Soil Nitrate, Total Nitrogen and Organic Matter in Relation to Dry-Farming

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SOIL NITRATE, TOTAL NITROGEN AND ORGANIC MATTER
IN RELATION TO DRY-FARMING

by

Krishnappa Ramaiah

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Logan, Utah
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Logan, Utah

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INTRODUCTION

Dry farming has been defined as production of useful crops, without irrigation, on lands that receive an annual precipitation of 20 inches or less. In some regions the term dry farming is applied to farming without irrigation under annual precipitation of 30 inches or less. Although there is no sharp demarkation between dry farming and humid farming, the term dry farming always means farming under difficulties due to limited annual rainfall.

Importance of Soil Nitrates and of Total Soil Nitrogen to Plants

Nitrogen being fundamental in protein manufacture is an essential factor in soil fertility, whether it be in dry farming or humid farming. Protoplasm, the life giving substance, consists largely of protein. Every time a crop is grown on land, some nitrogen is taken out of soil for manufacturing proteins. Nitrogen is not derived from any parent material in soil as in the case of calcium, phosphorus, and potassium; hence it cannot be replaced from any parent material. Nitrogen is found in the atmosphere in abundance in the free inert form, and this has to be incorporated into the soil if the nitrogen supply is to be maintained.

Atmospheric nitrogen can be returned to soil by biological nitrogen fixation, by natural chemical reactions, or by applying commercial fertilizers. Biological means of increasing soil nitrogen by growing leguminous crops have been practiced for a long time by farmers. In addition to this, the addition of barnyard manure to increase soil nitrogen has long been practiced. In recent years commercial fertilizers have been used for increasing nitrogen in soil where the supply of legumes and
barnyard manure fail to meet the demand for nitrogen by crops. The total soil nitrogen in any soil is greater than that found in soil nitrate, as nitrogen occurs in other forms also. It is mainly found in the form of proteins, amides, ammonium salts, and nitrates. The presence of nitrates in soil is important inasmuch as it is one of the forms most directly available to plants and is especially needed by dry land wheat as it approaches maturity.

Importance of Organic Matter in Soil

In soils of arid regions there has been very little accumulation of organic matter because of sparse vegetation and rapid oxidation processes. In practical agriculture, where economic pressure often forces immediate economic problems to play a more important role than long term considerations, the maintenance of the soil organic matter at the level at which it occurs in the virgin soil becomes difficult. However, since organic matter contains all the mineral elements essential to plant life in addition to being the first source for organic nitrogen, its maintenance in soils is important. Increases in soil organic matter eventually results in increased soil nitrogen.

The literature on soil management reveals many claims for the importance and value of organic matter. Organic matter in soil is credited with checking erosion, with increasing the plant food supply, with improving soil structure, with influencing weathering, with increasing the water holding capacity, with causing more rapid warming up in the spring, and etc. Whether all accept these attributes of organic matter or not, it is generally accepted without controversy that there is a close relationship between soil organic matter and productivity.
Problems of Dry Farming

The special problems of dry farming center mainly around precipitation and soil. In the words of Dr. John A. Widtsoe, (15, pp. 8 & 10)

"The fundamental problems of dry-farming are, then, the storage in the soil of a small annual rainfall; the retention in the soil of the moisture until it is needed by plants; the prevention of the direct evaporation of soil-moisture during the growing season; the regulation of the amount of water drawn from the soil by plants; the choice of crops suitable for growth under arid conditions; the application of suitable crop treatments, and disposal of dry farm products, based upon the superior composition of plants grown with small amounts of water."

All the region in the United States west of the 98th or the 100th meridian, except areas where climate has been changed by irrigation, faces these problems. Soil nitrates, total nitrogen, and organic matter become very important in dry farming on account of scarcity of annual rainfall.
SOIL NITRATES IN RELATION TO DRY FARMING

In general most of the nitrogen in soil is in combination with organic matter. Some of the soil nitrogen is readily soluble in water and immediately available to plants. Such soluble nitrogen is usually found in the form of nitrate nitrogen, ammoniacal nitrogen, amide nitrogen, and organic ammoniates.

Tillage and Soil Nitrates

Experiments conducted by the Kansas Agricultural Experiment Station during 1909-13 indicate that early July plowing and working the land until seeding time for seedbed preparation is beneficial in storing soil nitrates. Soil samples were taken for nitrate determination in July, August, September, and October of 1912 and March of 1913. Plowing in July and working the ground until seeding time resulted in increases in soil nitrates from July to September, while first plowing in August and September showed decreased nitrates in soil due to weed growth. The amount of nitrates in soil varied with the month of plowing. The average nitrate content of the experimental plots plowed in July was 454.80 pounds per three acre feet; for plots plowed in August, 294.55 pounds; for plots plowed in September, 69 pounds; and for plots not plowed but disked at planting time, 22.43 pounds. These experiments indicate that early plowing and thorough preparation of soil results in an increase of soil nitrates. On plots plowed late not enough nitrates were liberated and the crop yields obtained were poor. It appears from this that nitrogen is the limiting element of plant food in wheat production on poorly prepared ground. (5)
Similar results have been obtained in experiments conducted by the Washington Agricultural Experiment Station. (1) Bracken (2) reported in 1940 that early spring plowing of land in Utah has a beneficial effect on the yield of wheat due to increased soil nitrates. In dry farming care has to be taken to see that enough plant food is liberated by proper early cultivation; otherwise, in spite of availability of water in the soil, the crop yields will be low.

**Effects of Soil Nitrates on Crop Yield**

Experiments conducted by the Kansas Agricultural Experiment Station (5) show that the yield of wheat was relatively high where large amounts of nitrates were present at the time of seeding and relatively low where the nitrates were low at the time of seeding. There was a close relationship between quantities of nitrate present in soil and the resultant yield of wheat. That nitrogen is the limiting factor in crop yields is emphasized by fertility experiments. Wheat was grown on well prepared and poorly prepared ground, and both received nitrate fertilizers. In the case of well prepared ground, there was no increase in yield due to nitrogen fertilizer application because all the available nitrogen required was in the soil. On the other hand, yield of wheat on poorly prepared ground showed an increase of 100 percent from fertilizer application. (5) These results are important inasmuch as a farmer, who cannot plow his land early due to reasons beyond his control, can often obtain good yields by applying nitrogen fertilizers where soil moisture conditions are favorable.

In 1946 the Washington Agricultural Experiment Station reported the results of experiments conducted during 1921-45 on the effect of fertilizers on wheat production. The application of nitrate nitrogen, along with organic residues like straw and alfalfa hay, gave high wheat
yields. On the average, to produce each additional bushel of wheat, 5.7 pounds of nitrogen were required. However, in a few plots where both straw and sodium nitrate were applied, low yields were obtained due to lack of moisture. These results indicate that there is an inter-relationship between nitrogen and moisture in determining yields. (13) Application of nitrates to soil of low moisture content at the time of seeding may result in overstimulation of early plant growth and later at the time of plant maturity there may not be enough moisture in the soil. Under such circumstances the crop will be burned for lack of moisture.

Effect of Soil Nitrate on Quality of Wheat

Experiments conducted by the Washington Agricultural Experiment Station (1946) show that maximum nitrogen accumulation in wheat and straw occurred where either sodium nitrate was applied or sodium nitrate and straw were applied. (13) Where no supplemental nitrogen was applied, percentages of nitrogen in straw and grain were at a minimum. Of the two plots, which were treated with straw and sodium nitrate, under the annual wheat cropping system the average nitrogen in grain for 1922-44 was 2.50 percent in one plot and 2.39 percent in the other plot. In a plot which was treated with sodium nitrate alone, wheat contained an average of 2.54 percent nitrogen. Under a wheat-fallow cropping system similar treatments showed slightly higher protein content in wheat.

Peterson (10) reported in 1950 that in Utah early spring application of nitrogen fertilizers increase both yield and protein content of winter wheat when sufficient available moisture is present in the soil. The data he has presented indicate that the application of ammonium nitrate gave better yield and quality of wheat than the application of ammonium sulfate.
Factors Affecting Availability of Nitrogen

Availability of soil nitrogen to plants depends on two factors; namely, C:N ratio and the rate of decomposition of the organic matter. When the C:N ratio in soil is narrow, ammonium compounds are released due to decomposition of organic matter, and these are oxidized into the nitrate form. On the other hand if the C:N ratio in soil is wide, there may result a competition between microorganisms and plants for the soluble nitrogen. Although the total quantity of nitrogen present in soil serves as a storehouse for future use, only a small proportion becomes available to plants during any growing season. (13)

Experiments conducted by the Washington Agricultural Experiment Station (13) show that, under annual cropping with wheat, plots treated with nitrogen fertilizers alone or together with straw or manure or alfalfa hay maintained or increased the carbon and nitrogen content in the soil. This result is of practical significance to wheat farmers on dry land.

The C:N ratio has a tendency to maintain itself under natural conditions. Consequently, it is not possible to increase the effective and desirable organic matter in the soil unless the nitrogen in the soil is increased. All crop residues do not have the same C:N ratio. Straw has a C:N ratio of about 80:1, legumes have 20:1, and proteins have 10:1. During decomposition of organic matter, carbon is lost more rapidly than nitrogen. The rate of decomposition slows down as the C:N ratio approaches the stable level. In virgin soils the C:N ratio is at a stable level. The theoretical limit of the C:N ratio is the
same as the ratio found in the microorganisms responsible for the decomposition of the organic matter, or 10:1. As nitrogen content increases in the organic matter above that of virgin soil, the organic matter becomes resistant to further decomposition.

Addition of organic matter to soil is important, but such organic matter should not have a wide C:N ratio which will have an immediate depressing effect on nitrate accumulation or yield. Such a depressing effect is overcome only when the average C:N ratio reaches a stable level by loss of carbon through carbon dioxide. In other words, the beneficial effect of addition of organic matter to soil is largely proportional to its nitrogen content. Addition of wheat straw and stubble with a wide C:N ratio may depress plant growth for several weeks. However, given enough time for decomposition and consequent narrowing of the C:N ratio, there will be benefit in adding organic materials of wide C:N ratio.

Influence of Cultivation on Nitrogen Content of Wheat

Experiments conducted by the Washington Agricultural Experiment Station (1918) show that proper cultivation and supply of nitrogen through the growing of legumes will improve the quality of wheat by increasing the nitrogen content. (1) Increases in nitrogen or protein content of wheat depend on the amount of nitrogen available in the soil. It is reported that both soil nitrogen and carbon declined during the period from 1921 to 1944 under a wheat-fallow system of cropping with biennial applications of nitrogen fertilizers. Under similar circumstances, but with an annual wheat cropping system, both nitrogen and carbon increased in the soil. (13) This may be due to continuous cultivation which results in the liberation of nitrates as reported by the Kansas Agricultural Experiment Station, or it may be
due to less leaching, as much of the moisture is used up by the crop, or it may be due to more crop residues being added. (5) Bracken (1940) reported that early plowing for fallow in Utah, while increasing the yield of wheat by increasing soil nitrates, had little effect on protein content; whereas treatment with barnyard manure did increase protein content. (2) These results indicate that in order to obtain good yields of high protein wheat it is necessary to cultivate thoroughly, and fallowing alternate years is not regularly necessary if sufficient moisture is available for annual wheat cropping on land treated with nitrogen fertilizers. Where sufficient moisture is available, with the addition of nitrogen fertilizers or with crop rotation it is feasible to grow wheat year after year.

Increase in Nitrogen from Growing Alfalfa on Dry Land

Bracken and Greaves (1941) have reported that dry farm lands of Utah contain less nitrogen than virgin lands. (3) The differences in the loss of nitrogen between soils of Cache Valley and Juab Valley in Utah, with very little difference in the mean annual temperature, are attributed to higher annual rainfall and higher nitrogen content of virgin soils in Cache Valley. They have also reported that the soils in these two valleys have lost twice as much nitrogen as was removed by the crop. The greater loss of nitrogen from the soil not accounted for by the crops in Utah may be due to one or all of the following factors: "... leaching to lower depths beyond the feeding range of the plant; erosion; denitrification; and volatalization through biological and possibly chemical means." (5) The first three factors are reported to be of minor importance in dry farm lands of Utah. The major causes of the loss of soil nitrogen in excess of that removed by plants in Utah are high temperature and moisture content of
These facts indicate that, when virgin lands are brought under cultivation, soil nitrogen is depleted and it has to be replenished in order to obtain better yields and quality of wheat.

Bracken and Larson (4) reported in 1947 an increase of soil nitrogen at various depths of soil from growing alfalfa for various periods on dry land. The first period ranged from 15 to 30 years, the second from 10 to 13 years, and the third from 2 to 5 years. The data reveal that lands used for wheat cultivation over different periods contained 20.3 percent less nitrogen in the first and the second feet of soil than the adjacent virgin lands. Land used for alfalfa contained 13.1 percent more nitrogen in the first foot of soil than land used for wheat. There was no significant difference in the means of the three age groups of alfalfa, but the difference in the nitrogen content of wheat land and alfalfa land was significant. Growing alfalfa increased the soil nitrogen but not up to the nitrogen present in virgin land.

Virgin lands contained an average 9.9 percent more nitrogen than alfalfa land in the first foot of soil. Nitrogen recovery on land used for alfalfa for 2 years and 13 years ranged from 19.5 percent to 88.9 percent.

In the second foot of soil, land used for alfalfa had 11.1 percent more nitrogen than wheat land and had 11.9 percent less nitrogen than virgin land. These differences are significant. In the third foot of soil, nitrogen in wheat land was 14.5 percent and in alfalfa land 13.2 percent lower than virgin land. These data indicate that the growing of alfalfa results in accumulation of nitrogen largely in the first two feet of soil. This work is important and is of practical use to dry land wheat farmers inasmuch as lands which have suffered from a loss
of nitrogen can be improved by growing alfalfa. However, it may not always be possible to grow alfalfa effectively on all dry lands because of low precipitation. In semiarid regions nitrogen accumulation above the nitrogen content of virgin soils due to growing alfalfa has been reported. However, the data presented by Bracken, et al. (4) reveal that in Cache Valley accumulation of nitrogen reaches an equilibrium after growing alfalfa for 10 years and is found to be seven percent below that of virgin land.

The work of Metzger (1939) throws light on the nitrogen accumulation in soil by growing alfalfa and harvesting the hay. (9) It is often said that removal of hay results in no addition of nitrogen to soil. Such a result may be due to high initial nitrogen content of the land used for experiment. It is seen that in soils with low initial nitrogen, alfalfa stores the largest quantities of nitrogen. On the other hand, in soils with relatively high nitrogen contents, alfalfa stores comparatively small quantities of nitrogen.

Growing alfalfa on unfertilized plots for a period of 19 years resulted in an increase of soil nitrogen of 0.71 percent per year. As alfalfa does not usually survive for such a long time, its effect for shorter period is interesting to note. Various reports give varying periods of residual effect of alfalfa. Metzger (9) is of the opinion that alfalfa stands beyond three or four years may not add greatly to the soil's ability to accumulate nitrate nitrogen. His work reveals that there was a residual effect for at least eight years from two or more years of alfalfa cropping as evidenced by yield and protein content of wheat. He also stated that Mirmiani reported that "prolonged" periods of alfalfa cropping in Armenia produced a pronounced
effect on succeeding cotton crops for three years, but after three years the effect declined rapidly. (9) Bracken, et al. (1947) have reported that fields in alfalfa for a period of 10 to 13 years accumulated the same amount of nitrogen in the first foot of soil as fields on which alfalfa was grown for longer periods. (4)

These investigations indicate that there is no great benefit from growing alfalfa for long periods because residual effects are not permanent. Alfalfa has to be grown as a crop in a regular rotation to obtain best yield and quality of wheat on dry lands.

Direct Effects of Manure and Green Manures on Soil Nitrogen and Carbon

Manure and green manure treatments of soil in general result in more nitrogen and carbon in the soil. This may be due to two reasons; namely, the effect of the increased crop residues in the soil due to stimulated crop growth and the gradual accumulation of nitrogen or carbon, or both, not utilized by the crop. Metzger (9) has reported that in Kansas treatments of land under continuous wheat with manure did not leave any significant quantity of nitrogen or carbon, whereas treatment with green manure left appreciable amounts of nitrogen in the soil. Treatments of continuous wheat land with green manure resulted in considerable carbon in the soil, but when used with phosphorus or phosphorus and potash there was no residual carbon left. Continuous growing of wheat tends to widen the C:N ratio unless rotation is practiced, but the use of green manures tends to narrow it.
SOIL ORGANIC MATTER IN RELATION TO DRY FARMING

Bracken and Greaves (3) have reported that soils cropped for wheat in Utah have less organic matter than virgin soils. The steeper eroded lands have lost more organic matter than level cropped lands. The point of importance is that, when virgin lands are brought under cultivation, they lose organic matter and nitrogen and have to be maintained by cultural practices.

Crop Residue Management in Dry Land Cropping

Effect of straw on the soil. Experiments carried out by the Washington Agricultural Experiment Station (1919) show that the addition of straw to soils of Eastern Washington decreased the yield in the following crop year. (1) Addition of between 0.1 percent and 0.7 percent straw stimulated nitrification, addition of between 0.7 percent and 2 percent and above resulted in a decrease in soil nitrate. This decrease in nitrates of soil, due to addition of two percent and above of straw, results in temporary loss of nitrogen as plant food. (1)

Smith, Vandecaveye, and Kardos (13) reported in 1946 that addition of straw to experimental plots under an annual wheat cropping system from 1921 to 1944 resulted in 3.2 percent increase in soil carbon over that of the 1921 level and a decrease of 1.3 percent of soil nitrogen below that of the 1921 level. This result is probably due to the fact that on an average straw contains a C:N ratio of 80:1. (12) The C:N ratio tends to narrow as decomposition proceeds. The result obtained on Eastern Washington soils may also be explained on the basis of C:N ratio. The yields of crops following the application of straw decreased
because of a wider C:N ratio. In subsequent years the C:N ratio narrows due to loss of carbon during decomposition and the yield is restored.

Smith et al. (13) have reported that addition of straw to experimental plots from 1922 to 1944 under an annual wheat cropping system resulted in an average nitrogen of 1.91 percent or 11.9 percent of protein in wheat. The plot without straw treatment yielded grain with 1.97 percent nitrogen or a protein content of 12.3 percent.\(^\text{1}\) This shows that the addition of straw not only decreases the yield of wheat but also slightly decreases the quality of wheat. As already stated in this report, addition of straw together with sodium nitrate gives a better quality and yield of wheat as the C:N ratio is narrowed due to the addition of sodium nitrate. In one of the plots under an annual wheat cropping system treated with straw and sodium nitrate, wheat grown had 14.9 percent protein. If the benefits of adding straw to dry farms are to be effectively realized it is necessary to increase the nitrogen content of the soil so as to keep the C:N ratio as narrow as possible or time for decomposition of the straw must be allowed before subsequent crops are planted.

**Effect of crop residues on fallowed and cropped land.** Fallowing is practiced in dry land regions at least in part to store moisture for the use of crops in the following year. Land is kept free from vegetation during this period. Any crop residues left by the previous year's crop have one full growing season to affect the moisture content of the soil.

1. These investigators used 6.25 as the conversion factor in reporting protein content of wheat. The protein content of wheat would have been better reported if they had used the conversion factor of 5.7 used in milling industry.
In the Great Plains region stubble left on the soil disintegrates rapidly with the result that the organic residues are not large at the end of the fallow season. This happens even when all the crop residues are left on the soil. In areas of rainless summers the decomposition of crop residues is slow. (8)

The placement of all the organic residues on the soil surface, part of it on the surface, or all of it buried in the soil, had no appreciable effect on the yield of wheat under the wheat fallow cropping system in the Great Plains. In this region fall sowing results in enough growth to protect soil from wind erosion. On the other hand, spring sowing on fallowed land which is bare in winter leaves the land susceptible to wind erosion during winter unless protected by crop residues. Crop residues if left on fallowed land in winter collect snow and store moisture for use in the cropping year. (8)

The work of Mathews (8) indicates that crop residues on fallowed land are effective in conserving moisture, preventing wind erosion and that the yields are not affected by such cropping practices.

On cropped land following fallow yield, differences in wheat due to placement of crop residues were too small to be of much significance. Crop growth with residues on the surface was slightly better however than where residues were partly or completely buried. (8)

Since in the Great Plains region and in the drier parts of the Columbia River Basin, crop residues on the surface did not alter the yields materially, the benefits of surface residues must be sought for purposes other than immediate higher crop yields. In some areas of Oregon where crop residues on the surface decreased the yield of wheat, leaving the crop residues on the soil has to be practiced only when the other advantages derived by organic residues on soil surface outweigh the decrease in yield. (8)
Effect of crop residues on water and wind erosion. Leaving crop residues on the soil is not a cure-all for water erosion, nor does the absence of crop residues in soil necessarily mean high susceptibility to water erosion. However, crop residues on the surface help soils to resist water erosion. Surface residues break the force of raindrops and prevent the plugging of pores in the soil and the splattering of loose soil particles which can be carried away by water. Surface residues also reduce the erosion due to run off water by checking the rapid movement of water on the soil surface. Presence or absence of crop residues on the soil surface to prevent water erosion is not important on lands sown for spring wheat as the land newly worked is ready to absorb water. The danger from water erosion in the absence of crop residues is great on lands sown for winter wheat as the land may be settled down enough before seeding time to facilitate easy rolling of water along the surface. The greatest danger of water erosion is on fallowed land where the surface becomes compacted and resists the entry of water. (8)

Crop residues on the surface of soil check wind erosion during late winter and early spring when soil is frequently mellow and is susceptible for moving. Tall stubble is effective in preventing wind erosion. (6)

Effect of crop residues on water storage capacity of soil. Experiments conducted at Hays, Kansas, from 1930-42 indicate that crop residues left on the surface saved on an average one-third inch more water than the crop residues buried in the soil. (8) Similar experiments on fallowed land in North Platte, Nebraska, show that crop residues on the surface stored more water than crop residues buried in the soil. The differences in moisture content in lands with crop residues on the surface and
buried were greater in the surface foot of the soil than at other depths. This indicates that the straw on the surface is effective in checking evaporation during dry periods. (8) This practice is of importance in dry farming.

**Effect of crop residues on weed control.** On land with crop residues on the surface more weeds emerge than on land with crop residues buried in the soil. More weeds on the land with crop residues on surface may not reduce the crop yields during favorable seasons as the crop may outgrow the weeds, but during unfavorable growing seasons the weeds may dominate the crop and reduce crop yields. It is possible that more weeds grow when stubble is left on the land, but leaving the stubble on land is not the cause for weed growth. Lands with surface crop residues require more cultivation to overcome the weeds than lands with buried crop residues. (8) If the benefits of crop residues on surface are to be realized, weeds have to be eradicated by cultivation.
THE RELATIONSHIP OF PRECIPITATION TO SOIL ORGANIC MATTER

Data secured by Sievers and Holtz (12) show that there is a direct relationship between the total annual precipitation and the percentages of carbon and nitrogen in the soil. Soils coarse in texture had smaller percentages of carbon and nitrogen than soils of fine texture for the same amount of precipitation. Coarse soils are well aerated and have low water-holding capacity. Good aeration leads to a rapid decomposition of organic matter. These soils produce less vegetative growth because of insufficient quantities of plant food and moisture. Less vegetative growth on coarse soils results in less organic matter, as the organic residues returned to the soil depend on the vegetative growth. Fine soils retain more moisture and contain more nitrogen and carbon, hence are capable of supporting good vegetative growth. These soils receive more organic residues every year and are rich in soil organic matter.

Jenny (1930) established relationships of nitrogen and organic matter in virgin soils to moisture and temperature. (6) According to him, on original grassland soils with constant temperature, nitrogen and organic matter increase logarithmically with increasing moisture. Later it was shown by other workers that although this principle is true, the results obtained in the United States can not be extrapolated to obtain nitrogen and organic matter content of soils in different countries. Jenny, Bingham, and Padilla-Saravia (7) have accepted in 1948 this modification in their work on soils of the Columbia region in South America. In general, with a constant temperature, increase in precipitation increases soil nitrogen and organic matter, while
with a constant precipitation decreases in temperature increases soil organic matter and nitrogen. But the nitrogen and organic matter content of soil in Columbia region in South America was more than in the corresponding soils in the United States although the trend follows the principle enunciated above.
DECOMPOSITION OF SOIL ORGANIC MATTER

Virgin soils brought under cultivation lose soil organic matter at a rapid rate resulting in a narrow C:N ratio. As the quantity of nitrogen in soil decreases, the rate of loss of organic matter decreases. Soils containing more nitrogen can accumulate more nitrate nitrogen due to decomposition of organic matter than soils with smaller quantities of soil nitrogen. (12) Higher crop yield secured due to more moisture in the soil has to be looked upon as a result of the availability of more plant food. (12)

A variety of organisms are responsible for the decomposition of organic matter in soil. During decomposition of organic matter essential plant foods are liberated in addition to carbon dioxide and organic acids. Carbon dioxide and organic acids produced during decomposition of organic matter by their solvent action on soil minerals may convert them to more soluble forms that are readily available for plant use. When plant food is not adequate in the soil these organisms compete with plants for plant food and as a result poorer crops are obtained. Addition of large quantities of organic matter alone will not overcome this difficulty. Sufficient time must be allowed after the addition of organic matter before seeding so that there may be enough plant food available in the soil for organisms responsible for the decomposition of organic matter and for the plants. If such a practice is not possible, then soil has to be treated to overcome the deficiency of plant food in the soil. (14)
SUMMARY

Dry farming means farming under difficulties due to comparatively low annual rainfall.

Nitrogen is necessary for plants for protein manufacture. Nitrate is the form of nitrogen most needed in the soil by dry land wheat near maturity.

There is a close relationship between soil organic matter and soil productivity. Organic matter in soil is important for plant growth as it tends to make available all the mineral elements essential for plant growth in addition to being the first source of nitrogen.

Problems of dry farming center mainly around precipitation and soil management.

In alternate wheat-fallow dry farming early tillage results in an increase of nitrate nitrogen in the soil. There is a close relationship between the yield and the amount of nitrate nitrogen present in the soil especially when moisture is not deficient. Addition of sodium nitrate to late plowed lands with or without organic residue gives not only better yield but a better quality of wheat.

Availability of soil nitrogen to plants depends largely on the C:N ratio. This ratio should be narrow for best plant growth. The benefits of organic matter in the soil are largely proportional to the nitrogen it contains.

Annual cultivation of wheat with the application of sodium nitrate gives better quality wheat as the nitrogen in the soil increases due to the addition of sodium nitrate, or due to cultivation, or due to greater organic residue.
Alfalfa increases soil nitrogen but for some years the increase is not sufficient to restore all the nitrogen contained in the virgin soils. Alfalfa stands beyond three or four years may not add greatly to the soil's ability to accumulate nitrate nitrogen. The residual effect of alfalfa on wheat is observed at least eight years.

Manure and green manure treatments of soil in general result in more nitrogen and carbon in the soil.

The addition of straw to soils of some sections has a depressing effect on the yield and quality of the following crop of wheat due to widening of the C:N ratio. This effect can be overcome by applying sodium nitrate which helps to narrow the C:N ratio.

The placement of organic matter, whether on the surface of the soil or buried in the soil, has little effect on yield of wheat either on fallowed or cropped land. The advantages of one or the other are to be sought for benefits other than high yields.

Crop residues on the surface check water and wind erosion.

Crop residues on the surface of soil lead to better water storage than do crop residues buried in the soil. It also prevents the crusting of the soil. Crop residues on the surface while being beneficial increases weed growth unless properly cultivated.

In areas of constant temperature nitrogen and organic matter content of soil increases logarithmically with the increase in precipitation. With more nearly adequate precipitation, there is more nitrogen released by organic matter for plant use.

Sufficient time must be allowed after the addition of organic matter to the soil for the crop to reap the benefit.
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SOIL EROSION ON DRY FARMS

by

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INTRODUCTION

Soil blowing in dry farming regions is wide spread and is a serious problem in dry farming areas in Australia, the U. S. S. R., Canada, and the United States. Soil losses due to wind erosion is not as extensive as in the case of water erosion. However, wind erosion is spectacular and has attracted the attention of the public.

It is not by any means easy to estimate the damage caused by soil blowing. It not only affects the negligent farmer whose land begins to blow, but also affects good farmers. Not only farmers but also the whole nation is affected. Drifts of top soil deplete the fertility of the land from which it is blown. When the soil settles it buries fences, railroad tracks, groves of trees, houses, machinery, roads, and fertile lands.

The seriousness of damages caused by blowing soils became clear to the American nation during the 1930's when the dust storms originated from the "dust bowl." The dust bowl at its greatest extent covered 16,000,000 acres and was a nuisance for the whole American nation. This area has been shrinking since control measures were adapted. In the zone of soil blowing wind erosion is as serious as water erosion in humid regions. Wind erosion takes place on both level and sloping lands, unlike water erosion which is restricted to sloping lands. One of the formidable problems of dry farming is the control of soil blowing.

Soil blowing in the United States in the spring of 1934 was the worst in its history. The dust storm of 1934 reached as far as the Atlantic coast from its source in the Great Plains area. However,
this was not the first occurrence in the United States. An extensive area near Colby in Thomas County, Kansas, was seriously affected during the period of 1910-14, amounting to more than 65,000 acres by 1914. (6, 12) Drake (1937) has quoted Huska about the control work undertaken during this period. Control measures were put into effect in the early spring of 1914. Before substantial work could be done, nature came to the rescue. During the spring of 1914 rainfall enabled the growth of crops planted. These crops provided protection to the soil against blowing. On fallow land, because of favorable soil moisture conditions, weeds emerged and gave protection against soil blowing. Adequate rainfall in subsequent years pushed the control program into the background until soil blowing became serious again in the 1930's. (8)

Soil blowing in dry farming regions is not of recent origin. Soil blowing has been reported in Canada as far back as 1887. (11) Soil blowing on the Great Plains of the United States was restricted to small areas when the white man discovered this region. It was restricted to Indian trails, watering places for buffalo, and to places where the native vegetation was destroyed. Blowing was not a major problem when the early hunters, traders, and cattlemen destroyed some vegetation. It became a major problem, though, when the pioneers broke the virgin sod and placed the land under cultivation. Until about 1900 the cultivated acreage was relatively small. During the period between 1900 and 1920 extensive areas were brought under cultivation. This trend increased immediately after World War I when most of the grassland was brought under cultivation in the hurry to get rich. (8) Wind erosion has become more acute as the agriculture of the Plains has become older due to the rapid disintegration of the sod rootlets of the original grassland. (3)
The Great Plains region in the United States is noted for its fertility. Fertility is restricted mostly to the upper humus-bearing soil. Once this soil is blown away, fertility is depleted and the rich fertile soil can not be built up during a man's short lifetime.

The amount and intensity of soil blowing varies with the season and the type of soil. Soil blowing may occur during the fall and often during the winter, but the greatest danger from soil blowing is in the early spring. Low pressure areas passing eastward set up atmospheric disturbances. These disturbances are seen in the form of blowing winds often accompanied by rainfall. In the Great Plains area fall is the period of decreasing rainfall and spring is the period of increasing rainfall. Consequently, early spring is the period of severe and most frequently recurring winds and the soil is dry. Winds of high velocities prevail during this period. A wind velocity of 30 miles per hour or over is generally required to start considerable movement of soil on hard lands. Once the soil has begun to move, even wind with a velocity as low as 8 or 12 miles per hour will be enough to continue the movement. Branden and Keser (1936) report that soil blowing winds in Colorado generally come up in the forenoon and die down by evening.(3) However, the exceptional windstorms are the ones that cause most havoc and may come up anytime and continue for a long period. These high velocity winds blowing for a long period set some of the secure soils into motion.

The Great Plains region is the table land lying west of the 98th or the 100th meridian and extending up to the 5,000-foot contour line adjacent to the Rocky Mountains. It also extends north into Canada and as far south as Texas. The area is about 550,000 square miles. This is a vast area larger than Germany, Italy, and Japan put together.
At the Kansas-Missouri line the annual rainfall is about 38 inches, and it tapers off from east to west. Some areas receive precipitation of less than 10 inches per year. Native vegetation varies with the rainfall. The humid region of the prairies has tall grass, the sub-humid region has short grass, and the semiarid region of the West has desert grasses. In general the Great Plains is characterized by a treeless region of light rainfall, high velocity frequent winds in spring, high temperatures, and many sandy as well as fine grained soils susceptible to blowing if not held in position by vegetation. (16) This region covered with native grasses was exploited by early cattlemen through overstocking and reducing the vegetative covering of the soil. Later when the land was brought under cultivation, a wheat and fallow system of cropping came into practice because of the shortage of moisture. This resulted in leaving large areas of land under fallow, unprotected by vegetation, to the mercy of the blowing winds.
THE CAUSES OF WIND EROSION ON DRY FARMS

In nature soil is being blown from the land at all times, but under favorable conditions nature rebuilds the loss. This type of erosion is natural, and there is nothing to be alarmed about. It is the abnormal wind erosion that causes concern in dry farming. This type of erosion occurs when nature's balance is upset by the intervention of man. The causes of wind erosion may be grouped under two headings: (1) wind erosion due to farm management practices and (2) wind erosion due to natural causes.

Farm Management Practices that Cause Wind Erosion

When the pioneers started cultivation of the semiarid regions, they had to develop their farm management practices to meet the shortage of moisture. This leads to the wheat and fallow system of cropping in the Great Plains region. During the fallow period the land is left bare without any vegetal covering to protect the soil surface against wind erosion. This, together with the removal of natural cover of soil, is one of the causes helping the wind to sweep unrestricted over large areas of soil surface. The second cause of the management type is the burning of the stubble with the belief that it helps in good seedbed preparation and in increasing fertility. Stubble left on the land serves as a natural cover during the fallow period protecting the land against sweeping winds. Further, burning the stubble leads to a decrease in the organic matter content of the soil. The third cause of the management type is overcropping the land with cereal crops. The fourth cause is overstocking the land. Overstocking results in
overgrazing, and the soil is left bare. Excessive trampling of bare soil surfaces by livestock pulverizes the soil and makes it susceptible to blowing. (4, 8, 10) The fifth cause is the effect of the first four causes on the economic condition of the dry farmer. (4)

Some writers have attributed the rapid expansion of agriculture in the dry farm region to a response to a favorable price situation for food grains. This expansion has been held as a cause for the serious soil blowing on dry farms, but such a thesis can not be accepted completely. Expansion of dry farming is a major cause only on some of the drier and more sandy sections which should not have been brought under cultivation at all. Soil blowing would have occurred on other dry farms during the drought period of 1931-34 even if no additional land had been brought under cultivation. (4)

Natural Causes of Wind Erosion

Wind erosion from natural causes is concerned with climatic factors and insect damages. The Great Plains region suffered from severe drought during 1910-14 and 1931-34. (4) Kellogg (1935) reports that the fundamental cause of soil blowing is drought. (4) The dust storms of 1934 and 1935 were a result of continued drought in the Great Plains during the previous years. He reported that these storms were not only due to immediate drought, but also due to growing moisture deficiency in the soil from previous years. His statement is substantiated by the precipitation records at St. Paul where for 22 years before 1934 there was a cumulative deficiency of 46 inches of rainfall. During the eight years preceding the dust storms, there was an annual average deficiency of three inches of rainfall. (14) This impressive weather data is not illustrative of conditions in the Great Plains, although
Kellogg has stated that "Rainfall deficiency extended down into Kansas, east to Ohio, and west to central Montana and Colorado." Lack of moisture in soil makes it difficult to secure stands of wheat during drought periods, and the land is left bare. During drought periods and scarce feed, livestock are fed on stubble and on whatever vegetation there is. This removal of protective soil covering aggravates the situation and trampling by livestock results in pulverized soil easily susceptible to blowing. (4) Insect pests sometimes destroy vegetation and expose the soil to the direct action of wind. (10)

When wet soils freeze they become impervious to water and lower depths may remain dry. Freezing and thawing break the soil aggregates to granular condition. In southern Alberta, periods of cold weather are alternated by "chinooks," strong winds of high temperature, and low humidity. This condition results in severe soil drifting.

**Soil Types Susceptible**

All soils are susceptible to blowing, but the degree of susceptibility varies with the type of soil. The susceptibility to blowing depends on the physical conditions of texture and structure. The more uniform fine sand a soil contains, the more susceptible it is to blowing. On farms in Colorado the soil is pulverized every fall after a crop of beans has been removed. On fields sown for winter wheat or rye, the soil is pulverized during spring. (3) Kellogg (14) reports that in the Great Plains heavy soils, silt loam, and even clay soils are subject to frequent movement where the structural conditions are favorable. On these lands clay and silt often form aggregates about the size of sand particles that blow off easily because they are lighter than sand. However, soil aggregates larger than sand particles are resistant to blowing. The ideal size of soil aggregate for farming
would be large enough to resist wind erosion and not too large to interfere with cultivation and plant growth.

**Crops that Help Soil Blowing**

Brandon and Kezer (1956) have classified soils likely to blow in Colorado on the basis of the previous crop. (3) They have reported that soils on which bean crops were grown were the worst as they blew easily and were difficult to control. This is because the bean crop is cultivated late in the summer and harvested in the fall during a period of diminishing rainfall. Further, the harvesting machinery pulverizes the soil to a depth of about three inches. The crop itself leaves no root-clumps. Row crops are next to bean land for their susceptibility to blowing. The next greatest blow hazard is on land used to grow corn for livestock feed. The corn stalks are winter pastured, and this leaves the land bare and susceptible to blowing. Fallow land seeded to winter wheat or rye that has not made much growth is also a problem. Land used for small grains is not a serious problem unless the organic matter of the soil is depleted. (3)

**Soil Factors Affecting Blowing**

Hopkins, Palmer, and Chepil (1946) have discussed three groups of factors that influence soil drifting. They are the condition of the air, the ground surface, and the soil. (11)

Changes in the density of air have slight action on soil drifting. It is the velocity and the gustiness of wind that aggravate soil drifting. A gusty wind does more havoc than a uniform wind of the same velocity. Velocity and gustiness of the wind near the earth's surface are influenced by the atmospheric turbulence. Turbulent flow of wind close to the ground is due to convectional eddies which are caused by higher ground temperatures than air temperatures and by frictional
eddie caused by the air striking the ground surface. This indicates that soil blowing might be decreased by controlling the turbulence of the wind at the ground level. Practices such as clodding and leaving vegetal obstruction on the soil to control soil blowing increase the turbulence of the wind, but their success in controlling wind erosion is to be seen in that they serve as obstructions in the path of the wind and thus reduce the velocity of the wind near the ground level. The velocity near the irregular ground surface is practically zero. Convectonal eddies increase the velocity of wind on the surface of the ground. Bare fallow land exposed to sun's heat is more susceptible for such action than land covered with vegetative covering. Strip cropping dampens off the convectonal eddies created on the bare fallow, for when the air moves over the cropped region the velocity is reduced. Dangerous erosive wind has no particular direction of movement. It is turbulent and moves in all directions. The upward velocity of these winds near the ground is about one-fifth of the forward velocity. Soil is not directly lifted by the wind pressure but by the impacts of the larger granular particles of the size of sand. This is the reason why sandier soils are more erodible than others. (11)

Small Granules in Soil Increase Blowing

Hopkins et al. (11) have reported that soil granulation in the prairie provinces of Canada is caused by high content of calcium carbonate and decomposed organic matter. Decomposed organic matter induces the formation of soil aggregates. But it is the size of soil aggregates formed that is important in resisting wind erosion. Cultivation of soil expedites the decomposition of organic matter and makes the soil susceptible to blowing. The beneficial effects of organic matter are lost in course of time because of decomposition into inert humic
materials unless fresh organic matter is continuously added. When soil
has blown off a field, much of the fine material necessary for binding
the larger grains is taken away. Under such conditions even adequate
rain does very little good as soil begins to drift as soon as the
surface becomes dry. (11)
EFFECTS OF WIND EROSION ON COMPOSITION AND FERTILITY OF SOILS

Physical Changes in Soil Due to Wind Erosion

Erdman (1942) has conducted mechanical analyses of soil samples of normal accumulated drift and exposed subsurfaces. (9) Samples of the accumulated drift of coarse textured soils showed an average increase of 17 percent sand over that of the normal surface soil. These samples on an average lost 50.7 percent of silt. The clay content also decreased by 25.6 percent. The exposed subsurfaces of these coarse textured soils showed an average increase of 6.5 percent sand while the silt fraction decreased by 24.2 percent. Half of the samples showed increase, and the other half showed decrease in clay content. The net result was an average increase of 4.2 percent clay content. From these data it can be seen that on an average wind erosion removed about one-half of the original silt and one-quarter of the clay from coarse textured soils.

Similar mechanical analysis of accumulated drift of medium textured soils have shown an average loss of only one-fifth of the original silt and very little loss of clay. In case of fine textured soils the accumulated drift showed the same percentage composition of soil fractions as the original cultivated surface soil. These data indicate that coarse soils and medium textured soils are more susceptible to wind erosion than heavy textured soils and become sandy in course of time if wind erosion is not stopped. (9) Daniel (1936) reported similar results, but the percentage changes in soil fraction varies from the results of Erdman noted above. (6) Daniel and Langham (7) reported in
1936 that each time a soil is shifted some organic matter and also
a portion of clay and silt are removed, and as the process continues the
drifted soil becomes sandy regardless of the original texture.

Chepil (1941) has studied the relation of wind erosion to the dry
aggregate structure of a soil. (5) He reports that the threshold
velocity of wind or the minimum velocity of wind required to initiate
and continue the movement of soil particles was least for soil particles
of 0.05 to 0.15 mm. in diameter. These particles required wind velocity
of eight to nine miles per hour at six inches above ground. Below
this size range of soil particles the threshold velocity of wind increased
with the decrease in size of the particles, while above that it increased
with the increase in size of the particles. This shows that soil
particles of less than 0.05 mm. in diameter are more resistant to wind
erosion due to factors other than size or specific gravity of soil
particles. However, in nature such small particles seldom exist be-
cause they group themselves to form larger aggregates. Chepil reported
that soil aggregates of 0.32 to 2.00 mm. in diameter resisted erosion
by wind of 25 miles per hour at one foot height from the ground.
However, these aggregates began to move at higher velocities of wind.
The most resistant aggregates against wind velocities above 25 miles
per hour measured 2.0 to 6.4 mm. in diameter. In soil, mixtures
containing coarse non-erodible fraction, movement of the erodible
fraction stops under any velocity of wind when the surface becomes
protected by coarser aggregates. (5)

Changes in Nitrogen and Organic Matter Content of Soil Due to Wind
Erosion

Daniel et al. (7) have analyzed virgin, cropped, and drifted
soil samples near the Oklahoma Panhandle to determine the changes in
the total nitrogen and organic matter content of soil due to wind erosion. The medium and the fine-textured soils, in general, contained more organic matter and nitrogen than the sandy soils. They found that the drifted material had an average of 28.0 percent less nitrogen and 24.5 percent less organic matter than the virgin soils. Each time a soil shifts some organic matter, nitrogen, and fine soil particles are lost. As shifting proceeds the soil loses more of these materials and becomes more sandy regardless of the original texture. The subsurface samples had less nitrogen and organic matter, and there was not a significant difference between the subsoils of virgin land and cropped land. However, the important point is that organic matter and nitrogen in the soil profile decreases rapidly with depth. Once the top soil is allowed to be blown off, there is not much organic matter and nitrogen left in the soil for plant growth. This is particularly so in shallow soils. These writers have reported a decrease of 18.0 percent of organic matter and 15.0 percent of nitrogen in cultivated soils due to cropping and wind erosion.

Erdman (1942) estimated the organic matter and nitrogen losses of Alberta soils. (9) The accumulated drift of the coarse textured soils lost an average of 48.5 percent nitrogen and 50.3 percent organic matter. In the exposed subsurface there was an average decrease of 39.6 percent nitrogen and of 45.3 percent organic matter. The accumulated drift of the medium textured soils showed an average loss of 12.2 percent nitrogen and 11.1 percent of organic matter, while in the exposed subsurface there was an average decrease of 16.7 percent nitrogen and of 17.8 percent organic matter. In the accumulated drifts of fine textured soils there was an average loss of 4.6 percent nitrogen and 7.4 percent organic matter as compared to cultivated surface
soil. In the exposed subsurface there was an average decrease of 12.7 percent nitrogen and 17.0 percent organic matter. Losses in fine textured soils are almost similar to medium textured soils, but more erosion was seen on heavy soils. These results indicate that the coarse textured soils lose nitrogen and organic matter by wind erosion much more than either medium or fine textured soils. (9)

Erdman (1942) has analyzed some dusts for nitrogen and organic matter content. He found that dust collected at 5 to 25 feet above the ground level was twice as rich in nitrogen and had 75 percent more organic matter than the surrounding surface soil. (9)

Changes in Fertility of Soil Due to Wind Erosion

In the previous section changes in nitrogen and organic matter content of soil due to wind erosion has been noted. The coarse soils lose more fertility than medium or fine textured soils. Erdman (9) has conducted pot experiments in the greenhouse to determine fertility losses due to wind erosion. After 11 weeks he found wheat plants growing in normal, undrifting fine sand were 40 inches in height while those growing in accumulated drift and exposed subsurface were 25 inches and 18-20 inches, respectively. There was also a difference in the size of the heads grown on different soils. Plants grown on the drifted fine sand had heads only one-half as long as those grown on the normal fine sand. These heads also differed in fertility. Out of the three heads grown in each pot of fine sand, two were fertile in each of the pots containing normal soil; while those grown in accumulated drift and the exposed subsurface were all sterile. Erdman also has drawn attention to the work of Griffiths who obtained similar results under field conditions in Australia. The weight of grain was not taken as the plants advanced only to the dough stage.
However, total weight of the plants was taken for comparison. Plants grown on accumulated drift weighed less than one-half, while those grown on exposed subsoils weighed only about one-fifth as much as plants grown on normal soils. Results on silt loam also indicate a loss of fertility, but this was not as severe as in sandy soils. (9)

On loam soils there was no difference in air-dry weight of plants grown on normal and eroded soils. There was no difference in the air-dry weights of plants grown on normal clay surface soil and exposed clay subsurface soil. These results indicate that fine sandy soils are severely depleted of fertility by wind erosion so far as wheat growing is concerned. The silt loams are also depleted of fertility but depletion is not severe. On the other hand, loam and clay soils do not appear to be depleted enough to affect the productive capacity of the soil. (9)
CONTROL OF SOIL BLOWING

The important farm management causes of wind erosion are leaving the surface soil bare and depleting the organic matter content of the soil. Control methods aim to restore protective cover to soil and to increase the organic matter content. Organic matter decomposes rapidly in well aerated soils. Therefore, sandy soils require constant and more addition of organic matter than other types of soil. Means of control of wind erosion have to be adapted by all people in the area where soil blowing is prevalent. Adaptations of farm practices by a few farmers only will not help them much if their neighbors allow their soil to blow onto the land where wind erosion prevention methods are adapted.

Methods necessary for the control of drifting soil are considered under the following heads: (1) rotation cropping, (2) livestock management, (3) cropping and cultivation practices, and (4) wind breaks.

Rotation Cropping

Bare land surface is conducive to wind erosion. In dry farming regions where wheat is the chief cash crop, a two year rotation of wheat and fallow is practiced. This type of rotation is useful in utilizing efficiently the scant moisture available and in controlling weeds. However, during the fallow period land is left without any protective vegetation. The disadvantages of wheat and fallow system have to be overcome if this method of cropping is to be continued, particularly on light soils. It is desirable to seed the light soils to sod-forming crops which can be utilized for livestock feed.
This reduces the grain growing area, but because of better rotation
and return of barnyard manure grain yields usually increase. It is
not necessary to seed the whole area in a farm to sod crops unless the
entire area is sandy, susceptible to wind erosion, and submarginal in
production.

No particular rotation can be given as the best for all dry farming
regions. As the vegetative cover is important in preventing wind
erosion, importance is to be given to selecting adapted crops. Carter
has divided these crops into two groups: (1) "that in which a crop
of grain or forage may reasonably be expected to be harvested and (2)
that in which only protection of the soil against wind erosion is
expected." (13) Many crops can be listed for areas under these two
groups, and it will not be attempted in this report. Growing different
crops in rotation results in leaving different quantities and qualities
of organic matter in the soil. By growing adapted crops moisture is
efficiently utilized to provide a protective vegetative covering. (10,
13,14,15)

Livestock Management

Dust storms occurred during periods of drought even before the
Great Plains region was brought under cultivation for grain growing.
But these dust storms were neither so serious as those of 1934-35 nor
were they due to the same causes. Early cattlemen and sheepmen over-
grazed the grassland and allowed the livestock to heavily trample the
grassland. This resulted in bare pulverized soils susceptible to
blowing. However, soil blowing of this type is comparatively easy to
control. (14)

Brandon et al. (3) recommend that late fall and winter pasturing
of dead vegetable matter should be avoided on the Plains of Colorado. During winter precipitation is low, and almost all of it comes in the form of snow. When there is light snow, the surface soil is dry and is easily pulverized by trampling of livestock and particularly by sheep. If the vegetal covering must be utilized during winter for livestock feed, it is always better to cut it rather than to graze it.

Adapting livestock farming helps to utilize sandier soils for sod crops, and the organic matter in the form of barnyard manure is returned to the soil to prevent wind erosion. The main idea is to give a protective cover to the soil and enrich the soil organic matter. This means good growth of sod-forming crops has to be obtained. A good growth will help to carry more livestock per acre and thus facilitate fitting livestock into a well balanced rotation. It is usual to neglect sod-forming crops and expect them to grow well. It is always better to use a recommended pasture mixture for the region instead of any one crop. Recommended pasture mixtures include adapted species of grasses and legumes. Invariably the pasture mixtures contain at least one legume. Inclusion of legumes in pasture mixture not only increases the fertility of the soil but also provides high quality feed. Increased fertility will help the growth of the vegetative cover on the soil.

Improper management of pastures by overstocking and overgrazing will offset all the advantages gained by seeding improved pasture mixtures. Bad soil blowing can be caused by farm animals as easily as by cultivation if the land is overstocked and overgrazed. The common practice of allowing livestock to roam over a large area while pasturing should be avoided. This type of pasturing results in the animals making trails in search of palatable species, the overgrazing of palatable areas,
and the leaving of the trail and the area where palatable species were growing without vegetation. When trampled heavily, soil on these bare surfaces pulverizes and becomes susceptible to blowing.

Pastures should be laid in the form of long narrow strips with the length at right angles to the prevailing winds. If rotation grazing is practiced on such pastures and the animals are moved from paddocks before the pasture is completely eaten to the ground level, not only the carrying capacity but also the recovery of the pasture will be increased and protection against wind will be provided. (2, 10)

**Cropping and Cultivation Practices**

There are various methods by which a dry farmer can conserve water on his soil and avoid the destruction of wind erosion. The first step in this direction is to keep the surface of the land in roughened condition. This objective is achieved by using implements that leave deep furrows and thrust up big clods. A second step in conserving moisture and controlling wind erosion is to use all the farm machinery on the contour or at right angles to wind. These two methods are useful on both light and heavy soils.

On the heavy soils where it is possible for water to run over the land in spite of the first two methods, terracing the land to check the run-off of water and to conserve the water is used as a third step in control. The terraces have to be at right angles both to the slope and to the prevailing wind direction if possible.

Crops should be sown in strips. Strip cropping checks the turbulence of wind near the ground level and prevents wind erosion, in addition to leaving different quantities and qualities of organic matter in the soil. Further, it adapts itself easily for a good rotation of crops and economy of operations. Strips of crops should be at right angles to the direction
of prevailing winds. The width of strips depends on the type of crop and the soil on which used. As a fifth step straw and strawy manure easily destroyed by burning should be retained on the soil. Stubble left on fallow land checks wind erosion and also increases the cohesive property of the soil by increasing the organic matter. Forcing strawy material to the top of soil while working land protects the surface soil from being blown away. (8, 10, 12, 15)

Special Tillage Implements Needed for Blow-soils

Tillage practices are important in controlling wind erosion. Good farmers use tillage implements best suited for the purpose depending on the condition of weather, soil, and the previous crop. Tilling more than necessary to secure a crop is not helpful in controlling wind erosion, hence is to be avoided. (14)

Hopkins et al. (1946) have listed the machinery useful in soil drifting control. They include field cultivators, blade cultivators, one-way disk, rod weeder, disk harrow, spike tooth harrow, and seed drills. Their advantages in controlling soil blowing are briefly mentioned below.

Field cultivators. These, while being useful in destroying weeds, produce minimum pulverization of the surface soil. This implement is adaptable to a wide range of conditions but gets clogged in heavy stubble or weedy lands.

Blade cultivators. Blade cultivators work best on dry soils with heavy trash and weeds. They can be used with little disturbance of plant residues on the soil.

One-way disk. This is advantageous in weed control and in leaving the surface of the land rough, but it should be used in such a way as to leave enough trash on the land. A disk can be used advantageously
for the first operation on heavy combine stubble and/or on a heavy growth of weeds in the preparation of plowless summerfallow. It can be used also as a lister by removing most of the disks.

Rod weeder. These are useful in controlling weeds and soil blowing. They do not create a lumpy or cloddy surface but leave the surface undisturbed and preserve the existing condition of the soil surface.

Disk harrow. This is not a very effective implement for destroying well rooted weeds and also may leave the surface soil pulverized. However, it is useful for spring disk ing of summerfallow land that is to be plowed later. It is best used on soil somewhat too wet or too dry to pulverize.

Spike tooth harrow. This is useful in puddling wet soils and in creating a cloddy surface. It should not be used on dry soils as it pulverizes the surface soil.

Seed drills. Use of a hoe drill for seeding is found to be satisfactory in controlling wind erosion inasmuch as it acts as a cultivator, leaves ridges on the surface, and pulverizes the soil less than disks.

Harvesting machinery. The type of harvesting machinery used is determined by the height of the stubble to be left on the ground.

Tillage Adapted to Intensity of Danger of Blowing

Call (1936) has grouped the cultural practices to be employed in the Great Plains region under three categories. (4) They are (1)"the cultural methods used during the summer and fall tillage period prior to the winter and spring months when strong winds usually occur, (2) cultural methods used on land that is in condition to blow but which has not actually started to erode, and (3) cultural methods that may be employed to stop soil blowing after it has started."
The first category of cultural methods should be applied on summerfallowed land. The tillage operations are best conducted by suitable implements when the soil is moist. Operations should be reduced to the barest minimum -- just enough to eradicate weeds. The second category of cultural practices are adapted for summerfallowed land carried over for a spring crop, fallow land, land without a vegetative covering due to failure of securing stand, and fall plowed ground which is not cloddy. These lands should be worked in the early spring with implements that leave the surface roughened. When the soil begins to drift, as in the third category, immediate action is to be taken for controlling it. Usually the surface is deeply furrowed and clods are raised at intervals to obstruct the wind carrying fine particles of soil. This is done by listing the land at regular intervals. (4)

Aicher (1934) has reported on the cultural methods to be used on the annually cropped land and on fallow land in Kansas for controlling wind erosion. (1) On annually cropped land blank listing is done soon after the combining of grain. When volunteer wheat and weeds appear the ridges are leveled off by the ridge buster. If, as a result of favorable moisture conditions, there were to appear more volunteer wheat and weeds, a one-way plow with a subsurface packer is used to destroy them. These practices leave the soil surface in roughened condition covered with enough trash to prevent soil erosion.

On fallow land the first operation is blank listing. If there is danger of blowing, the land is again listed in the fall. Ridges are leveled off with a ridge buster when the first weeds appear. A one-way plow is not ordinarily used unless weed growth is rampant. Usually one or the other of the following implements are used for destroying successive
weed crops: duck foot weeder, revolving rod weeder, or the spring tooth harrow.

Wind Breaks

Trees grown in rows at right angles to the prevailing wind reduce the velocity, thereby making the wind less harmful in soil blowing. It has been estimated that the wind velocity on the leeward of a shelter belt is reduced to a distance of 15 to 50 times the height of the trees. The higher the velocity of wind, the greater is the sheltering effect on the leeward side. The reduction in the velocity of the wind is greatest near the wind break. The velocity of the wind gradually increases in proportion to the increase of distance from the wind break on the leeward side. This makes it necessary to have a series of shelter belts of trees at intervals to be effective in checking wind velocity which is not often feasible. (11) These shelter belts not only check the velocity of wind but also give protection to plants against hot winds. (14) In the Great Plains region it is difficult to establish shelter belt trees. But with adapted trees the difficulty is amply rewarded by protecting the soil from drifting.
SUMMARY

Soil blowing in dry farming regions lying west of the 90th or the 100th meridian and extending west up to the 5,000-foot contour line adjacent to the Rocky Mountains in the United States is not of recent origin but became a major problem when the pioneers expanded agriculture in this region. It is severe during the spring season. One of the major problems of dry farming is soil blowing.

The causes of wind erosion can be grouped under two categories: (1) wind erosion due to farm management practices and (2) wind erosion due to natural causes. Under the first category come the wheat and fallow cropping system, burning stubble, continuous cereal growing, overgrazing, and the economic condition of the farmer. Under the second category come drought, insect damage, and frost.

Susceptibility of soils to blowing depends on the texture and structure of soil.

Crops like beans, corn, winter wheat or rye, and small grains help soil blowing.

The condition of the air, the ground surface, and the soil are the three factors that affect soil blowing on dry farms.

Decomposed organic matter and calcium carbonate increase soil granulation and help soil blowing.

Coarse and medium textured soils are more susceptible to wind erosion than heavy textured soils. Each time a soil is shifted it loses fine soil particles and as the process continues the drifted soil becomes more sandy regardless of the original texture. Soil
particles of 0.05 to 0.15 mm. in diameter need the minimum threshold velocity of wind. The threshold velocity of wind increases with increase or decrease in size of soil particles from the range mentioned above.

The organic matter and the nitrogen content of the soil profile decreases with depth. Coarse textured soils lose nitrogen and organic matter through wind erosion much more than either medium or fine textured soils.

Fine sandy soils and silt loam soils lose fertility when soil blowing takes place, but the former loses more fertility than the latter. Loam and clay soils do not appear to lose enough fertility to affect the productive capacity.

Rotation cropping with adapted plants helps in increasing organic matter and fertility of soil and also helps in adapting strip cropping and stock raising on the farms. Sandy soils and particularly those which are submarginal in production should be seeded to sod crops. Rotation cropping helps to keep land covered with vegetation.

To prevent soil blowing late fall and winter pasturing which results in pulverized soils should be avoided. Improvement in stock carrying capacity by fertilizing and growing recommended pasture mixtures results in increased fertility and organic matter content of the soil. Pastures should be laid in long narrow strips at right angles to the direction of prevailing wind and should be grazed on a rotation basis to avoid overgrazing and exposing the soil to wind erosion.

Roughening the surface of soil by furrowing and leaving clods, using the farm machinery on contour, terracing the land, strip cropping, and leaving the strawy materials on the surface of the soil all help in
preventing wind erosion. Machinery to be used should be selected to meet the needs of soil drifting control. Some of the important implements are: duck-foot cultivator, rod weeder, one-way disk, and listing shovel attachments.

Shelter belts at regular intervals at right angles to the prevailing winds protect the soil against blowing by reducing the wind velocity. They also check hot winds and help conserve moisture.
LITERATURE CITED


SOIL MULCH AND SOIL MOISTURE IN RELATION TO DRY-FARMING

by

Krishnappa Ramaiah

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Krishnappa Ramiah

Logan, Utah
February 27, 1951
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INTRODUCTION

Dry farming is the term applied to the cultural practices used to produce crops in areas where the moisture supply is limited. Therefore the availability of moisture is a major problem in dry farming. In the United States the region of dry farming extends from the 98th or the 100th meridian westward to the 5,000-foot contour line of the Rocky Mountains.

It is common knowledge that crops fail if there is not enough moisture in the soil. The importance of moisture to crop production has been recognized for ages, but its importance has been interpreted in various ways. Some concepts have been misleading the real issues in spite of much good research. This is because the soil moisture problem is complicated by various other factors like the amount, the distribution, the character, the dependability of rainfall, temperature, humidity, soil character and the type of crop.

The character of rainfall may be more important than the total quantity. If it comes in small showers with long intervals between, nothing is added to the soil moisture supply. Almost all is lost in evaporation. If precipitation comes in the form of heavy rains, a part of it is often lost as run off water, another part is lost by evaporation, and the balance soaks into the soil. Even the part of precipitation that soaks into the soil is not completely available for plant growth. Thus it can be seen that available moisture in soil is only a fraction of total precipitation. However, only the available moisture is important in crop production. It is important to store as
such precipitation as possible in the soil for the use of plants.

Various practices have been tried for insuring sufficient available moisture to crops. Some of the practices are: mulching, fallowing, contouring, and terracing. Various mulches have been tried to conserve moisture. Over emphasis on the soil mulch has resulted in some of the farmers still believing in it in spite of recent experimental evidence that a soil mulch does not usually conserve moisture in dry farming regions.

Crop failures due to drought in dry farming regions are a menace to agriculture. In a highly commercialized agriculture, no farmer can afford to take chances on a series of crop failures. Therefore, any relationship of soil moisture that helps to predict the crop yields or to help abandon the crop in time to secure the next crop by breaking the spell of drought is useful.

In this paper an attempt is made to discuss some of the fundamental relationships of soil moisture in crop production in dry farming regions.
SOIL MULCH IN RELATION TO MOISTURE CONSERVATION

Various mulching practices have been developed in search of cultural methods for conserving moisture in the soil. Any lifeless object can be used as a mulch. The objectives of mulching are to retain a uniform degree of moisture in soil, to hold more water in the soil, and also to prevent erosion. These are brought about by reducing the influence of evaporation and run off water. Several materials have been used for mulching. They include soil mulch, stubble mulch, dead leaves, farmyard manure, sawdust, grass, and paper. (4, 16)

The relative effectiveness of these materials in conserving moisture varies. The effectiveness of some of them are over emphasized, some of them are impracticable, and some are good. The soil mulch or earth mulch has received much attention because it helps in the conservation of moisture under certain circumstances and under other circumstances it does not help. Its relative effectiveness under different circumstances is discussed in the following sections.

The term stubble mulch has reference to protecting the soil against erosion and conserving moisture in the soil by covering the soil surface partially or completely by some form of crop stubble or residue. Crop stubble may come from the previous crop whose stubble is left on the soil after harvest operations are over, or from other plant residues hauled in and spread on the soil. Stubble mulching involves tillage operations that do not turn the soil over. This is usually accomplished by subsurface tillage or by stirring the soil without inversion. (4)
The Theory of the Soil Mulch

Water rises to the soil surface by capillary action and evaporates. This loss of water can be checked by preventing the capillary rise of water. Soil mulching or loosening the surface soil by cultivation results in the soil particles being removed from intimate contact and they lose most of their water. In a nutshell, the dry layer of soil acts as a blanket in checking evaporation losses of soil moisture. (6) This theory has been substantiated by experiments under certain circumstances; notably moist surface soil and a high water table.

When Soil Mulch Conserves Moisture

Many experiments have been conducted to determine the effectiveness of a soil mulch in conserving soil moisture. Some early workers proved that under some conditions a soil mulch may help in conserving moisture. All their experiments were conducted with a water table relatively close to the surface of soil.

When evaporation takes place from the surface layers of the soil, the water lost by evaporation is replaced by capillary movement of water from the water table. In such an instance cultivating the soil would prevent the rise of water to the surface soil. This would reduce loss of water by evaporation. On the other hand if the soil is left uncultivated, the capillary movement of water from the water table to the surface soil would continue to supply water; and the loss by evaporation would be more. (19)

Several workers have shown that in sandy loams and loams in general, a water table within 10 feet from the surface soil helps the capillary movement of moisture to the surface soil. (19) Shaw (19) conducted experiments to redetermine the effectiveness of a soil mulch in conserving
soil moisture. He reported in 1929 that where the soil was cultivated the loss of water was less than in uncultivated soil. He maintained a water table relatively close to the surface of the soil. His conclusion is that a soil mulch is effective in reducing soil moisture loss only when the water table is within the reach of capillary rise to the surface. The source of water for capillary movement to the surface may come from a permanent water table or from a water table formed by intercepting the percolating water by an impervious layer in the soil.

All the evidence indicates that a soil mulch is effective in reducing the loss of soil moisture only when the water table, either perched or permanent, is within the maximum depth of capillary movement to the surface. However, even in such places it is doubtful whether a soil mulch is beneficial because in such areas the problem is not that of scarcity of moisture but the accumulation of salts and drainage. (19)

**Soil Mulch in Dry Farming**

Barnes (3) reported in 1938 the results of his experiments on soil mulch and moisture conservation in dry farming in western Canada. The data he obtained indicate that the mulched soils conserved moisture slightly more than the unmulched soils kept free from weeds. However, the difference was not significant enough to advocate soil mulching as a practice on dry farms to conserve moisture.

Call and Sewell (6) reported in 1917 the results of different treatments on dry farm soils of Kansas. They determined the effect on soil moisture of cultivation three inches deep, cultivation six inches deep, bare surface, and weeds allowed to grow. The cultivated soil was more effective in absorbing water than the uncultivated soil free of weeds. However, the cultivated soils were not more effective than the uncultivated soils free of weeds in conserving moisture. The plots where
weeds were allowed to grow lost more water than the plots receiving other treatments. (table 1)

Table 1. Average gain or loss of moisture under different treatments at Manhattan and Garden City with bare uncultivated surface as the basis.*

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Manhattan 1914 through 1916</th>
<th>Garden City 1912 through 1914</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep mulch</td>
<td>- 0.130</td>
<td>- 0.077</td>
</tr>
<tr>
<td>Shallow mulch</td>
<td>- 0.242</td>
<td>- 0.032</td>
</tr>
<tr>
<td>Weeds</td>
<td>- 0.717</td>
<td>- 0.200</td>
</tr>
</tbody>
</table>

* Table reconstructed from figures given by Call and Sewell (6), pp. 56 and 58.

These results indicate that soil mulch is not more effective than bare uncultivated soil kept free of weeds in reducing evaporation of soil moisture. The studies also indicate that the principal benefits of cultivation are the removal of weeds which consume soil moisture by reducing transpiration losses, and from reducing the runoff losses by making soils more absorptive of rainfall.

A correct understanding of the movement of moisture in the soil is necessary to evaluate the benefits of soil mulch. In dry farming, rarely does a water table exist within the depth where it can supply moisture to the surface. (1)

**Effectiveness of Different Mulch Materials**

Harris and Yao (16) reported in 1923 the effectiveness of various mulches in conserving moisture. After having established that mulching with straw conserved more moisture than the bare soil surface, they evaluated the effectiveness of mulch materials like fresh manure, wood shavings, grass, hay, and straw. Straw was efficient in conserving soil moisture. The relative effectiveness of other materials used for
mulching was in the order of hay, grass, wood shavings, and fresh
manure. The difference between the moisture conserved by straw and
the fresh manure was 54.1 percent. (Table 2) This indicates that
although mulch materials are effective in conserving moisture in the
soil, their relative effectiveness varies and judgment is to be used
in selecting mulch materials in dry farming.

Table 2. Loss of moisture under different mulch treatments during
33-day test.a

<table>
<thead>
<tr>
<th>Manure</th>
<th>Wood shavings</th>
<th>Grass</th>
<th>Hay</th>
<th>Straw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ce</td>
<td>Ce</td>
<td>Ce</td>
<td>Ce</td>
<td>Ce</td>
</tr>
</tbody>
</table>

Average loss with manure treatment as 100 percent
987.5  793.5  676.4  663.8  652.7

a Part of table II given by Harris and Yao (16) on p. 731.

Harris et al. (16) reported a correlation between the amount of
soil moisture lost and the amount of moisture retained by the mulches.
The more absorptive mulches were less effective in conserving soil
moisture than the less absorptive mulches. The more absorptive mulches
brought more water to the surface and it was lost in evaporation. These
investigators also reported that the efficiency of mulch material in-
creases with the depth of mulch. All their experiments were conducted
with a supply of water at the bottom of soil samples.

Bennett (4) reported in 1942 that at Statesville, North Carolina,
land covered with a two-inch layer of undecomposed pine needles and
land covered with a hardwood forest litter lost 8.06 percent of rainfall
while similar land cultivated continuously to cotton lost 16.3 percent
of the rainfall. Experiments at Lincoln, Nebraska, indicate that straw
mulch conserved 54 percent of the rainfall while summer fallow conserved
only 20.7 percent of the rainfall. Basin listing under similar conditions
conserved 27.7 percent of the rainfall. In this experiment basin lining virtually eliminated run off and yet was only half as effective as straw mulch. This indicates that prevention of run off does not mean a complete solution of the soil moisture problems.

Hooers, Waska, and Young (18) reported in 1948 on the effectiveness of straw, lespedea hay, and farmyard manure as mulch materials. All these mulch materials were effective in preventing soil moisture loss in the first year. The relative effectiveness of these mulch materials was in the order of straw, lespedea hay, and manure. The effectiveness of these mulch materials was greatly reduced in the second year. Of these mulch materials manure was effective only in the first year while the effectiveness of straw and hay was seen in the second year but not in the third year.

These results indicate that straw is an efficient mulch material in conserving soil moisture. Straw is, therefore, useful in dry farming, but its use must be adjusted to prevent depressed yield from wide C:N ratio.
RELATIONSHIP OF SOIL MOISTURE TO YIELD OF DRY LAND CROPS

Continuous Wheat Growing and Soil Moisture

In continuous wheat cropping available soil moisture and nitrogen are important factors influencing crop yield. In studying soil moisture relationships the total moisture available for crop production may be divided into two groups: moisture in the soil at seeding time and total precipitation during the growing season. The effect on crop yield of these two soil moisture groups, independently and in combination, is discussed in the following sections.

Soil moisture at seeding time. Hallsted and Mathews (14) reported in 1936 the importance of available soil moisture at seeding time on yield under continuous wheat cropping. They compared early plowing, early listing, early plowing and subsoiling, and late plowing at Hays, Kansas. In continuous wheat cropping they found that most of the water between harvest and seeding time accumulated in the first three feet of soil. Water rarely accumulated below three feet of soil but when it did the quantity of available water for crop production was small.

The results obtained by Hallsted et al. (14) at Hays, Kansas, indicate a close relationship between the yield of wheat and the quantity of water in the soil at seeding time. The early prepared plots stored more water in the soil and gave higher yields than the late prepared plots. The chances of complete crop failure were great when there was less than 1.5 inches of available water in the soil at seeding time.

When there was an average of 1.5 to 2.9 inches of available water in the soil at seeding time the wheat crop started well but the moisture was not enough to sustain a long period of drought. Favorable or unfavorable conditions following seeding determined the yield of wheat with an
available moisture of 1.5 to 2.9 inches in soil at the time of seeding. With an average available soil moisture of three inches at seeding time, the chance of failure was almost eliminated.

The quantity of available moisture in the soil at seeding time, although a good index of crop yield, is not easy to determine by farmers. In order to give a measure of index to farmers Hallsted et al. (14) have used the depth of moisture in the soil at seeding time as an index of crop production. The required depth depends on the type of soil and results obtained at Hays, Kansas, are applicable only to soils of the same type in this area.

In order to determine the depth of moisture at seeding time, any foot section with three percent of available moisture was considered wet. Three percent of available moisture in a foot section was treated as equivalent to about one-half inch of water. Hallsted et al. (14) have found out that there is a relationship between the depth to which water penetrates and the quantity of water in the soil at seeding time. The total quantity of water available is less than two inches when the soil is wet to a depth of one foot, it is 2 to 3.5 inches or more when the soil is wet to a depth of three or more feet.

The depth of soil wet at the time of seeding used as an index of yield of wheat gave similar results to the quantity of available water. They found three chances in five for the yield of wheat to be 10 bushels or less when the soil was wet only in the first foot and a one chance in seven for a yield of 20 bushels. When the soil at seeding time was wet to a depth of two feet there was one chance in three for a yield of 10 bushels or less and the chances of getting higher yields than 20 bushels were two in five. When the soil was wet to three feet or more the chance
of a yield of 10 bushels or less was one in 31 and the chances of a yield of 20 bushels or more were seven out of eight. (4)

Hallada et al. (14) have summarized the relation of the depth to which soil was wet at seeding time to the yield of wheat for western Kansas. These results do not apply to sandy soils. When the soil is dry at the time of seeding the probabilities of crop failure are 71 percent. With the soil wet one foot deep the chances of crop failure decreased to 34 percent, when the soil was wet to a depth of two feet the chances of crop failure further decreased to 15 percent. With the soil wet three feet or deeper the chances of crop failure were reduced to 10 percent. As the chances of crop failure decreased with increases in the depth of wet soil at the time of seeding, the chances of good yields increased.

Cole and Mathews (7) reported in 1940 the effect of the depth to which the soil is wet at seeding time on the yield of spring wheat in the Great Plains region. They used three percent and four percent of available moisture as indicating approximately the wet condition of coarse and fine-textured soils, respectively. When the soil was wet to a depth of one foot the average yield was slightly more than six bushels per acre but when the soil was wet to a depth of three feet or more the average yield was slightly more than 15 bushels per acre. When the soil was wet to a depth of two feet the yield of wheat was intermediate between soils wet down to three feet or more and soils wet to a depth of one foot at seeding time. However, the yield was closer to the yield on three feet of wet soil than on one foot of wet soil. (table 3)
Table 3. Summary of number of years and average yields of two methods at all stations in the Great Plains when the soil was wet to the depth specified.

<table>
<thead>
<tr>
<th>Soil wet to-</th>
<th>One foot or less</th>
<th>Two feet</th>
<th>Three feet or more</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial Yield</td>
<td>Trial Yield</td>
<td>Trial Yield</td>
</tr>
<tr>
<td>A. Continuously cropped - spring plowed</td>
<td>79 6.3</td>
<td>11b 11.7</td>
<td>68 15.5</td>
</tr>
<tr>
<td>B. Continuously cropped - fall plowed</td>
<td>87 6.7</td>
<td>93 11.7</td>
<td>66 15.9</td>
</tr>
</tbody>
</table>

* Part of table 2 given by Cole and Mathews (7) on p. 10.

Compton (8) reported in 1943 the influence of depth of moisture on wheat yields in western Kansas. Depth was reported in six inch intervals. When the soil was wet only to six inches the yield was five bushels or less per acre on 73 percent of the fields. When the soil was wet from 7 to 18 inches the yield of wheat on 49 percent of the fields was five bushels or less per acre. Crop failures were reduced to 23 percent and 12 percent when the soil was wet to a depth of 19 to 30 inches or more, respectively. (table 4)

Mathews and Brown (17) reported in 1938 a correlation between precipitation during harvest to seeding time and water in the soil in the southern Great Plains region. They found a close relationship between these two factors. About four inches of rainfall was required during the period of three months from harvest to seeding time before
any water could be stored in the soil. For each additional 2½ inches of rainfall above four inches during these three months the storage of water in the soil increased at the rate of one inch.

Table 2. The percentage of the time that specified yields of wheat were obtained when the soil was wet to designated depths at seeding time.*

<table>
<thead>
<tr>
<th>Depth of moisture at seeding time (Inches)</th>
<th>Times out of 100 that specified yields of wheat were obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 to 5 Bushels</td>
</tr>
<tr>
<td>0 to 6</td>
<td>73</td>
</tr>
<tr>
<td>7 to 16</td>
<td>49</td>
</tr>
<tr>
<td>19 to 30</td>
<td>23</td>
</tr>
<tr>
<td>31 or deeper</td>
<td>12</td>
</tr>
</tbody>
</table>

*Table 2 given by Compton (8) on p. 2.

These results on soil moisture at the time of seeding are important to dry farmers. The chances of gambling in crop production can be to some extent averted on lands continuously cropped with wheat with an understanding of the relationship of available soil moisture at the time of seeding to yields. In spring wheat regions low soil moisture at seeding time does not warrant spring wheat sowing. But subsequent favorable conditions of rainfall may be utilized for growing crops that may be seeded later. Such crops include corn, sorghums, millet, sudan grass, and small grains for hay. If rainfall is not favorable for crops which can be seeded later the alternative is to follow the land. (7)

When the available soil moisture before seeding time does not warrant sowing winter wheat and yet the farmer insists on taking a chance on anticipated subsequent rainfall, he will reduce the risk of heavy loss
if he sows only a limited acreage. Under such conditions delaying sowing till after a few rains and till the last safe date for sowing may improve the yield. Years with sufficient rainfall after the last safe date of sowing are few and far between hence this chance of delaying sowing may be taken if a wheat crop is to be grown in anticipation of good rainfall and with initial deficient soil moisture.

Early plowing stores moisture in the soil. With late sowing benefits can be received from any rains which come before sowing. These practices occasionally give the crop a chance to grow under favorable conditions of rainfall after seeding. Where wheat was sown on dry soils in Kansas even with subsequent favorable rainfall conditions the yield was never more than 20 bushels. This shows that bad initial conditions of soil moisture can not be completely corrected by subsequent favorable rainfall conditions.

As the relationship of the depth or the quantity of available moisture in the soil at the time of seeding to yield of crop varies with the type of soil, the crop grown and tillage practices, results obtained in one area are applicable only to areas of similar soil and climatic conditions. This indicates that experiments should be conducted in different areas to be fully beneficial to farmers. (10)

Precipitation between seeding and harvest. Even after seeding with a favorable soil moisture condition, rainfall during the growing season is still of great concern to dry land farmers. Compton (8) reported that in a soil wet to a depth of 18.8 inches at the time of seeding the 1936 crop yield was 9.8 bushels per acre. The yield of wheat during 1937 and 1938 was 7.1 and 11.7 bushels per acre when the soil was wet to a depth of 25.7 and 26.3 inches at the time of seeding, respectively.
This shows that in addition to soil moisture at the time of seeding there is some other factor affecting the yield. A study of the rainfall during the life of the crop explained this discrepancy in yield. The yield of 9.8 bushels of wheat in 1936 was obtained with a rainfall of 8.69 inches during the wheat growing period. In 1937 the corresponding rainfall was 5.74 inches and 1938 it was 12.4 inches.

Hollstedt et al. (14) reported the effect of rainfall during the crop growing season on winter wheat at Hays, Kansas. They used the average initial soil moisture under different tillage practices mentioned in the previous section and the effect of subsequent rainfall for reporting the results. Out of 49 cases, when wheat was sown with below average soil moisture at seeding, in 41 cases the yield of wheat was below the average in spite of the fact that in 26 instances the precipitation during the growth of crop was above average. With the same initial soil moisture but with above average rainfall during the growing period, above average yields were obtained in one third of the cases. In 36 out of 41 cases the yield was above average when wheat was sown in soil with moisture above average at the time of seeding. Of the 41 cases, 25 of them received rainfall below average during the growing period. There was one chance in five that below average precipitation would reduce the yield below the average with favorable initial soil moisture.

The results indicate that the chance is one in six that unfavorable soil moisture conditions at seeding time can be corrected by subsequent favorable rainfall. When the soil moisture at seeding time was above average the chances of getting above average yields are seven in eight. (14) These results indicate that both initial soil moisture and the
amount of rainfall during wheat growing period influence the yield of wheat.

**Total moisture effect on yield.** Total water used during the life of the crop is the amount of water removed from the soil plus the precipitation. (17) Compton (8) reported a study made on 2,451 demonstrations in western Kansas in which the depth to which soil is wet at seeding time and the precipitation during wheat growing period had a greater combined effect on yield than the effect of either of them individually. With the data obtained he has given a formula to predict wheat yields: "Bushels of wheat per acre equals 0.3552 times depth of moisture at seeding time plus 1.133 times rainfall October 1 to May 31, minus 10.5." This formula is applicable only to western Kansas.

Mathews et al. (17) reported in 1938 that the total water required for wheat crop production was almost the same for different cultural practices. They found that a minimum quantity of water is required before any grain could be produced. In Colby and Garden City, Kansas, data obtained indicated that 7.37 inches of water were required before any grain could be produced. Each additional quantity of 0.51 inch of water above the minimum of 7.37 inches of water produced a bushel of wheat up to a limit of 20 inches. They concluded that the yield of wheat increased by 3½ bushels per acre for each additional inch of water used by the crop above 10 inches and up to a maximum limit of 20 inches. This result holds good only when other inhibiting factors are not in operation and moisture is the dominant factor.

The results so far discussed indicate that sufficient moisture at the time of seeding is important for crop production but sufficient initial moisture does not necessarily mean good crop production without
rainfall during the growing period. These relations can be utilized profitably in predicting yields and in planning suitable farm practices to avoid a series of crop failures.

**Wheat-Fallow Cropping and Soil Moisture**

Fallowing has two main purposes: the conservation of soil moisture and the liberation and storage of plant food. Weed control is complementary to the conservation of soil moisture because weed growth utilizes soil moisture. (13)

Fallowing does not guarantee that enough moisture will be stored on all dry land farms. The storing of soil moisture depends on the water storage capacity of the soil. Shallow soils and sandy soils do not hold adequate water within the reach of wheat roots. On heavy soils water does not soak in easily and plant root development is inhibited. On heavy soils moisture is held near the surface and losses due to evaporation are greater. Also, unless good cultural practices are followed in fallowing there is the risk of soil blowing and loss of moisture due to weeds. (17)

Hallsted et al. (14) reported that on a well-cared-for fallow at Hays, Kansas, available moisture was usually stored to a depth of at least five feet at seeding time. From 1910 to 1934 an average of 7.7 inches of available water was stored in the first six feet of soil. In continuous cropping available moisture of three or more inches at seeding time was an assurance of crop production as indicated in the earlier section. The quantity of water available in the soil on fallow land would appear to indicate a positive assurance of a crop but experience has shown that this is not the case. There were no total crop failures on fallow land but the yield was not proportional to the
quantity of available water in the soil at seeding time. This is because too favorable moisture conditions or accumulations of nitrates in the soil might overstimulate vegetative growth resulting in lodging or firing. Where available water in the soil in a well-cared-for fallow is no longer a limiting factor for crop production, other factors determine the yield.

Fallowing does not necessarily mean obtaining double the yield of wheat grown under a continuous cropping system. But in wheat and fallow cropping the risk of crop failures is reduced. In some dry land farming areas fallowed land yields almost twice as much as the continuously cropped land. (Table 5) Further, crop production depends on the type of soil, the amount and the seasonal distribution of rainfall and other conditions during the life of a crop, which have no relation to fallowing. It is quite possible that in some years there will be enough soil moisture to give a good crop where wheat is grown continuously. Therefore it is important to know when to follow land if the advantages of a wheat and fallow cropping system are to be realized. (17)

A relationship has been established between the amount of precipitation and the quantity of water stored in fallowed land at Garden City and Colby, Kansas. No water was stored in the soil for a precipitation of 10.4 inches. For each inch of precipitation above 10.4 inches, 0.6 inch of water was stored in the soil up to a maximum limit of 7 inches. This initial soil moisture relationship, together with the amount of rainfall during the crop growing period are utilized to estimate the wheat yield on fallowed land by using the same formula as for continuous wheat cropping discussed in the earlier section. (17)
Table 5. Yields and crop failures of wheat on early prepared continuous prepared wheat land and on fallowed land at five stations in the southern Great Plains during 1907-1935.*

<table>
<thead>
<tr>
<th>Stations</th>
<th>Average yield</th>
<th>Number of years of crop failure **</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Early fall plowed</td>
<td>Fallowed fall plowed</td>
</tr>
<tr>
<td></td>
<td>Bushels</td>
<td>Bushels</td>
</tr>
<tr>
<td>Amarillo 1907-1917 except 1910</td>
<td>8.8</td>
<td>9.5</td>
</tr>
<tr>
<td>Colby 1915-1935</td>
<td>8.6</td>
<td>18.2</td>
</tr>
<tr>
<td>Garden City 1914-1935 except</td>
<td>7.4</td>
<td>12.9</td>
</tr>
<tr>
<td>1922 and 1928</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goodwell 1926-1935</td>
<td>6.8</td>
<td>13.9</td>
</tr>
<tr>
<td>Delbert 1927-1935</td>
<td>8.4</td>
<td>14.7</td>
</tr>
</tbody>
</table>

* Extract from table 8 given by Mathews and Brown (17) p. 27.

** Yield of less than 5 bushels of wheat is treated as crop failure.

Bracken and Cardon (5) have related high yields of winter wheat in the Great Basin area to fall emergence on fallowed land. They found that failure of the wheat crop to emerge before winter or early spring resulted in a maximum yield usually of less than 20 bushels per acre. Earlier maturing crops suffer less damage than late maturing crops. Failure of early emergence can not be rectified by favorable spring rains. These investigators have estimated the rate of increase of wheat yield for each inch of total water to be 0.87 bushels per acre.

These results indicate that following land is to be guided by the absence of enough soil moisture at the time of seeding for continuous wheat cropping. Following reduces the risk of failure but does not usually yield the same quantity of grain as continuous wheat cropping over a period of years with a given acreage. The results of experiments
conducted in the Southern Great Plains shown in Table 5 indicate that only at Colby did fallowing give a yield of little more than double that obtained on early-plowed continuously cropped land. (17) However, in tests conducted at Nephi, Utah, over a period of 50 years alternate cropping gave an average yield of 23.1 bushels of wheat as compared with 10.8 bushels per acre for continuously cropped land. Fallowing can not be practiced profitably on all soil types. Fall emergence of crops usually gives high yields.

**Wheat on Corn and Kafir Stubbles and Soil Moisture**

There is a marked relationship between soil moisture at seeding time and wheat yield grown on corn ground, but this relationship is not so close as in the case of wheat after wheat. Hallsted et al. (14) have noted in Kansas that the yield of wheat after corn is more erratic than yields of wheat after wheat. They attribute this behavior to lower quantities of water in the surface layers of soil on corn land. Sometimes corn leaves enough moisture in deeper layers. When wheat is planted on soil low in moisture in the surface foot the roots often do not reach the deep soil moisture and the crop suffers. On the other hand, when the soil is wet in the surface wheat roots penetrate and reach the available moisture in the deeper soil and yield better. Another reason accounting for the erratic yields of wheat after corn is the poor stands of wheat resulting from less moisture in the surface soil on corn ground. Poor stands often do better than good stands of wheat during early drought and give better yields in poor years than in good years. It is often difficult for farmers to establish the depth to which soil is wet at the time of seeding on corn ground because corn does not always dry the soil as much as wheat. However, when the soil becomes wet after
the harvest of corn, one can reasonably expect wheat yields as high as on wheat land wet to the same depth.

The yield of wheat after Kafir was lower than the yield of wheat after corn. Due to late maturity of Kafir, the soil often does not accumulate enough water by the time of seeding of wheat crop. Kafir roots can thoroughly exhaust the soil moisture. But the poor stand of wheat for want of adequate moisture at the time of seeding survives better than good stands of wheat in years of early drought. The depth to which soil is wet at the time of seeding wheat on Kafir land is not a good indicator of the prospective wheat crop. (14)
The question of whether to abandon the crop and prepare for fallow arises when winter wheat has made a poor growth in spring. This presents a problem to the farmer to decide between abandoning or taking chances on anticipated subsequent favorable rainfall conditions. If he decides not to abandon the crop and if the subsequent conditions are not favorable he not only incurs expenses but also takes chances on his next year's crop because of insufficient moisture in the soil if drought conditions continue. Therefore, it is necessary to note a few suggestions on abandonment of winter wheat crop.

The relationship of available soil moisture at seeding time, discussed in the earlier section, indicates that the frequency of insufficient quantities of water in the soil at seeding time should determine the frequency of the need for crop abandonment. Data collected at Hays, Kansas, indicate that yields of 12 crops sown on dry soil added to the yield of crops on early plowed land gave a total yield of 242 bushels. For the corresponding period on land fallowed after abandoning crops sown on dry soil there was a total yield of 268 bushels. These represented an increase in yield of 26 bushels of wheat by abandoning the crop sown on dry soil in time to follow. Abandoning a crop necessitates expenses of following but these expenses are slight when compared with the savings in 12 extra seedings and harvests.

From the data obtained at Hays, Kansas, Walled et al. (1936) have generalized that when the soil is wet to a depth of one foot at the time of seeding and when the rainfall is less than two inches from October through December it is safer to abandon the crop in time to follow the land effectively for the next crop. Under similar soil
moisture condition at seeding time but with more than two inches of rain from October through December it is difficult to say whether to abandon or not because there is enough water to start the growth of the crop and maintain it during the winter. Under such situations the growth conditions in spring should be the guiding point to decide about abandonment. (14)

As a general rule wheat sown under adverse conditions which are not corrected in the three months following should be abandoned early. Where the soil moisture relationship is favorable at the time of seeding and subsequently adverse moisture conditions set in usually the abandonment is delayed up to the middle of May. The sooner the farmer can decide that his wheat crop is going to be a failure the better it is for him because by abandoning the crop early and fallowing the land effectively he will secure an average better yield. Decision to abandon a crop later than the middle of May will not help in conserving moisture for the next crop. (14)
The major problem of dry farming is limited soil moisture. Some fundamental relationships of soil moisture in crop production in dry farming regions are discussed.

For a long time a soil mulch in dry farming was considered helpful in conserving soil moisture. Cultivating to form a soil mulch conserves moisture only where there is a water table close to the surface. In dry farming regions the water table is seldom close to the surface of the soil and, therefore, a soil mulch does not help in conserving moisture.

Any lifeless material can be used as a mulch. The effectiveness of different mulches in conserving moisture varies. A straw mulch is very effective.

In continuous wheat cropping moisture is usually the most important single factor influencing yield where enough soil nitrogen is available.

Available soil moisture at the time of seeding has a pronounced influence on the yield. Precipitation during the crop growing season also influences wheat yields.

The combined effect on the yield of the depth to which soil is wet at seeding time and the precipitation during the wheat growing period is more than the effect of either of the factors independently.

Fallowing on the plains should be practiced only when soil moisture at seeding time is not enough to secure a crop. Fallowing does not always increase the total quantity of wheat grown in a given acreage in all dry farming areas over a period of time but reduces the risk of crop failure. Early emergence of crops in fall with favorable
moisture conditions on fallowed land gives high yields. Fallowing is not profitable on all types of soil.

There is a direct relationship between the soil moisture at seeding time and wheat yields grown on corn land but the relationship is not so close as in the case of wheat after wheat. The yield of wheat on kafir land is lower than yield of wheat on corn land.

When wheat sown on dry soil is poor in spring, early abandonment of the crop and fallowing is helpful in conserving enough soil moisture for the next crop. Abandoning wheat crops for fallowing should be done not later than the middle of the spring.
BIBLIOGRAPHY


