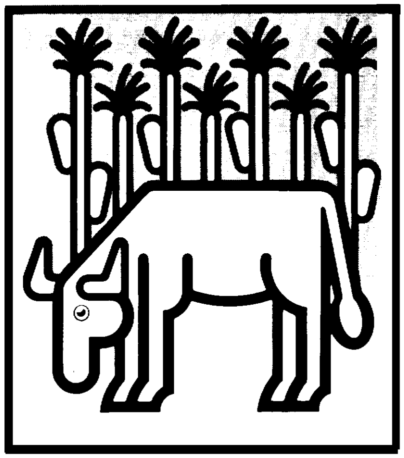

Technologies Affecting Water-Use Efficiency of Plants and Animals

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Chapter IX

Technologies Affecting Water-Use Efficiency of Plants and Animals

In the past, agricultural scientists and producers in the United States often chose agricultural technologies for their contribution to high productivity. Essentially, these practices made the natural environment less hostile for plants and animals, a change from depending on native organisms that were closely adapted to sometimes harsh conditions. Today, as natural resources become more limited and economic costs increase, biological technologies that use existing natural resources more efficiently are needed. In the arid and semiarid areas of the West, these practices would be water-sparing and would use the special features of the region.

This chapter focuses on technologies that "stretch" the amount of plant or animal produced per unit of water used. As such, these technologies are well-suited to the arid/semiarid region. The emphasis here is on working within the natural limits of arid and semiarid lands with sophisticated technologies to provide an array of opportunities for sustainable agriculture.

Regardless of the quantity of water available for irrigation agriculture, it is likely that these technologies will figure more prominently in the region's future. If the amount of water available for Western irrigation is maintained, these technologies can add diversity to agricultural production in the region. If, however, expectations of less irrigation water are realized, these technologies may be vital in easing the transition to more suitable production systems. In dryland and rangeland agriculture, where production is usually limited by water, these practices can help sustain some current styles of production.

THE WATER SETTING

Water—the principal ingredient in living tissue—plays a vital role in biochemical reactions, maintains cell rigidity, moves materials within plants and animals, and helps to heat and cool them. Water continuously flows through most organisms and a certain quantity is an absolute necessity. When plants open pores (stomata) in their leaves to take in carbon dioxide for photosynthesis, water is lost by transpiration, a process significant because it is both essential and considerable. Desert plants may consume 100 times their weight in water each day even though they physiologically require only about 10 percent of that amount. While some plants are able to slow transpiration, it cannot be stopped completely without also stopping all plant growth.

Because of the large amounts of water they use, plants are a major component of the hydrologic cycle, and technologies have been developed to make hydrologic changes by modifying vegetation (see chs. VI, VII, and XI). Because animals use much smaller amounts of water they are not usual l}' considered to be part of the hydrologic cycle. Both animals and plants, however, are vital to agriculture, In arid and semiarid lands, where water often determines survival and production, the efficiency with which organisms use water has important implications for sustaining all types of agriculture.

plants have evolved a number of different ways of coping with water shortages. They may almost totally escape drought by germinating, growing, and reproducing before water becomes limited or only after a heavy rainfall. They may "resist" drought with special anatomical and physiological mechanisms to take up, store, and retain water. Or they may "tolerate" drought with mechanisms to limit the destructiveness of internal water deficits.

The relationship between plant growth and water stress is complex. A number of different drought-resisting mechanisms may come into play during a plant's life, and its sensitivity to water stress may vary with each. The different mechanisms may involve disadvantages as well as advantages. For example, a crop variety with a short growing season may mature before drought occurs, but in rainy years its yields are likely to be less than that of a long-season variety. This complexity has slowed the development of drought-resistant agricultural plants.

Animals exhibit a similar range of adaptations to limited water supplies. Some, such as kangaroo rats, may never drink water, obtaining moisture instead from their diet or even from dew, and excreting little water.

In order to be meaningful, comparisons of these and other differences in water use must include both the amount of crop, forage, or animal produced and the amount of water used. The concept of water-use efficiency (WUE) allows this comparison. As a general measure of efficiency, this term applies equally well to plants and animals, but it is seldom applied to animals because their relative water use is small.

Plant Water-Use Efficiency

For plants, biological WUE is defined as the total dry weight of plant material produced per total water lost by transpiration. Agronomists often use a different definition of WUE known as "agronomic WUE, " which is the amount of harvestable or economic biomass produced per water lost by transpiration and evaporation. These two definitions allow distinctions to be made between inherent biological processes and the processes and conditions that apply to plants grown as crops (19).

Instantaneous measures of WUE are not meaningful, since plants constantly adjust water use to changing environmental conditions, Over the entire season, however, biological WUE is relatively constant for a given species. Variations are common among species (table 57); these differences relate to time of year that plants grow, evolutionary history, and plant physiology. For example, grasses as a group tend to use water more efficiently than shrubs (27). But individual species of drought-adapted shrubs may use water more efficiently than some grass species.

Attempts to increase WUE by altering either photosynthesis or transpiration have usually failed, For instance, antitranspirants, chemicals that reduce transpiration, have been investigated extensively but have not been widely used (14). While they can decrease transpiration effectively, they do not increase WUE because they also reduce photosynthesis and thus plant growth. There may be site-specific circumstances in which this is not a disadvantage, such as in the control of plants along streams.

Table 57.—Comparison of the Total Amount of Biomass Produced per Total Amount of Water Used in Transpiration for Crop Plants

Biological water-use efficiency has been divided by potential evapotranspiration in order to correct for climatic differences.

Crop	Biological water-use efficiency with climatic correction (kg/ha/da) [a]	Photosynthetic type
Alfalfa . . .	63, 90	C_3
Oats .	90	C_3
Soybean .	102	C_3
Potato . . .	106	C_3
Barley . .	106	C_3
Wheat .	112	C_3
Corn	151,213	C_4
Sorghum	200,240	C_4
Millet. . . .	198,260	C_4

[a]KIlograms/hectare/day

SOURCE Wayne R Jordan, Ronald J Newton, and D W Rains, "Biological Water Use Efficiency in Dryiand Agriculture," OTA commissioned Paper, 1982), table 1A, Original sources" L. J Briggs and H. L Shantz, "The Water Requirement of Plants II A Review of the Literature, " U S. Department of Agriculture, Bureau of Plant Industry Bulletin 285, 1913, C B Tanner, and T. R Sinclair, "Efficient Water Use in Crop Production, H M Taylor, W R. Jordan, and T R Sinclair (eds) (Madison, Wis.' American Society of Agronomy, 1983), H L. Shantz and L. N. Piemeisel, "The Water Requirement of Plants at Akron, Colorado," *Journal of Agricultural Research* 34:1093-1190, 1927, R. J Hanks, "Yield and Water Use Relationships An Overview, " ***Limitations to*** Efficient Water Use in *Crop Production,* H M. Taylor, W R. Jordan, and T R Sinclair (eds.) (Madison, Wis. American Society of Agronomy, 1983) water-use improvements in the past have often resulted from increases in agronomic WUE because of the flexibility plants show in allocating resources into different plant parts. For example, tepary beans respond to overirrigation by producing leaves instead of seeds. While biological WUE remains unaffected, agronomic WUE is decreased. Since beans are the desired product, a knowledge of agronomic WUE is more important to crop management and breeding. Also, crops can be managed to minimize soil evaporation or to change crop maturity to shift yields to before or after drought occurs. Both changes can increase agronomic WUE.

Animal Water Use

Significant differences exist in the amount of water required by different livestock and wildlife species (table 58). Some animals require large amounts of freshwater for drinking. Others require little drinking water, since they can reduce water requirements when it is limited, conserve available water, or acquire most of their needs from food. A list of animals, in order of increasing adaptation to drought would be water buffalo, European cattle, African (zebu) cattle, wool sheep, hair sheep, goats, and camels (28). Water use also will vary depending on the nature of the forage and weather conditions.

Because animals use comparatively little water, there has been little effort to use or breed animals that use less water. Instead, efforts have concentrated on ways to increase the efficiency with which animals convert plant biomass into their own. As long as water use remains unaffected, this process improves animal WUE,

Biological v. economic (agronomic) yield also applies to herds and single animals. Maintenance costs, in terms of water and food, are substantial for many single animals. In some cases breeding populations are maintained from year to year and their requirements must be counted in total water- and forage-use effi-

Box T.—Three Carbons, Four Carbons, and Cam: Plant Physiology and Water Use

Plant biological WUE falls into three broad categories corresponding to differences in photosynthesis: CAM, CA, and CS types. These processes, by which sunlight is converted into organic matter, are different enough to affect many features. CAM, or crassulacean acid metabolism, plants use water most frugally. Stomata open at night when evaporative demand of the air is low but, if water is plentiful, many CAM plants also take up carbon dioxide during the day, and water use increases dramatically. Maximum growth rates of CAM plants such as cacti are low because of very low photosynthetic rates. Pineapple, the only agricultural CAM plant, is more productive than most. A large number of food and forage plants use four-carbon, or C_4, physiology and have intermediate biological WUE—e.g., corn, sorghum, grain amaranth, and many warm-season range grasses. They have high photosynthetic rates and accumulate dry matter quickly. Most of the cereal grains, almost all woody trees, many vegetables, and cool-season range grasses belong to the the three-carbon, or C_3, group. This group has the lowest biological water-use efficiency and also is least effective in retaining the carbon absorbed.

These fundamental physiological differences have not been exploited agronomically yet. Few CAM species are of economic value now, but they may have potential for specific, high-value products. While four-carbon species are efficient water users, they also grow best during hot summers and therefore consume large amounts of water over the total season. These species are generally sensitive to low temperatures, so they cannot be planted earlier or later to reduce summertime water demands. Attempts to breed hybrids with the best features of each type have so far failed.

SOURCES: James R. Ehleringer, "Photosynthesis and Photorespiration Biochemistry, Physiology and Ecological Implications, " *Hortscience* 14(3) .217222. 1979; James R Gilley and Elias Fereres-Casteil, "Efficient Use of Water on the Farm, " OTA commissioned paper, 1982, Wayne R Jordan, Ronald J Newton and D W. Rains, "Biological Water Use Efficiency in Dryland Agriculture, " OTA commissioned paper, 1982

Table 58.—Comparative Water Use Of Animals

Low daily water turnovers reflect a high water-use efficiency. Thus, the animals listed first use the least water

Animal	Body weight (kg)	Daily water turnover (ml/kg$^{0.82}$)	Environment
Antelope:			
oryx . . . . ~ ~ . . ~ . . ~	136	70	African grassland
Wildebeest.	175	137	African grassland
Kongoni	88	116	African grassland
Eland	247	213	African grassland
Goat:			
Somali	40	185	African desert
Camel:			
Somali	520	188	African desert
Sheep:			
Dorper	42	170	African grassland
Merino	38	180	African grassland
Ogaden.	31	197	African desert
Karakul	31	205	African grassland
Cattle:			
Boran	417	224	African grassland
Boran	197	347	African desert

SOURCE L. A Stoddart, A. D Smith, and T W Box, Range *Management (New* York: McGraw-Hill Book Co, 1975), p 318. (Original source Mac Farlane. "Prospects for New Animal Industries: Functions of Mammals in the And Zone, " *Proceedings of the South Australian Water Research Foundation* (Adelaide, S Australia, 1972).)

ciency of the herd. Of the animals slaughtered, only a portion is economic yield. About 50 percent of an animal is used for meat, while byproducts of various kinds account for another 15 to 20 percent. Like plants, animals have been selected for "agronomic" efficiency: faster and greater weight gains in marketable products per total nutrients spent for animal maintenance.

THE TECHNOLOGIES

Methods of Improving Plants and Animals

Biotechnologies

INTRODUCTION

The term "biotechnology" has come to represent a cluster of methods for introducing and reproducing new genetic variation in bacteria, plants, and animals as well as a number of industrial applications of biological processes. In this section, only those technologies are considered that may increase the WUE of agricultural plants. The application of similar technologies to animals is discussed under "Animal Breeding. "

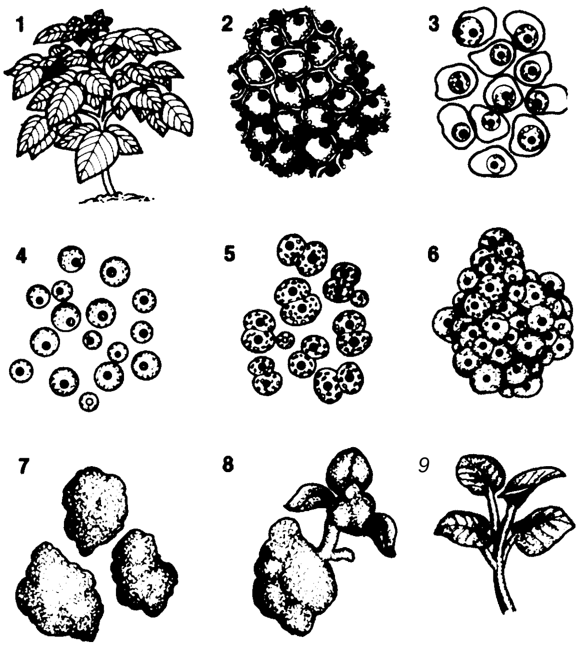
The promising technologies include tissue culture and other techniques for propagating organisms; fusion of plant cells (protoplasts) either within or between species; and precise recombination of DNA, the genetic material (figs. 57 and 58). These methods usually involve intensive laboratory treatment and may be used alone, in conjunction with one another, or with more conventional breeding methods.

ASSESSMENT

The application of various kinds of biotechnology to the specific problems of water use in arid and semiarid lands involves manipulation of the mechanisms that influence the uptake, use, and loss of water by organisms, For example, some experts speculate that the drought tolerance present in some western weeds could be added to unrelated crops. Or perhaps cell lines selected for salt tolerance could produce crops for irrigated areas with salt accumulation.

Figure 57.— Working With Protoplasts

"Clones" of a parent plant can be regenerated from its isolated protoplasts by the methods developed for culturing tissues as shown here. Protoplasm fusion Involves an additional step: protoplasts of two genetically unlike parents would be combined at step 4. The offspring are not like either parent, they often contain unique combinations of genetic material that could not be produced with conventional plant-breeding methods.



Small terminal leaves are first removed from a young potato plant (1). The leaves are placed in a solution containing a combination of enzymes capable of dissolving the cell wall (2). Another substance in the solution causes the protoplasts to withdraw from the cell wall and to become spherical, thereby protecting the living protoplasm during the disintegration of the wall (3). The isolated protoplants are next transferred to a culture medium (4), where they grow, synthesize new cell walls and begin to divide (5). After about 2 weeks of culture each protoplant has given rise to a clump of modifier-estimated cells, called a microcallus (6). The microcalluses are transferred to a second culture medium, where they develop into full-size calluses (7). At this stage the cells of the callus begin to differentiate, forming a primordial shoot (8). The shoot develops into a small plant with roots in a third culture medium and is then planted in soil (9).

SOURCE James F Shepard The Regeneration of Potato Plants From Leaf. Cell Protoplasts, *Scientific American 246156* May 1982

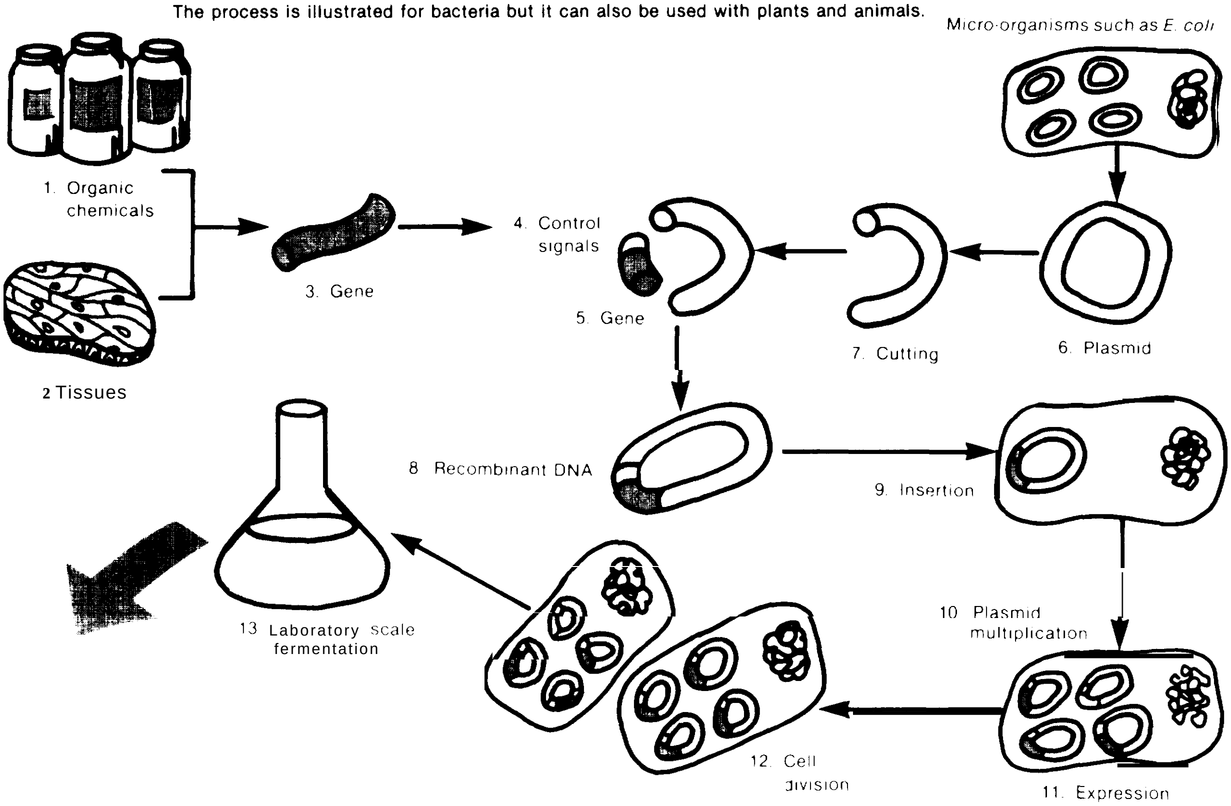
Some of these technologies are rapidly entering agriculture. Tissue culture is already in commercial use and, in the next 10 to 15 years, is likely to make important contributions (23). Other biotechnologies face a potentially long period of basic research before their applications will be available. Protoplasm fusion, like other more complex techniques, cannot be used now with much expectation that the desired results will occur. Recombinant DNA technology holds the most promise for precisely changing plant features, but it is farthest away from wide-scale development. Few practical applications of these technologies are expected within the next decade.

Institutional constraints exist in addition to the technical ones. There is concern, for example, that reliance on laboratory practices might narrow the genetic diversity of present crops to an undesirable degree. On the other hand, some believe that human-induced variation and the germplasm banks that might spring up could actually increase genetic diversity. Other concerns regarding the release of novel and potentially dangerous organisms into the environment have diminished. For example, experience has shown that safeguards are generally adequate to contain potentially troublesome organisms used in industry.

These technologies have already had an important effect on the way agricultural research is conducted. Some private universities and corporations are involved in agriculture for the first time. Few of these leading-research institutions are also involved directly in arid land studies. Furthermore, rapid industrial expansion has created at least a short-term shortage of trained personnel. As scientists and technicians move rapidly into the private sector, universities are concerned that their ability to conduct basic research and to train new teachers will be jeopardized. It is not clear to what extent the large involvement by profitmaking corporations may shape research priorities. If public sector research—e.g., at land grant universities, USDA laboratories, and State agricultural experiment stations—does not keep pace, there may be little progress in the application of new biological technology to problems of social importance that have little foreseeable profit. Also, since new life forms can be patented, there is concern that limited access to the results of private research may further limit public work,

Figure 58.-The Technique of Recombinant DNA Technology

The process is illustrated for bacteria but it can also be used with plants and animals.



SOURCE: U.S. Congress, Office of Technology Assessment, *The Impacts of Applied Genetics* (Washington, D. C.: US Government Printing Office, OTA-HR-132, 1981), p. 6; and Genentech, Inc

No consensus exists on biotechnology's near-term potential in agriculture. While much former skepticism has been allayed, these are capital-intensive enterprises that are capturing large amounts of public research money at a time when funds are limited. Therefore, the fear exists that less glamorous technologies—e.g., new approaches to classical plant breeding—will be overlooked.

Tissue Culture

Tissue culture is basic to the use of the other biotechnologies discussed here and to making the results of such biotechnologies available to agricultural scientists. It is accomplished by several methods (fig 57). In its simplest form, individual sexual cells such as pollen grains and eggs are stored and grown in artificial nutrient media, More complex methods allow identical plants to be developed from pieces of the parent after they receive several hormone treatments. In another type of culture, the initial unspecialized tissue, or callus, developed from a plant cutting is agitated to separate the cells; a new plant then regenerates from each cell. This more productive method can also be used to expose genetic variation among the individual cells of a single parent plant. If environmental stress is applied then to the culture, the survivors can be regenerated. This method may have important applications for problems of water stress.

Many important crop and forage plants can be regenerated from cuttings with these technologies. Strawberries, asparagus, pineapple, coffee, and horticultural plants are mass produced this way. More recently, mass propagation of alfalfa, jojoba, and some grass species

Photo credits: USDA-Agricultural Research Service

Wheat plants growing using tissue culture: white clump (left) are cells forming from live wheat anthers, masses of undifferentiated tissue grow from the cells (center test tube), in a special growing medium (right test tube 'and flask in right photo), a small plant develops from the cultured tissue.

has become possible. The savings in time and space can be substantial. For example, 25 gallons (about 100 liters) of Douglas fir cells in nutrient media can produce enough plants in 3 months to reforest about 120,000 acres of land (12).

When tissue culture techniques are used in conjunction with classical breeding methods, new germplasm can be made available rapidly, and the volume of material accumulated by difficult crosses can be increased quickly. For example, 65 new types of potatoes have been "cloned" from Russet Burbank cells and more than 134 virus-tree potato cultures have been developed.

A number of water-related stresses can be applied to plant-cell cultures, including salinity, drought, flooding, ion toxicities, nutrient deficiencies, and temperature extremes. Cell lines with resistance can be developed from the survivors. Recent experiments suggest that cell selection may provide researchers with material less susceptible to water stress (19). For example, alfalfa and rice cell lines have been obtained that tolerate 2 percent sodium chloride, a salt concentration lethal to nonselected cells, Gene dosage, or the number of duplicate sets of genetic material present within a given organism, can also be altered by treating cultured cells with chemicals. Varieties of rye differing only in gene dosage varied in susceptibility to cold and observations suggest that a similar relationship holds for susceptibility to water stress.

These treatments of plant cultures are recent, so it is difficult to evaluate their eventual im-

"pacts. Sodium chloride tolerance in cell lines, for example, is sometimes unstable and does not occur in later generations. In other cases, important water-related features characterize the whole plant but not isolated cells and tissues. Selection for these traits cannot be accomplished in cell culture.

Protoplasm Fusion

If single plant cells in cultures are treated further to remove the tough cell wall, protoplasts remain. Protoplasts can then be combined, a crude way of creating new mixtures of genetic material that normally are prevented by natural breeding barriers (fig. 57). This method has been used with petunias, plants in the cabbage family, and tomato/potato pairs (pomatoes). Protoplasts from more distantly related species, such as tobacco and soybean, also have been induced to fuse. So far, it is possible to complete the necessary steps—strip the plant cell wall, alter the protoplasm, regrow a cell wall, form a callus, and regenerate the plant—for only a few species. Until the fusion process is further refined, the features of the new plant will be unpredictable combinations of the parents.

This technique holds promise for creating unconventional hybrids before the more precise recombinant DNA technology is available. Combinations such as "pomatoes" do not have commercial value now, but investigators hope that closer crosses may. Wild relatives of crop plants often possess desirable features that adapt them to stress, but natural barriers exist to sexual crosses. For example, disease-resistant wild relatives often cannot breed with commercial potatoes. Protoplasm fusion may be able to add this desirable genetic material to potatoes without breeding (25). The same process, or recombinant DNA techniques, may be applicable to the transfer of water-related characters such as changes in growth rate and production of "heat-shock" proteins (6).

Recombinant DNA

Recombinant DNA technology uses enzymes to break apart the genetic material (DNA molecules) in one organism and recombine it with

Photo credits: *USDA.Soil Conservation Service*

The grama grasses are important native Western forage plants. Biotechnologies such as tissue culture and conventional plant breeding are used for these types of plants as well as for the major annual crops

DNA pieces from another (fig. 58). The "recombined" material expresses new predetermined characteristics in the organism into which it is inserted. This process takes place in four stages:

1. Desirable genes are chosen and "vectors" are identified to carry them to the host.
2. The gene is prepared for splicing into the vector.
3. The vector is inserted and maintained in the host.
4. A number of hosts are cloned and the most desirable is selected for further modification or conventional breeding.

This methodology is far from routine for plants. The lack of vector systems and problems with regenerating whole plants have hindered progress. The genetic material of micro-organisms is simpler and transfers of DNA among bacteria or yeast are common. Therefore, near-term agricultural applications are likely to involve only microbes, either directly or as models for higher plants. For example, bacterial osmoregulation has been manipulated by moving the gene for proline production into nonproline-producing micro-organisms. The recipient bacterium increased its rate of nitrogen fixation while water stressed (21). Since osmoregulation is the process by which organisms control the uptake of water, it is crucial where water is limited.

Ultimately, all agriculture depends on carbon compounds "fixed" by plants from atmospheric carbon dioxide. Bacterial carbon dioxide fixation systems are considered to be models for plant systems, and preliminary studies suggest that bacterial systems can be altered by genetic manipulation (3). Attempts focus on reducing photorespiration of C_3 plants, the process by which about 40 percent of the energy acquired by plants is lost before organisms can use it.

Recombinant DNA techniques are often more difficult to use with plants than with bacteria and yeasts. In plants, the genetic material is confined within a nucleus, and there are few vectors for passing genetic material from the nucleus of one plant cell to another, The first genes were inserted across natural reproductive barriers between plant species in 1973, but the ability to transfer plant genes at will is some time away.

Because of these constraints the thrust of recombinant DNA work in plants is developing laboratory techniques and understanding basic plant physiology. Much of the success of past plant-breeding programs relied on the transfer of large segments of genetic material. A clear knowledge of the DNA-level changes was not necessary. Recombinant DNA work requires that the role of transferred genetic material be understood if it is to achieve its purpose and have successful agricultural applications. This is not possible now.

Classical Plant Breeding

INTRODUCTION

Plant breeders have traditionally worked with whole plants instead of the cells or molecules that characterize biotechnology. Plant breeding generally involves six steps:

1. choosing the crop for breeding,
2. identifying the breeding goal,
3. selecting methods to reach that goal,
4. exchanging genetic material among organisms,
5. evaluating the resulting offspring under field conditions, and
6. producing seed for distribution to producers.

Some technical parts of these steps have changed little over time: hand-pollination to cross similar plants, data collection from extensive field plots, and identification, by art as well as science, of the most promising young plants. New methods have changed other steps a great deal. Centralized research and seed production centers, single-crop specialists, collections of worldwide germplasm, and modern statistical evaluation have changed the face of contemporary plant breeding. The availability of genetic engineering technology promises to make even more changes.

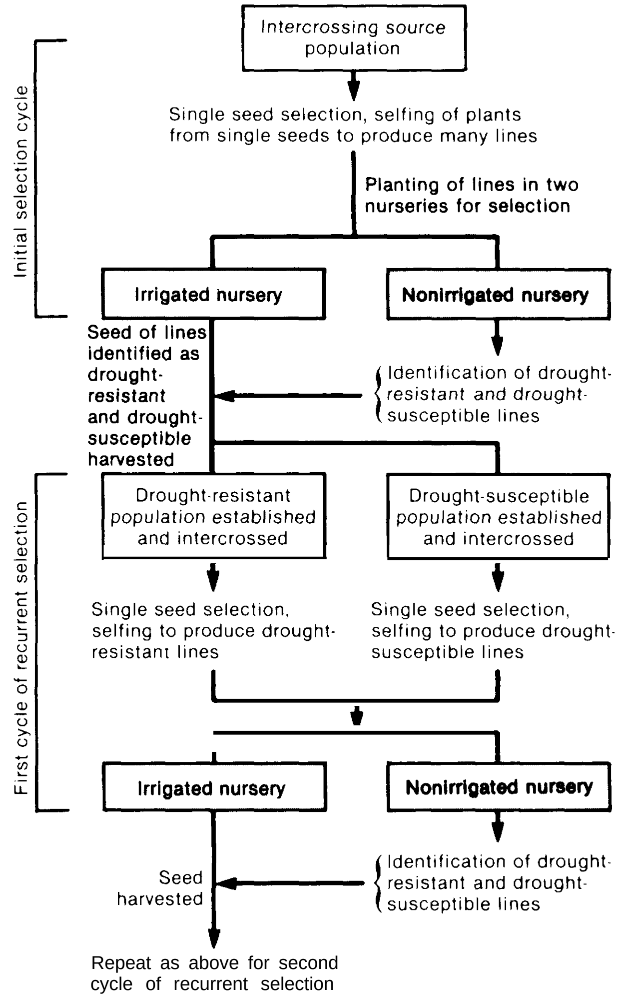
The philosophical basis for crop-plant breeding, which is fundamentally important in the initial steps, may also be changing. For example, the ability to be productive under harsh environmental conditions, such as those imposed by drought, has not been a major breeding goal for most crop species. In fact, most plant breeding has involved selecting plants for superior yield in fertile environments or under other conditions of high external inputs (7). This approach assumes that plants which have high yields under irrigation or high fertilization will also have high yields when water- or nutrient-stressed. General plant adaptability is sought to a range of conditions. This is the most common approach to crop breeding and, for dryland crops, it has increased yields without affecting agronomic WUE (10). In some cases, this type of plant breeding has reduced genetic variability for those factors, such as nitrogen fixation, stress tolerance, and photosynthetic efficiency, that may be beneficial in arid and semiarid environments.

Another approach to plant breeding seeks, in the case of water shortages, to enhance drought resistance in a manner similar to that used successfully for disease and insect resistance (fig. 59). Key features that confer resistance are identified and incorporated into less adapted varieties. Plant selection and evaluation are carried out under the same water-limited conditions that the crops are expected to endure because:

> Breeding lines that use water efficiently in a dry environment may not do as well as other lines under more favorable water conditions, This *is* because tradeoffs exist regarding plant responses in different environments. Therefore selecting plants for wide adaptability may be selecting for mediocrity. As a result, the most promising route for plant improvement under drought stress probably involves selection under water-limiting conditions (17).

Breeding programs of this type are common for forage plants, but similar ones for annual crops constitute only a fraction of the total breeding effort. Because these programs are new, they have yet to demonstrate their superiority to the first, more traditional, approach. They have the potential, though, for making major contributions to agricultural production

Figure 59.—A Generalized Method for Developing Drought-Resistant and Drought-Susceptible Plants



SOURCE A. D. Hanson and C. E. Nelson, "Water: Adaptation of Crops to Drought-prone Environments," *The Biology of Crop Productivity*, Peter S. Carlson (ed.) (New York: Academic Press, 1980), p. 97

because of the large geographic areas devoted to production of forage plants and the major areas of cultivated cropland that are susceptible to environmental limitations (table 59),

ASSESSMENT

Plant breeding for annual crops in the United States has a long and productive history. Experts estimate that crop improvements have accounted for gains of 1 to 3 percent in yields per acre each year for corn, wheat, soybeans, cotton, and sorghum (19). Yield increases have

Table 59.— Percent of the United States With Soils Subject to Environmental Limitations

Environmental limitation	Area affected (o/o)
Drought	25.3
Shallowness	19.6
Cold	16.5
Wet	15.7
Alkaline salts	2.9
Saline or no soil	4,5
Other,	3.4
None	12.1

SOURCE J S. Boyer, Plant Productivity and Environment," Science 218445, Oct 29 1982

come from gradually altering combinations of traits.

These include modifications of the partitioning of plant substances among organs and compounds, changes in seed retention characters, and alterations in the timing of flowering and of seed formation. For example, economic yield is usually a fraction of total plant dry matter, including roots (table 60). The size of the fraction depends on the plant species, water supply, and management. A significant portion of the yield increases obtained by plant breeding have been based on increasing this fraction, In wheat, the proportion of harvestable grain has increased from 35 to 50 percent over the last 20 years (4). Selection pressure in other plants would result in similar increases up to

Table 60.— Proportion of Crop Dry Matter Produced That is a Harvestable Product

'Plant breeding has successfully Increased the proportion of plant-produced dry matter that is a harvestable product The figures given below are for highly productive Irrigated varieties

Crop	Product	Proportion economic product (in percent)
Cotton	lint	8-12
Sunflower	seed	20-30
Bean	grain	25-35
Tomato	fruit	25-35
Soybean	grain	30-40
Sorghum	grain	30-40
Corn	grain	35-45
Sugarbeet	sugar	35-45
Wheat	grain	35-45
Rice	grain	40-50
Pineapple	fruit	50-60
Potato	tuber	55-65
Alfalfa	hay	40-80

SOURCE Adapted from Wayne R Jordan Ronald J Newton, and D W Rains "Biological Water Use Efficiency in Dryland Agriculture, " OTA commissioned paper 1982 p A 7, table 3A

the limits established by the anatomy of the crop. When these increases do not increase evaporation or transpiration, they result in higher agronomic WUE,

Until recently, little research has been conducted on range plants, but work in Utah, Montana, and the SCS Plant Materials Centers on plants for mined land reclamation has vitalized range-plant breeding. Vigorous, palatable, quickly established hybrid grasses are now available. Perennial range-plant breeding differs from breeding annual crop plants in several ways: survival, as well as production, is important; only enough seeds are needed to ensure genetic mixing and reseeding; and storage reserves for the next season's growth cannot be shunted into production. These requirements make breeding more complex,

Identification of the character or characters to be modified is the single most critical step in plant improvement; it dictates both breeding and evaluation methodology. Once characters are identified, breeders have been successful because they make selections from vast numbers of plants. One breeding program that uses computer-assisted seeding and harvesting allows seven staff members to test 30,000 plots of plants in four locations (29). Large selections may be important, especially for breeding drought resistance, since it probably involves many genes with small, difficult to measure, effects.

In many cases, the fundamental mechanisms of adaptation to water stress are not known, where critical features can be identified for breeding, they are not based on one or a few genes, unlike the many disease- and insect-resistance traits used successfully in past breeding programs. Instead, the complex physiological and biochemical features that enable a plant to tolerate water stress vary from species to species. The properties that enable one plant to survive in an arid region—e.g,, a large root system—may make another susceptible to severe dedication, or drying,

Under such conditions, accurate laboratory measurements of the actual physiological feature that confers drought resistance may require hours. Measurement technologies are too time-consuming for the large numbers of plants needed for mass evaluations. Therefore, direct plant breeding for the biological characters that determine drought resistance awaits development of better laboratory technology. This problem can be overcome by correlating these physiological features with ones more readily observed and measured. Such genetic markers are used to identify some genetic diseases in humans and in animal breeding programs.

With adoption of the 1970 Plant Variety Protection Act and its 1980 amendments, institutional constraints to the development of new plant varieties decreased. Private investment has increased, and several times as many cotton, wheat, corn, and soybean varieties are being produced as before its passage. Other concerns remain, however. The trend for small seed companies to be taken over by large ones concentrates economic power in fewer hands. There is concern that this may increase seed prices or hinder development of varieties that have fewer customers or require fewer of a company's other products—e.g., pesticides. Fears also exist that the new systems for patenting germplasm will decrease germplasm availability at a time when it is needed (5).

Animal Breeding

INTRODUCTION

Animal production is a major feature of Western agriculture. Large acreages in the West cannot be cultivated because of erosion hazards or other factors. For these lands, production of animal protein or other products by ruminants (goats, cattle, sheep, wildlife) is a beneficial use of unique resources. Also, large numbers of cattle are raised on Western feedlots. In both cases, animal breeding can increase productivity.

The major focus of most animal-breeding programs is increasing the amount of animal biomass produced per unit of land area or per amount of plant material consumed. This can be accomplished by increasing the number of young animals produced each year or by increasing the rate at which each offspring gains weight.

Some breeding programs are related specifically to conditions prevailing in arid and semiarid lands. For example, several new breeds have been established to achieve greater heat tolerance for Western rangelands. These have involved the introduction of African and Asian sheep and cattle germplasm into European stock, the common rangeland breeds. Santa Gertrudis, Beefmaster and Africander cattle, and Dorper sheep resulted from these crosses.

Standard animal-breeding technologies have been used to accomplish these goals: introduction of new breeds to create hybrids, intentional selection for high growth rates among pure breeds, and development of composite populations. A variety of more intensive technologies are also finding their way into the livestock industry.

ASSESSMENT

The productivity of ruminant farm animals has increased substantially during the past two decades. For example, selection for growth and carcass traits within beef cattle breeds has changed some traits by 2 to 3 percent every generation. Additional increases in productivity have been obtained by crossing several cattle breeds: calf weight was increased by 20 to 25 percent in a three-breed rotational breeding program, These programs have used European breeds such as the Simmental, Gelbviech, and Maine Angou, which are larger and later maturing. Other programs use Texas Longhorns to decrease calving difficulty, increase disease resistance, increase fertility, and adapt the animals to the harsh environmental conditions that often prevail on open rangelands.

More intensive technologies, first used by the dairy cattle industry, are being adopted for other animals. Artificial insemination has markedly increased milk production, and over 50 percent of dairy cattle are bred this way, Artificial insemination is used for only 3 percent of beef cattle, but recent treatments to synchronize ovulation promise to decrease labor requirements and make it more acceptable (20). For those 3 percent, though, artificial insemination has dramatically improved weight, quality and disease resistance.

Photo credit: IUDA-Soil Conservation Service

Texas longhorns, after hundreds of years of years of fending for themselves on the arid and semiarid ranges of Mexico, became the foundation of the U.S cattle industry. They were almost replaced by European cattle breeds in the 20th century but interest in these hardy animals is increasing now

These improvements are being enhanced by embryo transfer and storage, methods similar to those used for plant-tissue culture. In embryo transfer, genetically superior cows are treated with hormones and, as a result, produce 6 to 20 eggs instead of one. These eggs are removed, fertilized with semen from a genetically desirable bull, and transferred to surrogate mother cows. All of the calves will be related to the superior genetic parents but will also acquire the disease-resistance of the surrogate mother.

Some additional embryo manipulations are possible before transplantation. New genetic combinations can be made by combining two embryos, or one embryo can be divided to produce identical twins. All of these processes are complex and expensive. They require laboratory facilities, trained embryologists, and about $2,000 for each procedure. These techniques have developed in conjunction with embryo storage methods. It is now possible to freeze embryos, conserving important genetic resources on a worldwide basis. Frozen embryos are often used in embryo transfer, and new technologies promise to make both procedures less expensive and more widely available. For example, Rio Vista Farms in Texas have perfected a method of transferring frozen embryos in plastic straws filled with protective fluid. With these, thawing and implantation can be done by veterinarians or less specialized personnel.

Some of this technology is not equally available to ranches of different sizes and incomes. Smaller farms and ranches cannot usually manage the complicated rotational breeding programs that increase productivity. Since about 70 percent of the beef cattle in the United States are in herds of fewer than 100 animals, a large number of animals may be excluded, Composite populations of animals developed from a wide germplasm base selected from several breeds would make the advantages of hybrid vigor available to small cattle operators perhaps for the first time.

The cattle industry is in transition now, and changing economic conditions will affect the availability of credit and the location of livestock centers. Some people expect that the West will decline as a center for cattle feeding but retain its prominence in rangeland cow/calf operations (Ii). A continuing need will exist for animal germplasm suited for arid and semiarid rangelands, but declining markets for red meat may have unexpected effects on livestock producers.

Innovative Applications of the Technologies

"New Crops": Plants and Animals

> The greatest service which can be rendered any country is to add a useful plant to its culture . . . .
>
> Thomas Jefferson, 1821

INTRODUCTION

The domesticated plants and animals raised by American farmers and ranchers frequently change. Seventy years ago avocados were virtually unknown, soybeans were grown only in a few States, research on grain sorghum had barely begun, and European cattle were relative newcomers. Now each of these organisms is well established, filling demands for high-value or drought-adapted human and animal food.

Concern remains that other agricultural plants and animals are needed. These are:

- present agricultural organisms need diversification with new genetic material to prevent attack by new diseases and pests;

Box U.—Sunflowers: A Successful New Crop

Sunflowers are native American plants that, under some conditions, possess environmental and economic advantages over other crops in the northern Great Plains: they offer drought and flood resistance and tolerance for salinity and frost. Several North American Indian tribes used sunflowers extensively but large-scale commercial development of sunflowers occurred first in Europe. In 1964 the U.S.S.R. released the first high-oil variety, stimulating U.S. interest. Then, in the late 1960's, the sharp decline in Russian exports opened the European market to U.S. exporters. At the same time, several universities, USDA, and a commodity organization increased the agronomic and economic attractiveness of the crop. Since then, U.S. acreage has expanded 65 times to about 4 million acres. In **North Dakota, South Dakota, and Minnesota, the major producing States, sunflowers have maintained their economic edge over other small grains, stood up to adverse weather conditions, and provided growers with an alternative crop. In 1980, a future's market was established, and other countries became eligible for financial assistance for U.S. sunflower purchases. While acreage continues to fluctuate, the future of sunflowers appears bright.**

SOURCES: Gary L. Laidig and J. W. Twigg, "Historical Crop Studies," *Feasibility of lntroducing New Crops: Production, Marketing, Consumption (PMC) Systems,* E.G. Knox and A. A. Theison (eds.) (Emmaus, Pa.: Rodale Press 1981), pp. 174191; E.D. Putt, "History and Present World Status," *Sunflower Science and Technology, J.* F. Carter (ed.) (Madison, Wis,: American Society of Agronomy, 1978), pp. 1-29.

Photo credit: USDA-Soil Conservation Service

A field of sunflowers grown for oil, south of Forman, North Dakota

- current domesticated plants and animals are too demanding on the environment;
- conventional crops, forages, and livestock require unacceptably high energy inputs in the form of fuel, nutrients, pesticides, irrigation, or disease prevention; and
- the lack of diversified markets exposes farmers and ranchers to large foreign and domestic price instabilities.

Some of these concerns have been shown to be valid. For example, large geographic areas planted in hybrids with a common genetic background caused the rapid spread of corn blight in the 1970's, resulting in a nearly nationwide crop failure. Disease-resistant material in a germplasm bank was used to breed resistant plants for the next season, preventing the problem from continuing. A greater diversity of agricultural plants and animals serve as long-term investments and insurance for the future if they can alleviate such problems.

In the short term, different crops and forage plants and animals may be able to provide new profitable products and to diversify agricultural markets. Some plant products may provide unusual and high-value chemicals for the pharmaceutical, chemical, or energy industries, creating benefits for farmers and the Nation where such crops replace subsidized excess commodities or ones that exhaust important resources.

Some experts feel that "new" crops are needed especially for the arid and semiarid regions of the United States. Of the established crop plants, only barley, wheat, sorghum, certain beans, and cotton are adapted to dry conditions. Some of these have been bred for high production under heavy irrigation, decreasing their adaptation to drought. Other established crops, such as hybrid corn, were not originally arid-land plants and may have inherent limitations in genetic material.

Opportunities exist today for examining the potential of new plants and animals because of the uncertainty facing agriculture in the West, In some places irrigation is no longer possible. Lands need improvement to reach higher levels of productivity in other areas. Even in the large areas of the West that are too dry and prone to erosion for conventional tillage and harvest, it maybe possible to increase agricultural productivity without jeopardizing important national resources. To this end, well-adapted plants and animals are being examined, often for production without irrigation, heavy fertilization or other large inputs.

ASSESSMENT

A study for the National Science Foundation identified 54 potential crops. Either these plants are adapted to environmental stress or provide a product critical to the needs of American society. Seven specifically are suited for arid or semiarid climates (table 61). Other authors have suggested additional potential crops for arid or semiarid zones. For example, Johnston (18) estimates that good evidence for medical usefulness exists for about 300 plant species of the Southwestern United States.

The status of these plants varies widely, Some, such as amaranth, tepary beans, guar, and cowpea, have a long history of use in the Americas. Therefore, they are new only to conventional agriculture. These plants are already domesticated, and their cultivation is well developed for certain types of agriculture. A sizable ethnic market exists for these products, and supply cannot meet demand. Now these old crops are ready for new and wider uses.

Other arid/semiarid-land plants are now being domesticated, Some are at early stages of development (jojoba, guayule, saltbush), whereas others are undergoing basic preliminary research (kochia, buffalo gourd, milkweed, *Euphorbia*, most medicinal plants).

The potential contribution to national productivity is not known for many of these crops. Preliminary assessments of biomass production indicate that levels are about one-fourth to one-half that expected from irrigated crops (19,22), but productivity would be expected to increase with plant breeding (table 62), High-production levels over wide areas may not be the goal for all crops, however. Some, such as the traditional varieties used by Papago desert farmers, may be best cultivated on smaller scales to maintain sources of already-adapted germplasm.

Table 61 .—Information on Potential New Crops for Arid and Semiarid Lands

Crop	Life span	Part used	Product	Market competition	Adaptation	Land use competition	Cultural operations	Potential magnitude and significance	Needed work
Xerophytes:									
Buffalo gourd. . .	Perennial	Seed	Protein and edible oil	Soybean	Dry	Desert	Mechanized	Large	Agronomic Machinery
Guayule	Perennial	Stem, root	Latex	Synthetic rubber	Dry	Cotton	Mechanized	Large	Agronomic
Jojoba	Perennial	Seed	Industrial oil	Sperm-whale oil	Dry, infertile	Desert	Hand labor	Large	Agronomic Machinery
Mung bean	Annual	Seed	Vegetable	Other beans	Dry	Sorghum	Mechanized	Medium	Agronomic
Pigeon pea	Perennial/annual	Seed	Bean	Cowpea	Dry, infertile	Peanuts	Mechanized	Small	Agronomic Demand
Pinyon pine ...	Perennial	Seed	Nut	Nuts	Dry	Forest	Hand labor	Medium	Agronomic Machinery
Tepary bean ...	Annual	Seed	Bean	Other beans	Dry, infertile	Range	Mechanized	Small	Agronomic Demand

SOURCE Soil and Land Use Technology, Inc., A A. Theisen, E G. Knox, and F. L. Mann (eds.), *Feasibility of Introducing Food Crops Better Adapted to Environmental Stress"* (Washington, D.C U S Government Printing Office NSF/RA/780289, 1978), vol. 1, p 53, table 8.

Table 62.— Results of "New" Crop Experiments

Crop	Production (lb/acre)	Water available in growing region (in)
Amaranth (grain)	1,790	Not known (India)
Cowpeas (seeds)	895	5-1o
Guar (seeds)	625-805	16-35
Mesquite	1,790	12-16
	12,530	24
Guayule	1,790-3,580	Irrigated
Kochia	9,845	16
Russian thistle	5,370-9,845	Not known
Saltbush	7,160	Not known (UT)
	5,370	Not known (TX)
Present crops	22,375	Irrigated

SOURCE Various sources cited in: Wayne R Jordan, Ronald J Newton, and D. W. Rains, "Biological Water Use Efficiency in Dryland Agriculture," OTA commissioned paper, 1982)

The development of "new" animals has received less attention than plants. Individual ranchers are experimenting with previously unused animals such as elk. Generally, these efforts are not well known and the people involved are isolated from one another and from the established animal science community.

These plants and animals face barriers of several kinds if they are to be used widely. Domestication, when necessary, is a time-consuming process, but sophisticated technology should shorten it significantly. Tissue culture techniques and other biotechnologies may contribute to the rapid development and dissemination of new germplasm and organisms. However, more formidable barriers—both technical and institutional—exist. A great deal of research remains to be done for many of the species described here, and there is little evidence to suggest that major Federal or State initiatives will be forthcoming. Often, extensive field testing has not been completed.

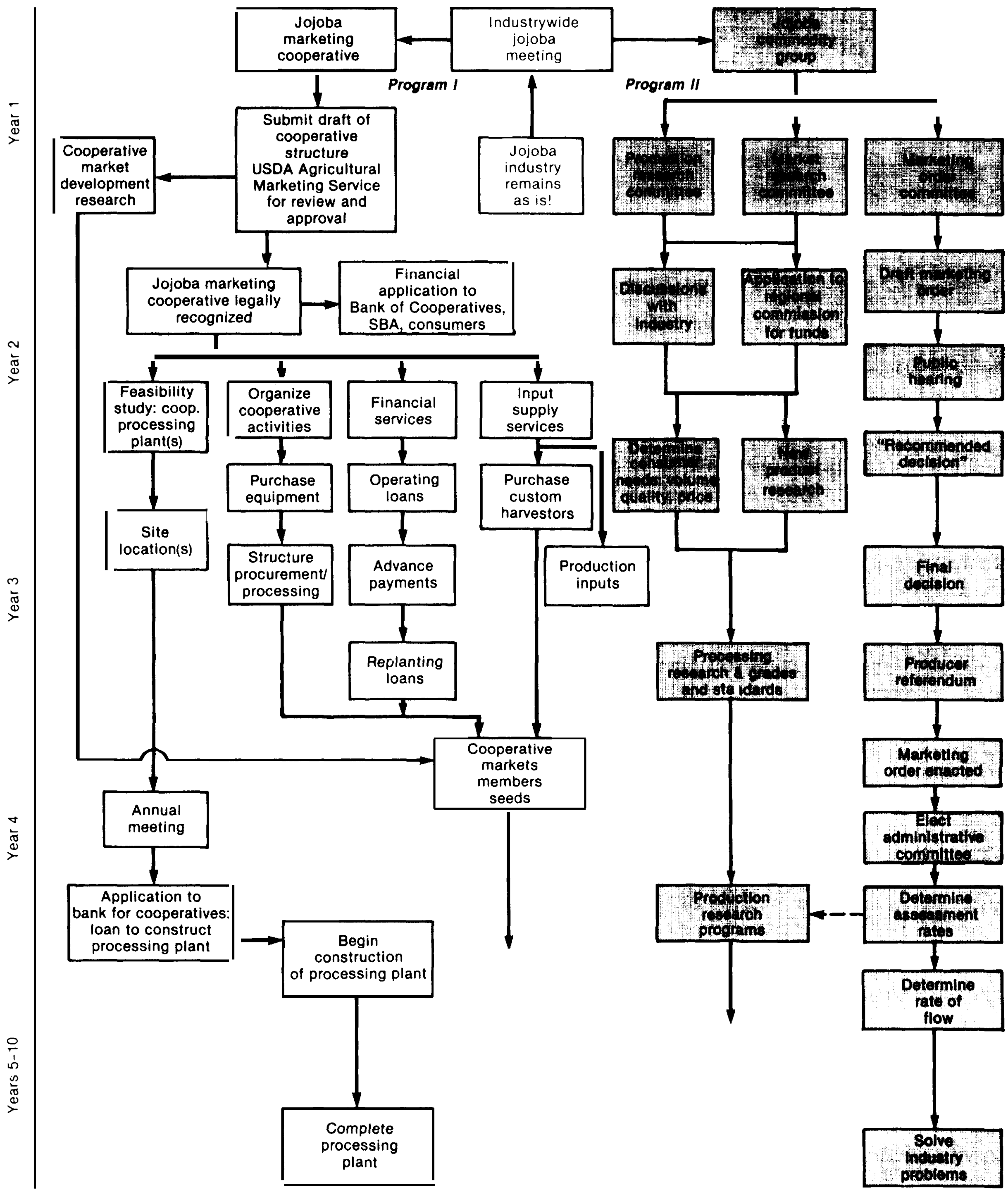
Once these crops produce acceptable yields under field conditions, they must be attractive to producers and must find markets. There have been previous attempts, both successful and unsuccessful, to introduce new crops. Experience shows that markets and the institutional infrastructure for adoption are crucial to success. For example, processing plants may be required, commodity organizations maybe necessary, consumers may have to be educated about new products, and marketing channels from farm to consumer may have to be developed (fig, 60). Even then, the adoption of a new crop is unlikely to be entirely predictable,

Once a market for a new product exists, germplasm will probably be available to all interested growers. At the early stages of introduction, however, new crop production may be limited to large landowners with the capital and interest for major new ventures. For plants with industrial uses, this may require corporations to develop processing facilities first, then to obtain raw plant materials from local farmers on a contract basis or to grow them on their own land.

Generally, there are few legal barriers to the introduction of new crops or animals. A major exception, however, relates to reclamation of arid and semiarid surface-mined lands. Both Federal and State laws restrict the kinds of non-native plant species that may be used for mineland revegetation. Therefore, potential new crop or forage plants that are not U.S. natives often cannot be included in some of the largest research programs and experimental plantings. Similarly, State laws that regulate ownership of wildlife and Federal regulations that control slaughtering and quarantine of imported organisms are cases where the adoption of technology is restricted legally. While these legal restrictions are small compared to the social and economic barriers faced by new products, they can be significant.

Generally, these drought-adapted agricultural products have the potential for tailoring agriculture more closely to prevailing environmental conditions. Where resources—e.g,, soils or water—are being used faster than they are replenished, adapted organisms hold hope for a more sustainable type of agriculture, For example, desert milkweeds may be able to replace dryland crops in the western Great Plains where increasing energy costs are eliminating irrigation (1). Or, where fragile lands have been plowed for annual crops and severe erosion has resulted, adapted perennial shrubs, grasses, and forbs may provide profitable products without land degradation. Such potentials are usually long term. Few of the crops discussed

Figure 60.—The Complex Production, Marketing, and Consumption Scheme For a New Crop Entering the Commercial Market. This Diagram Illustrates a Potential Strategy for Jojoba Producers and Processors



SOURCE: G. L Laidig, "Jojoba. *Simmondsia chinensis,*" Feasibility of Introducing New *Crops: Production-Marketing-Consumption (PMC) Systems,* E. G Know and A A. Theison (eds.) (Columbia, Md.: Soil and Land Use Technology, Inc., 1981), pp. 74-101.

Box V.—Rules, Regulations, and "New" Agricultural Plants

Federal and State laws restrict the types of plants that maybe used for reclamation of surface-mined lands. These legal limitations have had unexpected results on rangeland research programs.

The primary intent of most laws was to ensure a self-sustaining and persistent plant ground cover to protect soils. For example, Wyoming law requires that mine operators:

> . . . establish . . . permanent vegetative cover of the same diverse seasonal variety native to the area or of a species that will support the approved post-mining land use. This cover shall be capable of stabilizing the soil.

Wyoming law did not seek to prevent the use of all nonnative plant species but only those that: 1) were not self-renewing and required special management for persistence, or 2) gave a false impression of reclamation success and might encourage damaging early grazing. The unintended result of the law, however, was the limitation of introduced plants in many reclamation and rangeland programs.

Is this desirable? The question is still being debated. Some contend that the focus on using and improving native forage plants is long overdue and that it might lead to new styles of agriculture more adapted to arid/semiarid regions. Others believe that plant specialists should have worldwide germplasm at their disposal and that introduced plants may provide important new additions to American agriculture. For the time being, constraints on the use of nonnative plants provide an uncommon example of legal limitations on plant research.

SOURCE: Wyoming Department of Environmental Quality. Land Quality *Division Rules and Regulations ch.* IV.3.D.(2), August 1962.

here, with the possible exception of grain amaranth, are on the verge of becoming major national commodities, but timely research and development are likely to provide important payoffs with sustained support. The domesticated desert crops such as cowpea and tepary bean, since they are adapted for cultivation now and have developed markets, deserve especially close examination.

Plants for Food and Forage

Grain amaranth was a staple crop of Central American Indians before colonizers, in order to eradicate native cultures, methodically destroyed the fields. The remaining amaranth germplasm is highly variable, providing rich materials with which to work. Amaranth could provide biomass energy, seed starch, or leafy vegetables, but its high-protein grain is most promising. Both leaves and seeds contain proteins rich in lysine and methionine, amino acids that limit protein digestion in other grains (table 63). Amaranth is well suited to semiarid conditions but not to prolonged or excessive drought; some plants are adapted to nutrient-deficient soils but others require substantial fertilization, An accelerated program of amaranth research and development is underway at the Organic Gardening and Farming Research Center in Emmaus, Pa. The National Academy of Sciences and the National Science Foundation sponsor amaranth research and USDA is also *showing interest (30).*

Table 63.—The Protein Content and Quality of Various Grains

Grain	Protein (%)	Limiting amino acid(s)	Relative protein score (100 points optimum)
Amaranth	15	Leucine	67
Barley	9	Lysine	58
Buckwheat	12	Leucine	83
Corn	9	Lysine	35
Oats	15	Lysine	62
Rice	7	Lysine	69
Soybeans	34	Methionine, cysteine	89
Wheat	14	Lysine	47

SOURCE: J P. Senft, "Protein Quality of Amaranth Grain, " Proceedings of the Second *Amaranth Conference* (Emmaus, Pa Rodale Press, Inc 1980), p 45

Cowpeas, grown for their dry seeds in semiarid regions of the world, sometimes produce seeds in years when drought causes other crops

Photo credit: Rodale Press, Inc.

This grain amaranth plant was selected for its compact form

to fail. Cowpea vegetation makes excellent hay, and cowpea's high-protein seeds can be used as animal protein concentrates. Green cowpeas are used now in the U.S. commercial canning industry.

Buffalo gourds are native undomesticated plants with wide distribution in the Western United States. Each plant produces an abundant crop of gourds with oil and protein-rich seeds and plant roots contain high-quality starch (table 64). Its vines are a potential forage that can be repeatedly harvested. It is also reported to contain medicinal compounds. Domestication programs began for buffalo gourd in 1973 at the University of Arizona.

Plants for Biomass Energy

Current energy prices do not encourage the development of biomass crops. Some experts believe that fragile arid and semiarid lands should not be used for biomass production under most circumstances. But conditions may change, and with appropriate safeguards, the following plants may have potential for producing biomass and other products.

Table 64.-Starch and Moisture Content of Several Sources of Starch

Name of starch	Source	Moisture (°/0)	Starch (%0)
Buffalo gourd[a] root	*Cucurbita foetidissima*	68-72	15-17
Potato	*Solarium tuberosum*	75-78	19
Tapioca	*Manihot utilissima*	60-75	12-33
Arrowroot	*Maranta arundinaceae*	65-75	22-28[b]

aOnly buffalo gourd is an arid-land plant.
Industrial starch yield Is typically 15 percent owing to cell structure.

SOURCE: W. P. Bemis, J. W. Berry, and Charles W. Weber, "The Buffalo Gourd: A Potential Arid Land Crop," *New Agricultural Crops, G.* A. Ritchie (cd.) (Boulder, Colo.: Westview Press, 1979), p. 85.

Mesquites are a diverse group of woody legumes from North and South America. While they are commonly considered pests by ranchers, they have a long history of use for wood, flour, and fuel by other cultures. Mesquite grows in areas of low rainfall by tapping ground water, thus creating a potential problem in some areas. Annual yields are currently low and plants are usually sensitive to low temperatures. But mesquite is one of the few nitrogen-fixing legumes that can tolerate salinities equivalent to seawater and its diversity provides material from which to breed improved varieties.

Saltbush is a common Western drought-resistant shrub. Many species have protein concentrations equivalent to that of alfalfa so it is important for forage. It has also been important in revegetating disturbed lands.

Kochia (tumbleweed) and Russian thistle are both "weeds" with potential for biomass fuel as well as forage. Their reputation as weeds may hamper acceptability but it can also be exploited for high productivity.

In other cases, agricultural residues can be used for biomass energy, plant and animal residue have potential (15).

Plants for Industrial Products

Guar is a leafy annual legume that produces gum and forage. Guar gum is a strengthening and stabilizing agent in paper, cosmetics, processed foods, and industrial materials. Older plants withstand drought, and plant seeds withstand alkaline or saline conditions. In 1977, 20,000 tons of guar were produced but demand exceeded supply. U.S. consumption is expected to be 41,500 tons in 1983 (31).

Guayule is a wild shrub, native to Mexico and Texas. It is adapted to regions with low and erratic rainfall. Plant roots and shoots contain rubber comparable to that produced by the Asian *Hevea* rubber trees, rubber that cannot be duplicated synthetically. Guayule appears to be suitable for mechanized agriculture and requires little fertilization. It is not very salt tolerant, and guayule plantations are currently susceptible to insects and diseases. The Native Latex Commercialization Act of 1978 (Public Law 95-592) was designed to stimulate guayule production, and the commercial rubber industry is involved in guayule research and development. Two other sources of arid/semiarid lands natural rubber are rabbitbrush and sunflowers.

Soaps for shampoos are extracted from various species of yucca, and wax obtained from the seeds of jojoba is used for a variety of cosmetics. Neither plant has been cultivated in the United States but relatives of the yucca are grown in other parts of the world. Jojoba grows in Arizona, California, and Mexico on infertile or saline soils where rainfall is scarce. Jojoba wax is a substitute for sperm whale oil, with a large number of potential commercial uses in the cosmetic, pharmaceutical, and machinery industries. The first large-scale irrigated commercial jojoba plantations are expected to come into production in the Southwest in 1983. At that time the price for seeds should decrease, and the high-volume, low-cost lubricant market should open.

Many species of plants produce copious amounts of hydrocarbons that can provide chemicals or be cracked to liquid fuels. The principal species under development are milkweeds, gopherweed, and rabbitbrushes. Milkweeds could provide a variety of chemical products such as inositol and pectin and perhaps stimulate development of a honey bee industry. Gopherweed produces a milky latex that can be harvested without destroying the plant. Candelilla produces a wax with a high melting point, and is a product imported from Mexico. Candelilla wax sells for $4.19 per kilogram ($1.90/lb) and the market is good (9).

Animals for Arid and Semiarid Lands

The American bison, or buffalo, was once the most important large grazer of Western lands. Bison have recovered from near extinction, and several large public and private herds now exist (table 65). Buffalo ranchers suggest that these animals are more adapted to grazing on semiarid lands than are their domestic counterparts, They claim that buffalo use low-productivity resources frugally, produce high-quality meat, and generally exhibit greater hardiness than do domestic livestock.

Rabbits also have potential as new agricultural animals. They have short gestation periods, multiple births, and short parenting time. None of these features is shared with major domesticated animals of rangelands, and such characteristics provide the fastest way to increase animal productivity per unit of plant productivity (table 66). Rabbit farming is now practiced on a small scale, but the potential for open-range ranching is unknown. Control, containment, and slaughtering methods have not

Table 65.—Buffalo Sales in 1981

Sale	Number of animals[a]	Average price
Dakota Heritage Buffalo Sale, Mitchell, S. Dak.	131	$572
Wichita Mountains Wildlife Refuge, Cache, Okla.	123	$487
Kansas Fish and Game Commission, Canton, Kans.	56	$582
Custer State Park Hermosa, S. Dak.	470	$444
Durham Ranch	700	b

aThese figures include only one of the many private herds
Average price not available, individual price range $450 to $1,000

SOURCE: National Buffalo Association, "1981 Sales Results," *Buffalo* 10(1), 1982, pp 8-9

Table 66.—A Comparison of Cattle, Sheep and Rabbit Production on Western Rangelands

Feature	Rabbits	Sheep	Cattle
Offspring/100 females . .	1,485	120	90
Weight per offspring (kg). .	1	39	182
Population replaced annually (%).	30	20	10
Offspring harvested annually/100 females . . .	1,455	100	80
Harvested weight/ female (kg)	13	39	145
Energy use per individual (kcal)	200,000	1,600,000	9,000,000
Energy use per kg of offspring (kcal)	19,000	40,000	62,000

SOURCE Adapted from C W Cook, "Use of Rangeland for Future Meat Production," *Journal of Animal Science* 451480, 1977, table 4

been developed, and large populations of uncontrolled rabbits have sometimes become major pests. Limited markets are a major constraint to developing a Western rabbit industry.

Limited experiments are underway on replacing single-species domestic livestock with mixtures of species. The highest potential for these approaches appears to be on rangelands where multiple use is important (ch. XI).

Salt-Tolerant Organisms

INTRODUCTION

Salts occur in agricultural soils for a number of reasons. Some soils and ground water supplies are naturally saline, and both soils and water can gain salt from agricultural practices such as fertilization and irrigation. These processes are heightened in arid and semiarid lands. High rates of evaporation and transpiration return pure water to the atmosphere, leaving salts behind. The chemical characteristics of the salts vary. Chloride salts of sodium (table salt), calcium, and magnesium are all common, but sulfates and carbonates sometimes may replace the chloride ions. Large areas of nonirrigated croplands and rangelands in the northern Great Plains are experiencing salinity problems, but irrigated areas, especially in California and Arizona, are most affected.

Usually plant growth suffers once soils or water are salinized. Salty water is difficult for plants to extract from soils, and such soils often contain high levels of potentially toxic ions (24). Most common agricultural plants cannot tolerate salinities of 10 to 20 percent seawater. Many are sensitive to even lower concentrations (table 67).

The productive life of salinized areas could be extended by careful and intensive management. Current management technology, such as drain installation or periodic flushing with large amounts of water, has emphasized an engineering approach. Often this is costly in terms of dollars, energy, and water. Economically feasible engineering approaches do not eliminate salt; they only minimize it. Therefore, some experts believe that the development of salt-tolerant crops would provide an important biological method to supplement current management technologies. These plants might be suitable for land currently too saline for agriculture, or they might be irrigated with lower quality irrigation water, thus "saving" higher quality water for use on those plants that require it.

The use of salt-tolerant organisms is not limited to flowering plants. A number of programs are underway that use algae and micro-organisms to produce biomass for food or energy in brackish or saltwater culture. Both indoor and outdoor systems are used. Such systems could be used in conjunction with carbon dioxide emissions from coal generators or salt-gradient ponds to increase productivity or to generate solar energy (26) and would be another way to produce agricultural products while using water too salty for most current crops.

Proponents of these technologies do not advocate increasing the salinity of soil or water nor the indiscriminate use of saltwater irrigation. Instead they stress the need for continuous evaluation and careful management

ASSESSMENT

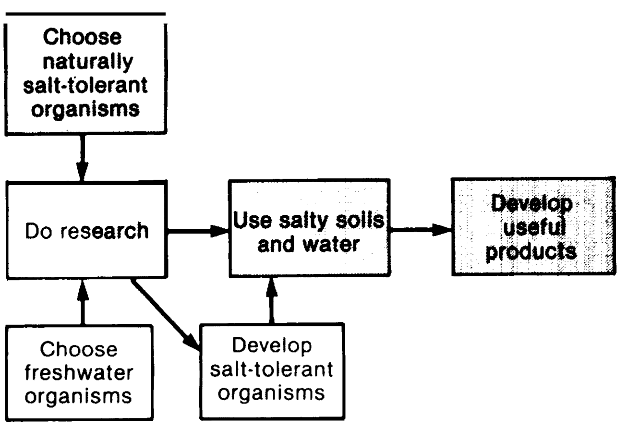
There are two approaches to developing salt-tolerant flowering plants: adding genetic salt tolerance to conventional crop and forage plants or developing naturally salt-tolerant, or halophytic, plants into productive agricultural species (fig. 61).

Table 67.—Salt Tolerance of Crops

Type of crop	Salt tolerance Low	Medium	High
Fruit	Avocado	Cantaloupe	Date palm
	Lemon	Date	
	Strawberry	Olive	
	Peach, apricot	Fig	
	Almond, plum	Pomegranate	
	Prune, grapefruit		
	Orange, apple, pear		
Vegetables	Green bean	Cucumber, squash	Spinach
	Celery	peas, onion	Aspragus
	Radish	Carrot, potato	Kale
		Sweet corn	Garden beet
		Lettuce	
		Cauliflower	
		Bell pepper	
		Cabbage	
		Broccoli	
		Tomato	
Forages	Burnet	Milkvetch	Barley
	Red clover	Sour clover	Western wheat grass
	Meadow foxtail	Meadow fescue	Canada wild rye
	White Dutch Clover	Oats (hay)	Bermuda grass
		Wheat (hay)	Nuttall alkali grass
		Rye (hay)	Salt grass
		Tall fescue	
		Alfalfa, Sudan grass	
		Mountain brome	
		White sweet clover	
Field Crops	Field bean	Castor bean	Cotton, rape
		Sunflower	Sugar beet
		Flax, corn	Barley (grain
		Sorghum (grain)	
		Rice, oats (grain	
		Wheat (grain)	
		Rye (grain)	

SOURCE” D Todd, *Ground Water Hydrology 2d* ed (New York John Wiley & Sons, Inc., 1980)

Figure 61.—Two Methods for Producing Salt-Tolerant Organisms



SOURCE: J. C. Aller and O. R. Zaborsky, "The Blosaline Concept," *The Blosaline Concept*, A. Hollaender (ed.) (New York: Plenum Press, 1979), p. 6.

Halophytes

Some experts feel that the halophyte approach may be more powerful since halophytes are adapted already to salty water and soil and are, in some cases, exceptionally productive (2), For example, some of these plants are more productive than alfalfa and grow in water at least as salty as seawater.

Salt tolerance is scattered widely among wild flowering plants. Various halophytes are potential forage crops, ornamental, potherbs, vegetables, grains or berries (table 68). All halophytes are not arid- or semiarid-land plants. However, a world-wide search for promising desert germplasm resulted in about 1,000 accessions from Argentina, Australia, Brazil,

Table 68.—Halophytes With Potential for Agricultural Use

Common name[a]	Potential use	Comments
Palmer's saltgrass	Grain	Used by Cocopa Indians, Gulf of California
Batis	Edible root	
Cord grass	Forage, grain	Feeds cattle, Argentina
Glasswort		23 MTU/ha; seawater irrig.[b]
Salt bush	Forage, grain	Seed yield 1 T/ha; 16°/0 protein
Cressa.	Animal feed	
Maireana	Forage	Feeds cattle, Australia
Mesquite	Forage	Feeds livestock, 20,000 ha, Chile

aScientific names are given in the appendix.
[b]MTU/ha = metric tons per hectare

SOURCE: N. P. Yensen, M. F. Fontes, E P. Glenn, and R. S Felger, "New Salt Tolerant Crops for the Sonorhan Desert," *Desert* **Plants** 3(3):111-118, G F Somers, "Natural Halophytes as a Potential Resource for New Salt. Tolerant Crops Some Progress and Prospects, " The *Biosaline Concept,* A. Hollaender (cd.) (New York' Plenum Press, 1979), pp 101.105.

Chile, New Zealand, Peru, and South Africa. Twenty-four species were identified from the Sonoran Desert (32).

Some of these arid-land plants are known to be useful and edible: they were gathered and eaten by native people in the past. Most, however, have neither been used nor cultivated. Extensive research is required before they can make an impact on agriculture, a process that may take at least 50 years.

Conventional Crops

A wide variety of conventional crops is currently being evaluated for variations in salt tolerance. Those plants that possess unusually high salt tolerances are being evaluated further. As of 1980, North American research on such crops occurred at seven U.S. localities and at least three Canadian sites. The plants evaluated include alfalfa, cowpeas, mung beans, melons, cucurbits,' tomatoes, wheat, lettuce, dates, and grapes. Israeli scientists are also involved: they are working with tomatoes, cotton, wheat, and sugar beets, as well as fodder and landscaping plants.

Screening for salt tolerance among only commonly grown varieties of crop plants appears unpromising. Much of the variability of these crops in salt tolerance may have been lost during breeding for other traits. Therefore, breeders have turned to the large seed collections held in germplasm banks around the world. For example, several thousand barley and wheat accessions from USDA collections were screened and irrigated with various dilutions of seawater in California (13). In some cases, single species collections are not promising. Germplasm from wild relatives may be required to supplement the low salt tolerance in these plants. Because this was true of tomatoes, crosses were begun with a wild, commercially useless tomato from the Galapagos Islands,

Other scientists are using tissue culture techniques to achieve results, a method that saves both time and space. For example, millions of cells, each a potential plant, can be grown in a 4-inch dish. If the dish contains salty growth media, only the tolerant cells will survive. This technique has been used for cell lines of wheat, oats, and tobacco. Results indicate that enhanced salt tolerance sometimes persists and can be passed on to offspring. Experiments are also underway on sugar beets, tomatoes, and corn. This approach cannot be applied to all plants now, Some species cannot be cultured and regenerated yet and other species lose their capacity for regeneration too quickly (8).

These experiments are preliminary, and it will be some time before salt-tolerant strains are ready for commercial use. There is another disadvantage: it appears now that salt tolerance is gained at the expense of productivity,

Micro-Organisms

The cultivation of marine and brackish water algae is short compared to cultivation of agricultural crops on land. Most of the technology is Asian; major research efforts in Western countries are recent. Many of the larger species have been cultivated in offshore beds using biological breakthroughs to supplement older technology. Smaller organisms, such as microscopic algae, blue-green algae, and bacteria, are harvested from inland ponds. The latter technologies may be adaptable to arid and semiarid lands, For example, Mexico produces large amounts of the high protein, blue-green alga, *Spirulina*, in large ponds and processing facilities and Israeli scientists are experimenting with the same organism in brackish water ponds in the Negev Desert.

Some of these organisms can be very productive in saltwater. Microalgae used in Hawaiian experiments produced 60 tons of biomass per acre per year in small outdoor ponds. Smith **(26)** speculates that such ponds would be a way to use brine left from the process to improve salty irrigation waters.

General concerns remain about the desirability of developing salt-tolerant crops, regardless of the method used. It maybe futile to develop salt-tolerant forages if the plant material is too salty for animals. Saltwater irrigation presents other potential problems. Without intensive management, ground water contamination may result, decreasing the quality of freshwater, The situations in which salt-tolerant crops provide an unusual opportunity are limited. Such crops are not a panacea for the mismanagement of irrigated lands.

CONCLUSIONS

A large number of opportunities to improve agriculture in arid and semiarid lands exists. Some technologies will not increase production in the usual sense. For example, the ability of plants and animals to survive harsh conditions may sometimes be as important as high yield. Attempts to decrease total plant water use have often failed in the past. New approaches, such as plant breeding for environmental stress, are more promising. The biotechnologies are blossoming with unpredictable results. While it is clear that agriculture is changing, it is not clear how older institutions will adapt to these changes.

The technologies that affect water-use efficiency are powerful, and the choice of goals to which they are applied is crucial. Efforts to improve drought resistance of existing agricultural plants and animals is quickening. Perhaps faster and larger gains can be made by applying these technologies to "new" arid/semiarid land plants. Rich germplasm from underused desert crops and wild plants is available to decrease water use while maintaining agricultural production. Although this is an important long-term goal, it cannot be achieved immediately.

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Appendix 9-1 .—Scientific Names of Potential "New" Agricultural Plants

Crop	Scientific name
Group 1:	
Buffalo gourd	*Cucurbita foetidissima* HBK
Cowpea	*Vigna unguiculate* (L.) Walp.
Euphorbia	*Euphorbia* spp.
Grain amaranth.	*Amaranthus* spp.
Guar	*Cyamopis tetragonoloba* (L.) Taub
Guayule	*Parthenium argentatum*
Jojoba	*Simmondsia chinensis* (Link) Schneider
Kochia	*Kochia scoparia* (L.) Roth
Mesquite	*Prosopis* spp.
Saltbush	*Atriple* spp.
Group II. Halophytes:	
Batis.	*Batis rnaritima* L.
Cord Grass . . .	*Spartina Iongispica*
Cressa	Cressa truxillensis
Glasswort	*Salicornia europaea* L.
Maireana	*Maireana brevifolia*
Mesquite	*Prosopis algorobo*
Palmer's saltgrass . .	*Disfichiis palmeri* (Vasey) Fassett
Saltbush	*Atriplex patula,* var. *hastata*