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The Desert Shall Blossom as the Rose

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THE DESERT SHALL BLOSSOM AS THE ROSE

D. WYNNE THORNE

FACULTY RESEARCH LECTURE
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The Desert Shall Blossom As The Rose

By

D. WYNNE THORNE
Professor of Agronomy

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UTAH STATE AGRICULTURAL COLLEGE
MAY 22 1951
LOGAN, UTAH

TENTH ANNUAL FACULTY RESEARCH LECTURE

The Desert Shall Blossom As The Rose

By

D. WYNNE THORNE
Professor of Agronomy

THE FACULTY ASSOCIATION
UTAH STATE AGRICULTURAL COLLEGE
LOGAN UTAH — 1951

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TENTH ANNUAL FACULTY RESEARCH LECTURE DELIVERED AT THE COLLEGE

April 27, 1951

THIS LECTURE by Doctor D. Wynne Thorne is the tenth in a series presented annually by a scholar chosen from the resident faculty at the Utah State Agricultural College. The occasion expresses one of the broad purposes of the College Faculty Association, an association of members of the faculty. These lectures appear under the Association's auspices as defined in Article II of its Constitution, amended in 1951:

> The purposes of the organization shall be . . . to encourage intellectual growth and development of its members . . . by sponsoring an Annual Faculty Research Lecture . . . The lecturer shall be a resident member of the faculty selected by a committee of seven members, one of whom shall be appointed from the faculty of each of the Schools of the College . . . In choosing the lecturers, the Committee shall take into consideration the achievements of faculty members in all the various areas of learning represented by the teaching and research of the Institution. Among the factors to be considered shall be outstanding achievement in one or more of the following: (1) publication of research through recognized channels in the field of the proposed lecture; (2) outstanding teaching over an extended period of years; (3) personal influence in developing the characters of students.

Doctor Thorne was selected by the committee to the tenth lectureship thus sponsored. On behalf of the members of the Association we are happy to present Doctor Thorne's paper: THE DESERT SHALL BLOSSOM AS THE ROSE.

COMMITTEE ON FACULTY RESEARCH

FOREWORD

IRRIGATION AGRICULTURE has not received attention commensurate with its significance in either ancient or modern times. Although most ancient civilizations depended on irrigation for their very existence, one can consult volume after volume of history only to find irrigation scarcely mentioned. To the agricultural specialist the great challenge and the strength and weakness of irrigation agriculture is not in constructing Boulder Dams nor in planning winding canals and syphons to carry water from the Columbia River to California. The critical point is on the farms where water is applied to the soil and crops are harvested. There the real battles are being waged. This lecture has been prepared to emphasize some of these on-the-farm problems, particularly those involved in the relationships among irrigation water, soils, and the growth of crop plants.

I appreciate this honor of being the Faculty Research Lecturer for 1950-51. In preparing the material presented here I have drawn freely on the ideas and data of my colleagues, often without proper credit. In many instances I have no way of knowing just where concepts originated. To the many who have aided me directly and indirectly, I express my deep appreciation.

D. WYNNE THORNE

The Desert Shall Blossom As The Rose

by D. WYNNE THORNE

Department of Agronomy
Utah State Agricultural College

ON THE DAY after the arrival of the first small group of Mormon pioneers in the Salt Lake Valley, a special service of Thanksgiving was held. Orson Pratt was the principal speaker. He developed a prophetic vision of the parched desert land on which they stood. His text was from the words of Isaiah: "The wilderness and the solitary place shall be glad for them; and the desert shall rejoice, and blossom as the rose."

To one unaccustomed to the desert this must have appeared a formidable task. Certainly the fervor of a prophet was needed to foresee lush meadows and beds of flowers where there were dry grass and sparse gray-hued struggling shrubs on parched soil. But the words of Isaiah were an inspiration then, and they have grown in significance until making the desert "blossom as the rose" has become the watchcry of workers in irrigation agriculture.

SIGNIFICANCE OF IRRIGATED LANDS

TODAY THE TASK of making the desert bloom is attaining new significance. Nearly one-third of the land surface of the earth is desert. About 55 percent of the land area receives less than 20 inches of rain and must be irrigated if there is to be intensive crop production.

About 300 million acres of the world's land is irrigated. The Food and Agriculture Organization estimates there is a total of about 3,000 million acres of arable land in the world (1930). Pearson and Harper (1945) estimate, however, that only 2,580 million acres are adapted to intensive agriculture and that only 1,529 million acres are now used to produce food crops. Irrigated lands probably represent close to 20 percent of the intensively cropped land. Furthermore, because of the high productivity of irrigated lands compared with the average for other lands and because the major irrigated areas furnish food for people living principally on plant products, it has been conservatively estimated (Pearson and Harper 1945) that irrigated lands supply food for at least 25 percent of the world's population.

Arid lands comprise about half of the total area of the United States. These lands, lying mostly west of the 100th meridian, are about 16 percent (150 million acres) desert with less than 10 inches of rainfall, 55 percent (588 million acres) semi-desert with a rainfall between 10 and 20 inches, and 32 percent (314 million acres) dry sub-humid land of the Great Plains. About 415 million acres of land in the United States are cultivated. Less than 25 million of these acres are irrigated. Irrigation is thus of relatively less significance here than in many parts of the world. However, with the present rapid shift of population toward the West, irrigated lands are becoming increasingly important in providing a balanced economy for a large segment of our people.

The challenge to workers in irrigation agriculture lies in the fact that many of the trouble spots of the world where freedom of mankind is hanging in balance are in lands dependent on irrigation for much of their food supply. If we accept the premise that continual hunger weakens man to where he will trade freedom for food or where he will exchange liberty or the hope of liberty for the certainty of physical comfort, then we must agree that solving the problem of food supply must precede or accompany any lasting social or political reform. It is the nature of man to look first to the body and then to the spirit.

In the face of the need for greater production we are being warned that man is now waging a losing battle with nature—particularly in desert regions. We are told that "deserts are on the march," our agriculture has resulted in "vanishing lands," and we have been asked, "Is Utah Sahara bound?" Well-informed men, writing under these and other titles, are pointing to our mistakes, particularly the mistakes that have led and are leading to the destruction of the soil. These reports, while generally correct in fact, seem frequently misleading in implication. A fair appraisal of our status cannot be reached by looking only at our mistakes.

LESSONS FROM THE PAST

WITH OUR OWN limited history in irrigation agriculture it is difficult to chart our course. Are our soils deteriorating in such a way that they will eventually be unfit for crop production? Is soil productivity being generally impaired by present practices so that yields will eventually decline? If such are the trends, what are the destructive processes involved? Can we find solutions before the damage is irrevocable? Does history indicate that nations have frequently failed because they have mismanaged their soil resources?

On the more positive side—Can we avoid the mistakes of the past? Can we look forward to improved crop production? Can we maintain crop yields at their present or higher levels and also maintain or improve the productive capacity of soils? These are questions being asked of the soils specialist. We shall not immediately find answers to all of these questions, but there is much more information on these problems than is generally recognized. And the even incomplete answers now available enable much intelligent action in place of blind adoption of schemes that appear to solve half-imagined problems.

Modern intensive irrigation agriculture has been practiced in the United States for 100 years or less. Scientific studies into principles and practices date back only slightly more than 50 years. This country is, therefore, only an infant in this type of farming. Farmers in Egypt, China, India, and countries of the Middle East have been practicing irrigation for at least 4,000 years. The remains of great ancient irrigation developments occur in Mesopotamia, Ceylon, Peru, southwestern United States, and in Tunis and other parts of North Africa. A brief review of historical findings relating to irrigation agriculture in some of these countries and a consideration of general causes of the decline of their civilization may furnish partial answers to some of our questions.

Tigris-Euphrates Basin

The Tigris-Euphrates basin has often been considered the cradle of civilization. This is a desert land with flooding arroyos and raging rivers following storms and seared vegetation during long periods of drought. Before 3,500 B. C. the Sumeric Society brought the waters under control and created productive fields and thriving cities out of an inhospitable plain (Toynbee, 1934 and 1939, v. 1 & 4). The Babylonians expanded the systems of canals and drains and became renowned for their beautiful fields and gardens. The Babylonic Society was replaced by the Syriac and this finally disintegrated and allowed the ancient irrigation works to be abandoned after they had been successfully operated for more than 3,000 years.

Did the failure of irrigated agriculture bring about the disintegration of these civilations? Evidence clearly indicates that there were soil problems. Around the site of ancient Babylon there are now accumulations of soluble salts in soil totaling as high as 5 percent. In all areas the banks of canals are built high with silt, showing considerable labor was required to keep the canals clear. These situations indicate that the problems there were typical of the problems of nearly all irrigated areas.

The salts no doubt accumulated after the drains were allowed to fall in disrepair. There is no evidence of the gradual deterioration of the land by processes peculiar to irrigation agriculture. Herodotus, the Greek historian of 450 B. C., visited this land near the end of the Babylonian culture after much of it had been in cultivation for more than 2,000 years. He wrote:

> But little rain falls in Assyria, enough, however, to make the corn begin to sprout, after which the plant is nourished and the ears formed by means of irrigation from the river . . . The whole of Babylonia is, like Egypt, intersected with canals. The largest of them all, which runs

> towards the winter sun, and is impassible except in boats, is carried from the Euphrates into another stream, called the Tigris, the river upon which the town of Nineveh formerly stood. Of all the countries that we know there is none which is so fruitful in grain. It makes no pretension indeed of growing the fig, the olive, the vine, or any other tree of the kind; but in grain is so fruitful as to yield commonly two-hundred-fold. The blade of the wheat-plant and the barley-plant is often four fingers in breadth. As for the millet and the sesame, I shall not say to what height they grow, for I am not ignorant that what I have written about the fruitfulness of Babylonia must seem incredible to those who have never visited the country (Herodotus 1949).

Herodotus was often an inaccurate historian and undoubtedly exaggerated in estimating grain yields. But his report clearly indicates that after more than 2,000 years of irrigation agriculture, and well toward the end of the height of advanced civilization in this area, crop yields were still high. More than 1,500 years before Herodotus' visit laws had been enacted to control water and land use. The Laws of Hammurabi included provisions such as the following which prevented many abuses common under irrigation canals:

> If a man open his canal and he neglect it, and the water carry away the adjacent field, he shall measure out grain on the basis of the adjacent fields.
>
> If a man open up the water and the water carry away the improvements of an adjacent field, he shall measure out ten measures of grain for each unit of land (Davis 1950).

Not long after Herodotus' visit, the period of disintegration began. One war after another apparently sapped the vitality of the people. In the midst of these troubles the Euphrates River burst over its bank and made a new bed eleven miles to the east. Old irrigation canals were left dry and drainage channels were blocked. The damage was never repaired and the area served by these canals has since remained uncultivated. Toynbee (1934 v. 2, p. 44) sums up the situation:

> Thus, here again, we find a decline of civilization and a decay of irrigation proceeding; but, here again likewise, there is no suggestion that the failure to retrieve the physical disaster was either the consequence of a loss of technique or the cause of the accompanying dissolution of an ancient society. According to the greatest living authority on the subject it is rather the decrepitude into which the Babylonic civilization had already sunk by the time when the physical disaster occurred, that accounts for the failure to bring the waters under human control again.

The final abandonment of almost the entire irrigation system of the Tigris-Euphrates basin followed the Mongol invasion of 1258 A. D. Thereafter, there was no strong interested government to demand the necessary cooperation in restoring the irrigation and drainage systems. The people were discouraged. Why labor to rebuild what will only be ravaged by invading hordes? And so the drains went untended, the canals filled with silt. Diversion dams were not repaired. Starving peoples mined the shrinking acreage of cropland. The desert and the swamps returned.

North Africa

In North Africa the Sahara Desert covers the remnants of once productive fields and even important forests. Severe sheet and gully erosion has denuded the hills and cut much of the land in Tunis, Tripolitania, and Algeria with deep gullies. This was once the granary of Rome and undoubtedly helped support Carthage and other important coastal cities. According to Calder (1950) who has investigated agriculture in this area for the United Nations, irrigation waters in the Sahara region were developed in ancient times by means commonly considered contrary to all good management practices. Hillsides were deliberately eroded of soil so the rain would run off the surface rather than sink into the ground. This runoff water was conducted into reservoirs and thereafter onto the plains below for irrigation. Such a system must have required extensive labor in silt and flood control. But agriculture did flourish there and helped support the leading nations of the earth for hundreds of years.

With the disintegration of the Roman Empire the abandonment of ancient irrigated lands was again repeated. The development and operation of large irrigation works cannot be accomplished by men working alone. We cannot look at these eroded fields, denuded hills, and shifting sand dunes and conclude that the desert will always reclaim her own. As long as man repaired the dams and canals, terraced the land and conserved the soil, crops thrived. When man no longer worked with man to accomplish these ends the floods were unchecked, gullies developed, winds heaped the soil in dunes. Only the nomad with his sheep could survive. Modern experimental farms in the area show the soil is still productive. Workers there believe much of the former productiveness can be restored with the same cooperative effort used by the ancients.

Ceylon

Ceylon is divided into the humid tropical side and a hot desert region. During the past 400 years nearly all activity has centered on the humid side of the island. But exploration has shown that ancient man chose the desert region and there developed the great Indic civilization. This ancient people diverted streams from the forests into series of large artificial reservoirs or tanks. Some of these individual tanks covered more than 4,000 acres. The tanks were arranged so that the water could be used and reused before making its way to sea (Toynbee, 1934, v. 2 p. 5-9).

In this present desert region the only sign of the failure of agriculture is that the tanks had one by one broken their banks and, without irrigation water, the farmers became nomads. But the civilization had already failed before the tanks were allowed to go unrepaired. The strength that built the large tanks and irrigation systems could have easily restored a break in the bank. Man failed, the soil did not.

The great problems of historical interest in relation to irrigation agriculture are these: (1), the need for a strong central government or a cooperative society to construct and maintain extensive irrigation systems, and (2), the careful control of irrigation practices so that the persistent problems of erosion, silting, salt accumulation, soil permeability and aeration, and soil depletion can be controlled. Failures have been first in the spirit of man. Where man has learned to work with Nature she has not failed him.

Soil Depletion and Civilizations

The problem of soil depletion has been interpreted by some as a significant factor in the disintegration of civilizations. Why have nations risen rapidly to power in one part of the world after another only to decline? Toynbee says they decline because they fail to respond to the challenge of their environment. Where is this will to succeed lost? Does man wear out his spirit in wars or in the persistent struggle with his physical environment?

Those concerned with nutrition have pointed out the listless spirit and the lack of energy of those with inadequate diets. In controlled nutrition experiments men on starvation diets within a few weeks reported they had lost the "will to activity."

The thesis has been offered that nations rise to power on new and fertile soil, that soil depletion is followed by inadequate nutrition, and this in turn leads to the loss of the vigor that built the nation. This spiritual and moral decline has been followed in each case by physical disaster.

While this theory has plausible aspects it has had scant support from historians. Man does live close to the soil, though, and if through too intensive cropping, available soil minerals are exhausted,—human welfare suffers. This explanation of the rise and fall of civilizations applies equally to humid and arid regions. To the extent that there may be substance in such a theory we can take renewed hope in the future. For in few fields has science made greater progress than in finding the elements to keep soils permanently productive.

Malthusianism

Recently there has been increasing concern over certain aspects of Malthusianism. Vogt (1948) in his *Road to survival* has renewed interest in the age-old problem of population and food supply. Others have sought to dispel such fears by pointing to lands that can be put into production, the possibilities for increasing yields on lands now cultivated, and the use of other sources of food not now employed. These considerations only serve to increase the limit to which population can rise and do not give the ultimate answer to the problem.

With the present trend in population we are told that each year the world must feed nearly twenty million more people. Our increase in the United States alone is two million a year. Such rapid increases in population already mean starvation in some parts of the world and will soon tax our own productive capacity. Soil and crop scientists and our farmers cannot provide an unlimited food supply. However, by studying nature and applying the principles found, food supply can be greatly increased and man can be allowed a still longer period in which to work out his social problems.

SOIL AND WATER

IN THE DESERT early man found much of his stimulus to cooperate and build civilizations. Now man is turning again to the desert for food and clothing. Range lands are the great source of wool, and irrigated lands are producing more food and fiber than ever before. Plans for expansion of irrigated land are formidable. The present 20 million acres in the United States are to be increased 50 to 100 percent. Plans are now under way in various parts of the world to increase the 300 million acres of irrigated land by an additional 70 million acres. However, land and water resources are limited.

Throughout the world only a small proportion of the land is adapted to intensive crop production. This applies equally to the desert. The opinion is often expressed that in our desert areas water is the limiting factor for intensive agriculture and soil is plentiful. This idea of abundant land and little water seems self-evident to nearly anyone travelling across our state. The development of successful agriculture, therefore, would seem largely assured by merely diverting water onto the really good lands and bypassing the poor lands.

While more water would increase plant growth in much of the desert, the idea that only water is needed to make fertile fields out of long stretches of land now covered with sage, rabbitbrush, and greasewood is often wrong. In fact, contrary to general opinion, good soil may be as limiting as water. And often the good soil and water are too far apart.

According to our best estimates, Utah has about 3,176,000 acres of arable land. Water supplies seem adequate to irrigate about three million acres. This seems to be a fortunate balance. Unfortunately

UTAH STATE AGRICULTURAL COLLEGE

though, because of land location, lack of ample good reservoir sites, and need of water for municipal and industrial purposes, there seems little chance that much more than two million of these acres will be irrigated.

About 60 percent of the possible arable land of Utah has been classified. Assuming the remaining 40 percent is similar to that which has been surveyed, less than 20 percent of Utah's arable land is class 1, about 49 percent is class 2, and 31 percent is class 3. Much of the class 3 land cannot be used for intensive crop production, maximum crop yields should not be anticipated on much of the class 2 lands, but the class 1 land should support high yields of a wide variety of crops.

Some desert areas have relatively more good soil and less water than Utah. Nevertheless, there are no vast frontiers of new land. Our great frontiers are in the land already under cultivation. This is substantiated by present crop yields in Utah and the yields commonly obtained by our better farmers on good land. Our average state yield of sugar beets is only 13.5 tons per acre. Yields between 20 and 30 tons are common, while the maximum yields reported are near 50 tons per acre. Our average yield of potatoes is 165 bushels per acre. Yields between 600 and 800 bushels are fairly common. Yields of more than 1200 bushels have been recorded. The average yield of alfalfa is 2.1 tons per acre. Many farms produce 6 tons per acre fairly consistently, and yields in Utah as high as 8 tons have been obtained. The average yield for tomatoes is 9.5 tons per acre, 15 tons is common, and 25 tons have been obtained. Our average barley yield is 43 bushels. A good crop usually produces 80 to 100 bushels, and yields up to 140 bushels have been procured. Thus the average yields of the state are only half of "good" yields and less than a third of maximum yields.

Some soils do not have the inherent capacity to support maximum crop yields. And attaining such ultimate goals depends on the weather as well as on crop varieties, diseases, insects, fertilizers, moisture control, and other factors within man's control. Nevertheless, there appears greater possibility in obtaining higher crop production on land now irrigated than from the maximum development of new land. Our desert must be kept in bloom by finding better answers to the age-old problems of erosion, drainage, salt and alkali control, and of increasing productivity on land now irrigated. To appreciate the problems concerned, we must recognize the distinctive features of soils of arid regions.

CHARACTERISTICS OF ARID SOILS

SOILS OF ARID REGIONS are different from those of humid areas. Having developed under low rainfall and scant vegetation, they have been weathered and leached less and contain smaller quantities of organic matter than their humid region analogues. Desert soils usually contain appreciable quantities of lime, magnesia, and other mineral elements in unweathered and precipitated minerals. Soils of humid regions are generally leached of these ingredients. Arid region soils are normally alkaline in reaction and in some situations are being enriched in basic constituents through irrigation. Humid region soils tend toward acidity.

These distinctive characteristics of arid soils must be considered in managing them for maximum crop production. Farmers on these soils escape the problems of acidity and liming but have the different problems of excess lime, alkalinity, and soluble salts. Research and experience in soil management in humid regions are of little help and are often misleading in dealing with these special problems.

EFFECTS OF IRRIGATION ON SOILS

THE MORMON PIONEERS arrived in Salt Lake Valley, July 24, 1847, to face an almost hopeless situation from the viewpoint of crop production. But by diverting the waters of City Creek onto the baked land they were able to plow, sow, and reap a crop.

When this water was put on land which had developed under 15 inches of rainfall, a new cycle of nature began. The 15-inch annual rainfall had fallen on soil where the potential evaporation was 60 inches. Consequently, leaching had occurred only during exceptionally stormy periods and these infrequent percolating waters had not leached any but the highly soluble products of rock weathering from the soil. Suddenly with irrigation the soil environment was changed from an arid to a humid state. The natural balance between precipitation and evaporation was reversed.

The first unfavorable result noted was the gradual building up of ground water in some areas. Unfortunately, many early settlers in the Salt Lake Valley as well as in other areas chose the lower lying lands of fairly level topography. Later settlers diverted water onto the higher benchlands. The drainage water seeped into the lands below, reducing aeration and bringing in excess salts until these once highly productive lands were reduced to low production levels. A recent survey of the soils of Salt Lake County indicates that about 9,000 acres, or more than 7 percent of the good soils have deteriorated through such events.

No doubt, in many irrigated areas the most severe problems arise from too much water rather than too little. But the proper balance among water, soils, and crops is difficult to determine and maintain. Excessive use of water leaches many plant nutrients from the soil and leads to problems of drainage, aeration, and salt. Too economical use of water may lead to deposits of undesirable minerals in the soils irrigated.

Soluble Salts and Sodium

Irrigation waters differ from natural precipitation in that they always contain some dissolved impurities. The effects of waters on soil and their desirability for irrigation depend on the amount and nature of these dissolved salts. The soil solution around plant roots can be no lower in salt content than the irrigation water added. If the water contains large amounts of salt, the soil must be leached of the residual salt from previous irrigations at periodic intervals or the soil will eventually be rendered barren from salt accumulation. Waters such as those in the Sevier River below the Yuba Dam or those in the Virgin River below the Washington Fields diversion represent streams in which high salt will always be a problem.

Sodium is the most common injurious ingredient of irrigation waters. Sodium is not more toxic to most plants than calcium or any other element. But if irrigation waters in which the concentration of sodium appreciably exceeds calcium and magnesium are added to soils, the sodium will become adsorbed on the clay, displacing the normally high proportion of calcium. Clays with high proportions of adsorbed calcium are stable in water, are easily worked into granules and crumbs, and present a desirable environment for plant roots. But when sodium is adsorbed, displacing the more desirable calcium, the clay disperses and swells in water until drainage is impeded or stopped almost entirely. The soil bakes hard on drying and breaks into large tough clods instead of friable granules. Such soils have a caustic alkali reaction. Because of such effects waters high in sodium are undesirable for irrigation and in many instances must be rejected entirely.

Low quality waters may be used more successfully on some soils than on others. Sandy soils permit easy leaching and contain less clay to accumulate sodium so are best adapted to irrigation with low quality waters. Similarly, soils containing gypsum, lime, or other calcium compounds can better counteract sodium accumulation than soils low in calcium. Farm management practices are also important and one farmer often succeeds better than his neighbor in getting continuously high yields with low quality water.

Calcium Carbonate

There are also dissolved substances in water that may be deposited in relatively insoluble compounds in soil. The principal deposition is that of calcium and magnesium carbonates. We might illustrate this with waters of Logan River. By most standards this is excellent quality water. It contains only one-fourth ton of salt per acre-foot. This salt is more than 90 percent calcium and magnesium bicarbonates. The water entering the irrigation canals is cool and clear and contains some excess carbon dioxide. Thus we have the common situation:

$$CaCO_3 + H_2O + CO_2 \rightleftharpoons Ca(HCO_3)_2$$

Calcium carbonate	plus	water	plus	carbon dioxide	is in equilibrium with	calcium bicarbonate

The presence of calcium bicarbonate in solution depends on carbon dioxide being dissolved in the water. If there is a 15° C. rise in temperature of the water on entering the soil, the solubility of carbon dioxide is decreased about 40 percent. The rise in water temperature is accompanied by concentration of the soil solution through evaporation and utilization of water by plants. Action of the combined factors results in precipitation of calcium and magnesium carbonate. This is the same process that resulted in a lime layer inside of the tea kettle that used to sit on the back of the kitchen stove. When just enough water is added in each irrigation to moisten the crop root zone, there is almost a complete conversion of the bicarbonates to carbonates. If excess water is added in each irrigation and if the concentration of carbon dioxide in the soil air is high, there may be little calcium carbonate deposition or there may even be some leaching of that already in the soil.

There is evidence that use of irrigation waters high in calcium, magnesium, and bicarbonate ions combined with certain irrigation practices results in a steady accumulation of lime in soil. Some soils on the Mapleton bench in Utah County that were apparently free of lime before being irrigated are now quite rich in lime. Similar trends have been reported in Idaho.

Eaton (1950) has pointed out that precipitation of calcium and magnesium carbonates may result in relatively high proportions of sodium in the soil solution. When this happens, waters commonly considered safe for irrigation may lead to the formation of alkali soils. The effects of sodium in forming alkali are more immediately disastrous than the effects of accumulations of calcium and magnesium carbonates. Over long periods of time, though, the lime accumulations may also be damaging.

There is some evidence in fruit orchards that continued irrigation with certain waters high in bicarbonate ions has resulted in coating of soil particles and even some plant roots with lime. This obstructs direct contact between plant roots and soil particles and thereby prevents proper plant nutrition.

SOIL ALKALINITY AND ACIDIFICATION

Because irrigation waters often deposit alkaline salts in soil, there is a widespread concept that irrigated soils should be regularly treated with acid materials to keep them from becoming excessively alkaline. Proponents of this practice argue that acidification of irrigated soils to prevent excessive alkalinity is a logical parallel to the regular liming of soils of humid regions to keep them from becoming too acid. This is a plausible theory and seems to be readily accepted by many agricultural workers.

All irrigated soils are not becoming more alkaline with use. Most of the benchland soils along the Wasatch Front between Brigham and Salt Lake City were originally non-calcareous and they are still mostly free of lime and about neutral in reaction after 100 years of crop production. Apparently in this important farming area salts in the irrigation waters are maintaining soil reaction near the desirable neutral point. Conditions for increasing alkalinity include the conservative use of irrigation waters, the presence of high water tables, and the use of waters containing moderate to large amounts of calcium, magnesium, and bicarbonate ions or waters containing relatively high proportions of sodium.

Should a well-drained soil high in lime content be acidified for good crop production? The soil here on the campus contains approximately 50 percent calcium and magnesium carbonates. The soil on our North Logan experimental farms contains equally large amounts of lime. High yields of many crops are obtained on these soils comparable with those procured elsewhere. Acre yields of 80 bushels of wheat, 110 bushels of barley, 800 bushels of potatoes, 30 tons of sugar beets, and 6 tons of alfalfa are not unusual. In a 13 year experiment on these high-lime soils, sulfur treatments did not increase the yields of any crop in a six year rotation. Experimental results from various types of acid treatments on alkaline calcareous soils have also been mostly negative. Phosphoric acid has benefited yields almost exactly to the same extent as an equivalent amount of phosphate applied as superphosphate. The acidifying effect of the acid has not been of demonstrated value (Thorne 1944a).

Acid treatments are effective on calcareous soils high in adsorbed sodium, however. In this case the acid releases calcium by reacting with soil lime and the calcium promotes reclamation. The diagnosis of alkali soil conditions (high proportions of adsorbed sodium) is so well understood, though, that there is no justification for indiscriminant acidification of all soils just to catch the alkali spots.

EFFECTS OF LIME ON PLANTS

CERTAIN PLANTS are not well adapted to soils containing free lime. Such plants are often called calciphobes, signifying that they do not like calcium. This does not tell us, though, why these plants dislike calcium or lime. And we have no fully satisfactory answer to this question. Unfortunately many of our most prized plants fall in this group. Among them are most of our fruit trees and berries, roses, and many of our flowers and ornamental shrubs. The manufacture of chlorophyl in these plants is disturbed by conditions associated with free lime in the soil. The plant leaves become yellow and we describe the disease as chlorosis, or more specifically lime-induced chlorosis.

Some people seeing widespread chlorosis believe that all plants on irrigated soils will be eventually affected. However, chlorosis in Utah is associated with calcareous soils and principally those irrigated with waters containing relatively large amounts of bicarbonate.

One interested in plants can hardly fail to be impressed by the sickening panorama of yellow orchards as one drives west into the Virgin River Valley from Zions National Park. Here in the Tocquerville and LaVerkin areas irrigated with waters from Ash and LaVerkin creeks the trees are generally yellow, yet just to the south orchards irrigated with waters from the Virgin River show only occasional instances of chlorosis. The same relationship holds lower down the river with fruit trees irrigated with water from the Santa Clara River being seriously affected with chlorosis, while those irrigated with Virgin River water are generally green. From the viewpoint of both total salt and soluble sodium percentage, the Virgin River water is much lower in quality than these other streams. The other streams do, however, all carry free carbonate ions and have a high proportion of bicarbonate ions in comparison with total anions.

We do not yet know the specific effects of such waters on soils nor the ultimate results from their long-time use. Perhaps lime-sensitive plants will have to be replaced by lime-tolerant plants where such waters are used. Possibly some parts of our desert will continue to produce alfalfa and grain but will literally cease to blossom as the rose. Present knowledge about this problem is meager and we must leave it as a danger spot marked for needed investigation.

The effects of lime on calciphobe plants vary with changes in soil moisture and aeration. Maintaining soils in a continuously moist condition increases the degree of plant chlorosis. This possibly results from several indirect effects, including the hydrolysis of lime giving increased alkalinity in the soil solution, reduced aeration in the soil, and disturbed functioning of plant roots. Experimental results have shown that excess moisture must be avoided where chlorosis is a problem and the soil should be permitted to become moderately dry between irrigations.

Poor aeration around roots also increases chlorosis. Aeration is commonly reduced by excessive use of irrigation water, by soil compaction through use of heavy equipment, and improper soil management practices, and by deep cultivation which forces the plants to obtain food from roots in the deeper and more poorly aerated portions of the soil.

Even in the presence of free lime in soil and under conditions of lime accumulation high crop yields can usually be obtained through modifications in soil management practices. There are some areas of soils, though, that at present cannot be used successfully in growing calciphobe plants.

Some plants have a high tolerance for soil lime. In controlled experiments with synthetic soil mixtures, the proportion of calcium carbonate to clay has been varied from zero to 10 times the clay (Thorne 1946). Barley was not influenced in either yield or content of principal mineral ingredients by these changes. With tomato plants the increasing proportions of lime were accompanied by decreasing yields, higher uptake of calcium, and decreased uptake of phosphorous. But few studies of this type have been reported and there is need for clarifying the specific effects of excess calcium and magnesium carbonates on plants.

SOIL EROSION AND CONSERVATION

Of all factors affecting crop production soil erosion has received by far the most attention. There are almost daily warnings that our soils are being washed and blown away. Silt-laden streams are pointed to as striking evidence that the best of our soils are being carried to the ocean.

Irrigated soils are usually of moderate grade and fairly uniform topography, so erosion is not as noticeable as on most other agricultural lands. The most serious threat of erosion to irrigated agriculture is in the destruction of watersheds. In the mountain valley areas of Utah there is also the direct threat of floods carrying rocks and material of low fertility onto productive farm lands. The erosion problem in the watersheds of Utah has been dramatically emphasized by Cottam (1947).

Although erosion is seldom dramatic on irrigated lands, it does occur almost universally. A short trip through any of our irrigated benchland areas is sufficient to see that wherever slopes are as much as 2 to 4 percent the lower ends of fields have been built up with 1 to 3 feet or more of soil washed from the upper ends of the fields.

With more extensive development of irrigation canals there has been a gradual development of upper lands on steep slopes. Irrigated orchards are now being grown on slopes of 20 percent or more. Fortunately, most farmers using such lands have been far-sighted enough to terrace or plant on contour grades. In a few orchards irrigation is being made directly down steep slopes and serious erosion is occurring.

There is no question but that soil erosion is a real threat to the permanence of all types of agriculture. In 1923 and 1930 intense rain storms along the Wasatch Mountains resulted in devastating floods pouring from such short canyons as Three Mile Creek, Willard, and Parrish Creek. This was again repeated in 1946 at Mount Pleasant. Homes were destroyed; fertile land was covered with boulders and coarse debris (Bailey 1941). On many of our irrigated lands away from danger of floods, careless irrigation has ripped 6, 12, or even 18 inches of soil from the upper ends of fields and deposited it as a layer of silt at the lower ends. In spite of these damages, though, our plight is not one of hopeless despair. Investigations and time have re-emphasized the marvelous healing powers of Mother Nature. Controlled grazing and reseeding have healed raw sores on our hillsides. Some changes in farm irrigation systems, some land levelling, and more care in irrigation are effective in greatly reducing erosion by irrigation water. Satisfactory answers to these erosion problems are available. Often the will to act seems lacking.

The total effects of erosion are often grossly exaggerated. Statistics can be alarming. We are told 870 million tons of United States soil are carried yearly to the ocean. Bennett (1941) says this represents a lass of 200 million dollars annually in reduced crop yields, a 200 million dollar annual loss in available plant nutrients, and a 500 million dollar annual loss in unavailable nutrients. Such estimates of nutrient loss assume a fertilizer bag value for elements still in the rock form. The statements also ignore the fact that materials left below the eroded surface are generally equally high in most total plant nutrients except nitrogen. A typical statement is the following: "A thin layer of topsoil, often less than a foot deep, is all that stands between life and death of the world's inhabitants" (Burch n.d., p. 19). To make the situation even more sinister we are repeatedly told that 300 or more years is required to make each inch of productive soil.

There can be no solace in the knowledge that some aspects of the seriousness of erosion have been exaggerated. Erosion does limit crop production and exposed subsoils and gullied fields mean eventual reduced food supplies and higher prices. In spite of the many advancements of science the soil is still our principal source of food and clothing. Wise land policies and best soil management practices must, though, be based on honest facts rather than hysteria.

Plants usually get most of their nutrients from the topsoil and in most cases the loss of the topsoil means greatly reduced crop yields.

In a few cases exposed subsoils have been better adapted to intensive crop production than original topsoils. In most instances subsoils can be made productive in a few years by adding organic matter and fertilizers. The idea that thousands of years are required to make a productive soil refers to the formation of soil from bedrock and not to the improvement of unconsolidated subsoil materials.

There is no prospect for preventing all erosion. It should be controlled, though, as far as is consistent with intensive long-time crop production. Erosion control is a by-product of good soil management. The Soil Conservation Service was established to control soil erosion, but it is fast coming to the broader viewpoint that erosion control is only one phase of soil conservation, and sometimes a minor one.

The principles of soil erosion control are well understood. Farmers are becoming more conscious of the problem each year but much remains to be done before erosion will cease to be a threat to crop production on large areas of land. However, the situation is not hopeless nationally, and on our irrigated lands we are coming closer to reaching a balance between soil-building and soil-eroding processes than in any other type of land use.

In Utah the protection of our watershed areas is undoubtedly the most critical erosion problem at present. Willful destruction of vegetation in our watersheds by uncontrolled grazing and unchecked floods could dry up our streams and return most of our fertile fields to the desert.

WATERLOGGING AND DRAINAGE

WATERLOGGING and salt accumulation were among the great physical problems of irrigation agriculture in the Tigris-Euphrates basin and in the Nile delta for thousands of years. They are also important problems in most of our irrigated areas today. They might be called the twin evils of irrigation agriculture. They seriously affect more irrigated lands than erosion and are harder to control than soil depletion. Salt accumulation is the child of poor drainage. Where water can move freely through the soil soluble salts can be readily leached away. Where there is no high water table, there are seldom rapid accumulations of lime and other salts of low solubility.

The significance of the drainage problem in Utah is shown by the fact that 37 drainage districts containing approximately 203,000 acres have been organized. A recent survey (Maughan, Israelsen, and Hanson 1949) indicates, however, that drainage has been satisfactory on only 100,000 acres. An additional large acreage of poorly drained land lies outside organized drainage districts.

The first answer to the problem of waterlogging is to select lands for irrigation that have permeable profiles and natural drainage outlets or lands that can be artificially drained without excessive costs. This can usually be done because there is more land than water. In any event public funds should not be spent to store water and to convey it to land unfit for irrigation.

While careful land selection should eliminate many of our acute drainage problems in future irrigation development projects, there remains the correction of past mistakes that have given us the extensive waterlogged soils of the present. Constructing drains, treating soils to improve permeability, and lining irrigation canals are not enough. Farmers on upper lands must stop using excessive amounts of water which move through substrata to lower lands.

The entire problem of control of abuse of our natural resources has never been realistically faced in the United States. The significance of our soils has been recognized in the support of various soil conservation programs, including the work of the Soil Conservation Service and benefit payments under the Production and Marketing Administration. But after public monies have been spent to rejuvenate injured lands there are no controls to prevent the careless practices that made public assistance necessary in the first place.

Does the individual farmer have the right to manage his soil and water as he wishes even though destruction lies ahead? Shall the government at great expense correct the damage only to permit its recurrence? Education has helped. But some rugged individualists will not conform. The American philosophy of land use has yet to reach maturity.

SOIL DEPLETION

THE EXTENT of soil depletion on irrigated farms is indicated by the rapid increase in mineral deficiencies apparent in growing crops and by the steady expansion in commercial fertilizer sales. Trends in Utah are typical of those in most irrigated areas. Marked responses in crop yields from phosphate fertilizers were first noted less than 25 years ago. Now at least 50 percent of the irrigated lands of the state need periodic additions of phosphate fertilizer for maximum crop yields. Nitrogen deficiency symptoms are more general than those of phosphate. Responses to nitrogen are observed on row crops on nearly all farms except those devoted principally to livestock and on which liberal amounts of farm manure are returned frequently to the land. In the last ten years, fertilizer sales in Utah have increased from 2,000 to about 20,000 tons per year. In addition to nitrogen and phosphorus, deficiencies of iron, zinc, and manganese have also been noted. Soils of Utah are generally well supplied with potassium but a survey of a number of farms in this area indicates that on an average the amount of potash removed in harvested crops each year exceeds that returned to the soil in manures, seeds, and fertilizers by almost 40 pounds per acre. Some soils are now nearing the critical level in this element.

The need for supplemental mineral elements in Utah soils is typical of irrigated soils elsewhere. In Asia, soils near large population centers have been maintained in fertility by gathering organic wastes in the cities and returning them to the land. Many soils, though, are depleted of available minerals and where fertilizers are not used crop yields are low. In much of the world nitrogen deficiencies are greatly reducing yields. Lack of other minerals is of equal importance in more limited areas.

The maintenance of adequate quantities of available plant nutrients in soil has probably received more research attention than any other soil factor. As a result, the mineral needs of plants are rather completely known. The problem of soil depletion can be met in two ways: first, by managing soils so that essential mineral elements present will be rendered most available to plants, and second, by soil treatment with natural and commercial fertilizer materials containing elements that cannot be supplied in adequate amounts from soil minerals.

Locked in soil minerals are tremendous reserves of most elements essential for plant and animal life. Except for nitrogen, these soil reserves far exceed known quantities of elements in commercial deposits. Unfortunately, these soil minerals weather too slowly to release enough minerals for maximum crop yields. So when the supplies of readily available elements in soils are exhausted, the quantities slowly released from soil minerals must be supplemented by manures and fertilizers or yields decline.

While we have the technical knowledge to improve crop production greatly on depleted lands of the world, there are formidable barriers to the attainment of this objective. Non-industrial countries and countries lacking deposits of the necessary minerals have difficulty getting enough fertilizer materials to meet their needs.

The vast nitrogen reserves in the air are equally available to all. Those nations lacking equipment to utilize air nitrogen directly must rely more on natural nitrogen fixation by legumes and soil microorganisms. Supplies of inorganic minerals are one of the biggest problems in the world food picture. In countries without prospects of any adequate amounts of fertilizer materials farmers must turn back to the soil for their mineral supply. If ways can be found to speed up the rate of release of plant nutrients from soil minerals world food supplies will be improved more than can be achieved through seeking new lands. This is one of the great challenges to all interested in agricultural production.

IRRIGATION AND SOIL MANAGEMENT FOR MAXIMUM CROP YIELDS

THE IRRIGATION FARMER, pressed by economic necessity, is usually more interested in getting the largest immediate returns from land than he is in long-time trends within the soil. This primary concern with immediate returns is generally compatible with permanent prosperous agriculture. Soil and plant relations are such that high yields of crops cannot be maintained while the soil is being severely depleted of essential plant nutrients or while the soil is gradually accumulating sodium or harmful salts.

The farmer who consistently obtains low crop yields is far more likely to be injuring the soil than the one who maintains high yields. Crops may barely survive on soils until depletion, alkali accumulation, erosion, or other harmful processes have injured the soil beyond immediate economic redemption. The old concept that continuous production of bumper crops is the equivalent of mining valuable minerals from the soil should be replaced by the idea that continuous abundance is the only safe criterion of good soil management.

There can be no universally prescribed irrigation and soil management practices for guaranteeing maximum crop yields. The nature of the soil and type of crop must be balanced against various combinations of irrigation and management practices. Investigations in Utah during the past five years have demonstrated that yield of crops not only depends on such diverse factors as plant nutrient supply, availability of soil moisture, plant population, soil aeration, and climate—but that the optimum conditions and practices for any one of these factors can only be determined and specified relative to the others. A given amount of nitrogen fertilizer may be adequate for corn under one irrigation regime but with a more abundant water supply and the same fertilizer treatment, the corn will show severe nitrogen deficiency symptoms. On a given soil the maintenance of ample available water gives a definite increase in yield. Application of adequate fertilizers gives another increase. Still a third increased yield may come from a greater number of plants per acre. By combining these improved practices so the best combinations are obtained, the increased yields often show a pyramiding of benefits. The final yields may thus be higher than would be estimated from considering the separate benefits from each practice.

ONE HUNDRED YEARS of practice and fifty years of research on the development and management of irrigated soils in Utah reaffirm the vision of Isaiah as applied to our arid lands. The desert can and is blossoming as the rose. There is no serious threat to almost eternal blossoms on most of our irrigated desert lands, except the failure of man to do the things he knows are essential. There are problems and real threats that the desert may reclaim a part of our productive lands unless research and practice find solutions to some aspects of water-logging, lime accumulation, and alkali formation. For most of our desert lands there will certainly be greatly increased production. In this abundant production there is renewed hope for a world free from hunger and able to throw off the shackles of tyranny and fear that oppress the weak.

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