DRY FARMING has its own peculiar and difficult problems. This article tells about the nature of the soils in dry-land regions, shows why nitrogen is seldom a problem, and suggests measures to reduce wind erosion. Most of the article, however, is devoted to the problem of soil moisture, which is the limiting factor in production. The authors discuss means for increasing the available water supply, preventing water losses, and making the best use of what water there is by various tested practices.

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Special Dry-Farming Problems

By O. R. Mathews and John S. Cole

DRY-LAND FARMING, or dry farming, has many problems that are peculiarly its own. They are the direct results of a relatively low and uncertain rainfall that in the past has controlled the formation and character of the soil and now determines the conditions that farmers working the soil must face.

Dry farming in its broadest aspects is concerned with all phases of land use under semiarid conditions. Not only how to farm but how much to farm and whether to farm must be taken into consideration.

Knowing the best way to grow wheat will not insure success in an area better adapted to grazing than to crop production. A section may be unsuited to intensive wheat production but well adapted to the growth of feed crops in conjunction with livestock production. However, on land suitable for arable agriculture, good farming methods may constitute the difference between success and failure.

Yields of crops that may be obtained over a long series of years, the extent to which annual yields may be modified or stabilized through cultural practices, and the response of different crops to each other are matters of fundamental importance in determining land use. Such information must cover a long period to serve as a secure basis for agricultural practices. Much of the present distress in the dry-land areas is the result of overexpansion of crop production in high-risk sections during a period of favorable years.

There are parts of the dry-land region that are suited to general mixed farming, other parts where one particular crop is so well adapted that the production of a large acreage of other crops is unjustified, and still other parts where yields of crops are so uncertain that farm-

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ing, if practiced at all, should be confined largely to the production of feed for livestock. In the aggregate, the yields and dependability of the different crops that can be grown determine to a large extent the type of agriculture that should be followed, the size of farm necessary to produce a livelihood, and the proportion of the farm holding that should be devoted to arable agriculture.

**DRY-LAND SOILS**

The soils of the dry-land areas as a whole belong to the pedocalic group (soils with a zone of lime carbonate accumulation). Having developed under a light rainfall, they are unleached and have lost little of the elements of fertility present in the parent material. As a group they are rich in nitrogen and other elements needed for plant growth. The fertile soil extends to a depth unapproached by soils developed under humid conditions. Marbut (239) draws the following comparison between forest and dry-land soils:

> The humid land forest soils are fertile, chemically so, when first cleared of forests; but the layer containing a high percentage of the constituents of fertility is very thin and is soon exhausted. The soils of the semiarid lands are entirely different in this respect. Not only is the percentage of what we call fertility constituents high, but the layer in which they are present is thick. Its thickness in feet is as great as the corresponding layer of the humid forest soils is in inches. It is so great that the world's experience up to the present time affords no basis for placing an estimate on the duration of the productivity of these lands.

Not all dry-land soils, however, are as deep as the typical soil described by Marbut. With the shallower soils fertility problems may soon assume importance.

The fertility of semiarid soils is their greatest asset, but it is also the cause of their greatest misuse. Crop returns are so abundant in years of ample rainfall that a succession of years with above-average precipitation has almost invariably led to an expansion in production that was entirely unjustified when yields that could be expected over a series of years were taken into consideration. This has frequently led to disaster when good periods have been followed by successive years with below-average precipitation.

In general, the fertility of dry-land soils is so great that the normally deficient precipitation is the controlling factor in crop production. In only a small proportion of years is the precipitation high enough or well enough distributed for fertility factors to limit the quantity of crop produced. Probably the greatest single dry-land farming problem is to adjust the entire farming system to the production that may be expected over a long period of years, so that years of failure may be endured.

**THE NITRATE PROBLEM**

The nitrate problem in dry-land farming differs from that in humid areas, where fertility frequently is the limiting factor in crop production. As a general rule, the nitrates released during the preparation of a seedbed and during the period of moisture conservation in dry-land areas are sufficient to produce as large a crop as the moisture is capable of maturing. Excess nitrates are frequently disastrous in dry

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*Italic numbers in parentheses refer to Literature Cited, p. 1181.*
years, as they may cause a stimulation of growth that the moisture is incapable of maintaining to maturity. As a rule the addition of nitrate nitrogen, whether in the form of manure or commercial fertilizer, causes a vigorous early growth and a higher stover or straw growth than on unfertilized land. In many cases the water in the soil is incapable of maintaining this growth to maturity, and the yield of grain is lowered.

At Ardmore, S. Dak., 20 years of experiments with manured and unmanured fallow showed that the addition of manure increased grain yields in years of high precipitation, but decreased them in years of low precipitation. Instead of stabilizing yields, it made them more erratic. At North Platte, Nebr., 28 years of experiments with manures and green manures demonstrated that they increased the yields of straw and stover but decreased the yields of grain. At Goodwell, Okla., results at the Panhandle Experiment Station demonstrated that the presence of an above-average quantity of nitrate nitrogen had a depressing effect upon wheat yields. At Woodward, Okla., on a sandy soil probably as low in nitrogen as at any field station in the Great Plains, it was found that manures increased stover growth materially, but that crops fired more quickly in dry years. On the sandiest, lightest soils on the station the situation was most aggravated. These light soils were the most deficient in nitrogen and the most in need of fertility. Yet owing to the limited water-holding capacity of the soil (a result of soil type) crops were especially subject to injury during droughts when manures were applied.

As a whole it can be stated that in the Great Plains additions of nitrate nitrogen are not likely to effect much increase in yields of grain except in unusual seasons when water sufficient to maintain the excess growth is available.

In the intermountain dry-land areas of winter rainfall a somewhat different situation exists. There the lack of nitrate nitrogen may be a limiting factor in crop production. The reason lies in the fact that under continuous crop production the soil is frequently dry during the period of the year when temperature conditions are suitable for bacterial action. When moisture conditions are favorable, temperatures may be too low. Part of the value of fallow in that section lies in the fact that it provides moisture sufficient for bacterial action during a period of favorable temperature. This accumulates nitrate nitrogen, which is carried over to the next crop year. The results in average years are increased yields and improved quality. If the nitrogen is in excess in dry years, burning may result as in the Great Plains.

There has been a loss in total nitrogen in most dry-land soils since they were put under cultivation. The reduction was most rapid the first few years after the soil was broken, but has since continued at a gradually diminishing rate. The reduction in nitrogen has not yet become a controlling factor, however, and it is still a question on many soils whether the nitrogen content will become stabilized above or below the point where moisture is the controlling element in crop production. It may be safely stated, however, that at the present time few dry-land soils have reached a stage of nitrogen depletion. Maintenance or increase of the organic-matter content of the soil
through the application of manures or green manures will not pay for the cost where crops are grown for grain. Stover yields may be increased enough to justify the added expense.

**WIND AND WATER EROSION**

The prevention of wind erosion is one of the ever-present problems in dry farming. Ever since crop production started in the semiarid sections there has been soil blowing. During periods of drought the situation is aggravated, and with extreme drought and the large areas of land now under cultivation, it has become a national problem.

Losses of soil from wind erosion have been enormous. In many cases uncontrolled soil blowing has removed more of the elements of fertility in a single season than would be removed in generations of cropping. Some shallow soils have been rendered unfit for further cultivation.

In much of the agricultural land of the Great Plains and of the Pacific Northwest, wind erosion is a factor that must always be guarded against but that is a serious hazard in only a few years. In some sections and on some soils, however, it is the controlling factor. It may determine what crops can be grown, the practices that may be used, and in some cases whether the land should be farmed at all. For example, some sandy land that cannot be safely planted to wheat can be planted to sorghums without danger of serious blowing if the sorghum stover is allowed to remain standing. Some soils that cannot be fallowed safely in large blocks can be handled without undue risk if the fallowed and cropped land are arranged in alternating strips.

The best control over wind erosion is by preventing the soil from reaching a condition that permits it. Soils covered with a crop, with a crop residue, or with clods are in condition to resist wind action. Ridged soils likewise check soil drifting.

Tillage to conserve moisture does not always fit in with wind-erosion prevention. A soil covered with weeds will not blow, but neither will it reach a moisture condition suitable to the growth of a crop. If crops are to be grown, the necessary tillage must be given. The tillage, however, must be of a type that will maintain a surface as resistant as possible to erosion, while attaining the satisfactory moisture condition. This is not always wholly possible, but the use of implements that will leave crop residues and clods over the surface is one of the principal means of combating wind erosion.

One of the greatest dangers of wind erosion arises from crop failures, which leave the land free of protective residues. Too frequent failures may well indicate that the land cannot be safely farmed.

Preventive cultivation can be given to check soil blowing on land where movement has started. This is a recommended practice, but if proper tillage methods are used, the number of times that preventive cultivation is needed will be greatly lessened.

Water erosion is not so important a factor in dry-land sections as in more humid sections, although damage sometimes occurs. The greatest evil is the loss of water that may be vitally needed for crop production. For this reason the prevention of run-off is advocated to increase crop yields rather than to prevent soil loss, although it ac-
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complishes both ends. The entire trend of cultivation has been to
hold water where it falls until it penetrates the soil, rather than to
lead it from the field by easy stages to prevent washing.

SOIL-MOISTURE PROBLEMS

Since water is generally the limiting factor in crop production, it
follows that making the best use of the precipitation is the basic
factor to be considered in a well-ordered farming system. This differs
from the condition in humid areas where precipitation much above
the average is likely to depress yields.

Owing perhaps to its relative newness as compared with agriculture
in the more humid sections of the United States, dry-land farming has
been a fertile field for theorists and opportunists. Most of the theories
have been concerned with soil moisture. During the past 30 years
numerous panaceas for the prevention of failure by drought have
been proposed, accepted to a greater or less extent for a time, and
finally discredited by most of those familiar with the problems.

Among the theories or remedies widely accepted were the dust-mulch
theory, which proposed that the top layer of soil be worked to form a
dust mulch to break up capillary connection and prevent loss of mois-
ture from the surface; the idea that exceedingly deep plowing or sub-
soiling would permit more water to enter the soil and to increase the
zone where crop roots could develop freely; and the belief that water
rises from the water table or deep subsoil by capillary movement.

Investigators soon discarded the maintenance of a dust mulch
as a practice, because the finely pulverized surface increased run-off
and was exceedingly subject to wind erosion. Deep plowing and
subsoiling were discarded because of their expense, and because the
rain that fell between harvest time and seeding time was often not
sufficient to wet the loosened layer. The loose open soil favored loss
by evaporation, and such deep tillage was more harmful than benef-
cial in dry years and ineffective in normal or wet years. It was also
found that the depth of cultivation had little or no effect on root
development, as root growth under most conditions fully occupied
the moist soil area and was sufficient to exhaust the available water.

The fallacy of the rise of subsoil moisture from the water table or
deep subsoil has been the hardest to dispel. Investigators soon found
that movement of water upward except as carried by plant roots or as
vapor was practically nonexistent in dry-land sections. They also
found that the subsoil within the zone occupied by the roots of crop
plants was normally dry at harvest time each year and remained dry
except when wet from the surface, regardless of whether the subsoil
beneath that zone was wet or dry. Yet there is a persistent belief that
drought is caused by the exhaustion of subsoil moisture and the lower-
ing of the water table. It seems not to be generally understood that
in most of the dry-land areas there has never been a water table near
enough to the surface to benefit annual crops even in favorable years.

At the present time a number of remedies that sound reasonable are
being advanced for the prevention of crop failure caused by drought,
but their economic and practical value is still to be determined.

The fundamental facts concerning soil moisture as a basic factor in
the control of dry-land crop production as they are now understood
should be given consideration in any dry-land farming enterprise. A summary of these facts and their effects follows.

Crop Yields and Available Water Not Directly Proportional

The quantity of crop produced is not directly proportional to the quantity of water used. A considerable quantity of water is required before a measurable yield is produced. Any quantity less than this minimum results in failure. After the minimum requirement has been satisfied, yields, up to a certain point, appear to be proportional to the quantity of water above the minimum requirement.

A concrete example may be given to illustrate this point. Assume that in a certain section a precipitation of 10 inches represents the minimum requirement for wheat to produce grain. Under this condition a 9-inch precipitation would result in complete failure, but a precipitation of 12 inches would produce some grain. The difference in yield is not proportional to the amount of precipitation. It is the difference between no crop and a light crop. A precipitation of 14 inches would produce, not one-sixth more, but double the yield produced by a 12-inch precipitation, as there would be twice as much water above the minimum requirement.

This explains the value of comparatively small quantities of water in dry-land farming. The value of fallow and of other moisture-conserving practices is all out of proportion to the quantity of water stored compared to the total quantity required for crop production. This is because the additional water contributed is generally water above the minimum requirement. Over the Great Plains as a whole the value of 1 inch of conserved water is from 3 to 4 bushels of wheat per acre, provided the precipitation is sufficient to meet minimum requirements. At most places a difference in water content at seeding time can be translated directly into a difference in bushels of yield.

In parts of the winter wheat area the depth to which the soil is wet at seeding time (an expression of the available water stored in the soil) is so important that it serves as a basis for predicting at that time the order of yield that is likely to be obtained. This is probably because the rain that falls between seeding and harvest time is so often near the minimum quantity necessary to produce a crop that the quantity in storage at seeding time is the most important factor in determining the ultimate yield.

Precipitation Sole Water Supply

Except in certain lands along streams the only source of moisture for crop production is precipitation. This would appear to be too evident to require emphasis, but it is a fact that many persons still believe there are magic formulas for growing crops from sources of water other than precipitation. Along watercourses, however, water may be near enough to the surface to be reached by deep-rooted perennial crops such as alfalfa.

Soil Normally Dry at Harvest Time

Small-grain crops normally use before harvest time all the water in the soil that is available to them, leaving the soil dry, although in an occasional wet year there may be some carry-over of moisture.
Composite results for all years of record for all the dry-land field experimental stations in the Great Plains, numbering about 20, show that land where small-grain crops were grown was dry at or before harvest time in fully 90 percent of the years.

This fundamental fact shows why tillage of small-grain stubble immediately after harvest has been so ineffective in the northern portion of the Great Plains. The possible benefit from such cultivation lay in preventing the loss through weeds of precipitation that fell between harvest and freezing. Since this period is short and precipitation during it is low, such loss is small in comparison with the moisture gained during the winter from snow held by undisturbed stubble. In the southern section of the Great Plains, on the other hand, small-grain crops are harvested early, and there is a long period between harvest and freezing during which the moisture from rains may be lost through weed growth. Cultivation after harvest in this area is often highly effective—but it is effective because it destroys weeds and helps the soil to absorb and hold rains that fall after harvest, not because it retains water already in the soil.

In more humid areas, cultivation after harvest may be useful in holding moisture already in the soil. Under dry-land crop production this is seldom the case. A definite knowledge of the purpose of cultivation after harvest should be a guide in determining under what conditions it should be practiced.

Means of Increasing Available Water

The quantity of water available to a particular crop may be augmented to some extent by growing it after a crop that does not exhaust the water supply of the soil to the same extent. It may also be augmented by reducing or eliminating crop production in one year to provide moisture for the next, as by growing corn or sorghums in very wide rows or by summer fallowing.

Water-Consering Crops

In the northern portion of the Great Plains dry-land area, the carry-over in cornland of moisture available to small grain is reflected in higher yields following corn than following small grains. In the southern part of the Great Plains, there is a similar carry-over of moisture following corn, but early preparation of small-grain stubble frequently stores water equal to or greater than the carry-over on corn ground. Consequently the carry-over does not result in a materially increased yield of grain crops following corn.

Sorghums are another crop that may leave a carry-over of water. In the northern part of the Great Plains frost ends their growth about the time corn is harvested. Consequently yields of grain following sorghums are likely to equal or nearly equal yields of grain following corn. Farther south, most sorghums grow for a long period in the fall after small grains and corn are harvested, and they are still using moisture when land on which small grains or corn was grown may be storing it. Consequently, although sorghum does not usually reduce the moisture content of the soil to so low a point as do grain crops, sorghum land usually contains less moisture in the late fall than cornland or small-grain stubble land. This is reflected in a low yield of
grain crops following sorghum. The carry-over on sorghum land, moreover, is generally smaller than on cornland, because sorghums live and continue growth under conditions which cause corn to fire and cease growth.

Much of the value of the different row crops in dry-farming rotations lies in the reserve of moisture available to grain crops that they leave in the soil.

**Wide Spacing**

In the central and southern Great Plains, wide spacing of corn and sorghum to carry over moisture to supplement the next year's precipitation is being widely advocated, and has been the object of considerable experimental study. Little of this work has been long enough continued to permit positive statements, but certain trends are evident.

The results at Akron, Colo., of growing corn in rows twice the usual distance apart in comparison with rows of regular width and following each with winter wheat indicated an increase in the yields of the wheat, but this increase was obtained at the expense of a decrease of nearly 2 bushels per acre in the yield of corn grown in the wider spaced rows for each bushel of increase in the yield of wheat following it. The surety of corn production in dry years was not greatly increased by growing it in double-width rows. The yields of wheat following good yields of corn were higher on the double-spaced rows. When corn was badly injured by drought, the yields of wheat following it were little higher where the rows were double spaced than where they had the standard spacing.

Results with grain sorghums are more favorable to double spacing, chiefly because the grain yield of sorghums in double-width rows is nearly as high as in regularly spaced rows. When the sorghum does not suffer too severely from drought, the yields of wheat the following year are generally higher where the sorghum is double spaced. When the sorghum fails or nearly fails because of drought, double spacing the rows has little effect on the following yields of wheat. In drought years both corn and sorghum in double-width rows are able to exhaust all the available water from the soil, and the method provides no carry-over of water beyond that provided by planting in rows with the ordinary spacing.

From the experimental results that have been obtained, it appears evident that if the effect of a partial fallow is desired, the rows of cultivated crops must be spaced more than double the distance between regular-width rows, preferably a rod or more. Such widely spaced plantings are intended primarily to provide a condition of partial fallow, and at the same time grow a crop that may not be so valuable in itself but the residue of which should help in checking wind erosion. Its value will be chiefly in the extent to which it accomplishes this purpose. Experimental results on these very wide spacings are still too meager to afford a sound basis for recommendation for agricultural practice.

**Fallowing**

The greatest supply of moisture can be carried over from one year to the next by means of a summer fallow, which sacrifices one crop to
store moisture for the next. It provides a reserve of moisture unequaled in land that has grown a crop.

The most common method of handling fallow is to permit the stubble from a crop to stand over winter, to plow in the spring before weeds have removed much water, and to keep the land free from weeds but in a condition to absorb rains during the summer. In the Great Plains little advantage is gained by plowing early in the spring. The double purpose of holding water already in the soil and absorbing water from rains is best served by plowing when weeds are well started but are not using water rapidly, usually from May 15 to early in June, and thus leaving the land cloddy during the periods of heaviest rains in late May and all of June. Plowing as late as it can be done without serious loss of moisture is desirable, because it reduces the number of cultivations needed to keep the land free from weeds during the summer. Too long a delay, however, results in loss of water by weeds and a decreased efficiency of fallow.

In the Pacific Northwest, under winter rainfall, absorption of water during the summer is a factor of little importance. Conserving during the summer water that is already in the soil is the chief function of fallow. Consequently plowing is done there early in the spring to prevent loss of water by weeds and to avoid the loss of moisture incurred when plowing land in hot weather.

In recent years the prevalence of soil blowing has brought the plowless fallow into wide use. The land is not plowed, but is worked with a duckfoot cultivator or some other implement that destroys weeds without turning under the stubble. The exposed stubble helps prevent wind erosion during the winter months. Plowless fallow generally requires a greater number of cultivations than plowed fallow, but none of the operations is as expensive as plowing.

The lister, sometimes used on the contour, often replaces the plow for the initial operation on fallowed land. Regardless of the implements that may be used, the principles underlying the cultivation of fallow remain the same. They are the prevention of loss of water by weed growth and the maintenance at the same time of a surface condition resistant to run-off and to wind erosion.

Even on summer-fallowed land, however, it is possible to hold over only a comparatively small portion of the year's precipitation. So much water is lost by the drying of the surface soil following rains that comparatively little is available for deeper penetration. In the Great Plains it has been possible, on the average, to store only 20 to 25 percent of the precipitation. This is owing to the fact that most of the precipitation falls during the season when air and soil temperatures are high and humidity is low, conditions favoring a heavy loss by evaporation. In the intermountain regions, where much of the precipitation occurs in the late fall or winter, it is possible to hold a larger proportion of it in fallowed land.

Losses by evaporation are confined largely to the surface layer of soil, but crops remove water that is stored beyond the reach of surface evaporation. Consequently more water will be conserved in fallowed land than on land with a crop, no matter how thin the stand of crop may be.

The results of the carry-over of moisture are shown in the greater
surety and increased yields of crops on fallowed land. The value of fallow in any given section lies in the extent to which it increases yields above those obtained through other methods of cultivation and reduces failures. Yields must be materially increased for fallowing to be an economic practice, as no return is received from the portion of the land that is being fallowed.

In portions of the dry-farming regions grain crops, particularly winter wheat, are so outstandingly productive on fallowed land that the inclusion of a large amount of fallow in the farming system is sound practice. In other portions, yields on fallowed land are considerably less than double the yields on cropped land, but the inclusion of a limited acreage of fallow may be valuable as a means of controlling weeds and as an insurance against total failure.

The extent to which fallow can increase yields is largely limited by the quantity of water it holds within the reach of crop roots beyond that held by other methods of tillage. Fallowing or any other method of conserving moisture for the next year is of little or no value on very sandy land, shallow soils, or land too heavy to absorb and hold material quantities of water within the reach of crop roots.

**Preventable Water Losses**

The controllable sources of water loss are run-off and dissipation by weeds. The extent to which losses from these two causes may be reduced represents the limit to which the water available to crops may be increased by ordinary means.

Run-off occurs during heavy or torrential rains in most dry-land areas. The actual quantities of water lost by run-off have been determined at relatively few points. It is recognized, however, that losses by run-off are an important factor in most sections and on most soils. The more torrential the rains, the greater the losses by run-off are likely to be. In the northern Great Plains, water from melting snow running off from a frozen soil is an additional source of loss.

The rate of infiltration of water into a firm soil is definitely fixed by the soil type. It follows that if the precipitation rate exceeds the infiltration rate, there will be run-off unless the water is trapped on or near the surface. In some sections the trapping space provided by a loose, rough surface is sufficient to hold all water from ordinary rains. In all sections it is a material help. At Havre, Mont., it is said that there has been no run-off from properly maintained fallow in 20 years. In many other locations there has been run-off, despite the use of good cultural practices.

The fact that water needed for crop growth is lost through run-off has led, in recent years, to special practices for trapping water on the surface. Among those that may be mentioned are use of the basin lister, an implement that forms dams in lister furrows; contour listing and other contour cultivation; and level terracing. All these practices are designed to and do hold water that might otherwise be lost by run-off. Their value is in proportion to the quantity of water held at points where it can be used for crop production above quantities that may be held by ordinary good cultivation. At the present time it appears likely that the greatest usefulness of the basin lister and contour cultivation will be found in the production of row crops and
the maintenance of fallows. Their usefulness in small-grain production is limited by the fact that land occupied by a small-grain crop or stubble is less subject to heavy loss by run-off during the greater portion of the year.

Avoiding losses of water by run-off is one of the few practicable means of increasing the quantity of water for crop use. In very dry years, it cannot be expected to conserve enough water to insure crop yields, as in such years there may be little or no run-off. In most years it should be of value, although there is the possibility that it may have a depressing influence in very wet years.

Destroying competing weed growth is a practicable means of increasing the supply of water available to crops. Weeds use water very rapidly after they have made a substantial growth. As the total quantity of water available is not often sufficient to produce maximum crops, its reduction by weeds can result only in decreased yields. The destruction of weed growth increases crop production. There is a practical limit, however, to the effort that can be expended on the destruction of weeds, as the cost must be less than the value of the increased yield.

**Efficiency of Water Use by Dry-Land Crops**

Crops under dry-land conditions are not ordinarily more efficient in the use of water than the same crops grown under more humid conditions. On the contrary, more water frequently is required to produce a unit of dry matter, as the humidity is usually low and water loss by transpiration is high. Crops best adapted to dry land are those that make their maximum growth when climatic conditions are not too severe and the best use can be made of the limited water supply. Varieties of grains that make their maximum growth before the hottest part of the summer are generally most productive, although in an occasional wet year later maturing varieties may do better. More efficient use of moisture is probably the reason why winter wheat has generally displaced spring wheat in the area where both can be grown. Winter wheat is usually mature before the hottest part of the summer, whereas spring wheat, being somewhat later, most frequently completes its development under much more severe conditions of temperature and transpiration. Sorghums are particularly adapted to the southern dry-land section, because their growth requirements conform to the precipitation of the section. Their periods of greatest need for water come in June, for starting them and carrying them through their early growth period, and in August, for heading. Precipitation in these two months is normally higher than in July. Sorghums complete their growth in September and October when temperatures are moderate. They are also able to suspend growth and reduce transpiration during periods of stress, and to resume growth upon the return of favorable conditions, conforming to the water supply that may be available.

With these basic facts concerning soil moisture in mind, it is possible to perform cultural operations with a definite idea of what they may accomplish, and to adopt farming practices that are suitable to the section and the soil. The most that may be accomplished is to make the best use of the precipitation and of the stored water. No miracle
is going to produce a crop without the use of a considerable quantity of water.

TILLAGE AND ROTATION PRACTICES

It will be apparent from the preceding that tillage and rotation practices are closely concerned with the soil-moisture problem. The control over crop production by tillage is small in comparison with the control effected by precipitation, but the quantity of precipitation is not subject to change through human agencies. Hence it is important that the measure of control that can be obtained through tillage practices be exercised.

Tillage may be divided roughly into two divisions: (1) Tillage in preparation for a crop, and (2) tillage during the life of a crop.

Tillage practices in preparation for a crop should create a moisture and nitrate condition favorable to growth and maintain a surface condition resistant to wind erosion. Such practices must be necessarily those that reduce or prevent run-off and that destroy competing plant growth. The kind of tillage called for depends upon the section and the crop grown. In the wetter section of the southern Great Plains early working of wheatland after harvest is an important means of storing water for the next wheat crop. Cultivation during the period between the harvesting of one wheat crop and the seeding of the next should be the amount necessary to control weed and volunteer wheat growth and to maintain a surface sufficiently open to permit ready penetration of water and cloddy enough to resist wind action. The use of implements that leave the residue of the previous wheat crop on the surface is desirable, as this assists in preventing run-off and checking wind erosion. In the northern portion of the Great Plains the snow held by stubble is an important source of water, and letting the stubble stand over winter is a moisture-conserving practice. Cultivation can be delayed until spring. In portions of the Plains neither of these methods conserves enough moisture to reduce greatly the risk in continuous grain production. Where this is the case, and the soil type is suitable, following a portion of the land is desirable in order to provide by tillage enough moisture to give a reasonable assurance of producing a crop.

With all cultivation, one principle should be the maintenance of a surface condition that encourages water penetration. Whether this will be in the form of any of the varied types of cultivated surfaces left by the several cultural implements or by an undisturbed stubble depends on the location and on the type of precipitation.

Another principle of cultivation should be the destruction of competing weed growth. This is important when weeds are removing stored water. Such cultivation should be with implements that do a thorough job of weed killing while leaving the surface in condition to absorb water and to prevent blowing.

The number of tillage operations should be the least that will accomplish the desired purpose. Too much cultivation breaks down the cloddy structure of the soil, destroys crop residues, leaves a surface that favors run-off and wind erosion, and increases costs.

The fact that dry-land farming is carried on on extensive areas with crops of relatively low acre value makes it imperative that the costs
be held down. The proper choice of implements and of times to perform the needed operations is the best means of accomplishing this object.

Tillage of growing crops under dry-land conditions may be considered as having one main purpose, that of destroying weeds. If cultivation sufficient to accomplish this purpose is given, no additional cultivation for the maintenance of a surface mulch is needed or desirable.

Crop rotations under dry-land farming have some basic differences from rotations for more humid areas. The maintenance of soil fertility is important but not nearly so immediately important as other factors.

In selecting crops and assigning them a place in the rotation more stress must be placed on their soil-moisture relations than on their effect on the soil fertility. Considerable stress must also be placed on the vegetative cover maintained at critical periods of the year, as this affects moisture conservation and wind erosion, and on the amount and distribution of labor required under any particular system.

Limitations in the possibilities of crop rotations are (1) the number of crops that are adapted, (2) the effect of the adapted crops on each other, and (3) the type of farming practiced.

The number of crops whose net value per acre is somewhat near the same is small in comparison with humid areas. Where there are several, a rotation can be easily planned. Where one crop is outstandingly more productive or more valuable than any other crop, a rotation involving relatively large acreages of other crops finds little favor. For example, in portions of central Kansas winter wheat is a comparatively sure crop and is so outstandingly more valuable than other crops that every acre of cropped land not devoted to it means a loss of revenue. Under such conditions, the growth of other crops is largely limited to the needs for feed for the livestock maintained on the farm. In such an area, however, the effect of rotation need not be altogether lost. Hallsted (139) found at Hays, Kans., that a rotation of 3 years of wheat and 1 year of fallow was as productive as planting all the land to wheat every year on early plowed land. In addition, it provided a means of combating noxious weeds and distributing the yield more uniformly from year to year. The use of fallow had the effect of reducing the total yield in years of high production and increasing it in years of low production.

In some sandy soils sorghums are grown to the almost complete exclusion of other crops. Under such conditions some of the effects of rotation may be obtained by planting strips of legumes between strips of sorghums.

As a rule rotations for dry-land farming can be made comparatively simple. In fact, the limited number of crops that can be grown in many sections makes this necessary.

The use of crops in rotations depends upon their effect on each other. In the Great Plains corn and small grain work admirably together, because corn ground usually leaves a residue of moisture available to small grain. A further advantage is that the growth of the two types of crops affords a good distribution of labor. Where corn and small grain can be successfully grown, these form the back-
bone of rotation practice. The two crops are well adapted to rotations for farming systems where livestock production is carried on in conjunction with grain farming.

In the southern Great Plains sorghum and winter wheat do not fit in well together. The sorghum leaves the ground too dry for fall-sown grain. Where sorghum, small grains, and fallow are all adapted, the sorghum land can be fallowed, and the severe reduction in small-grain yield thus avoided. In the north, on the other hand, sorghum and spring grains are admirably fitted to follow each other.

Sod crops are considered a fundamental part of the rotation in many humid sections, but in dry-land farming they have not won a recognized place. The inclusion of sod crops in short rotations has not been a success. Establishing a stand of grasses is often too expensive unless it is to be left for more than 2 or 3 years. Further, while the long-time effect of a grass crop may be good, its effect on the crop immediately following is generally bad, because it leaves the soil exceedingly dry. In deferred rotations, where the grass is allowed to stand for a longer period, and a longer period intervenes between grass crops, such crops may be found better adapted. Information is still too scanty, however, to justify definite recommendations.

In the intermountain region the available crops are even more limited than in the Great Plains. In the strictly dry-farming areas alternate fallow and crop are essential for profitable yields. A simple rotation of fallow and wheat is the best for all conditions. Field peas, barley, oats, or rye may be used to advantage in limited amounts, but only with due consideration of the principles previously outlined.

The rotation must depend to a large extent upon the farming system. A system depending largely upon grain production for income can include only relatively small quantities of feed crops, as these are generally not profitable unless fed on the place. A mixed farming system consisting largely of livestock production must involve a greater use of feed crops and a lesser use of grain or cash crops.

With all crop rotations, an effort should be made to select crops and practices that leave the ground in condition to blow as little as possible.

Dry-land crops are grown on an extensive basis and arranging them in rotations and using methods that reduce the amount of labor without reducing the yields proportionately are effective means of increasing the farm income.