Bulletin No. 367 - Agricultural Problems in Arid and Semiarid Environments

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AGRICULTURAL PROBLEMS IN ARID AND SEMIARID ENVIRONMENTS
Oscar Howe, Indian Artist of the Middle Border

by George Agogino
Assistant Professor of Anthropology
University of Wyoming

Oscar Howe, a full-blood Sioux Indian, was born May 13, 1915, at Joe Creek, a small community in the Crow Creek Indian Reservation of South Dakota. His early life was characterized by extreme poverty and illness. At ten, almost blinded with trachoma and suffering from a painful skin condition, he contemplated suicide, then wisely decided against such action.

In the years that followed, his physical condition improved so much that he was able to return to the Pierre Indian School of South Dakota and later to transfer to the more progressive Santa Fe Indian School in New Mexico. Here for the first time his artistic ability was encouraged and given direction, and by graduation he was considered a promising "Indian artist."

With the advent of World War II, the young craftsman exchanged his brushes for military equipment and spent nearly four years with combat battalions in North Africa, Italy, and Germany. In Germany he met Heidi Hampel, now his wife and a naturalized U. S. citizen. With German efficiency she also became biographer, historian, business manager, and publicity agent for her still struggling artist-husband. One most important decision was that Oscar Howe, already noted for his "Indian art," should return to school for more advanced art education.

His ability, dedication, and drive quickly obtained him a B.A. degree from South Dakota Wesleyan University and by 1954 he had secured his MFA degree from the University of Oklahoma. By this time his native state sought his services and he became the "artist in residence" at the State University of South Dakota. He is also an Assistant Professor of Fine Arts at that institution.

Today his position in the art field is firmly established with a waiting list for all his completed work. His art has been exhibited widely in this country and in Europe. His paintings have been exhibited by the Chicago Art Institute, the Smithsonian Institution, the Denver Art Museum, the San Francisco Museum of Art, the Philbrook Art Center (Tulsa), the Gallery for Living Artists (Brooklyn), Stanford University Museum of Fine Arts, Museum of Fine Arts, Museum of New Mexico (Santa Fe), Southwest Museum (Los Angeles), and the Museum of Modern Art (NYC).

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Agricultural Problems in Arid and Semiarid Environments

Edited by Alan A. Beetle
Professor of Range Management
University of Wyoming

A symposium held before the thirty-fifth annual meeting of the Southwestern and Rocky Mountain Division of the American Association for the Advancement of Science and the thirtieth annual meeting of the Colorado-Wyoming Academy of Science, May 6-7, 1959. University of Wyoming, Laramie, Wyoming.
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Not all investigators are agreed concerning the extent of the arid zones, but Shantz’s concepts (6) seem reasonable. He defined these zones as areas where plants are adjusted to climatic—as contracted to physiologic—drought by being either short-lived annuals or more or less xerophytic. Such areas encompass about one-third of the land surface of the earth, including a considerable part of the United States west of the hundredth meridian.

Throughout the arid regions of the world, irrigation has been practiced for millenia. Many of the great civilizations arose in areas where in the words of Fabian Garcia (former Director of the New Mexico Agricultural Experimental Station) “El agua es rey.” Some of these civilizations, as in the valleys of the Nile and the Indus, continue to this day, having undergone only cyclic changes with the rise and fall of succeeding governments. Others, as in Mesopotamia, faded away when soil problems engendered by irrigation became too great for the people to cope with. Today the traveler may fly over millions of acres in North Africa and western Asia where, as attested by remains of ancient irrigation canals in North Africa and western Asia.

### TABLE 1. IRRIGATED LANDS OF THE WORLD

<table>
<thead>
<tr>
<th>Country</th>
<th>Acres of Irrigated Land (thousands)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. China</td>
<td>90,000</td>
</tr>
<tr>
<td>2. India</td>
<td>40,000</td>
</tr>
<tr>
<td>3. Pakistan</td>
<td>35,000</td>
</tr>
<tr>
<td>4. United States</td>
<td>21,170</td>
</tr>
<tr>
<td>5. Russia</td>
<td>8,000</td>
</tr>
<tr>
<td>6. Mexico</td>
<td>7,500</td>
</tr>
<tr>
<td>7. Egypt</td>
<td>6,250</td>
</tr>
<tr>
<td>8. Argentina</td>
<td>3,200</td>
</tr>
<tr>
<td>9. Chile</td>
<td>3,000</td>
</tr>
<tr>
<td>10. Australia</td>
<td>1,000</td>
</tr>
</tbody>
</table>
What, then, are the major soil problems that accompany irrigation, and what can be done about them? To what extent are they responsible for the abandonment of irrigation? The most important are those of salinity, waterlogging, erosion, and loss of fertility. Accurate estimates of the amount of land affected are not available, but it is probable that 30 percent, and possible that 50 percent or more, of our irrigated land is affected by one or more of them.

**SALINITY**

Harmful effects of salinity are due to specific ions or to physiological drought caused by the high osmotic pressure of the soil solution.

All irrigation waters contain some salt. As shown in Table 2, which shows salt concentrations in several surface waters of the western United States in 1954, the amount may vary from the very low value—81 ppm—for the San Joaquin River near Biola, California, to more than 6,000 ppm in the Pecos River below Carlsbad, New Mexico. Although this salt concentration may exert a profound effect on the development of soil salinity under irrigation, it is by no means the only effective factor. Kind of salt in the water, soil permeability, salt content of the original soil, depth to the underlying water table, amount of water available, and tillage and irrigation practices, all influence salt accumulation in the soil.

Because of the resulting increase in exchangeable sodium, which leads to deterioration of soil structure and to consequent loss of permeability and accumulation of salts, irrigation waters high in sodium salts are less desirable than those with similar concentrations of chlorides and sulfates of calcium and magnesium, which have a beneficial effect on structure and hence on permeability.

<table>
<thead>
<tr>
<th>River</th>
<th>Salt Concentration (parts per million)</th>
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</thead>
<tbody>
<tr>
<td>Rio Grande, at Otowi Bridge, N. M.</td>
<td>285</td>
</tr>
<tr>
<td>Colorado River, at Glenwood Springs, Colorado</td>
<td>420</td>
</tr>
<tr>
<td>Pecos River, near Orla, Tex. 6,010</td>
<td></td>
</tr>
<tr>
<td>Columbia River, at Grand Coulee, Wash.</td>
<td>81</td>
</tr>
<tr>
<td>Snake River, at King Hill, Idaho</td>
<td>341</td>
</tr>
<tr>
<td>San Joaquin, near Biola, Calif.</td>
<td>52</td>
</tr>
<tr>
<td>Green River, at Green River, Wyo.</td>
<td>412</td>
</tr>
<tr>
<td>Gila River, at Kelvin, Ariz. 492</td>
<td></td>
</tr>
</tbody>
</table>


Problems arising from irrigation of slowly permeable soils high in salt are well illustrated on the western slope of the Rocky Mountains, where Mancos shales are widespread. When these soils are irrigated, salts accumulate as a white surface crust, which permits the growth of only the most salt tolerant of crops. Even where adequate water of good quality is available, removal of the accumulated salts by leaching is difficult because of low soil permeability.

As a result of capillary rise of water which carries dissolved salts from a shallow water table, even permeable
soils irrigated with good-quality water may suffer harmful accumulations of salts as the rising water evaporates. Thus, thousands of acres of once productive land in the San Luis Valley of Colorado, the most extensive sub-irrigated area in the United States, have been abandoned because salts accumulated as a result of a shallow water table.

Hilgard (2), at the turn of the century, recommended leaching as the most effective way of removing excess soluble salts from soil, and that is still the only practicable method. As Kelley (4) states, however, this process is not compatible with water conservation. If the available supply of irrigation water is spread too thin, salts may accumulate even in permeable soils where the water table is too low to present a problem.

Special tillage practices can do much to lessen the danger of salt accumulation. Farmers in the Pecos Valley of the New Mexico and Texas area have learned to cope with the salty water they must use by planting their row crops the same way they do alfalfa and small grains, without throwing up the customary beds. By that method of planting, they avoid accumulating salt in the rows, since water covers the entire field at each irrigation, and the salts are always leached downward, away from the plants.

This practice, coupled with further leaching during the winter, when no crop is on the ground and evaporation is low, serves to minimize the salt build-up that would otherwise make the land unproductive.

WATER LOGGING

The term “water logging” refers to excessive wetness of soils, caused either by slow permeability of the soil or by presence of a free water table at or near the soil surface. Most crop plants, with the notable exception of rice, cannot stand to have their roots surrounded by free water for more than a few days at a time. Salts also accumulate more rapidly in wet soils than in well-drained soils.

Water logging is such a constant hazard in irrigation agriculture that engineers generally consider irrigation and drainage to go hand in hand. There are few instances where it does not become necessary to install a drainage system within a few years after the first water is applied. Neglect of the need for drainage has led to a marked reduction in crop yields or even to abandonment of thousands of acres of land in the West. It is ironic that in the arid regions, disposal of excess water is one of the biggest problems in irrigation.

The San Luis Valley of Colorado affords an excellent illustration of how a properly controlled water table permits high yields of some of the best potatoes we can buy. But the same valley has many examples of the damage that is caused when the water table is not controlled and the soil becomes water logged.

One reason that water logging is so widespread is that it generally requires community effort to control. Excessive irrigation without regard for disposal of the water by one farmer frequently leads to water logging of the neighbor’s land as well as his own. Or, as in the San Juan Valley of New Mexico and the Salt Lake Valley of Utah, seepage problems occur on lower lying lands when farmers on higher land over-irrigate. Drainage water from the higher lands moves through the substrata to the
lower land, raising the ground water level even though the farmer on the lower land handles his water carefully. Then, too, leaky irrigation canals contribute to drainage problems in the adjoining lands. Because of this interdependence of one farmer upon another, drainage becomes a community problem and must be dealt with on a community basis.

**EROSION**

Soil erosion has two principal aspects in the arid zone, that of removal and that of deposition. Each of them is frequently destructive, but sediment deposition can be beneficial. In the Nile and Indus Valleys, for example, annual flooding deposits fine materials that represent the relatively fertile topsoil of upland areas and that serve to help maintain the productivity of the irrigated lands. McGeorge (5) noted that silt from the Colorado River was beneficial in increasing the water and nutrient-holding capacity of the sandy soils of the Yuma Mesa.

Aside from the relatively limited number of instances where sediment deposition is beneficial, soil erosion is a destructive process. Water and wind erosion on rangelands show up as deep gullies that scar the land surface, or as shifting sand dunes that are easy to identify. On irrigated lands, erosion is more insidious because it is less obvious to the casual observer. Small channels may form at the upper end of a steep irrigation furrow, but the next cultivation reshapes the furrow, and the incipient gully is covered over.

Similarly, sediment deposited at the lower end of the field may fill the furrow after the irrigation but, again, cultivation cleans out the furrow. Erosion in irrigation furrows is a small-scale replica of the erosion on arid-zone watersheds, where flash floods cut deep arroyos, then spill sand, gravel, and boulders onto the land below. The dramatic type of erosion that draws newspaper headlines is the kind that occurs when flood waters pour out of the Sandia Mountains east of Albuquerque, destroying homes en route and dropping massive sediment loads in Albuquerque and on the irrigated lands. Erosion in irrigation furrows is much less dramatic but considerably more common.

Wind erosion in irrigated fields doesn't ordinarily build up impressive dunes, anymore than water erosion is allowed to cut deep gullies. Its potential for damage, though, is demonstrated when the right combination of strong wind, exposed sandy soil, and young seedlings comes together. That's when blowing sand can cut off the seedlings at ground level as the sand blasts through the air. After the wind has died down, there may only be a little sand accumulation in the furrows, but the crop has been ruined.

Sedimentation in reservoirs reduces their water-storage capacity, and sedimentation in irrigation canals reduces the volume of flow that can be carried. There is a never-ending battle in irrigation systems to remove the silt that threatens to fill the canals. One of the principal factors that led to the abandonment of irrigation in the Tigris-Euphrates Valley in ancient times was inability to maintain the irrigation ditches that carried the life-giving water. When the canal began to fill with silt, there simply was not enough volume of flow to supply the needs of the farmers.
LOSS OF FERTILITY

Soils of the arid region, before irrigation, usually contain more plant nutrients than do soils of the humid regions. Contrary to the optimistic stories of land salesmen, however, they are by no means inexhaustible. Bountiful crops are customary for the first few years after irrigation has begun; but nitrogen deficiencies soon show up, followed by phosphorus deficiencies, if no provision is made for replenishing the supplies of plant nutrients in the soil.

The magnitude of soil depletion in irrigated lands of the U.S. is shown by the rapid increase in use of commercial fertilizers in the western states during the past 10 to 20 years. Fertilizer consumption in the 11 western states for the 10-year period from 1945 to 1955 rose from 707,000 tons to 1,650,000 tons. Arizona showed the greatest percentage increase in going from 30,000 tons in 1945 to 145,000 tons in 1955. Nitrogen and phosphorus fertilizers make up the bulk of the commercial fertilizers sold in the West. Very little potassium fertilizer is used except on the Pacific Coast. Iron, zinc, and manganese deficiencies are generally limited in extent but are locally important, especially on orchard crops.

Loss of soil fertility under irrigation can be minimized by rotating legumes with non-legumes and by applying natural or commercial fertilizers. In the Orient, where commercial fertilizers are in short supply and expensive, night soil is widely used to maintain soil fertility. Manure is customarily used for making dung cakes to use as fuel instead of being applied to the soil. Since the hand-to-mouth existence of vast numbers of farmers in Asia does not permit land to be planted to soil-building crops instead of food crops, soil depletion is common and crop yields are low. This makes for a vicious cycle, where low yields fail to bring in enough money to pay for the fertilizers or crop rotations necessary if yields are to be increased.

By contrast, better farmers in the United States feel that they cannot afford not to fertilize, an attitude that is shared by farmers of such intensively cultivated areas as the Netherlands. The cycle here is a beneficial one: good soil management leads to better yields; this makes it profitable to use even better soil management.

Of the four soil problems, loss of fertility is the one that is the most widespread and is the most limiting in crop production. Fortunately, it is also the easiest to correct, and each farmer can take care of his own problems without having to call for assistance or cooperation from his neighbor. Salinity, water logging, and erosion are much more serious because their effects can lead to eventual abandonment of land. Fertility levels may go very low, but they never reach the point where it is impossible to obtain any crop yields at all.

IRRIGATED SOILS PROBLEMS OF THE PAST

Two examples of the destructive effects of salinity, water logging, and erosion will serve to illustrate the hazards attendant upon irrigated agriculture.

In the central Tigris-Euphrates Valley, successful irrigation was practiced for thousands of years before the land was abandoned in the twelfth and thirteenth centuries A. D. Mon-
gol invaders from central Asia under the leadership of Hulagu Khan have generally been accused of destroying the irrigation system there. Jacobsen and Adams (3), however, concluded from an intensive study that the country was already devastated by the time the Mongols came on the scene in the thirteenth century. Their investigations showed that sedimentation of fields and canals, together with salinity and water logging, had become so acute that virtually the entire area had been deserted more than a century before the Mongol invasion. At most, the Mongols could only have put the finishing touches to the dissolution of the government that remained.

It is important to note that irrigation agriculture flourished in Mesopotamia for at least three thousand years. As long as a sufficiently strong central government existed to insure maintenance of drainage systems and the clearing of silt from canals, the country prospered. There is no indication that control of the soil problems was ever an insurmountable task for the ancient peoples, if they worked together.

The problems overwhelmed them only after the central government became disinterested in maintenance of the irrigation system or became too weak to enforce cooperation among the villages served by the system. Individual small communities at the lower end of the main canal, for example, did not have the resources to remove the silt from a canal more than 100 miles long. With the diminution in flow of irrigation water as the canals became silted up, salinity problems were aggravated because there wasn’t enough water to leach the soil. Lack of maintenance of the drains reduced their effectiveness, and water logging of the soils resulted. Troubles piled upon troubles, and finally the people gave up the fight.

The second example comes from North Africa. There, as Calder (1) has noted, irrigation agriculture was successful for hundreds of years, even though soil denudation was done deliberately. The purpose of clearing all vegetation from the watersheds was the same as some people recommend today: to encourage rapid and complete runoff into the irrigation reservoirs. As can easily be imagined, soil erosion was excessive when the vegetative cover was removed, and sedimentation of reservoirs and canals became a major problem.

Even so, irrigation continued for many years until the local governments became so preoccupied with the Roman wars that they neglected or were unable to maintain the irrigation system. After that, it was only a matter of time before silt filled the canals and reservoirs, and ultimately the price of ruination of the watersheds was paid in abandonment of the land.

In contrast to the failure of irrigation in Mesopotamia and North Africa, the picture is much brighter in the Nile and Indus Valleys and in China. There, where the main rivers overflow their banks periodically, irrigation has continued without interruption. Periodic flooding causes extensive damage to canals, fields, and human habitations, as well as costing many lives, but it has the merit of rejuvenating the soil when fine particles are deposited on the surface. As the flood waters subside, they leach the soil of accumulated salts, making it ready for another crop.

Under such circumstances, irriga-
tion could persist in the absence of strong central governments, but at a great cost in human lives and comfort. When flood waters are partially controlled, however, as they are in present-day Egypt and Pakistan, the soil problems become the same as they were in Mesopotamia and North Africa, and as they are in the United States.

CONTROL OF THE PROBLEMS

Applying large amounts of irrigation water to an arid-region soil has the effect of suddenly giving it an artificially humid climate. Soil characteristics that were relatively unimportant before assume a new significance under irrigation. Low organic-matter content, alkalinity, lime accumulations, soluble salts, and low permeability are typical of the valley lands, where most irrigating is done. As long as the land was not cultivated or grazed, natural selection provided a vegetative cover that was adjusted to these conditions. When man came along to upset the ecological apple-cart, something had to give.

Solution of the soil problems of irrigation agriculture requires recognition of the relations among soils, plants, and climate in an arid environment. Where evaporation is high, salt accumulation is a logical result of the application of irrigation water to slowly permeable soils. Similarly, water logging is easily understood when soils are not permeable, when water backs up above a deep, impermeable layer, or when canals are leaky. After all, the amount of water applied in most irrigated areas is upwards of 3 acre-feet per acre, and it may go as high as 15 or more acre-feet per acre.

Erosion is understandably high in the arid regions, where protective vegetative cover is scanty and rainstorms are intense. Low fertility is the natural result, in both humid and arid regions, of the removal of plant material without replacing the nutrients the plants extract from the soil. Desert soils can wear out, too.

A considerable part of the troubles that have beset irrigation agriculture in the United States is due to lack of realization that soils of the arid regions are different from those of humid regions. Settlers coming from the humid regions, accustomed to the problems there, expect that irrigating arid-region soils will make them just like soils of the wetter areas. They hear about the richness of desert soils and believe that all that’s needed is water and more water. It comes as a surprise to learn that the “unusual” problems of the humid regions are frequently the usual ones in the arid region, and that always a much greater measure of cooperation is necessary to solve them.

Fortunately, irrigation farmers are learning how to handle their soils in a way that will preserve or even increase their productivity. There are examples where soils that were deteriorating rapidly or were abandoned have been brought back to a state of high productivity. These can be found in each of the western states. Research is leading to further improvements in control measures, to development of management practices that minimize salt effects, and to selection of salt-tolerant varieties of crops. These last two points do not represent a lessening of soil salinity but rather an adaptation to saline conditions. They mean that we are learning to live with the salt prob-
lem instead of trying to eliminate it. The peoples of the Tigris-Euphrates Valley used a similar method to stave off the effect of salt by gradually replacing wheat, a more salt-sensitive crop, with barley, a salt-tolerant crop. That helped but it wasn’t enough when the salt content of the soil continued to increase.

THE FUTURE

Pessimists have contended that irrigation agriculture in the United States is doomed to failure. They point to the history of irrigation in Mesopotamia particularly, and say that it is only a matter of time before the same fate befalls us. But these pessimists overlook the fact that irrigation there was successful for thousands of years and that its failure was not due to lack of knowledge of how to cope with the soil problems. Today, with vastly improved techniques and facilities, and with continuing research, there is no reason to believe that irrigation cannot continue as long as the water supply lasts. But it must be recognized that neglect of the problems today can mean failure tomorrow.

Cooperation is necessary, which is why some people maintain that irrigation can be successful only when the government is dictatorial and forces acceptance of improved techniques for conserving soil and water resources. Whether or not the government must be dictatorial is a moot point, but there can be little question of the necessity for a community approach to the problems that inevitably arise. If research and practice go hand in hand, irrigation can be successful. Here, as in so many other aspects of our complicated civilization, human ecology assumes a dominant role, and success or failure will depend upon man’s willingness to utilize the resources at his command.

REFERENCES

CROP ADAPTATION IN RELATION TO THE ECONOMIC USE OF WATER

by K. H. W. Klages*

The relationship of the plant to soil and atmospheric moisture is complex.

Most of our crop-producing areas of the western states receive less precipitation than could be used to advantage by the crops grown. Because of limited precipitation, the physiological growing season in most of the area is decidedly shorter than the thermal growing season. While this situation is not as acute in the irrigated as in the non-irrigated areas, economy in the use of water is also a necessity in these areas.

THE GROWTH CURVE OF PLANTS

The growth curve of annual plants is illustrated in Figure 1. This figure shows the various phases of growth and the trend of the curve during each phase of development. A symmetrical curve like the one illustrated is attained only with the aid of ideal climatic conditions.

The exact shape of the growth curve is determined by the environmental factors. Figure 2 gives a curve approaching the ideal for Ceres spring wheat at Brookings, South Dakota, in 1932, Klages (5). This curve, more or less symmetrical, has a steep slope rising at the average rate of 11.01 cm. per week. The curve obtained in 1931 lacks symmetry and rises at the rate of only 5.95 cm. per week. The limiting factor in this case was low temperatures. Temperatures of 20, 22, and 21° F. for three successive weeks account for the three depressions in the curve for 1931.

The results shown in Figure 2 indicate a line of work that may well be engaged in by crops and soils investigators. Weekly measurements of plant height and soil-moisture determinations at 1 ft. intervals to a depth of 5 feet may offer many explanations to the behavior and final yields of field-test plots. With the present available equipment for determining soil-moisture levels, such as tensiometers and resistance blocks, this task is not too arduous.

The configuration of growth curves by the availability of moisture, especially during the developmental or grand period of growth, is indicated in Figure 3. This figure also provides a graphic presentation of the practical meaning of adaptation. The climatic rhythm is illustrated by curves showing the availability of moisture throughout the growing season. Adaptation is shown by harmony between the vegetation and the climatic rhythms; i. e., moisture is available at a

*Head, Department of Agronomy, University of Idaho. Published with approval of the Director, Idaho Agricultural Experiment Station, as Research Paper No. 490. Presented at the Arid-Land Symposium held at the University of Wyoming on May 6, 1959.
time when the demand for it is high. Poor adaptation is illustrated by the depressed growth curve, prematurely leveled out by decreasing availability of water with the advance of the season.

Figure 4, in addition to providing another good illustration of the meaning of adaptation, shows the role of timeliness. The growth curves of spring and winter wheats are shown in relation to the seasonal availability of soil moisture. Winter wheat, because of its establishment in autumn, gets off to an earlier start than spring wheat. The timing of its developmental phases in relation to the decreasing availability of soil moisture as the season advances is better for the winter than for the later starting spring wheat. Winter wheat shows a higher degree of correlation between its vegetation and climatic rhythms than spring wheat. This provides the primary reason for its higher yielding capacity on dryland. Winter wheat is an opportunist; spring wheat is forced to complete its cycle of growth with decidedly reduced soil moisture.

The effect of drought on the shape of the growth curve is shown in Figure 5. Low availability of moisture results in early initiation of the reproductive stage, the shortening of the post-heading period, and early maturity. These factors depress yields and influence the quality of the harvested crop.

**ADAPTATION AND CROP QUALITY**

Adaptation should not be evaluated by yield alone. The quality of the crop in relation to special uses and market demand must not be disregarded. With the present loan pro-

gram, many farmers evaluate wheat varieties on the basis of yield alone. Soft white varieties of winter wheat have been moved into the dry areas of the Pacific Northwest and have found acceptance by producers simply because they produce more than the hard red winter wheat to which these areas are adapted. The quality of the soft wheat grown in these dry areas is poor; it does not develop the qualities demanded by the bread, cracker, or pastry trade. Such wheat grown out of its area of adaptation rightly classifies as feed in that it cannot be used for any specific purpose by the trade.

**USE OF GROWING SEASON BY CROP PLANTS**

Many crops make only partial use of the growing season. Other factors being equal, the comparative yields of crops utilizing the major portion of the physiological growing season have an advantage over those crops that make only partial use of it. This is well illustrated by the comparative yields of oats and corn in the Corn Belt, Fig. 6. Oats completes its growth cycle in 16 weeks; corn uses 24. Not only does corn use a larger portion of the season, it also makes use of the most effective portion of the climatic rhythm when solar radiation and nitrification are at their heights. Combine with this the facts that corn is a larger plant with a much greater leaf surface than the small grains and that the climatic rhythm of the Corn Belt corresponds with the vegetation rhythm of this demanding plant, and you have the reason for the outstanding importance of corn in American agriculture.

In the comparison of the potential
Fig. 3

Available soil moisture and weight of plant

Time from emergence

Available moisture

Fig. 4

Available moisture and growth

Winter Wheat

Spring Wheat

Available soil moisture

yielding capacities of corn and the small grains, oats, and barley, in the Cornbelt it may be said that the small grains operate a small production enterprise active for only a short period of time and, to make matters worse, a part of this time with the handicap of material and power shortages. Production under these conditions is low. Corn, on the other hand, may be compared with a larger manufacturing plant operating for a longer period with its peak activity corresponding to the time when power and material is most abundant. The grand period of growth is favored by an abundance of solar radiation and a high rate of nitrification.

The corn plant is an opportunist in that it is able to take full advantage of all the favorable factors that the environment has to offer. The relationship of its growth demands to the soil and climatic conditions of the Cornbelt provides an excellent example of what Stahl (cited by Neger, 11) designates as converse adaptation.

North and west of the Cornbelt corn meets a rival feed crop, namely, barley. To the north the growing season is shortened by temperatures and to the west by moisture deficiencies during the summer months. The net result is that barley utilizes the physiological growing season as well as corn, and the yields attain equilibrium, Fig. 7.

Another good example of the partial use of the growing season is given by Roemer and Scheffer (14), Fig. 8. These plant breeders show the portions of the growing season used by barley at nine stations located from northern Finland south to Czechoslovakia. In the far north the plant uses 95 percent of the season as contrasted to only 60 percent of the sea-son in the southern area.

Fig. 9 offers a good example of the movement of the sugar-beet industry from an area with a short to a longer growing season. Factories at Sugar City, Idaho Falls, and Blackfoot, Idaho, were closed and the industry moved to southwestern Idaho to take advantage of the longer growing season. The growing seasons are 110 as contrasted to 149 days. The short-growing-season areas produced 15 to 17 tons per acre as compared with 25 to 30 tons in southwestern Idaho.

ECONOMICAL USE OF WATER IN RELATION TO SOIL FERTILITY

The obvious increase in the yield of corn grown under increasing levels of fertility with and without application of manure is shown in Figure 10. As is to be expected, more water is transpired per plant at the increasing levels of fertility corresponding to the increases in yield. Fig. 11 gives the data on the efficiency of use of water by these same plants expressed by the co-efficient and by the efficiency of transpiration. The plants definitely make more economical use of moisture as the level of soil fertility is increased; additional increases in the efficient use of water resulted from the application of manure (4).

The terms water requirement and efficiency of transpiration should not be confused with water utilization of plants growing under field conditions. In controlled transpiration experiments, losses of soil moisture, other than through the leaves and stems of
Fig. 7

Barley 17 wks
Corn 17 wks

Apr. 26 May 17
Aug. 23 Sept. 13

Fig. 8

- Unused Portion of Growing Season
- Utilized Portion of Growing Season

Length of Growing Season

N. Finland S. Chechoslovakia
Fig. 9

Dry Matter per Plant in grams

500
40
300
// - Manure
200
100
Low Int. High Fert. Level

Total Water Transpired per Plant – Kg.

500
400
300
200
100
Low Int. High
Soil Fert. Level

Fig. 10

Elevation
Length of Growing Season

Total Water Transpired

40
30
20
Low Med High
Soil Fert. Level
the plants grown, are prevented by
the special experimental methods
used. Furthermore, the experimental
plants are supplied with optimum
amounts of water throughout the
growing season. This happy situation
does not exist for plants grown under
dryland conditions.

Fig. 12 is based on field results ob-
tained at 9 stations in North Dakota,
Zubriski and Norum (18). Spring
wheat was grown with and without
N + P fertilization. Increases in yields
due to fertilization varied from 3.1 to
19.5 bushels per acre. The interesting
fact about Fig. 12 is that in the ma-

Fig. 11

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<th>Coef. of Transpiration</th>
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Fig. 11a

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Fig. 11b

Low Med High

Low Med High

Soil Fertility Levels

the majority of the trials the moisture re-
mainining in the soil profile, to a depth
of 5 feet, after harvest was about the
same in the fertilized and the non-fer-
tilized plots. Fertilizer did, however,
advance the maturity of the wheat;
this resulted in correspondingly ear-
lier withdrawals of moisture from the

Caution must be used in the appli-
cation of results of fertilization to the
economy in water use on dryland areas. In many areas increases in
yields and, within limitations, in-
creases in the efficient use of water
can be realized; nevertheless, the fact
remains that wheat should not be
stimulated in its vegetative develop-
ment beyond the available sources of
moisture to support the increased
growth induced by nitrogen fertiliza-
tion.

This situation is quite different
under irrigation, and especially with
the availability of an abundance of
water. Fig. 13 taken from Longe-
necker (7) illustrates the close inter-
relationship between variable levels
of soil fertility and increasing appli-
cations of water. As ranker growth is
induced by additions of nitrogen, the demand for water is increased materially. Increasing the fertility level shifts the point of highest profit toward heavier water applications. With light fertilization best results were obtained with from 25 to 30 acre-inches of water as compared with around 40 inches with heavy fertilizer applications.

RATE OF EVAPORATION FROM A FREE WATER SURFACE IN RELATION TO THE EFFICIENCY OF TRANSPARATION

No environmental factor is so closely correlated with the efficiency of transpiration as the rate of evaporation, usually determined from a free water surface. The relationship is definitely inverse; as the rate of evaporation increases the efficiency of transpiration decreases. This is well illustrated in Fig. 14, reworked from the data given by Shantz and Piemeisel (16). These investigators evaluated the efficiencies of transpiration of a large number of crops by their water requirements. The data for four crop plants were calculated in terms of efficiency of transpiration and presented in that form in Fig. 14. The inverse relationship between rates of evaporation and the efficiency of transpiration for the four crops over a period of seven years is evident. As the evaporation increases, efficiency in water use decreases, and likewise, as the rate of evaporation decreases, the efficiency of water use increases.

The above relationship, as also the fact that efficiencies in water use decrease with higher temperatures and
Fig. 13
Well-Drained Loams and Sandy Loams

Inches of Water Per Acre

Cotton Yields

150-200 lb N/Acre

80-100 lb N/Acre

40-50 lb N/Acre

x = greatest net return

Fig. 14

Crops and Seasonal Evaporation - in inches

Efficiency of transpiration

Sorghum

50" Corn

Evaporation

40"

Oats

Alfalfa

30"

1911 1913 1915 1917
reduced humidity of the air surrounding the plants, offer one of the real challenges to the agricultural utilization of land in semiarid and dry areas. These areas receive less water than the humid regions; at the same time plants produced in the dry areas with the associated higher evaporation rates, lower atmospheric humidity, and usually higher daytime temperatures demand a significantly higher rate of transpiration and water loss than plants growing in humid areas. That is, the efficiency of water use by plants growing in dry is less than for those growing in humid areas. This case of having less and being called upon to spend more poses the most important problem in the wise use of our dryland areas. It provides the reason why many practices commonly used in humid areas must be modified before they can be used to advantage on the drylands of our western states.

Organic-matter additions plus the favorable physical soil modifications resulting from the inclusion of grass crops in a system of cropping are as important in dry as in humid areas. The question is how much moisture may be expended on the production of the grass crops. Fig. 15 illustrates the point. Sweet clover was grown at the Tetonia, Idaho, Branch Experiment Station to varying heights of from 6 to 36 inches. The weight of the sweet clover returned to the soil increased significantly with the increase in height of the plants, but so did the amount of water withdrawn from the soil. According to Siddoway and McKay (17) under the conditions at Tetonia (13 inches of annual precipitation), sweetclover green manure must be plowed early in the fallow year, when from 6 to 12 inches high, depending on average annual rainfall. If allowed to grow beyond this stage, soil moisture is depleted materially. A young, good stand of sweetclover contains a considerable quantity of nitrogen. Under dryland conditions, it is safer to plant the crop more frequently in the course of the rotation and return it to the soil early in the season rather than to allow it to make an abundant growth and deplete the soil-moisture reserves.

**AIR HUMIDITY IN RELATION TO WATER REQUIREMENT**

Since the humidity of the air influences evaporation rates, it is to be expected that increasing dryness of the air increases transpiration losses. Other conditions being equal, the amount of water lost is proportional to the moisture deficit of the air in contact with the plants. Fig. 16, Briggs and Shantz (2), shows that the water requirements of all plants compared were higher for the plants grown in dry than in humid air. Theoretically, the efficiency of transpiration is inversely proportional to the moisture deficit.

**AIR TEMPERATURE IN RELATION TO WATER REQUIREMENT**

Fig. 17, Briggs and Shantz (2), shows that the water requirement of cool-weather crops is approximately doubled in the warm (27° C.) house, while that of the warm-climate crops is greatly increased in the cool (10-18° C.) house. Deviations from the optimal temperature demands of the plants tested resulted in reduced efficiencies of transpiration.
Fig. 15

Available Moisture - Inches

Inches of moisture

Clover Wt.

Lbs of Sweet Clover - Dry Basis

0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300

Water Requirement

Kub Wheat
Barley
Spr Rye
Oats
Alfalfa
Corn
Millet
Sorgo
Rice

Air Humid
Air Dry

Fig. 16
Here again we are dealing with an adverse factor met with in the production of crops in dry areas, where both the temperature and the saturation deficit of the air during the day are generally high.

It is also evident from the data given by Briggs and Shantz that only plants adapted to an area can be expected to make efficient use of available water. Conditions must favor the attaining of high yields. The evaluation of the efficiency in the use of water is based on the ratio of dry matter produced to water transpired. Both parts of this ratio enter into this evaluation. Any condition inordinately increasing the rate of transpiration as well as any factor, or combination of factors, interfering with the elaboration of dry matter, or attainment of yield, widens the ratio and thus decreases the efficiency of transpiration.

**MOISTURE STRESS AND IRRIGATION**

Numerous experimental results could be cited to show that maximum production of irrigated crops is obtained where soil moisture is maintained at or near the optimum moisture content of the soil for the entire period of growth. To achieve this objective would require applications of water at frequent intervals. This not only increases the cost of production but also results in poor water economy.

Fig. 18, Meyers et al. (10), shows the response of Pinto beans at the Twin Falls, Idaho, Branch Experiment Station to four methods and three frequencies of irrigation. The methods refer to the application of water to different rows. The frequencies are designated as short, medium, and long. In the short treatment, irrigation water was applied when about one-half of the available soil moisture in the root zone was depleted. The medium-treatment plots received water when around two-thirds of the available soil moisture was depleted. Water was not applied to the long-frequency treatment until the plants showed a marked visible drought stress or approached the wilting point.

While significantly greater yields of beans were obtained in the method where water was applied in every row at each irrigation rather than in every other row, the real significant differences were obtained between frequencies of irrigation—26.4 for the short, 22.4 for the medium, and only 16.3 cwt. of beans per acre for the long frequencies.

The seasonal consumptive use of water for the three frequencies showed large differences. The consumptive use for the short frequency was 13.09, for the medium, 8.68, and for the long, 4.19 inches.

Fig. 19 gives the daily consumptive use of water by Pinto beans for the three frequencies of irrigation.

Maximum yields are the objective of most crop producers; however, they may not always be the most economical from the standpoint of labor costs or of economical use of water. In areas where shortage of irrigation water is a factor, necessary economies in the use of water may have to be resorted to for the attainment of maximum yields for the land and water resources available.

Luxury consumption of water is to be avoided; it is wasteful from the standpoint of additional labor involved and certainly uneconomical.
### Figure 17

Temperature

- Cool 10-13°C
- Warm 27°C

### Figure 18

Irrigation Methods and Yields of Dry Beans - Cwt per A

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from the standpoint of water use. Fig. 20 illustrates luxury use of water by oats. Oats is capable of consuming large quantities of water. According to Mayer (cited by Prjianischnikow (13), oats produces its maximum yields at 90, wheat at 80, rye at 75, and barley at 62 percent of the water-holding capacity of the soil.

Leamer (6) gives a good example of plant response to moisture stress on the fruiting of cotton measured by number of squares developed. Ample moisture throughout the season resulted in the largest number of squares. The rate of setting new squares drops as soon as moisture stress develops. Once plants have been subjected to stress, the rate does not increase as soon as the stress is relieved. The plants which were dry early in the season but received ample water during squaring produced no more squares than those under severe stress during this period. Periodic moderate stress also keeps the fruiting rate down. These points are illustrated in Fig. 21.

Kezer and Robertson (3), in addition to investigating the response of spring wheat to irrigation during its various phases of development, report that light applications of water distributed through the growing season gave best results but are impractical.

Von Seelhorst and Tucker (15) indicated the need of moisture by cereals, especially during jointing, flowering, and the early filling stages. Where definite critical periods in the development of a crop are established, as in the tasseling and silking stages of corn, or the jointing stages of the small grains, the water demands during these periods must be satisfied if high yields are to be realized.

PLANT PROTECTION AGAINST EXCESSIVE LOSS OF MOISTURE

Maximov (9) gives a simple definition of xerophytes as plants capable of enduring without injury a prolonged period of drought. Nevertheless, even after defining the xerophytes in simple terms, Maximov makes the statement that "an examination of the physiological, anatomical, and morphological peculiarities of xerophytes leads us to the conclusion that the same results, i.e., adaptation to life in dry habitat, may be attained in diverse ways."

Only two examples will be given to show that crop-plant varieties differ in their abilities to retain or at least conserve their moisture contents under conditions of stress. Bayles et al. (1) gives the rates of water lost from spring wheat plants upon being removed from the soil. These plants were grown to an age of 11 weeks in a greenhouse under optimum soil-moisture conditions. Fig. 22 shows the percentage of water remaining in the plants after the number of hours of drying indicated.

A difference in the behavior of the varieties tested is evident. Baart has a well-earned reputation for drought resistance. Ceres has fair resistance. Hope and Hope crosses were notoriously poor performers under dry conditions.

Fig. 23 shows the results of the same type of experiment with winter barley variety seedlings four weeks old. Idaho Club and Dicktoo plants retained their moisture distinctly better than Tennessee Winter and the spring barley Trebi. These differences in performance may be accounted for by
Fig. 19
Frequency of irrigation and daily use of water by beans.

Fig. 20
Luxury Consumption of Water — Oats

Water Holding Capacity of Soil

Consumption of Water — Oats
Fig. 21

1 - Ample moisture all season
2 - Dry after blooming started
3 - Dry emergence to first square
4 - Dry first square to first bloom
5 - Moderate stress between each irrigation

Fig. 22

% of water remaining in plants

Exposure of plant in hours.
variations in the cutinization of the leaves, the size of the plant cells, size differences, and the number of stoma-ta. Drought resistance is closely correlated to winter-hardiness and to the quantities of hydrophilic colloids. Newton (12) and Martin (8) showed that relative quantities of hydrophilic colloids measured as bound water were associated with the winter-hardiness of certain varieties of wheat.

**SUMMARY**

Economy in the use of water demands above all the adaptation of the crop to the area where it is to be grown. An unadapted crop cannot make efficient use of water. The vegetation and the climatic rhythms must be in harmony, if not for the entire growing season, then at least for the portion of the season utilized by the crop to be grown.

Information is needed on the adaptation of crops to the varying moisture conditions encountered in our western states. One method of obtaining this needed information is to plot and study the growth curves of selected plants in relation to soil-moisture availability throughout the growing season.

Most of the water absorbed by plants is spent. One of the chief problems confronting dryland plants is not to allow them to spend more water than they absorb. Becoming liable to too great a water deficit spells disaster. This situation becomes acute in the dryland areas, where annual receipts of moisture are not only less than in humid regions, but where environmental conditions conspire to demand greater expenditures of the more limited moisture available for absorption.
The environmental factors responsible for the greater expenditure of moisture under dryland than under humid conditions are the greater saturation deficit of the atmosphere, the greater solar radiation, higher daytime temperatures, and greater air movement. All of these factors increase rates of evaporation from a free water surface as well as transpiration losses from exposed plants.

Under the best of conditions, plants transpire large quantities of water in the production of relatively small quantities of dry matter. This ratio is wider in dry than in humid areas. Since the dryland farmer is definitely limited in altering the environmental conditions that establish rates of transpiration and evaporation, his most promising recourse is to establish conditions favoring the production of high yields. In other words, being confronted with the important ratio of dry matter produced to water transpired, the producer realizes that little can be done to reduce transpiration losses, so he directs his efforts to increasing the yields of his crops.

The attaining of as high yields as the environment may permit is attempted by means of establishing the best sequence of cropping, by improved tillage, fertilization, etc. Monoculture is a common practice in dryland areas. The sequence of cropping is designed to provide the best possible conditions for the main income crop. Tillage methods are modified to enable the trapping and holding of moisture for future use and to provide maximum protection to the cash crop. Varieties are selected to provide the best possible adaptation.

Needs for the economical use of water are by no means confined to the drylands; they also present challenging problems to crop producers on irrigated areas. Even humid areas are visited by periodic droughts.

The irrigated areas are beset with many problems centering on the development and maintenance of our land and water resources and on putting these closely related resources to their best possible uses. Economies in the use of water are vital. They may best be realized by combining the wise use of water with good crop and soil management. This is shown graphically in Fig. 24, taken from Longenecker, who states that irrigated cotton yields are determined (a) by ample fertility, plus (b) ample moisture, plus (c) good soil physical conditions, plus (d) adequate control of diseases and insects, and finally, plus (e) good climatic conditions.
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During the past 25 years major efforts have been made to improve a vast acreage of semiarid and arid rangeland in southwestern United States. The area considered here extends from the plains of eastern Colorado and extreme western Kansas southward to the Trans-Pecos area in Texas and the southern portion of New Mexico. While considerable progress has been made, particularly in developing techniques and methodology, the major portion of these rangelands still is producing substantially less than its presumed potential. A more comprehensive understanding of the ecology of these rangelands would help in further developing locally adaptable measures for range improvement.

PAST ECOLOGICAL STUDIES

Basic ecological research studies dealing specifically with the nature of natural plant communities within the area are but few in number. Several generalized ecological classifications and maps have been developed.

As a part of their classification of the vegetation of the United States, Weaver and Clements (10) classified the vast majority of this area as a part of a Grassland Formation subdivided into Mixed Prairie and Desert Plains Grassland Plant Associations. Following concepts developed by Clements, each association represented a climatic climax characterized by certain climax-dominant species. Existing plant communities in which these species were not dominant were considered as disturbance climaxes or one of a series of developmental plant communities. Varying patterns of primary or secondary succession would ultimately result in plant communities closely resembling that of the climatic-climax plant association. Based on this concept, the approximate northern two-thirds of the area was considered Mixed Prairie, characterized by a mixture of shortgrasses and midgrasses. The existing vast acreage of shortgrass represented a disturbance climax due to the removal of midgrasses by grazing. Extensive stands of brush in portions of the Desert Plains Grassland were thought to be a post climax attributable in large measure to past grazing use.

Shantz (8) did extensive vegetative mapping in this locality. While recognizing plant communities resulting from disturbance, he more nearly accepted existing plant cover at its face value. He mapped and described a number of existing plant communities as relatively stable plant associations characterized by the currently most abundant plant species. Some
of the areas classified by Clements as grassland were considered as brushland by Shantz.

Quantitative research studies in this area dealing specifically with the ecology of plant communities are limited in number. Among these are the studies of Campbell, Costello, and Gardner.

Campbell (1) studied successional stages of clay soils on the Jornada Experimental Range in southern New Mexico. He described several successional stages culminating in tobosa grass (*Hilaria mutica)* as the most important climax dominant on such soils. Gardner (4) studied the vegetation of the lower half of the Rio Grande Valley in New Mexico. He considered this area as a portion of the Desert Plains Grassland, with black grama (*Bouteloua eriopoda*) and its associates dominant on the uplands, and tobosa grass and its associates dominant in shallow swales. He considered the present shrub dominance in portions of this area a grazing disclimax or, under certain conditions, a stage in primary succession. Costello (2) studied the shortgrass vegetation in the vicinity of Nunn, Colorado, and described a shortgrass type in eastern Colorado. Here he considered blue grama (*Bouteloua gracilis*) as the dominant species, and buffalo grass (*Buchloë dactyloides*) as an important secondary species. Various midgrasses were relatively abundant in wet years but became inconspicuous in dry years.

Some of the ecological studies of Weaver and Albertson (9) and their associates extended into portions of this area. That portion of these studies dealing with the nature of plant communities corresponds to the classification system described by Weaver and Clements.

**NEED FOR MORE SPECIFIC ECOLOGICAL GUIDELINES**

Rangelands in the semiarid and arid regions of Southwestern United States pose some unique problems in ecology and in the development of applicable range-management and improvement measures. These problems are due primarily to climatic limitations. Low annual precipitation, recurrent drought, strong winds, high temperatures, and high evaporation rates contribute to low and unpredictable levels of effective soil moisture as compared with more humid and cooler climates. A significant amount of the total annual precipitation occurs in the form of light showers that frequently are dissipated without contributing to effective soil moisture, or as torrential rains that result in high run-off and low water-intake rates. Levels of herbage production and plant-residue accumulation are inherently low. These physical limitations materially extend the time required for range recovery following deterioration. They also modify, or, in some instances, exclude the adaptation of certain range-improvement practices that have been successfully employed under more favorable environmental conditions.

Principal management practices advocated included stocking in accordance with predetermined grazing capacity, various forms of deferred and rotation grazing, and seasonal graz-
ing use. Range-improvement practices grouped themselves into those intended primarily to facilitate livestock handling and distribution, and those intended to improve on-site forage quantity or quality. Principal handling and distribution practices were fencing and stockwater development. Primary forage-improvement practices included artificial range reseeding, brush control, erosion-control structures, and waterspreading.

While a significant number of these measures and practices were successfully installed and maintained in such a manner that they served their objective, there were also a number of failures in the case of certain practices. In the case of management practices these were due in part to (1) failure of some rangeland operators to stock their rangelands in accordance with proposed stocking rates, and (2) major variations in annual forage production which largely offset benefits anticipated from adherence to a rigid predetermined grazing capacity. The need to adjust stocking rates in accordance with available forage supplies soon became apparent.

Failures in artificial range reseeding were due in part to (1) lack of adequate methodology, and (2) over-optimism as to the adaptability of species. There was a tendency to seed species with mesic requirements on xeric sites, lowland species on upland, and cool-season species in essentially warm-season habitats. Seed sources were frequently from strains grown at distant latitudes and longitudes and in different environments. Major emphasis was on exotic species whose precise environmental requirements in this country were not fully determined.

Failures of mechanical measures aimed at erosion control, water retention, or waterspreading were due in part to (1) installation on improperly selected sites or soils, (2) improper maintenance, and (3) failure to obtain degrees of grazing use that would result in the kind of vegetative stabilization essential to the continuing function and lasting benefits anticipated from such measures.

CURRENT TRENDS IN RANGE MANAGEMENT AND IMPROVEMENT

Currently there are widely divergent opinions as to how range resource improvement is to be attained. Some contend that the inherent productivity of these range lands is so low that little is to be gained by managing them on the basis of perpetuating or improving the native vegetation. Advocates of this concept would modify sites and existing cover by such means as fertilization, tillage, and substitution of non-native vegetation to such a degree that management based on the ecology, and particularly on the secondary succession of native vegetation, would have limited application.

Others would manage these lands with the objective of improving existing native vegetation but without considering concepts of climax vegetation and principles of secondary succession as essential to such management and improvement. Any relatively productive vegetation, regardless of its natural ecological status, would be acceptable. The inherent climax plant-community would have no essential status either as a management objective or as a guideline to evaluation of direction in changing range conditions.
Those that would base range resource use and management on the ecology of natural plant-communities also propose divergent theories. Some conflicting viewpoints involve (1) monoclimax versus polyclimax concepts, (2) continuums, population patterns, or environmental gradients as opposed to discrete homogeneous plant communities, and (3) predictable patterns of secondary plant succession as opposed to an indeterminant and accidental grouping of plants.

It is recognized that such widely divergent viewpoints are to be expected in a phase of plant science dealing with factors as variable as those responsible for existing natural plant-communities. It is also thought that, despite these conflicting viewpoints, there is sufficient knowledge to effectively use ecological concepts of plant succession and climax plant-communities as an effective guideline to wise range-resource use and management. One such method based on this premise is currently being used by the Soil Conservation Service of the U.S. Department of Agriculture in its program of providing technical assistance to soil conservation districts (3, 5, 7).

This method involves the determination of range site and range condition as a prerequisite to the development of ranch conservation plans by individual ranch owners or operators. Range sites are defined as kinds of range land that differ from each other in their ability to produce a significantly different kind or amount of climax or original vegetation. Range condition, as used here, is an expression of the present state of the vegetation in relation to climax conditions for a specific range site. Range-condition classes, designated as excellent, good, fair, and poor, are used to express the degree of departure from climax for a given site.

In effect, a range site is a local area of land of indeterminate size in which the physical environment is sufficiently homogeneous to have the potential for the development of a distinctive climax plant-community. The nature of these essentially physiographic and edaphic climax plant-communities, as well as those plant-communities representing a departure from this climax, is determined by intensive field evaluation of relict and near-relict areas and of numerous grazed pastures that contain the specific range site involved. While a site is a product of the total physical environment, it can generally be characterized by distinctive soils and topography within a local segment of climate. Thus, moderately deep clay loam soils with gentle relief in an area of eastern Colorado having from 14 to 16 inches' annual precipitation support a climax plant-community dominated by blue grama grass with buffalograss as an important secondary species. Midgrasses such as side-oats grama (Bouteloua curtipendula) are insignificant on this site. Within the same area deep, loamy sand soils support a climax plant-community dominated by tall and midgrasses such as sand reedgrass (Calamavilfa longifolia), sand bluestem (Andropogon hallii), and little bluestem (Andropogon scoparius).

Again, in the same local area, moderately deep upland clay soils have climax plant-communities characterized by mixtures of blue grama and western wheatgrass (Agropyron smithii). Extensive field evaluation indicates that there are approximately 10 distinct range sites each capable of
producing distinctive climax plant-communities in this localized section of eastern Colorado. It is realized the environmental factors for each site are subject to local variation and graduation. Consequently, a reasonable degree of latitude is allowed in describing climax plant-communities. A discrete plant-community with a precisely defined composition for each component species is not envisioned.

Range sites, carefully determined by evaluation of local environments, particularly climate, soil, and topography, provide a valuable guide to the management and use of rangelands. Coupled with an evaluation of range conditions, they aid in establishing management goals, in determining whether range condition is improving or declining, and in assessing prospects for range recovery by means of management. While each site, unless it has been subjected to rather severe physical deterioration, is deemed capable of supporting a distinctive climax plant-community, the attainment of this climax is not of necessity an immediate or prospective management objective. For various reasons the management objective may be the maintenance of plant-communities representative of successional stages below the climax. Evaluation of range site and condition provides valuable information concerning the applicability of various range-improvement practices such as range reseeding, brush control, erosion control, and waterspreading. It also helps to select those areas of land which can, with present methodology, be successfully converted from native vegetation to introduced grasses and legumes for the purpose of meeting specific seasonal forage needs of individual-ranch operating units.

The Soil Survey Division and the Range Conservationists of the Soil Conservation Service participate in joint fieldwork aimed at developing mapping techniques and mapping units that will facilitate the identification, description, and delineation of range sites on non-federal range lands. Particular emphasis is being given to those factors of the soil and physical environment that result in significant differences in plant and soil-moisture relationships. The soils contained in each range site are identified. The classification and detailed description of these soils are included in published soil-survey reports.

It is realized that locally adapted ecological research dealing with the nature and ecological status of natural plant communities is lacking in much of the semiarid and arid rangelands of southwestern United States. Additional research of this kind undoubtedly will be of value in improving the quality of existing criteria for range management and improvement practices in this portion of the United States.

SUMMARY

1. During the past 25 years there has been major intensification of programs and practices aimed at improving semiarid and arid rangelands in southwestern United States.

2. While many range-management and range-improvement practices have been successfully carried out, there has been a significant number of failures, particularly with certain practices. These failures are due to a number of factors. One of these is believed to be the
lack of a comprehensive understanding of the ecology of these rangelands.

3. Basic ecological research studies concerned specifically with the nature of natural plant-communities within the area are few in number. Earlier ecological classification and descriptive mapping provides some valuable information but is too generalized for specific guidance of range-improvement programs at local levels.

4. The range-site-and-condition method of evaluating rangelands provides essential ecological guidance to the development and application of range-management and range-improvement plans and practices.

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CONSERVATION OF IRRIGATION WATER

SUPPLIES IN ARID CLIMATES

by Lloyd E. Myers, Jr.

Irrigated agriculture has been historically associated with arid and semiarid environments. Such environments are generally defined by annual rainfall, which in time or amount is not adequate for the reliable production of crops other than rangeland forage. Under these conditions irrigation is necessary for development of a stable agricultural economy. That of many western states is based on irrigation, and income from irrigated lands contributes materially to the economy of all the 17 western states. Irrigated lands in these states exceed thirty million acres; the annual value of crops and forage produced is in the order of three billion dollars.

Irrigation is the artificial application to soil of the water needed for plant growth. Before such water can be applied, it must obviously be obtained, and so the first requisite for irrigation is a reliable water supply. Early irrigation projects in the United States merely diverted water from perennial streams. The acreage which could be irrigated was generally determined by the lowest flow which occurred in the stream during the year.

Increased demands for irrigation water by new farmers moving into the irrigated areas required the planning and construction of facilities for storing water during periods of high stream flow for later use during periods of low stream flow. Natural resources, including water, seemed inexhaustible; if water was not available in one area, people could move to another area where water was available.

The West was settled by pioneers who came for the golden promise of new and limitless opportunities based on new and limitless lands, water supplies, and other resources. The idea that these resources should ever be limited was generally unpopular and not acceptable. We have now seen the end of that philosophy and of that pioneering era in water-resource development. It has become painfully obvious in recent years that new water resources are not readily available. We are in the beginning of a new era in which we must make the best use of what we have. Conservation and efficient use of available water resources are not only desirable; they are mandatory.

Water-supply problems in the arid and semiarid regions of the United States have been intensified at an accelerated rate by the fact that many hundreds of thousands of our citizens have decided that they prefer to live in arid or semiarid environments. Populations in such areas are expand-
ing at an explosive pace. These new residents must have water for drinking, sanitation, and watering lawns and gardens. Many industries have decided that arid and semiarid environments are most favorable for their operations. These industries also must have water.

When new people and new industries move into an area in which all the water supplies have previously been developed for use by irrigated agriculture, agricultural water supplies are appropriated for municipal and industrial use. Increased appropriation of existing water supplies by municipalities and industry, the development of new irrigated lands without the development of new water supplies, deliberate mining of underground water supplies, and other related factors have all resulted in rates of use in many areas which exceed the safe yield of available water resources. California, for example, is pumping about five million acre-feet of water annually in excess of the safe ground-water yield. Water tables in the Salt River Valley of Arizona are falling at the rate of from eight to ten feet a year. Similar problems exist or are developing in many other areas.

Irrigated agriculture indeed must now compete with municipalities, industry, and other users for the use of water supplies which are now in existence or which will be developed in the future. The cost of developing new water supplies is now so high that project justification must ordinarily include the assumption that a considerable portion of the developed water will be sold to industries or municipalities at a price higher than the price now paid by irrigated agriculture. It appears quite certain that all long-range planning must assume that the total quantities of water available for irrigated agriculture will decrease.

This means that irrigators must plan to use less water in the future and must take positive steps drastically to reduce all waste and avoidable losses. The potential for improved water use and conservation is great. At the present time about 70 percent of the water diverted for irrigation is not available for crop production because of storage, conveyance, and application losses. Improvement of the existing situation will not be easy, for corrective measures are often expensive, and in many cases the required information is not yet available.

Irrigation in arid and semiarid environments is necessarily accomplished by the transfer of water from high-precipitation mountainous areas to low-precipitation agricultural areas through use of natural and artificial channels and storage structures. At present only a very small percentage of the total precipitation on the watersheds reaches the stream channels to become available for use. Most of the total precipitation is consumptively used by evaporation and transpiration in the watersheds.

An obvious source of increased water supply would appear to lie in the development of methods or practices for vegetation management and soil treatment to decrease evaporation and transpiration and to increase runoff. The issue is complicated by the need for considering multiple use of watersheds for cattle grazing, timber production, recreation, and other uses in addition to the production of water for lower lying lands.

Watershed research is extremely complex and must consider many fac-
tors, including the interesting possibility that some changes in vegetative cover may alter energy-balance relationships in such a manner as actually to reduce precipitation. Investigations concerning watershed management to increase water yield must be considered to be in preliminary stages, but the preliminary results are encouraging. The day is fast approaching when management programs will be planned to include improved water yield in addition to other presently accepted watershed uses.

Water flowing from the watersheds in natural stream channels is depleted by evapotranspiration associated with tamarisk, willows, cottonwoods, greasewood, and other phreatophytes. Non-beneficial use by such vegetation is estimated to exceed 25 million acre-feet of water annually in the 17 western states. From a water-supply standpoint this use is essentially waste, and eradication of much, although certainly not all, of this vegetation is desirable from a water-conservation standpoint.

Unfortunately, from this point of view, most of these plants are very well adapted to survival under environmental conditions which are generally most unkind to plant life. Through such adaptation they have developed a tenacity to life which makes their eradication difficult and expensive. The search for less expensive control methods, such as selective disease organisms, continues. Channel lining and drainage to lower water tables are other means of salvaging non-beneficial evapotranspiration which will see increasing use in the future.

Water stored in surface reservoirs is subject to loss through evaporation. It is estimated that annual loss exceeding 6 million acre-feet occurs from man-made reservoirs in the 17 western states. Great interest has recently been aroused in the potential use of materials such as cetyl alcohol for reducing evaporation by maintaining monomolecular films on water surfaces.

Evaporation reduction on the order of 20 percent appears possible on small reservoirs, but satisfactory methods have not yet been developed for maintaining such films on large reservoirs. Some chemicals other than cetyl alcohol seem promising, and the use of floating plastic films appears feasible on small ponds where reduction of evaporation is of great importance. Existing methods for evaporation control are expensive and cannot ordinarily be justified under present conditions. When the value of water becomes sufficiently great, evaporation control can and will be accomplished.

Irrigation-water supplies are frequently obtained by pumping from buried sand and gravel aquifers which form natural reservoirs under the lands being irrigated. These aquifers are commonly buried under deposits of silt and clay which restrict the natural downward movement of water into the reservoirs. Replenishment, or recharge, commonly occurs at points where the aquifer material intersects the ground surface and where overlying restrictive materials are absent.

When natural recharge of such reservoirs occurs at a rate lower than the rate of use, some means of artificial recharge must be developed to alleviate the problem. Clay deposits overlying aquifers in the areas associated with the High Plains of
Texas prevent about 99 percent of the rainfall from percolating downward to the aquifers. A considerable amount of the rainfall is lost through evaporation from playa lakes. Artificial recharge can be accomplished in this area by using existing irrigation wells to inject water from the numerous playa lakes through the restricting layers of clay directly into the aquifers.

Artificial pits and shafts can be used to inject water into aquifers where overlying restrictive layers are shallow. In some areas artificial diversion of water onto natural recharge areas is practiced. All artificial-recharge operations must consider the necessity for protecting the recharge structures against deterioration through sedimentation, micro-biological activity, salt deposition, and other potentially harmful phenomena. Contamination of the aquifers must be prevented.

Increasing attention is being given to the practice of artificially recharging natural underground reservoirs. For example, the California water plan calls for recharging underground reservoirs in the Central Valley with over 16 million acre-feet of water annually during good water-yield years.

Use of underground reservoirs has a number of advantages from a water conservation standpoint. Evaporation from such reservoirs is usually negligible, and conveyance problems are greatly reduced. Artificial recharge of underground reservoirs also has good potential for providing methods for utilizing municipal, agricultural, and industrial waste waters, flood flows, and other intermittent or unpredictable water supplies which are ordinarily wasted.

Seepage losses from artificial conveyance channels have long been recognized as a serious problem in the conservation of irrigation-water supplies. The 1950 United States Census of Agriculture reported that the total conveyance loss in the 17 western states was in excess of 20 million acre-feet. These losses included only those reported by irrigation enterprises and do not include losses from farmstead conveyance systems. Correction of seepage problems is made difficult by absence of satisfactory methods for measuring seepage loss and by absence of any inexpensive methods for controlling seepage.

There is no one lining material which is truly satisfactory under all site conditions. Plastic films, asphaltic membranes, bentonite, and many other materials have been and are being investigated in attempts to develop good, low-cost lining materials. Some of these materials perform satisfactorily under favorable site conditions but cannot yet be considered suitable for general use. Concrete is presently the most generally satisfactory lining material, and great strides have been made in reducing installation cost. Ingenious methods for casting buried concrete pipe in place at reasonable costs have been recently developed.

The design and construction of satisfactory canal lining installations must consider plant and animal environmental factors as well as the ordinarily considered factors of climate, soil, and water quality. For example, crayfish, muskrats, gophers, and certain types of plants can seriously damage non-rigid canal linings. Most canal linings are installed at present to provide greater ease in operating the distribution system or to correct drainage problems rather than to con-
serve water.

When it is considered that the average cost of irrigation water in many western states is considerably less than $1 per acre-foot, it can readily be seen that water conservation is usually not a major reason for installing canal linings. Increased competition for available water supplies is certain to increase charges made for water. When charges for irrigation water begin to equal the true value of the water, canal lining to conserve water will become a common practice.

Irrigators commonly apply water to individual fields with an efficiency averaging less than 50 percent. This means that on an average basis about half the water delivered to the field is lost through surface runoff from the field or through downward percolation beyond the root zone. The quantity of water lost in this process has been conservatively estimated as exceeding 30 million acre-feet annually for the 17 western states.

Some of this loss occurs because of poor practices or carelessness on the part of the irrigator, but much of it occurs because he has not been provided with the information or the equipment needed to accomplish efficient irrigation. His irrigation systems are presently designed on a trial-and-error basis. Satisfactory methods for measuring soil moisture are not available to him. He has not received information permitting him to determine the rate at which his soil moisture is being depleted. He has not been provided with a satisfactory device for measuring the irrigation water he applies. Prospects for increasing efficiency in water application are good, but a considerable amount of new and improved information must be developed.

Reducing the amount of water consumed through evapotranspiration from irrigated fields has always been an intriguing possibility and has received considerable attention from research workers. Variations of fertility levels, soil-moisture levels, and scheduling of water applications have been tried, and some research results have been reported which appeared favorable for increasing the amount of crop produced per unit of water applied.

Possibilities for conserving water by reducing evaporation from bare soil in irrigated fields appear promising. Experiments in which thin plastic films were used to cover the soil surface not occupied by plant stems have indicated that substantial reductions of water use may be obtained. Such plastic film mulches also appear favorable for increasing both quantity and quality of certain vegetables and fruits. It seems probable that plastic films will ultimately be widely used to conserve water in the production of high-valued crops grown in arid regions, where water supplies are short and water costs are high.

Opportunities to improve and conserve irrigation-water supplies and to increase the efficiency of their use are numerous. It has been estimated that approximately 25 million acre-feet of water is lost annually to non-beneficial use by phreatophytes in the 17 western states. Approximately 6 million acre-feet evaporates from artificial reservoirs, over 20 million acre-feet is lost through seepage from artificial channels, and approximately 30 million acre-feet is lost in the process of applying water to irrigated fields. These are not all net losses, for re-use of initial seepage and deep percolation losses is a common prac-
tice. Total reduction of some other losses, such as evaporation, cannot be expected.

A conservative estimate of net losses which can be reduced would appear to be in the order of 50 million acre-feet annually. A 20 percent reduction of these losses would increase usable agricultural water supplies by 10 million acre-feet. Substantial increases can also be realized by other means such as increasing runoff from watersheds and reducing evaporation from irrigated fields. The development and utilization of these real and substantial opportunities can result in solution of many agricultural water-supply problems.

The growing severity of irrigation water-supply problems has resulted in increasing attention to these problems by many responsible agencies, groups, and individuals. State agricultural experiment stations, irrigation districts, state and federal agencies, farmers organizations, and other groups are devoting increased attention to the conservation and efficient use of agricultural water supplies. The Agricultural Research Service has very nearly completed construction of the Southwest Water Conservation Laboratory at Tempe, Arizona, which will devote its entire research effort to solve agricultural water-conservation problems.

The future of irrigated agriculture in our arid and semiarid regions is far from gloomy. Radiant and advective energy available to plants is greater under arid and semiarid environments than under humid environments. Better control of the crop environment and better planning of farming operations are ordinarily possible, which means that a wider choice of crops to be grown is also possible. Irrigated agriculture in most of our arid and semiarid areas has great potential for highly efficient crop production. This great potential, combined with the solution of present water-supply problems, can and will make certain the continued large-scale practice of efficient irrigated agriculture in arid and semiarid environments.
In discussing genetics and plant breeding in the Southwest there is similarity to genetics and plant breeding in other areas. Certain environmental conditions may differ, yet the principles of inheritance and the use of the gene in improvement are the same.

Man, in addition to using improved varieties of crops, has modified the environment by improving soil fertility, irrigation, cultural methods to minimize competition, and tailoring his crop to meet new harvesting methods. He has tried to control the environment to meet his needs. Breazeale (1) states, "A plant, like a fine watch, is an intricate system of interlocking parts. Every part is adjusted to, and is coordinated with, every other part, and the whole is so accurately regulated that it may be considered a unit. Like a watch, a plant must be regulated in all positions. An accurate coordination of parts in one position does not necessarily mean coordination in all positions."

A plant is finely and accurately adjusted in its native habitat only, and this adjustment is the result of long ages of adaptation. Change in environment such as increasing the nutrition level may eliminate the plant through inability to compete with other species better able to take advantage of the changed environment. A good example of this is the effect of high fertility level (400 N) on a sedge/rush meadow. In one year the composition of the sward changed from about 85 percent sedges and rushes in the composition of the sward to over 55 percent wild and introduced species of grasses in the following year.

Since the dawn of history, man has always had to struggle for existence and to find a means of producing food and clothing. Up until recent times this was a less serious problem because, as the population increased, new land was developed for production of food and fibre. Since less new land is now available, improved methods and improved crops will have to meet the demands of increasing population.

This higher food production to meet the demands of growing populations to come is still one of our most important problems. This has been done in the United States by introducing crops new to this continent. A good example of this in the Southwest is the sorghum crop. Many different types of *Sorghum vulgare* have been introduced and adapted to conditions in the United States.

A fine example of adaptation to a new environment is milo. The his-
tory of the introduction of milo to the Southwest is somewhat obscure. Giant milo (Karper and Quinby) (5) was probably introduced in about 1885 to Florida and North Carolina. It soon became distributed over the South as far west as Texas. This variety was tall and late maturing; by 1900 it no longer existed and had been replaced by Standard Yellow Milo, which matures earlier and has shorter stalks.

The next step in the improvement of milo was the development of dwarfs and double-dwarf types. In 1937 a recessive gene for resistance to milo disease (Periconia circinata) was found; this gene has been incorporated into all varieties being grown at present. An additional character, “yellow endosperm”, has been located in material found by O. J. Webster in Nigeria in 1952, and this is now being incorporated into our sorghums. This will give us a vitamin A source in sorghums.

Sorghum is a short-day species, since maturity is hastened by short day lengths. Varieties differ in their responsiveness to day length. All strains of milo are sensitive to a short photoperiod and cannot be distinguished from one another as far as time of first anthesis when grown under 10-hour days at Chillicothe, Texas (Quinby and Martin) (7).

In studying the inheritance of maturity and height in milo, three genes were found which influence time of maturity. The independent assortment of these genes results in eight homozygous genotypes but only four phenotypes: Ultralate, Late, Intermediate, and Early. Another set of genes Dw dw, Dw2 Dw2, Dw3 Dw3, and Dw4 Dw4 influence the height of the plant. At Chillicothe, Texas, strains recessive for three genes are frequently about 50 cm to the upper leaves; those recessive for two genes, 100 cm; and those recessive for one gene, 150 cm or more.

Inheritance of the two genes that influence internode length in milo, studied by Karper, is the same as that in broomcorn as reported by Sieglinger. Both genes in the dominant (Dw Dw2) condition produce a tall plant. One recessive and one dominant produce two kinds of dwarf plants, which are for convenience called dwarf (dw Dw2) and tall dwarf (Dw dw2); both genes in the recessive condition produce a double-dwarf plant (dw dw2). All of the height classes within a single maturity type have the same number of leaves, the difference between them being in the internode length only. To show the development from the Giant Milo to our present double-dwarf types, the following genotypes are given by Karper and Quinby (5).

To obtain hybrid vigor (heterosis) Stephenson and Quinby have located a gene for cytoplasmic male sterility which, combined with a Mendelian male-sterility gene, produces only male-sterile plants. In recent years, by growing cytoplasmic male-sterile plants of the proper genotype and by use of pollen-producing parents of the

<table>
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proper genotypes, $F_1$ hybrids can be produced in the field. By this method, hybrid sorghums have resulted which may outyield standard open-pollinated varieties.

This brief discussion has shown how an unadapted introduced plant has been modified by recombination of genes to adapt itself to conditions found in Nebraska, Kansas, Colorado, Texas, and other southwestern states.

In locating genes for use in the improvement of adapted crops (grain, fibre, and forage), a statement by Harlan (2) brings out pertinent facts which in many cases have been overlooked. "In well-established crops in this country, most introduced varieties give a performance inferior to that of standard varieties currently grown. For parents, however, such introductions may have outstanding qualities which would not be suspected from their performance as pure varieties. It is no longer adequate, in such crops, to introduce material, screen it, and throw away the inferior types. There should be more interest in the introduction of genes than in the introduction of superior varieties as such."

This fact is especially important in improving our native grasses and forages, since many introduced grasses are tested in environments different from those in which they originally occurred. Length-of-day response may prevent an introduced plant from flowering and setting seed. It may, however, have many desirable characteristics not found in our native species. By controlling the environment and the use of breeding techniques it is possible to transfer a gene, a chromosome, or genomes. In this way, desirable characters may be transferred from one variety to another and from one species to another. By the aid of embryo-culture techniques (Unrau and McGinnis) (9), new hybrid combinations are being attempted in the cereal crops. Jenkins at the University of Manitoba, Canada, has produced various Triticales. He has added the genome of diploid Agropyron elongatum to tetraploid wheat and is attempting the synthesis of wheat with various species of Aegilops.

Single chromosomes from Secale, Aegilops, and Agropyron are being substituted for chromosomes in hexaploid wheat, and the effect of these alien substitutions is being studied.

Many desirable characters and some undesirable ones may thus be transferred from one species to another. Some of the end products may not produce the same type of bread we are accustomed to, but when the pressure for food becomes great enough, this will be of minor importance. Similar transfers could be made in the improvement of our range plants and higher yields and better adaptation could be obtained.

In studying the inheritance of winter habit, we are compounding the influence of length of day and temperature. Winterhardiness is influenced by temperature and also by day length. Some plants have winter habit but are not resistant to low temperatures. Another factor which often influences the survival of a crop is the breaking of dormancy in the spring. In Colorado, some strains of alfalfa suffer from winter killing more in the Arkansas Valley at an elevation of 4000 feet than they do at Fort Collins with elevation of 5000 feet. A few warm days in February may start growth in the valley; a drop in temperature within the next few days may cause severe frost damage and killing.
This latter condition has not been studied, but varieties which maintain their dormancy until late in the spring survive under both conditions.

In a study on the winter habit of barley, Takahashi, R., and Yasuda, S. (8) studied the segregation of early vs. late heading under 12-hour daylight and under 24-hour daylight. In the 24-hour daylight studies a clear 1 early to 3 late segregation was obtained. When seeds of the same cross were planted in the spring in the field, one-fourth of the plants headed early, one-fourth headed between June 15 and July 15, and two-fourths did not head at all. If the field data alone were available, it would be hard to arrive at a conclusion regarding the mode of inheritance. However, with data obtained from the 24-hour daylight period, a good fit to a 1:3 ratio was obtained by bulking the group of plants heading or not heading after June 15 and comparing them with the group heading before June 15.

In considering the environment in which to study the inheritance of characters, different results may be obtained in different environments due to the expression of the character being studied. When we consider that a character is due to the interaction of the genes plus the environment, this phenomenon may be easily understood. Plants introduced from one locality to another may show characters not expressed under their original environment. This condition brings up the question under what environment we should select from a segregating population.

In a study of the effect of photoperiod and temperature on the development of spike primordia in barley, Johnson and Taylor (3) found that a photoperiod of 17 hours had a greater effect on primordia development than did temperature. Within the photoperiod ranges different effects were obtained with the early-maturing varieties.

In an experiment involving 6 populations grown on 2 levels of fertility with 40 replications, Powers et al. (6) showed that there was a significant interaction for populations times treatments. This means that the populations of sugar beets: (1) A54-1, a commercial variety, (2) A54-1BB, resulting from harvesting seed from A54-1 grown in a polycross nursery with 22 other populations of beets, (3) 50-406, an inbred, (4) 50-406-1BB, an F1 hybrid between 50-406 and 52-507, and (5) 52-307, an inbred, did not react the same to both treatments. Both percentage of sucrose and weight of beet were studied. When the \( NO_3^-N \) was determined in the petiole of the beets from different populations six days before harvest, a significant interaction at the .05 level was obtained for populations x treatments. This, again, indicated that the populations were acting differently at the different fertility levels.

The parts per million of \( NO_3^-N \) in the petioles involving the above comparisons are of interest. On the non-fertilized plots, A54-1 has an average of 588 parts per million of \( NO_3^-N \) in the petioles for the first three groups, and the average percentage of sucrose is 18.2. The same values of the F1 hybrid for the first three groups on the fertilized plots are 630 and 18.3. Apparently the F1 hybrid and A54-1 have the same optimum concentration of nitrogen in the petioles for maximum percentage of sucrose in the roots. However, the F1 hybrid reaches the optimum at the high-fertility level, whereas A54-1 reaches ap-
Table 1. Spike-primordium Lengths in Millimeters on Barley Varieties after 12, 29, and 43 Days' Growth Under Controlled Conditions of Light and Temperature (F) after Johnson and Taylor (3).

<table>
<thead>
<tr>
<th>Variety</th>
<th>Stage 13-hr. Exposure</th>
<th>17-hr. Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>days</td>
<td>75°</td>
</tr>
<tr>
<td>Atsel (D.T.H. 48)</td>
<td>12</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>2.5</td>
</tr>
<tr>
<td>Beecher (D.T.H. 51)</td>
<td>12</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>1.8</td>
</tr>
<tr>
<td>Bonneville (D.H.T. 63)</td>
<td>12</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Approximately this same concentration of NO₃-N at the lower fertility level. It seems that either A54-1 is more efficient in taking up nitrogen at the lower fertility and retains it in the petioles, or at the higher fertility the F₁ uses more nitrogen in metabolism or does not retain it in the petiole. This difference in reaction of populations may have a decided bearing on breeding varieties and on hybrids better adapted to sugar production at higher fertility levels.

It is evident that we should control our environment to a greater extent than has previously been the case. In studying genetics and in applying our knowledge of genetics to our breeding programs.

Table 2. Means of Percentage of Sucrose, Parts per Million of NO₃-N in the Petiole, and Weight Per Root for the Interaction of Replications x Populations x Treatments.

<table>
<thead>
<tr>
<th>Population A54-1</th>
<th>Replication Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilized</td>
<td>No. 1-8</td>
</tr>
<tr>
<td>Sucrose</td>
<td>17.1</td>
</tr>
<tr>
<td>NO₃-N ppm</td>
<td>1724</td>
</tr>
<tr>
<td>Weight (lbs.)</td>
<td>2.90</td>
</tr>
<tr>
<td>Non-fertilized</td>
<td>18.0</td>
</tr>
<tr>
<td>Sucrose</td>
<td>671</td>
</tr>
<tr>
<td>NO₃-N ppm</td>
<td>1.93</td>
</tr>
<tr>
<td>Weight (lbs.)</td>
<td>1.39</td>
</tr>
</tbody>
</table>

F₁ 50-406 x 52-307

| Fertilized       | No. 18             | 374               | 524     |
| Sucrose          | 18.2               | 18.5               | 18.2    |
| NO₃-N ppm        | 852                | 390                | 648     |
| Weight (lbs.)    | 2.29               | 2.49               | 2.19    |

Non-fertilized   | 17.6               | 18.3               | 17.7    |
| Sucrose          | 234                | 374                | 524     |
| NO₃-N ppm        | 1.60               | 1.39               | 1.20    |
problems, techniques are available which enable us to substitute genes, chromosomes, and genomes from different varieties and from different species. This should enable us to transfer characters to desirable plants from less desirable plants when the latter will aid in survival of the more desirable individual, e. g., the hardiness of rye to winter wheat.

By use of cytoplasmic male sterility we have been able to make use of heterosis commercially. Other phenomena found in plants, but less well known and studied, have possibilities for maintaining heterosis, e. g., apomixis. Polyploid inheritance and the use of increasing the number of genomes in a species need studying as a possible means of improving our native grasses and forage.

The importance of homeostasis or the ability of organisms to regulate and to utilize genic variability must be considered in heterozygous populations. Jones (4) states, "It is one of the most important factors in the success of hybrid corn and offers great promise for the further improvement of many naturally self-fertilized crops."

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It has been stated that parasites are subject to the same general laws that govern all free-living organisms and that, while the latter are adapted in various ways to widely different biotopes, parasites have adapted themselves to a very specialized and consequently limited environment (1). This statement is appropriate so far as association with a particular host animal is concerned, but in the interest of propagation, internal parasites utilize diverse ways of infecting new hosts. They may do this directly or indirectly.

Direct transmission involves the production of eggs or larvae which pass out of the host animal. If eggs are produced, they may, at the time of deposition, contain a larval form which is infective to a new host. However, direct transmission usually entails a period of development outside the host before an infective stage is reached. Many nematode parasites produce eggs that develop and give rise to non-infective larvae, which in turn develop into infective larvae, the whole process requiring several days under optimum conditions.

Indirect transmission involves one or more intermediate hosts—animals of a different species, usually an invertebrate—in which part of the developmental cycle must take place.

Egg production by parasites transmitted indirectly is the usual thing, and the eggs pass to the outside, where a period of development may or may not be required before the intermediate host can be infected. The malaria organism, the filarid worms, and a few other species have no free-living stages; they are transmitted by arthropods which feed directly on the tissues of the definitive host.

CLIMATIC FACTORS AFFECTING FREE-LIVING STAGES OF PARASITES

Climate may influence the distribution of parasites directly by acting on the free-living stages and indirectly by acting on intermediate hosts. Extensive research has shown that moisture, temperature, and sunlight may have a marked effect on the free-living stages of parasites and hence on the distribution of parasitism. This subject was well covered by Lucker (2); his publication is the source of some of the material about to be reviewed.

The exact importance of sunlight in controlling parasites in arid regions has not been determined, but observations made in other localities prove that sunlight can be lethal to both...
eggs and larvae (3, 4, 5, 6). It seems probable that the abundance of sunlight in arid regions is a potent factor in destroying the free-living stages.

The part played by moisture in the development and survival of the pre-parasitic stages of many species has been demonstrated in laboratory and field experiments and is very evident from distribution records of parasites. Water is necessary for the development and hatching of the eggs of *Fasciola hepatica*, the common liver fluke of sheep, cattle, and many other animals; also for the penetration by the miracidium of the snail intermediate host (7). Several parasites are transmitted by aquatic intermediate hosts and are therefore restricted to areas where the necessary water can accumulate.

The large intestinal roundworm, or *Ascaris*, of man is one of the commonest and most widely distributed of parasites; yet its egg and also that of the widely distributed pig *Ascaris*, once they have become dry, will not develop in atmospheres less than 80 percent saturated with moisture (8). Drying seems to be one of the most important factors in killing eggs of the human *Ascaris* (9). Eggs of the dog whipworm require a high degree of moisture in order to develop embryos (10).

Cattle, sheep, and other ruminants acquire most of their gastro-intestinal worm parasites by grazing vegetation contaminated with infective larvae which have developed from eggs deposited with feces. To a varying degree these forms require moisture for their development and survival, and the knowledge that drying and other climatic factors are detrimental to them is utilized in control programs based on pasture rotation.

Stomach worms of the genus *Haemonchus* are widespread among ruminants and are extremely pathogenic. The eggs and preinfective stages of this parasite cannot resist desiccation (11), and this is in accord with recent observations (R. E. Gilmore and W. W. Becklund, in manuscript) in southern New Mexico. Even though irrigated alfalfa field plots were used, it was found that less than 10 percent of the infective larvae placed on the test plots lived as long as 21 days, and when haemonchus eggs were placed on the plots, no more than about 3 percent of the potential yield of larvae from the eggs was ever recovered from the plots.

Observations made in Arizona by Dewhirst, Reed, and Trautman (1959, personal communication) indicated that the free-living stages of cattle nematodes did not survive longer than three weeks in the desert at 2,500 feet; at 9,500 feet there was some survival as long as eight weeks.

These are but a few of the many references in the literature which provide experimental data on the importance of moisture in the propagation of parasites.

**DISTRIBUTION AND PREVALENCE OF SOME INTERNAL PARASITES IN HUMID AND IN SEMIARID PARTS OF THE UNITED STATES**

The human hookworm is found only in regions of considerable humidity (12). The large roundworm of man is not as limited in distribution as the human hookworm, but its eggs are designed to withstand adverse conditions (9); furthermore, the larval stages do not hatch out but remain...
within the eggshell until ingested by a new host.

In this country, the large stomach worm (Haemonchus) is more abundant in the South, the Middle West, and in low, wet areas throughout the country; it is less a problem in the high, dry, and cool areas of the Rocky Mountain States (13).

The foregoing review indicates that we might expect to find appreciably less parasitism in semiarid regions of the western part of our country than in the areas which have moderate to high rainfall. Although limited in scope, the surveys that have been made have shown this to be the case so far as intensity of infection in individual host animals is concerned. However, incidence can be surprisingly high in semiarid regions, and we find almost as many species of parasites occurring there as elsewhere in the United States. Selected references on the helminth parasites of ruminants will be used to demonstrate this point because they are the most complete records available.

A 1942 survey of cattle parasites in the southeastern states, a high rainfall area, recorded 15 species, one of which numbered 129,360 in one host animal (14). Additional information obtained in 1953 from cattle in the southeast covered nine species of nematodes; two animals each harbored over 400,000 of one species alone, and one animal harbored a total of more than 568,000 worms (15). Also in 1953, examinations of cattle turned up four species, one of which numbered 288,000 in one animal (16).

A 1957-58 survey in the same general area revealed 20 species, with numbers of one species ranging up to 292,000 in one animal (W. W. Becklund, 1958, personal communication). Eleven species of helminths were found in post-mortem examination of six sheep which died of parasitism in the East, and intensity of infection ranged up to 19,650 worms (17). Six species of helminths were recorded from white-tailed deer in Minnesota (18).

Turning to the semiarid western states, we find that North Dakota records include 15 species from pronghorn antelope, with total numbers up to 6,614 in one animal (19), and 12 species from domestic sheep (20), with numbers up to 21,400 in one animal. Nine species were recorded from domestic sheep (21) and nine species from antelope (L. Seghetti, 1944, personal communication) in Montana. In Wyoming 22 species of helminths were found in a survey of domestic sheep, and the numbers of worms in one animal were as high as 20,941 (22). Fourteen species were recorded from cattle in the same state (23), as were 15 from bighorn sheep, 14 from antelope, and 16 from mule deer (24).

In the Southwest, 10 species were found in a small survey involving cattle in both New Mexico and Arizona (25), with up to 2,312 worms in one animal. Nine species have been recorded from bighorn sheep in New Mexico (26, 27), as have 12 species from pronghorn antelope (R. E. Gilmore and R. W. Allen, in manuscript). Barbary sheep in New Mexico harbored 13 species (28) and in subsequent work, still unpublished, four more have been found. The largest number of worms found in any one antelope in the New Mexico studies was 7,100; in no case did bighorn or Barbary sheep harbor a larger number.

In Arizona a recent survey of cattle parasites, based partly on fecal exam-
ininations, turned up 12 species (29). Four species of helminths have been found in bighorn sheep in Arizona, with a maximum number of at least 1,220 worms (30). Available records pertaining to mule deer in New Mexico (31) and Arizona (32) show an extremely low incidence of parasites.

POSSIBLE ADAPTATION OF PARASITES TO A SEMIARID CLIMATE

Some worm parasites appear to be peculiar to semiarid regions, and a few seem to be well adapted for survival in absence of appreciable moisture. All of the ruminants we have discussed, except cattle and antelope, are parasitized by pinworms, and man has his species as well. It is an interesting fact, elucidated recently in the case of the pinworms of sheep and goats (33), and known for some time about the human pinworm, that the eggs are infective immediately upon deposition. Thus the development of the free-living stage is not subject to the climatic hazards encountered by other species whose free-living stages have to develop in the open for a time before they are infective.

Although records of the numbers of pinworms occurring in ruminants in high-rainfall areas are not readily available, these parasites were more numerous than any other in bighorn and Barbary sheep in New Mexico and in bighorn sheep in Arizona. Up to 6,000 pinworms have been reported from one bighorn sheep in Colorado (34). The deer pinworm, Skrjabinema parva, has been reported only from Idaho (35) and Colorado (36). Also, there are indications that the pinworm of man is less prevalent in humid than in dry regions (37).

Another such parasite is Thysanosoma actinioides, a tapeworm which occurs in the bile ducts and small intestines of a high percentage of domestic and wild sheep and to a lesser extent in other ruminants in semiarid parts of both North and South America. Its means of transmission is unknown. Since all attempts at direct infection have failed, it seems probable that a vector is involved. It is possible that the range of the parasite is limited to semiarid regions because its vector is so limited, but it is noteworthy that this tapeworm produces eggs which are extremely resistant to drying and freezing.

According to present records, other helminth parasites of ruminants which are largely restricted to the semiarid parts of the country include Nematodirella longispiculata of antelope, domestic sheep, moose, and Barbary sheep; Nematodirus abnormalis of mule deer, antelope, bighorn sheep, and domestic sheep; Pseudostertagia bullosa of antelope, bighorn sheep, Barbary sheep, and domestic sheep; Ostertagia marshalli of bighorn and domestic sheep; Elaeophora schneideri of mule deer and domestic sheep; and Wyominia tetoni of bighorn sheep. When knowledge of the bionomics of the immature stages of these species becomes available, it probably will help explain the distribution of these worms.

OTHER FACTORS INFLUENCING PARASITISM WITHIN THE SEMIARID REGION

The semiarid part of the United States has within it certain areas which are not typical of the whole. Some of these are manmade; some are not. For example, with an increase
in elevation there may be an increase in rainfall, which is beneficial to some parasites but not to others. Thus within a restricted area we may have differences in the fauna which result directly from climatic differences. Lungworms transmitted by snails constitute a serious problem in some herds of bighorn sheep in Colorado and Wyoming; here the sheep have access to moist areas at high elevation. On the other hand in southern New Mexico and southern Arizona, where the elevations are lower and less rainfall occurs, no lungworms are present, presumably because the climate is not suitable for the snail vector.

Irrigation of pasture land within an arid region can have a substantial effect on parasitism in animals grazing such pastures. Observations made in Wyoming by Honess (22) showed that range sheep were less heavily parasitized than pasture sheep. Clinical parasitism occurs frequently on irrigated pastures, especially during the summer months. The additional moisture is an important factor in promoting development of the free-living stages. Also, the density of vegetation on irrigated land is usually sufficient to afford them protection from sunlight. Moreover, the carrying capacity of irrigated pastures is such that a large number of susceptible host animals are confined in a small area. Under these conditions the level of the contamination of the forage increases within a short time, and an increase in the parasite loads of grazing animals results.

Epizootics of worm parasitism occur under range conditions when unusual weather conditions, favorable for the development of parasite larvae, occur (38).

SUMMARY AND CONCLUSIONS

The important climatic factors influencing parasitism are moisture, sunlight, and temperature. The free-living developmental stages of most parasites require moisture, and they survive longer in shaded than in sunny habitats. In semiarid areas with temperatures within normal ranges, dryness and sunlight are potent factors in controlling parasitism. These factors affect the transmission of parasites directly by acting on the free-living stages of some species and indirectly by acting on the intermediate hosts required by other species.

Information now available on the prevalence of helminth parasites of ruminants indicates a lower intensity of infection in semiarid localities than in areas of high rainfall, but the incidence of parasitism is surprisingly high in semiarid areas, and the number of different kinds of parasites occurring there is not substantially lower than in nonarid regions.

In semiarid localities the spread of parasites from one host animal to another is deterred by low rainfall and low humidity, abundance of sunlight, low density of vegetation, and consequent low density of host animals.
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EFFECT OF A SEMIARID ENVIRONMENT

ON PLANT DISEASES

by R. B. Streets

The effect of a semiarid climate upon the prevalence and severity of plant diseases is very distinct and often striking. For example, the situation in the semiarid Southwest (southern Arizona in particular) may be summarized as follows:

(1) Humidity appears to be the critical factor limiting the spread of foliage diseases. The typical very low humidities are the result of low rainfall (3 to 15 inches annually) and high temperatures, which give low relative humidity (often below 10% in the afternoon). The effect of high rates of evaporation from irrigated lands raises the relative humidity locally, but the general effect is small, as only 2½ percent of the state is under irrigation.

Low humidity results in quick evaporation of any surface moisture present on plant surfaces and robs the spores of fungi of the moisture necessary for germination and penetration of the host. True, the relative humidity in the area below the plant tops in fields of closely planted crops is very much higher than that in the air above. This microclimate effect, at rare intervals, produces conditions favorable to epiphytotic development of certain plant diseases in vegetable and field crops.

(2) Many foliage and fruit diseases of orchard crops are entirely absent or are sporadic and of minor importance. Diseases such as scab, bitter-pit, and black rot of apple, and cherry leaf spot are unknown. In one orchard the fungus causing brown rot of stone fruits never developed the Sclerotinia stage and died out after a severe early May frost which destroyed all the young fruit. Downy mildew of grape has not been seen.

(3) Small-grain diseases are limited principally to the smuts. These are seed borne and usually controlled by seed treatment. Grain rusts are rare and usually do not recur in noticeable amounts the next year. They easily survive the mild winters but usually perish during the hot, dry summers. Barley stripe and spot blotch are examples of seed-borne diseases known to have been introduced repeatedly on seed from other states, but the infestation is short-lived.

(4) Angular leaf spot of cotton is readily transmitted on the seed, and lesions appear on the cotyledons and first leaves. In many cases the infection dies out during the warm, dry, early part of the season. A little rain, however, may start an epiphytotic.

(5) Late blight, which is devastating under high-moisture conditions, is unknown on potatoes at any altitude, and early blight occurs in varying
amounts on the summer crop at higher altitudes, where it is subject to showers—but not at all on the spring crop in the desert.

(6) The fungi best adapted to our warm, dry conditions are the powdery mildews—and they disappear when hot, dry weather arrives—and reappear in the fall. Powdery mildew on roses, lettuce, and cantaloupes is prevalent some years—scarce in others. Powdery mildew occurred early in 1959 (April 23) in two fields of cantaloupes at Yuma.

(7) Citrus trees in Arizona are not sprayed for disease control—foliage or fruit diseases are rare.

(8) Among diseases of ornamentals, blackspot and anthracnose of rose are conspicuously absent. Rose rust occurs on imported nursery stock but does not recur the second year. This, plus the freedom of much of our soil from crown gall and nematodes as well as a favorable climate, has given Arizona a prominent place in the rose-growing industry.

(9) The diseases of major importance (and these cause serious losses) are those which attack below the soil line, where moisture and temperature conditions (on account of irrigation) are similar to those in less arid regions.

(10) The most important of these diseases are: (1) cotton root rot, caused by a fungus indigenous to semiarid soils of the Southwest; (2) crown gall, caused by a bacterium; (3) the root knot nematodes which attack many hundreds of different species of plants; and (4) root rots caused by Rhizoctonia and wilts caused by Verticillium are neck and neck for fourth place.

(11) The one group of plant invaders which appears to be relatively little affected by the climate is the viruses which attack many of our crops and ornamental plants. Symptoms of some viruses are masked when the plants are grown under high temperatures and high light intensities, but the viruses persist. As the virus lives and multiplies in the cell sap of a plant and is transferred from one plant to another by the feeding of sucking insects (aphids, leaf hoppers, etc.) and thrips, or by budding, grafting, or mechanical transfer, it is not exposed directly to the semiarid environment.

(12) The viruses of major importance are curly top, cucumber mosaic, watermelon mosaic, aster yellows, and tobacco mosaic virus. The sugar-beet leaf hopper, which vectors curly top, is a strong flier and migrates to cultivated crops when its desert and range food plants dry up.

(13) It might be appropriate to mention that crown gall has proved to be much more prevalent and destructive in the arid Southwest than in any other area. Loss has been exceptionally heavy in plantings of peaches, plums, and apricots and often is serious in apples and pears. The explanation appears to be that the galls are under exceptionally favorable temperature and moisture conditions and grow rapidly the year around. Gall measurements have confirmed this observation.

The manner in which natural spread of one of our most serious plant diseases has been definitely limited in each of three directions by one or two factors is of considerable interest.

Cotton root rot is caused by Phymatotrichum omnivorum, a fungus indigenous to the semiarid Southwest (Texas, Southern New Mexico, South-
ern Arizona, a little of California and Nevada, and parts of Old Mexico).

The eastern boundary of its occurrence is approximately the Texas-Louisiana line, where the soils gradually change from the strongly calcareous black, waxy soils of central and east Texas to neutral and then acid Mississippi delta soils. The organic and acid soils thus constitute the eastern barrier.

On the north, root rot is limited by winter temperature. On the open plains the isotherms show gentle curves, in the mountains and valleys of New Mexico and Arizona they follow contour lines. An Arizona map which I drew in 1937 predicted severe root rot in areas up to 3300 feet and the prevalence of less severe root rot up to 5000 feet. This prediction has proved to be accurate.

The western barrier is the sand hills and desert mountain ranges of southeastern California. The Imperial and Coachella valleys have soils and crops very favorable to root rot infection but no natural occurrence. In several cases the fungus was accidentally introduced and quickly became destructive.

The requirements of this aggressive parasite are, then—

1. an alkaline soil.
2. a soil low in organic matter.
3. a warm climate with mild winters.

To the south, although our data are incomplete, root rot is known to occur on the east and west coastal plains and in certain areas on the central plateau of Mexico, where the above conditions are met.
During this fourth symposium sponsored by the Committee on Desert and Arid-Zones Research, we have learned from Dr. Dregne that the most important problems of the 215 million acres of irrigated land of the world are those of salinity, water-logging, erosion, and fertility. It was estimated that between 30 and 50 percent of this area has been affected by one or more of these problems.

Salinity exerts its influences by means of physiologic drought, toxic effects of specific ions, and soil decline. Water-logging results in anaerobic conditions, which depress plant growth. High water tables also aggravate salinity problems. Soil erosion damages lands and crops by soil removal and deposition. In addition, wind-blown sand may mechanically damage tender young crops. While virgin arid lands are high in natural fertility, they soon decline with use until good crop production is difficult without fertilization, and fertility, too, becomes a problem of arid lands.

Millions of acres of irrigated land were abandoned in ancient times because operators lacked the knowledge or facilities to meet these problems.

Dr. Klages observed that plant growth is rhythmic in nature. These rhythms may be compared with climatic rhythms, complex though they may be. He mentioned some climatic factors and their effects, such as: excessively low or excessively high temperatures inhibit plant growth; drought influences both quantity and quality of plant growth; both factors may also affect the rate and kind of nutrient uptake.

Many crops use only a portion of the annual climatic rhythm. The nearer the two rhythms coincide, the more efficiently is the crop using the climate. Crops make more efficient use of the available water when all other environmental factors are optimum.

The economics of organic-matter additions becomes successively more complex as moisture becomes more critically limiting. Throughout all the arid and semi-arid areas, water is in short supply at some time. Studies revealing more efficient ways to use this water are essential to the future of arid-lands agriculture.

Mr. Heerwagen discussed practices and problems common to the more than 100 million acres of rangeland in the western Oklahoma panhandle, eastern and southern New Mexico, and western and southwestern Texas. During the past 25 years major efforts have been made to improve these vast acreages. Though progress has been made, it has been greatly impaired by...
such factors as climatic limitations, costs of installing and maintaining improvement measures, lack of a sense of urgency or of assured benefits on the part of the land owners, and, not the least of these factors, lack of a common understanding of the ecology of semiarid lands.

Basic studies to supply the latter deficit have been few in number, and even current studies are sparse. Several generalized ecological maps and classifications have been developed, but these lack the detail necessary to a sound program. At the present time it would seem that the "Range Site and Condition" evaluations of the Soil Conservation Service furnish the best guidance available, but even these need the support of basic ecological data and understanding to establish management practices.

Irrigated agriculture in the arid and semiarid areas of the United States, according to Mr. Myers, has progressed through the historical doctrine of "limitless resources" to one in which we must make the best use of those resources we already have. The problem of our limited irrigation-water supply has been greatly intensified by the fact that hundreds of thousands of our citizens have decided that they prefer to live in arid and semiarid environments. Since these new residents need extra water for domestic purposes and for the industries which also have followed them, the diminishing water supplies already developed for agriculture are rapidly being diverted to these higher priority uses. In the face of these inroads, the whole future of irrigated agriculture depends upon our ability to make more efficient use of the water that falls as precipitation on our watersheds.

Water falling on the watershed is depleted by evaporation and transpiration by noneconomic vegetation. It is further depleted by phreatophytic plants as it courses through natural conveyance channels. It suffers evaporation losses in the storage reservoirs. It evaporates and seeps from canals and ditches. Inefficient use on the fields causes another serious loss in the form of tailwater excesses, evaporation, luxury transpiration, and salinization. At each stage in the life history of the water, strict attention must be paid to the properties of the environment if optimum benefit is to be obtained from our water, and if irrigated agriculture is to continue to exist in arid and semiarid United States.

Plant breeding in the arid and semiarid zones, Dr. Robertson assures us, is similar to that in more humid areas except for certain experimental conditions and for some of the properties sought.

Breeding programs developed sorghum from giant milo to the present dwarf varieties which possess hybrid vigor and which produce high-quality grain while using less water in a shorter growing season. He feels that breeding for desired characteristics can greatly improve the crop outlook for arid lands, particularly in those crops used for forage, fiber, and grain. "It is no longer adequate, in such crops, to introduce material, screen it, and throw away the inferior types. There should be more interest in the introduction of genes than in the introduction of superior varieties as such."

Dr. Allen considers moisture, sunlight, and temperature to be the most important climatic factors in the distribution of small-animal parasites.
Free-living developmental stages of most parasites require moisture and they live longer in shaded areas. Thus, dryness and sunlight are potent factors in controlling animal parasitism in areas where temperature range is normal.

Information now available on the prevalence of helminth parasites in ruminants indicates a lower intensity of infection in arid localities than in those of higher rainfall, but, even so, the incidence of parasitism is surprisingly high. In addition, the number of different kinds of parasites occurring in semiarid areas is not substantially smaller than in non-arid regions.

Dr. Streets stated that climatic environmental factors are critical in limiting the spread of certain plant diseases and that humidity is the most pertinent of these. Low humidities cause such rapid evaporation of surface moisture from plants that disease spores fail to germinate. His article relates many examples of these climatic effects on the distribution of plant diseases in the arid areas.