becomes possible to affect not only growth itself but such developmental processes as flowering and fruiting. Advances in this area have been a by-product of basic physiological studies. The field was given great impetus with the discovery of substances that are toxic to plants in very small amounts—the modern herbicides. A number of materials are known that dwarf plants, set or remove fruit, and induce rooting and flowering; many are routinely used in intensive horticultural operations. It is very likely that future changes in cropping patterns will involve chemical manipulation of plant growth processes, which may well usher in revolutionary methods of crop production.

Cropping practices also extend to market preparation of the plant product and to storage and distribution. The path of agricultural products from the growing plant to the ultimate user is complex. **Marketing**, the activities that direct the flow of goods from producer to consumer, often becomes an integral part of cropping systems.

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