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Conservation and Better Land Use for Oklahoma

By HARLEY A. DANIEL, HARRY M. ELWELL, and H. F. MURPHY

Vegetative dams and crop residues control gully erosion.

OKLAHOMA AGRICULTURAL EXPERIMENT STATION

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Conservation and Better Land Use for Oklahoma *

By HARLEY A. DANIEL, HARRY M. ELWELL, and H. F. MURPHY**

Directly or indirectly, civilization is depending upon some type of agriculture for its way of life in Oklahoma. There are wide variations in types of farming in the state; but in general, small grain crops, mainly wheat, predominate in most of the northern part, and row crops, principally cotton, in the southern part. Both types of farming are supplemented by livestock; and, as a whole, the agricultural interests are about equally divided between cropland farming and livestock industries which are dependent largely upon pastures. In the land devoted to these industries, notable variations occur from east to west in climatic, geographic and ecologic conditions.

GENERAL CLIMATIC, GEOGRAPHIC, AND ECOLOGIC CONDITIONS

Although every resident of Oklahoma is familiar with the wide variation in its climatic conditions from east to west, and from north to south, the importance of these differences as affecting conservation and land use problems in various parts of the state is not always realized by those who have to deal only with one section. Therefore it seems desirable here to discuss briefly some of these differences.

Oklahoma winters, as a whole, are mild but characterized by sudden changes in temperature. Usually, there are only short periods of time when the temperature is below zero. The soils rarely freeze below a depth of 3 to 6 inches in southern Oklahoma and not over 12 to 18 inches in the northern part, and they generally remain frozen only a few days. Snowfall is comparatively light. The summers are hot, and at times there are hot, dry winds. The frost-free period, or time from the last killing frost in spring until the first frost in fall, ranges from about 180 to 230 days, which gives ample time for crops to mature.

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In eastern Oklahoma, the average annual rainfall ranges from 35 to 50 inches, while towards the west there is a general decrease to a low figure of 10 to 20 inches of annual precipitation. In the eastern part, more precipitation occurs in winter than in summer (14); however, the average quantity of total rainfall during the warm season is higher than that recorded in central and western Oklahoma where most of it falls in the spring and summer months. The erratic distribution of rainfall throughout the year presents a wide variation of problems. The precipitation in the central and eastern parts of the state is usually in sufficient amounts for normal crop production, but droughts are more frequent in the western portion.

The topography, likewise, changes from east to west, with a general increase in elevation from about 250 feet up to an elevation of over 4,000 feet in the high plains. The soil also changes with these climatic variations from highly leached material to a lime accumulating profile. In eastern Oklahoma, the soils are generally low in minerals (3, 4, 25); while in portions of the western part Caliche Outcrop is common.

The original vegetation, in the area of high rainfall of eastern Oklahoma, was timber. Toward the west it changed to tall grasses, and finally to a sparse cover of short grasses in the panhandle. Due to climatic changes from north to south, the timber in northeastern Oklahoma is largely oak and hickory while in the southeastern part, pine predominates. In the central part of the state there are large areas of scrubby oak which are intermingled with prairie grass. Even though there were great variations in the type of original plant cover, the virgin soil was protected by vegetation.

LOSSES OF SOIL AND FERTILITY THROUGH CULTIVATION AND EROSION

What has our civilization done with the state's most valuable resources, upon which it depends for food, clothing, and a large proportion of the industrial products which are regarded as essential to daily life? The State of Oklahoma was opened for settlement about 1889 (42). The pioneer homesteaders broke the virgin soil and plowed parallel with land lines established when the territory was sectionized. This method of cultivation gave no attention to slope and many of the farms were cultivated up and down slope. Some slopes as steep as 15 percent were planted to clean-tilled crops. Little attention was paid to rotation of crops, renewal of soil fertility, or pasture management. When the new soils were first plowed, roots and residue decayed slowly and gave the soil a springy, spongy texture that for many years prevented hardening by beating rains. For some time these soils retained their granular structure, but under continuous cultivation the plant material was gradually oxidized and destroyed, leaving a highly erodible soil. As these land use practices continued, severe sheet erosion and varying conditions of gullying occurred over much of the sloping lands where rainfall is most abundant in the eastern and central parts of the state. Toward the west, under conditions of deficient rainfall the problem of wind erosion becomes acute and is now a serious menace to successful cropping in the panhandle. In 1935, the National Resources Board estimated (50) that about 81 percent, or 36,588,881 acres, was suffering from accelerated erosion.

Wind Erosion

Dust storms are not new (29), because Udden (cited by Twenhofel (46)) and other investigators were making studies of the soil-transporting power of the wind before 1900. But dust storms appear to have been more severe in Oklahoma during recent years and are now a serious problem to persons in all walks of life. During the recent drought, the soil in some places was blown out to the plow depth several times. Rocky sub-soil was exposed on some of the more shallow types.

A survey made by the Soil Conservation Service in 1937 (28) showed that 42.5 percent of 25,000 square miles of land in the wind-eroded area of Oklahoma, Kansas, Colorado, Texas and New Mexico has been seriously affected. Some of the land in all of the 20 Oklahoma counties in the area has been badly damaged. Cultivated or idle land with soil highly susceptible to wind action has suffered most. According to the National Resources Board (50), 7,014,990 acres of land were found to be affected by wind erosion in Oklahoma in 1935, of which area 4,736,046 acres were seriously affected and 1,958,505 acres were essentially destroyed. In many places, drifting material from adjacent cultivated fields has blown over areas of native sod and it is difficult to determine whether the land was cropped or virgin soil (Figure 1). Moving sand cuts away the vegetation and in a short while the land starts blowing as badly as cropped fields. Where large areas of native pasture land have not been badly overgrazed and have been protected from burning, vegetation has protected the soil from wind erosion.

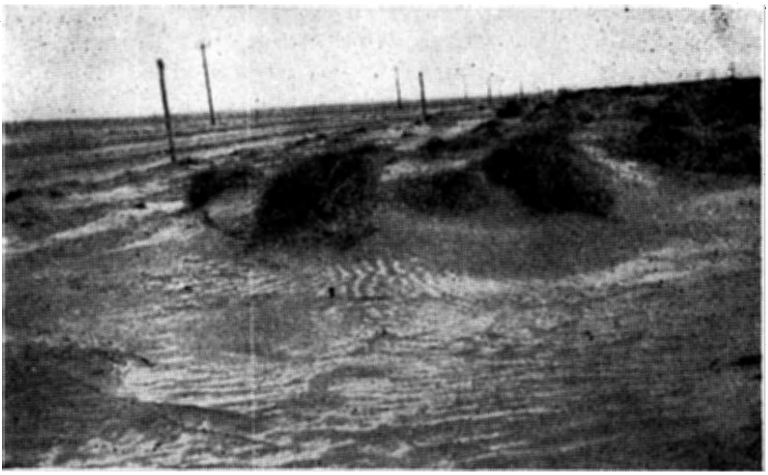

Figure 1. These hummocks are on virgin land north of Guymon, Oklahoma.

Information accumulated at the Panhandle Agricultural Experiment Station (15) shows that soil drifts collected around fences or other stationary objects (Figure 2) contain 24.5 percent less organic matter and 28 percent less total nitrogen than the adjacent virgin soil. In cultivated fields where wind erosion has occurred, 15 percent of the total nitrogen and 18 percent of the organic matter has already been either blown away or depleted by cropping. Soil drifts (12) contained 29.9 percent more sand and 37.8 percent less silt and clay than the virgin surface soil. Although some of this material settled on adjacent land, dust originating from this area was reported throughout a large part of the United States on several occasions. During April and May in 1935, Murphy (35) found that dust was deposited at an average rate of 82.1 pounds per acre per storm at Stillwater, Oklahoma.

Some of the other problems due to wind erosion may be seen in the results of a study of the amount of dust in the air and infiltration into buildings at Goodwell, Oklahoma. The storms that occurred in April and May, 1936 (Figure 3) and during the dusty season of 1937 (31) contained an average of 0.073 pound of soil per 1,000 cubic feet of air at plant height. Dust that entered four different buildings (16) during the worst dust storms of 1936 and 1937 was collected after it settled on the floor. The average was 1.08 pounds per 100 square feet of floor surface.

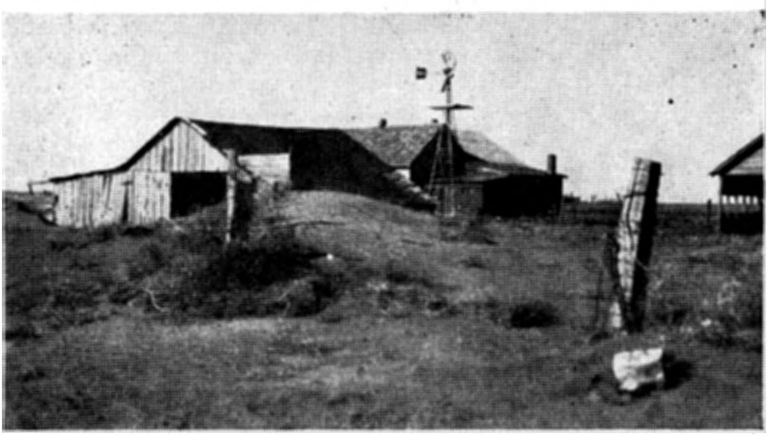

Figure 2. Due to wind erosion, soil was often deposited around the houses and barns.

Living conditions under such circumstances are extremely disagreeable and often become almost unbearable. Grit and grime must be endured in food, on beds, furniture, and floors until the wind subsides. Then it is necessary to clean thick layers of loose soil from everything, knowing that the experience will be repeated when the next storm occurs. If drifting soil did not cause any damage whatever to anything except the homes and their surroundings, its influence on the health (5) and morale of the people, especially the housewife, makes this problem of tremendous importance.

Drifting soil appears to irritate animal life, especially range livestock. It damages all types of machinery, and some of the machine companies say that their repair bills have increased tremendously due to drifting soils. Car owners, who are compelled to drive in the storms, often have experienced heavy repair expenses, as the dust mixes with the grease and oil and forms excellent grinding compounds. The cost of maintaining railway rights-of-way is greatly increased. Highways are often drifted over and even made entirely impassable. Fences, shelter belts, and field windbreaks, after becoming clogged with weeds, check wind velocity and may become completely covered with the soil. The moving particles cause physical injury to the young plants, which are also desiccated by the dry winds and may be buried or smothered by a deep layer of drifted soil.

Water Erosion

Much of the area affected by wind erosion is also affected by water erosion during torrential rains. The reconnaissance erosion survey of Oklahoma made for the National Resources Board in 1935 (50) indicated that sheet erosion had removed more than three-fourths of the top-soil generally from 19,788,-710 acres, or 44.4 percent of the area of the state, and that one-fourth to three-fourths of the top-soil had been removed from an additional area of 8,313,484 acres. Gullies (Figure 4) were found to be prevalent on 25,225,815 acres, of which 12,-754,599 acres were severely affected.

Figure 3. A "black blizzard" at Goodwell, Oklahoma, in 1937.

Figure 4. A large gully in central Oklahoma.

Some fields have been completely denuded of surface soil as shown in Figure 5; and in places the sub-soil has been removed, leaving only clay, sandstone or other parent material. According to Winters (48), 85 percent of the cultivated fields are losing soil very rapidly from uncontrolled rainfall in Oklahoma and (49) over 1,359,000 acres of land was abandoned by 1930. The most severe erosion occurs in the central part of the state, especially on the shallow, rolling soils of the cross-timber areas. The Ozark regions are probably not as extensively eroded as these areas.

Figure 5. A field denuded of surface soil by erosion and abandoned from further cultivation.

Erosion affects the rivers and reservoirs (19) as well as the farm lands. Many of the streams are red in color a large portion of the time. Data reported by Harper and Murphy (26) show that floodwater near Stillwater, Oklahoma, contained an average of 0.67 percent suspended matter. The maximum amount recorded was 2.68 percent. Many river channels are now nearly full of soil and the damage from floods is thereby greatly increased. Much land (16) was practically free of vegetation during the recent drought and in an ideal condition for the water to run off. As a result, enormous amounts of floodwater often went down the streams following torrential rains (Figure 6), destroying valuable soil, bridges, highways, and other property. The rebuilding of bridges and highways cost an enormous sum of money, and there is nothing to prevent this destructive process from continuing after each heavy rain unless proper conservation practices are put into operation and the water stored in the soil.

Plant Nutrients Removed by Crops

The loss of soil resources by erosion is in addition to the plant nutrients removed from the soil (Figure 7) as the crops are harvested. The exact amount is difficult to determine, but the calculated values recorded in Table I indicate the extent

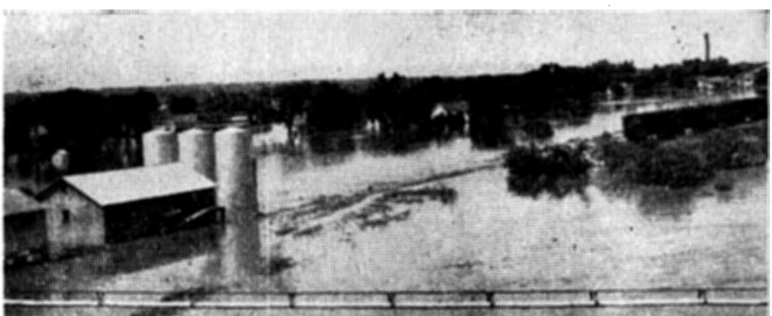

Figure 6. Floodwater of the Cottonwood River, May 4, 1941, covered over 5 blocks of Highway 33 in Guthrie, Oklahoma for 12 hours and caused approximately one hundred families to leave their homes, in addition to doing enormous damage to crops, soil, highways, bridges and other kinds of property.

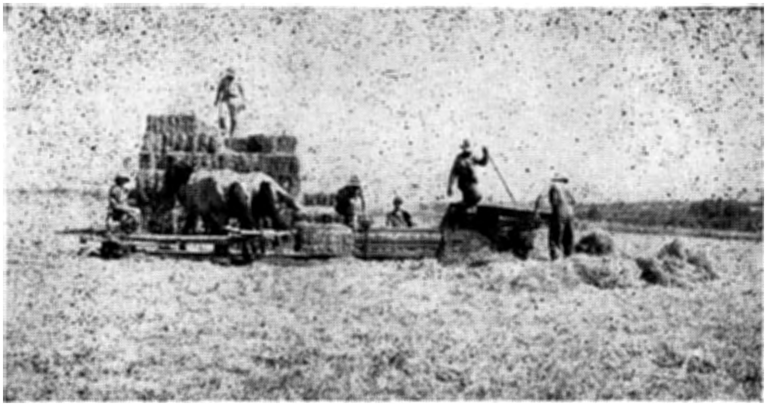

Figure 7. The minerals necessary for crop production and retained in the plants are removed from the soil as the crops are harvested.

of such losses. These data are based on the average annual estimated crop yields compiled by Blood and Whittier (6) and the average chemical analysis of the respective crops reported by Morrison (32).

Even though these tabulations are estimated values, they indicate that field and hay crops removed more than 369,972,000 pounds of minerals or total plant ash annually during a 12-year period from about 13,684,000 acres of land in Oklahoma. Of this enormous quantity, over 36,566,000 pounds was lime, 75,134,000 pounds was phosphoric acid and 89,245,000 pounds was potash. The remainder is composed of sulphur, iron, magnesium and other elements which are essential for plant growth. Over 172,883,000 pounds of nitrogen was also removed by these crops annually. In these tabulations, no account was taken of the nutrients removed by pasture, forest, and horticultural crops. If such were included in these estimates, the losses would be much greater.

The importance of these enormous losses of plant nutrients by cropping may be more clearly emphasized when compared with the amount of commercial fertilizers sold to farmers annually. Reports by the State Board of Agriculture (52) of such sales, including all nitrogen, phosphorus and potash fertilizers from 1930 to 1941, show an average annual sale of about 8,527,000 pounds. The largest amount, 14,842,000 pounds was sold in 1940-41 and the smallest 3,042,000 pounds in 1932-33. This material was used mainly in the area of high rainfall of

Table I.—Average Annual Amount of Plant Nutrients Removed by Crops in Oklahoma, 1928-1939.[1]

Kind of crop	STATE BASIS (IN THOUSANDS)						
			MINERAL, POUNDS				
	Crop production	Acres	Total ash	CaO	P_2O5	K_2O	Nitrogen pounds
Corn	35,118 bu.	2,478	27,532	275	12,664	7,664	30,482
Wheat	49,388 bu.	4,118	59,265	1,244	29,306	15,646	41,228
Oats	25,073 bu.	1,230	28,884	1,010	6,089	3,851	15,404
Barley	1,922 bu.	121	2,675	64	806	575	1,743
Rye	190 bu.	23	211	5	90	68	208
Grain sorghum[2]	12,636 bu.	1,402	11,746	396	5,208	2,971	12,666
Tame hay[3]	670 tons	530	73,590	8,991	5,231	21,836	14,985
Wild hay[4]	437 tons	492	60,306	6,485	1,005	5,139	5,069
Alfalfa hay	403 tons	229	66,898	16,120	4,263	19,537	18,941
Legume hay[5]	66 tons	90	12,276	1,921	764	2 296	3,524
Potatoes	2,723 bu.	38	179	22	187	881	571
Cotton seed	365 tons	2,867	25,550	1,752	9,234	8,322	26,718
Peanuts	17,099 lbs.	36	393	14	149	110	834
Cowpeas	172 bu.	26	359	14	110	178	387
Soybeans	37 bu.	4	111	5	28	48	123
Total		13,684	369,972	36,566	75,134	89,245	172,883

See footnotes at end of table, next page.

Table I.—(Continued.)

Kind of crop	Average Crop Yield		ON ACRE BASIS: MINERAL, POUNDS: Total ash	CaO	P_2O5	K_2O	Nitrogen pounds
Corn	14.00	bu.	10.9	0.1	5.0	3.1	12.1
Wheat	11.80	bu.	14.1	.3	7.0	3.7	14.9
Oats	20.30	bu.	23.4	.8	4.9	3.1	12.5
Barley	15.40	bu.	21.4	.5	6.5	4.6	14.0
Rye	8.00	bu.	9.0	.3	3.8	2.9	8.8
Grain sorghum[2]	9.00	bu.	8.4	.3	3.7	2.1	9.0
Tame hay[3]	1.27	tons	138.6	16.9	9.9	41.1	28.2
Wild hay[4]	.89	tons	121.4	13.1	2.0	10.3	10.2
Alfalfa hay	1.77	tons	293.8	70.8	18.7	85.8	83.2
Legume hay[5]	.74	tons	137.6	21.5	8.7	25.8	39.5
Potatoes	72.00	bu.	46.2	.6	4.8	22.7	14.7
Cotton seed	.13	tons	8.8	.6	3.2	2.9	9.2
Peanuts	479.00	lbs.	11.0	.4	4.2	3.1	23.4
Cowpeas	6.50	bu.	13.7	.5	4.2	6.8	14.8
Soybeans	8.00	bu.	27.0	1.4	7.0	11.7	30.1

1 Data based on estimated crop yields by Blood and Whittier (6) and the average chemical analysis of the respective crops recorded by Morrison (32).
2 Based on average analysis of kafir, darso, feterita, milo, and hegari.
3 Based on analysis of grass hay.
4 Based on analysis of prairie hay.
5 Based on analysis of cowpea and soybean hay.

eastern Oklahoma. Even though more fertilizer was used last year (1940-41) the loss of plant nutrients in crops is many times greater than the replacements in fertilizers.

There is considerable variation in the quantity of total ash, lime, phosphoric acid, nitrogen, and potash removed per acre by the various crops, but in general the amount of minerals removed by grain and other seeds was much less than that removed by forage and hay crops. Alfalfa hay removed the largest amount of minerals per acre and grain sorghum the smallest.

The statement is often made that a particular farm is "one of the best in the county; in fact, it has been producing good alfalfa for 20 years." Based on the data reported, the total quantity of minerals removed during this 20-year period was 5,876 pounds per acre. Of this quantity, about 1,416 pounds were estimated as lime, 374 pounds as phosphoric acid and 1,716 pounds as potash. The remainder is composed of sulphur, iron, magnesium and other elements which are essential for plant growth. During this time, over 1,600 pounds of nitrogen per acre was also removed in the alfalfa. It is true that alfalfa and other legumes assimilate nitrogen from the air when inoculated with bacteria living in symbiotic relationship with the plants. It is difficult to determine what percentage of the total nitrogen in the legumes had its origin in the air and in the soil, but Hopkins (27) concluded that on normally productive soils one-third of the nitrogen in legume plants is taken from the soil and two-thirds from the air. Regardless of the nitrogen content, the alfalfa absorbed from the soil large quantities of minerals that can be replaced only by mineral fertilization. The value of the material removed by the alfalfa is difficult to determine, but based on the present price of commercial fertilizer it probably would cost between $75 and $100 per acre to replace the lime, phosphorus and potash alone. The amount of plant nutrients removed by other crops may be calculated in a similar manner.

Corn, wheat, grain sorghum, and other grain crops remove a rather large amount of phosphorus and only a small portion of lime per acre. There are many fields that have been in continuous wheat and other grains since the native sod was destroyed. If a particular field had been in continuous wheat for 20 years, with an average yield of 11.8 bushels per acre, about 140 pounds per acre of phosphoric acid would have been removed. This would be equivalent to about 700 to 900 pounds of superphosphate.

In addition to the losses of minerals and nitrogen through cropping, the soils are rapidly losing organic matter (36, 37). Table II gives the organic matter content of 206 paired samples of soil where a virgin soil was accompanied by a sample of the same soil after some years of cultivation. The virgin soil samples were taken from a pasture, meadow, or timbered area which had never been under cultivation, while the cropped soil samples were taken from nearby typical areas. There was considerable variation in the various samples and sections of the state, but the cultivated soils have lost an average of 26.8 percent of their original organic matter.

The sticky point, which Keen (30) regards as indicating the amount of moisture in a soil when the attractive force for water is exactly satisfied, was determined on 304 paired samples which included 206 paired samples for which organic matter determinations were made. Any water in the soil above the sticky point causes the soil to work into a more or less puddled condition when tilled; hence, this determination gives the moisture content at a maximum for tillage for loams and heavier soils. As an average, the results show that the virgin soils would retain 22.64 percent of moisture while the respective cropped soil would retain 19.77 percent, or a difference of 2.87 percent, which represents water available for plant use. Most of the cultivated soils in the state are very fine sandy loam or heavier in texture. Wilting point determinations (8) on these soils show 8 percent or more moisture in the soil when permanent wilting occurs. For sandier soils, the wilting coefficient is lower. Vernon fine sandy loam has a wilting point of about 6 percent. Any moisture in the soil at wilting point or less is of no value for growth and if 8 percent is taken as the aver-

Table II.—Percentage of Organic Matter in 206 Paired Samples of Cropped and Virgin Soils of Oklahoma.[1]

Section of State	Virgin soil	Cropped soil	Percent loss
Northeastern	3.28	2.39	27.1
Southeastern	3.06	1.98	35.3
Northwestern	2.72	1.89	30.5
Southwestern	2.51	2.06	17.9
State Average	**2.91**	**2.13**	**26.8**

[1] As determined by the Schollenberger (44) method.

age wilting point for these soils, the cropped soils retained only 80 percent as much available water when their attractive forces for water were satisfied as did the virgin soils. When the same amount of water was added to the cropped soils as it took to satisfy the attractive forces of the respective virgin soils, the cropped soils became very muddy. This is a very important item when it is realized that moisture more than any other one factor controls crop production in western Oklahoma.

PRODUCTIVITY OF THE SOIL AND EROSION RELATIONSHIPS

The amount of plant nutrients removed in crops and lost by erosion annually is enormous. The significance of these losses can readily be seen when comparisons are made with the total mineral content of the soil. The soils of the state differ in characteristics according to the character of the parent material, climatic and other environmental factors. The soils of the eastern portion have developed under conditions of relatively abundant moisture and are leached of much of the soluble plant nutrients (Table III). The normal soils are free of calcium carbonate except on eroded calcareous parent materials where the imperfectly developed soil layers still retain a portion of the limy material. Most of the upland soils of this part of the state respond readily to applications of lime and phosphorus. In the central part the soils are in the transitional zone between the highly leached material in the east and the lime accumulating soils which occur in the western prairies and high plains. Some of these soils, therefore, respond to lime and fertilizers and others do not. Many of the upland soils are shallow and highly erosive. The soils of the arid or western portion are high in minerals and, under favorable weather conditions, the deep agricultural land with medium textured soils produces good yields of wheat and sorghum. The buffalo and grama grasses that predominate on the plains (43) are high in minerals (9, 11) and other nutritional constituents and produce excellent pastures.

Plant Nutrients in the Soil

Due to variations in climatic, geographic and ecologic conditions, the soils of Oklahoma have been classified by Harper (4, 25) into 13 different soil areas (Figure 8). As a result of the differences in topography, rainfall, age, kind of soil material and the effects of vegetation on soil development of the

Table III.—Average Total Nitrogen and Phosphorus Content of Soils from the Different Soil Areas of Oklahoma.[1]

Soil Area	Number of Samples	TOTAL[2] Nitrogen	TOTAL[2] Phosphorus	Percent low[3] Phosphorus	AVERAGE VALUE Soil Reaction	AVERAGE VALUE PH
Northern Ozarks	12	1954	444	83.3	medium	5.81
Southern cross-timbers	19	796	231	78.9	neutral	7.13
Southern Ozarks	60	1484	442	75.0	slight	6.37
Eastern prairies	185	2712	561	67.8	slight	6.00
Interior coastal plains	27	1718	534	59.8	neutral	6.61
Central cross-timbers	111	1386	411	54.1	neutral	7.03
Average		2004	483			
Central prairies	205	2176	489	40.0	slight	6.56
Granitic soils	5	965	320	40.0	neutral	7.04
Black waxy soils	33	4001	904	28.1	neutral	7.05
Sand hills and sandy land	94	962	337	24.7	neutral	7.16
Average		1998	485			
Alluvial soils	142	2756	864	10.6	neutral	7.19
Western prairies	467	2072	598	3.6	neutral	7.33
High plains	42	1709	735	0.0	basic	7.80
Average		2198	665			
State Average		2092	568			

[1] Data compiled by Harper (4).
[2] Pounds per acre to depth 6⅔ inches.
[3] Percent of soil samples analyzed from the respective areas found to be low to very low in available phosphorus.

various soil areas, there are wide variations in the productivity and erosion relationship of the land.

Samples of soil have been collected from each of the areas and analyzed for total nitrogen, total and available phosphorus, and soil reaction. Results in Table III show that the black waxy and alluvial soils contain the highest total nitrogen and total phosphorus content, but with these exceptions the prairie soils were higher in total nitrogen than the other areas. From the analysis of 1,402 samples of soils, the average total nitrogen content for the state is 2,092 pounds per acre (to a depth of about 6⅔ inches) and the total phosphorus 568 pounds per acre.

Based on the data recorded in Table I, continuous alfalfa will remove the average amount of total phosphorus per acre in about 70 years, and continuous wheat in 185 years. These

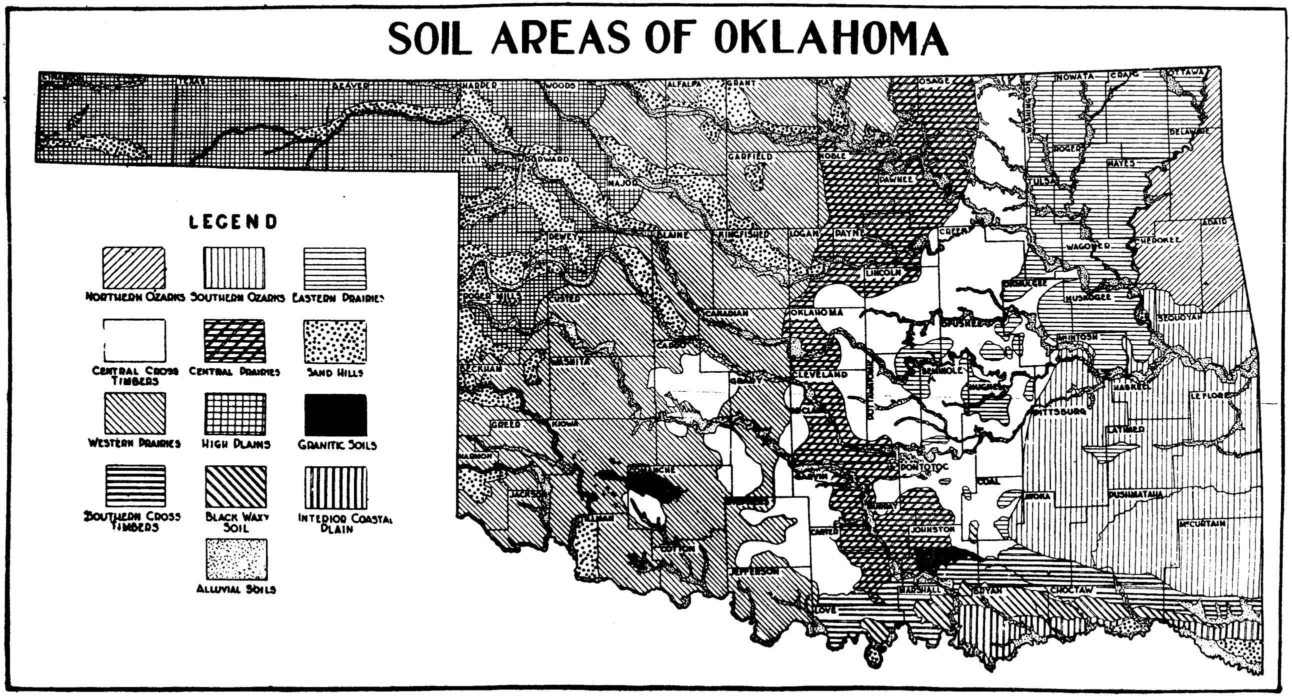

Figure 8. Soil areas of Oklahoma according to a classifi cation by Harper (4 25), based on differences of topography, rainfall, age, kind of material, and effect of vegetation on soil development.

assumptions seem to agree with a statement by Hopkins (27) in which he said, "It is doubtful if there has ever been a land on the face of the earth where the same soil particles have been turned with the plow year after year that remained productive for two centuries with no return of minerals." Laboratory tests (25) showed from 54 to 83 percent of the samples studied from the different soil groups of eastern Oklahoma were probably deficient (24) or had a low content of available phosphorus. In the western part of the state only 3.6 percent of the soils from the western prairies, and none from the high plains, were low in available phosphorus. Experiments with arid soils of Colorado (23), however, indicate that a lack of available phosphorus and nitrogen in the subsoils accounts for a large part of the decreased crop yields following the loss of surface soil.

Although western Oklahoma soils are not deficient in minerals now, if they are farmed continuously to wheat, cotton, grain sorghums, alfalfa, and other cash crops without careful consideration being given to the conservation of soil and minerals, there is a great danger of a large amount of these soils becoming deficient in phosphorus within 100 years. The average total nitrogen content of the high plains and western prairie soils is less than that in the eastern and central prairies, but large quantities of nitrates are formed by natural fixation of nitrogen on neutral and basic soils and especially on dry-land areas (33). From observation and available information (14, 15, 16) it appears that organic matter is the most deficient constituent in the western prairie and high plains soils at the present time. In the organic matter is the life of the soil (2) and it is needed for the absorption of water, which is often the limiting factor for crop production. Organic matter also has an important mechanical effect in controlling wind and water erosion (14, 18) and improves the physical condition of the soil.

Plant Nutrients and Crop Yields According to the Depth of the Soil

A great deal of emphasis has been placed on the losses resulting from erosion since the soils of the state were brought under cultivation. The seriousness of this problem is more definitely shown, however, from the result of a recent study in which the amount of plant nutrients and crop yields were determined in relation to the depth of the soil.

For this experiment, seven cropped soil profiles and the same number of nearby virgin soil profiles were excavated from soil series common to eastern and central Oklahoma. At this time an estimate of the surface soil which had been lost from each cropped soil was made. It was roughly determined that the various profiles had lost from about 6 to 18 inches of topsoil. All profiles were taken to a depth of 4 feet and were approximately 6 inches wide. They were made to fit a wooden box 4 feet long, 6 inches wide and 6 inches deep. The profiles were laid in a horizontal position on a greenhouse bench, planted without soil disturbance, except enough to cover the seed, and kept at an optimum moisture condition with distilled water. Two crops each of Sudan grass and mungbeans were produced. The plants were thinned to a distance of approximately 3 inches apart and each one-foot layer of the profiles had the same number of plants growing on it. Crops were harvested from each foot layer of the profiles and the forage yield calculated to an acre basis.

The crop yields and average chemical analysis of the cropped and virgin soils are given in Table IV. This information and other data (15, 23) show that available phosphorus, organic matter and total nitrogen content of the sub-surface layers was much lower than that of the surface soil. The crop yields also rapidly decreased with the depth of the soil on the 14 cropped and virgin profiles studied.

The surface virgin soil produced an average of 1.59 times more total forage than that of the same layer of cropped soil, while the average yield from this layer of both the cropped and virgin soil produced 1.96 times more forage than the second foot layer of these soils. Similar results were also secured under field conditions (Table V) which is further evidence that erosion removes soil fertility and rapidly decreases crop yields regardless of the depth of soil.

Clean Cultivation, More Erosion, and Less Crops

Due to the increasing erosion hazards in the southwest, experiments were undertaken in 1929 at the Red Plains Conservation Experiment Station, Guthrie, Oklahoma, to determine the importance of checking erosion in its early stages. Table V gives the results, for a 12-year period, of continuous cotton planted on surface and desurfaced land with rows up and down the slope. These data show that a plot where about 10 inches of topsoil had been removed (Figure 9) lost 2.23 times more

Table IV.—Average Chemical Compositions and Yield of Crops According to the Depth of Soil.[1]

Item Compared	CONDITION OF SOIL AND DEPTH OF PROFILES IN INCHES							
	0-12		12-24		24-36		36-48	
	Cropped	Virgin	Cropped	Virgin	Cropped	Virgin	Cropped	Virgin
Chemical Analysis								
Phosphorus[2] (P. P. M.)*	0.80	3.00	0.50	1.40	0.20	0.20	0.20	0.20
	6.94	6.97	6.67	7.15	6.67	7.09	6.54	7.08
Potassium[3] (P. P. M.)*	121.00	107.00	138.00	105.00	120.00	112.00	117.00	152.00
Organic Matter (Percent)	.99	1.33	.73	.86	.29	.69	.25	.46
Crop Yield Pounds of Forage Per Acre								
Sudan grass[4]	1421	2255	718	989	351	421	194	237
Mungbeans[4]	1528	2448	898	1369	505	845	466	618
Average	1475	2352	808	1179	428	633	330	427
Virgin/Cropped	1.59		1.46		1.48		1.29	
Average yield of cropped and virgin layers	1914		994		530		378	

1 The soil profiles used were Canadian, Knox, Derby, Kirkland, Hanceville, Bates and Parsons.
2 Available or soluble in 0.1 N acetic acid.
3 Available or base exchange.
4 Average of two crops of Sudan and two crops of mungbeans. The mungbeans were inoculated.
* Parts per million.

water in runoff and 1.69 times more soil than an adjacent area of surface soil. The surface soil, at the time, produced 1.65 times more seed cotton.

Table V.—Average Annual Soil and Water Losses and Crop Yields from Continuous Cotton on Surface and Desurfaced Soil on the Control Plot at Guthrie, Oklahoma, from 1930 to 1941, inclusive.[1]

Soil condition in 1929 when put under cultivation	Rainfall (Inches)	Run-off (Percent of Rainfall)	Soil Loss Per Acre (Tons)	Seed Cotton Per Acre (Pounds)
Virgin	31.12	12.03	16.06	515
Desurfaced-about 10 inches of top soil removed	31.12	26.82	27.22	313

[1] Size of plot 1/100 acre, land slope 7.70%, soil Stephensville fine sandy loam.

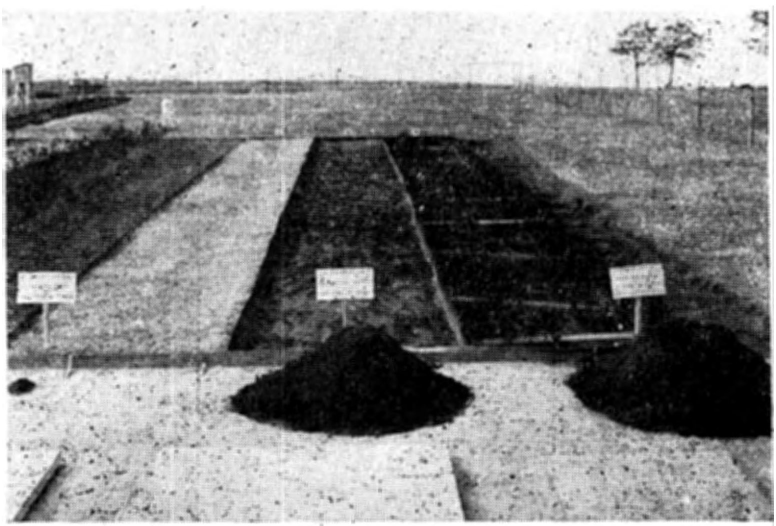

Figure 9. This is part of the control plot at the Red Plains Conservation Experiment Station, Guthrie, Oklahoma. Plot 7 on the left is in continuous Bermuda grass, 8 bare hard fallow, and 9 on the right is desurfaced and in continuous cotton. Approximately 10 inches of the top-soil was removed from this plot in 1929. The piles of soil represent the amounts of soil removed annually by erosion since 1930 from the respective areas.

Further evidence concerning soil and water losses was obtained from measurements on terraced, virgin, and eroded land during an 8-year period. A field which had been under cultivation since about 1900 was badly eroded (13) and lost 1.51 times more water and 1.6 times more soil than virgin land. The cost of terracing the badly eroded and gullied land has been over six times as much (48) as the cost of terracing virgin land before gullies have developed.

On the eroded soil, the organic matter and plant nutrients had been removed, biological activities reduced, the natural sandy loam surface destroyed, and the soil particles closely packed. This had reduced porosity, especially the volume of large pores through which water penetrates readily and through which the soil receives the necessary ventilation. As a result of these changes in structure, root development was hampered, the storage capacity of the soil for water reduced, and crop yields decreased. The excess water accumulated and formed deep narrow gullies, and, if such conditions had been allowed to continue for a long time, the highly erodible unweathered parent material would have become exposed. As this process continued, further erosion would be accelerated.

CONSERVATION PRACTICES

Even though some of the most fertile soils in the country are in this state, they are, as a whole, gradually being depleted of plant nutrients by wind and water erosion and the continual production of cash crops. The business of every farmer is to remove as large a crop as the soil is capable of producing, but failure (27) results eventually regardless of the productivity of the land unless provisions are made for maintaining fertility. It should, therefore, be the policy of every landowner to adopt a system of farming which will conserve the maximum amount of soil resources. If such a system is adopted, the farmer must have land suitable for the production of the particular crop being produced, as well as a thorough understanding of crop requirements and conservation methods.

The research findings and educational work have been of great value in conserving soil resources during recent years, but erosion is still destroying topsoil at a rapid rate on much of the arable land. In addition to land already abandoned, there are many other fields approaching marginal production that may be abandoned soon. Some of the crop requirements, as far as plant nutrients are concerned, may be observed from the data in Table I, which show the amount of minerals and nitrogen removed annually by field and hay crops. Many soils of the state are deficient (3, 24, 25) in calcium, phosphorus, potassium, nitrogen and iron, and there is great danger of more plant nutrients becoming deficient as cropping, erosion and leaching continue. These facts, as well as other information in this report, clearly emphasize the importance of conserving the productivity of the land.

Vegetation Controls Erosion

The value of vegetative cover in preventing erosion on both forest and prairie land has long been recognized. Further evidence of the effectiveness of grass and forest cover in controlling soil and water losses at the Red Plains Conservation Experiment Station is given in Table VI. During a 12-year period the average soil loss from bare hard fallow land (Figure 9) was 1,060 times more and the run-off 31 times more than that from Bermuda grass with the same land slope. Land with a slope of 7.70 percent in continuous cotton lost 803 times more soil and 13.4 times more water than the Bermuda grass area. The soil loss from continuous cotton on a land slope of 6.02 percent was 863 times more and the run-off 104 times more than that from undisturbed virgin woodland on a slope of 5.17 percent. Similar results (13) were secured from larger watershed areas. This information shows that soil erosion was not a major problem when this country was covered with grass or other native vegetation.

The dense cover of the original vegetation (Figure 10) protected the soil from the extreme heat of the sun and broke the impact of driving rains. Underneath the vegetation a dense layer of litter formed an additional protective carpet, readily

Table VI.—Effect of Plant Cover on Soil and Water Losses at Guthrie, Oklahoma, from 1930 to 1941, Inclusive.

Plant cover[1]	Land slope (Percent)	Run-off (Percent)	Soil loss per acre (Tons)
Bare, hard fallow	7.70	27.92	21.20
Continuous cotton[2]	7.70	12.03	16.06
Continuous cotton[2]	6.02	11.40	8.63
Bermuda grass, clipped	7.70	0.90	.02
Woods (undisturbed)[3] [4]	5.17	.11	.01

[1] Size of plot 1/100 acre, soil Stephensville, fine sandy loam.
[2] Rows planted up and down slope.
[3] Scrubby black-jack oaks intermingled with native grass.
[4] Results from 1931 to 1941, inclusive.

Figure 10. A good protective cover of native grass at Guthrie, Oklahoma.

permeable to water. The litter of dead grass also retarded evaporation, gave protection against temperature extremes, and made conditions more favorable for worms and insects. This organic matter decayed, slowly releasing to the soil a part of the essential elements that it contained. This rejuvenated soil fertility (1) and left a humified residue that still further improved the physical condition of the soil.

Beneath this residue was a mass of tough fibrous roots ramifying throughout the soil. These roots were perennial and some of them gradually forced their way into the deeper horizons of the subsoil. The surface roots anchored the soil in place, functioning in this respect as myriads of micro-dams. The deeper roots gradually absorbed plant nutrients from the deeper horizons. These substances found their way into the plants and then back into the surface soil. By means of such a cycle (7) the fertility of the surface soil was further enhanced.

Reclaiming Abandoned Land

Since vegetation controls erosion, experiments (13, 20) to reclaim and rebuild areas of shallow abandoned highly erodible soil were conducted at the Red Plains Conservation Experiment Station. The various experiments occupied about 75 acres of land which had been abandoned from crop production due to gully and sheet erosion. This land has been protected from fire since 1932, low cost gully control work conducted, and several areas seeded or sodded to some of the more important grasses.

The gully control work was conducted principally with temporary dams made of various materials found on the farm. They were designed to catch soil on which vegetation could be established. Brush, poles and rock dams of various types were tried, but the most satisfactory results were obtained from check dams made of stalks, straw, hay, and other mulch material (Figure 11 and picture on cover) after plowing down the sides of the gully banks to about 1.1 slope. An attempt was also made to divert the run-off from the original channels by construction of small, cheap contour ridges between and above the source of the gullies.

The gully areas are low in organic matter and plant nutrients and in poor condition for the absorption of water, all of which are necessary for plant development. Various vegetative plantings were made, which included grasses and legumes. The best results have been obtained from legume plantings, especially biennial sweet clover (Figure 12) which received light applications of lime and phosphorus (13). Lespedeza sericea made fair growth in some areas without fertilizer. After these legumes had an opportunity to build up the organic matter content of the soil, grasses were introduced.

Figure 11. A gully on the East Farm at the Red Plains Conservation Experiment Station after the banks had been sloped and prepared for construction of vegetative dams and revegetation.

Where good stands of sweet clover were obtained, it was possible to seed grass the second year following the planting of the legumes. The vegetative cover produced, however, depends on the accumulation of residue and organic matter afforded by the legumes and on the fertility, water holding capacity, and general physical condition of the soil.

The establishment and survival of various individual native and introduced grasses was also studied. They were seeded as individual and mixed plantings on well prepared seedbeds. In general, the native grasses have given the best results. Where mixed seedings were made, the tall grasses such as little and big bluestem, Indian grass, and switch grass, seemed to predominate in the gullies and blue grama and side-oats grama in the intervening areas. Buffalo grass seems to grow quite well on the areas of heavy soil. When all the plantings are considered, blue grama is making the best growth. Bermuda grass appears to make a nice growth in the little valleys of more fertile land. Another grass, an introduction to this country (Figure 13) known as weeping lovegrass (Eragrostis curvula), has made a nice growth during the last three years at this station. Broadcast strips of this grass produced over 3,500 pounds of hay last year on poor land. It is also making a nice growth in mixed planting of native grasses.

Figure 12. This is the same gully as shown in Figure 11, two years after the establishment of sweet clover and other vegetation.

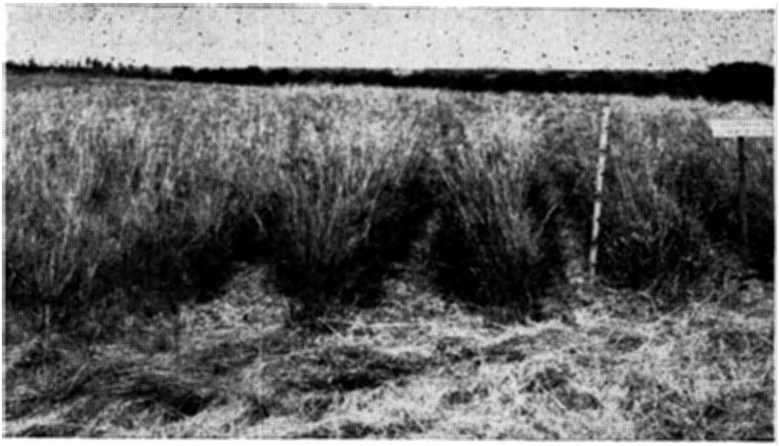

Figure 13. Weeping lovegrass (Eragrostis curvula) produced over 3,500 pounds of hay per acre on poor land at Guthrie, Oklahoma, in 1940.

Pasture Investigations on Abandoned Land

A grass mixture was seeded in April, 1939, on severely eroded soil of plots 13, 14, 15A, and terrace 6E at the Red Plains Conservation Experiment Station and the 1940 results are recorded in Table VII. The latter three areas were terraced in 1930 and the terraces on plot 14 have closed ends. All plots were cropped to a rotation of cotton and cowpeas from 1931 to 1938, inclusive. Blue grama predominates on the ridges, intervals, and unterraced areas. The most outstanding result is the high percentage of switch grass in the channels of the terraces and especially in the channels of the closed-end terraces. It appears that this grass predominates in the areas of excess moisture. Since these areas produced an average of 1,696 pounds of forage per acre in 1940, it was pastured during the 1941 season at the rate of one 2-year-old steer per 6.86 acres. There were 34.3 acres in this pasture and the five steers which occupied it from May 1 to September 30, 1941, made an average gain of 272 pounds per head. This is an average of 39.65 pounds of beef per acre.

In 1939, a grazing experiment was started at this station (21) on 110 acres of pasture, known as the East Farm, which is typical of a large amount of the cross-timbered area of Oklahoma and Texas. The pasture contained 75 acres of formerly cultivated and abandoned land, and the remainder was virgin pasture from which the scrubby oak has been removed. The cattle used in this study (Figure 14) were under the supervision of the Animal Husbandry Department of the Oklahoma Agricultural Experiment Station. It was planned to graze the pasture during the growing season, but, due to a delay in getting the experiment under way, 14 grade yearling steers grazed from June 6 to October 3, 1939, or a total of 119 days. The average gain per steer was 194 pounds, which was an average daily gain of 1.63 pounds per head or 24.68 pounds of beef per acre. The same pasture was grazed by 20 steers from May to October 1, 1940 or 153 days. These cattle were also grade yearling steers and they produced an average gain of 276.5 pounds each, or a daily gain of 1.81 pounds per animal, which was an average of 50.27 pounds of beef per acre. In 1941, 17 steers produced an average gain of 226 pounds each or 34.93 pounds of beef per acre, while grazing during the growing season on this pasture.

The highest utilization occurred on the virgin land (21) but there was sufficient vegetation left at the end of each growing season on both areas to protect the land from erosion.

Table VII.—Revegetation of Badly Eroded Terraced and Unterraced Land at Guthrie, Oklahoma.[1]

	PERCENT OF TOTAL PLANT COVER:						Hay yield, 1940 (pounds per acre)
	Blue-stem	Switch grass	Blue grama	Indian grass	Drop seed	Annual grass	
Plot 13, Unterraced	10.56	11.15	36.58	2.68	7.76	31.25	1366
Plot 14, Terraced Ridge and Interval	6.11	8.55	15.53	14.66	12.76	42.38	1230
Channel	12.01	82.74	0.00	2.76	0.00	2.48	2405
Plot 15A, Terraced Ridge and Interval	11.84	8.16	15.70	7.84	3.25	53.38	1363
Channel	5.93	89.41	0.00	3.31	0.00	1.32	21.39
Terrace 6E Ridge and Interval	13.80	8.98	23.83	22.75	3.37	27.28	1344
Channel	20.57	46.48	7.85	4.90	9.60	18.71	2026

[1] Broadcast seeded April, 1939, at the rate of 30 pounds per acre to a grass mixture consisting of 7 pounds of big bluestem, 14 pounds of little bluestem, 5 pounds of blue grama, 2 pounds of switch, 3.5 pounds of Indian grass, and 2 pounds of buffalo.

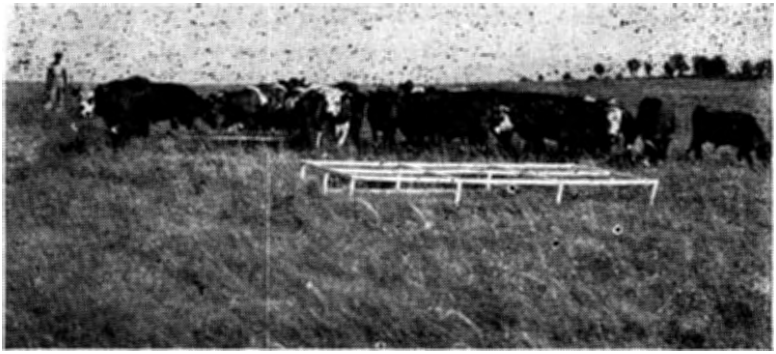

Figure 14. Cattle harvest grass and produce beef, and the grass protects the soil.

The annual production of 25 to 50 pounds of beef per acre compares favorably with that produced on the range land of this area.

Arable Soils for Cash Crop Production

Although thick-growing vegetation controls erosion, rebuilds soils, produces beef, and other valuable materials, all of the land cannot be put to grass or other permanent vegetation. Annual cash crops, such as wheat, sorghum, corn, cotton, and vegetables are essential for the continued existence of civilization. The deep soils, or those best suited for these crops, therefore cannot be overlooked. Their productiveness should be maintained, which will require careful conservation and thrifty management.

Crop Rotation and Fertilization

The effect of a rotation of cotton, oats, cowpeas, and darso on Kirkland soils has been studied at the Oklahoma Agricultural Experiment Station at Stillwater for 24 years. Three systems of farming, namely, a livestock system, a grain system, and a commercial fertilizer system, were included in the experiment. The source of nitrogen was the basis of the differentiation between the systems. In the livestock system, manure was applied equivalent to that which would be produced if the crops were fed to livestock, with the exception that lint cotton was considered a cash crop. In the grain farming system, all crop residues were returned to the land; while in the commercial fertilizer system all crops were removed and nitrogen was furnished as nitrate of soda.

The earlier findings concerning this study have already been reported by Murphy (38, 39, 40) but a summary of 24 years of results is presented in Table VIII. A study of these results reveals that organic matter (manure and crop residues) which furnished the nitrogen (along with any nitrogen fixed through the growing of the cowpeas) in the livestock and grain farming systems has proved superior to the use of commercial nitrogen. In many soils, the need for organic matter as a physical conditioner is vital and of greater concern than the nitrogen problem. This is particularly true of soils with a fair level of fertility and a tendency to crust or pack at the surface. If a soil has the crusting characteristics and a moderately dense to claypan sub-soil, the need for organic matter increases.

In such soils, water entrance is handicapped and the total amount of moisture is limited to that portion of the profile penetrated by crop roots.

The yield data in Table VIII indicate that manure was more effective than crop residues, that superphosphate was superior to rock phosphate, and that limestone showed some effect. Cost data, calculated from cost of materials and farm prices during the 24 years (41), show that each ton of manure at the rate used for the production of crops was worth approximately \$0.41 for cowpea hay, \$0.82 for oats, \$0.59 for darso and \$1.43 for cotton. These figures may not appear to be large, but certainly they show a contribution to those many factors which go into the productivity complex of soil and region.

The data indicate that different crops respond quite differently to fertilizer applications. The greatest increase from the use of superphosphate was with cotton and oats. Relatively, cotton produced a greater increase in yield from the rock phosphate combinations than did the other crops. The superphosphate combinations increased the yields of all crops except darso grain. Superphosphate has hastened the maturity of several crops, and particularly cotton and oats. It has been of little value to sorghums, since they are rather drought resistant and are able to make use of a long growing period. Darso failed to respond to manure applications 8 years out of 24, while each of the other crops did not respond 4 years of this period. Again this indicates the efficient feeding habit of sorghums and their ability to produce on relatively poor land. Another observation from the yearly data is that darso pro-

Table VIII.—Average of 24 years Results of Fertilizer Treatments and a Rotation of Cotton, Oats, Cowpeas and Darso on Kirkland Soil at Stillwater, Oklahoma.

Cropping system and kind of treatment	Seed and grain yield (pounds per acre): Seed cotton, Produced	Seed cotton, Gain or loss	Oats, Produced	Oats, Gain or loss	Darso, Produced	Darso, Gain or loss	Average Gain or loss
Livestock System							
Checks	689		1088		1233		
Manure[2]	772	83	1259	171	1353	120	125
Manure and lime[3]	782	93	1255	167	1391	158	140
Manure, lime and rock phosphate[4]	837	148	1298	210	1418	185	181
Manure, lime and superphosphate[5]	868	179	1426	338	1385	152	223
Grain System							
Checks	698		1086		1280		
Residue[6]	739	41	1160	74	1310	30	49
Residue and lime	772	74	1240	154	1363	83	104
Residue, lime and rock phosphate	804	106	1163	77	1294	14	66
Residue, lime and superphosphate	872	174	1402	316	1366	86	192
Commercial Fertilizer System							
Checks	737		1102		1282		
Nitrate[7]	691	−46	1077	−25	1245	−37	−36
Nitrate and lime	753	16	1184	82	1255	−27	24
Nitrate, lime and rock phosphate	804	67	1225	123	1284	2	52
Nitrate, lime and superphosphate	833	96	1387	285	1338	56	146
Miscellaneous Treatment							
Checks	731		1066		1264		
Limestone	729	−2	1174	108	1322	58	65

Table VIII.—(Continued.)

Cropping system and kind of treatment	FORAGE (POUNDS PER ACRE) Darso Fodder Produced	Darso Fodder Gain or loss	Oats Straw Produced	Oats Straw Gain or loss	Cowpea Hay Produced	Cowpea Hay Gain or loss	Average Gain or loss	Cowpea Seed[1] Pounds per acre Produced	Cowpea Seed[1] Pounds per acre Gain or loss
Livestock System									
Checks	2536		1110		2031				
Manure[2]	2750	214	1332	222	2355	324	254		
Manure and lime[3]	2874	338	1394	284	2526	495	373		
Manure, lime and rock phosphate[4]	2854	318	1559	449	2572	541	436		
Manure, lime and superphosphate[5]	2939	403	1683	573	2606	575	517		
Grain System									
Checks	2539		1135		1824			312	
Residue[6]	2637	98	1189	54	1894	70	74	313	1
Residue and lime	2702	163	1266	131	1976	152	148	318	6
Residue, lime and rock phosphate	2566	27	1258	123	1980	156	100	340	28
Residue, lime and superphosphate	2784	245	1518	383	2216	392	340	403	91
Commercial Fertilizer System									
Checks	2645		1139		2101				
Nitrate[7]	2383	−262	1151	12	2077	−24	−91		
Nitrate and lime	2670	25	1285	146	2175	74	82		
Nitrate, lime and rock phosphate	2699	54	1310	171	2219	118	115		
Nitrate, lime and superphosphate	2831	186	1586	447	2437	336	324		
Miscellaneous Treatment									
Checks	2629		1108		2027				
Limestone	2690	61	1200	92	2141	114	89		

[1] Average of 18 years results.
[2] Manure where used was applied every four years equivalent to that which would be produced if the feed crops were fed to livestock. The average annual rate per acre was 3.013 tons.
[3] Lime where used was applied at the rate of two tons per acre every four years
[4] Rock phosphate where used was applied at the rate of 1,000 pounds per acre every four years.
[5] Superphosphate where used was applied at the rate of 125 pounds per acre annually.
[6] Crop residue consisted of the straw, stalks and cowpea vines. Cotton stalks were left on all plots when this crop was grown. The residue was generally plowed under, but has been used as top dressings in a few instances.
[7] Nitrate of soda where used was applied at the rate of 100 to 200 pounds per acre annually.

duced more grain 7 years out of the 24 than was produced by the best oat crop. Such information indicates the value of sorghum in the farm operations in many localities.

The fertilizer results shown in this experiment, along with other information (2, 24, 25, 27) gained by observation and experimentation, show that phosphorus and organic matter are the most deficient soil constituents, although there are many soils, especially in eastern Oklahoma (3), which are acid and give response to lime for certain crops. Some eastern Oklahoma soils are also deficient in potash. Areas where cotton rust prevails are typical of potassium deficiency and potash fertilization should pay. Usually these soils are also in need of other nutrients such as phosphorus and nitrogen.

Nitrogen (45) may be secured by including legume crops in the cropping plans (13, 24). To secure this benefit, it is essential, however, that soil conditions be favorable and that these legumes are inoculated. Legumes lacking inoculation are not contributing toward the nitrogen supply of the soil. In the rotation mentioned above (cotton, oats, cowpeas, and darso), the cowpeas, even with inoculation, were not able to maintain the nitrogen content of the soil. Data show that at the start of the experiment the soil had an average nitrogen content of 2,263 pounds per acre, while at the end of 24 years this had been reduced to 1,485 pounds. Where the cowpea vines were returned to the soil, the nitrogen content was still much less than the original content. This clearly shows that an annual cultivated legume grown in 42-inch rows is limited in its nitrogen-building ability. Its root system does not occupy sufficient soil volume, and it cannot maintain the nitrogen content when grown only once in 4 years on a soil where all the crops in the rotation are cultivated.

Certain soil organisms other than those operating in cooperation with legume crops are capable of fixing some nitrogen. Little is known of their efficiency under field conditions. They are probably of greater importance in western than in eastern Oklahoma.

Nitrogen availability is largely a matter of organic matter decomposition. Conditions favoring organic matter decomposition favor the release of available nitrogen. Mathews and Cole (33) state, "As a general rule, the nitrates released during the preparation of a seedbed and during the period of moisture conservation in dry-land areas are sufficent to produce as large a crop as the moisture is capable of maturing. Excess nitrates are frequently disastrous in dry years, as they may cause a stimulation of growth that the moisture is incapable of maintaining to maturity." In the more humid regions, nitrates may be leached from the soil rather rapidly and completely; consequently the return of organic matter in the form of manure, crop residues, or green manure and the application of nitrogen fertilizers must be timed properly with the next season's planting program.

The only way to replace minerals which have been removed by cropping, leaching, or erosion is by applying them in the form of mineral fertilizers, including lime. Accordingly, in order to just maintain the phosphorus content of the soil an annual application of about 20 to 50 pounds of superphosphate or its equivalent per acre is necessary for grain and row crop farming. Where alfalfa is grown, it will require about 100 pounds, because alfalfa is a heavy user of mineral plant nutrients, including phosphorus, potash and lime. Where the soil is deficient in phosphorus and needs phosphate fertilization, annual applications of 100 to 400 pounds per acre of a phosphate fertilizer may be made.

Not all crops, as has been shown in the 24-year experiment reported above, show equal response to fertilization; therefore, it is well to consider this and apply the fertilizer mainly to the crop or crops giving best response. Where soils are acid, ground limestone may be necessary for certain crops and is a desirable soil-building practice for such soils. About 2 tons per acre is a common rate of limestone application for acid soils. The rate and frequency of application will depend on the degree of acidity, rainfall, and cropping practices, but one application as mentioned may be sufficient for 6 to 12 years or more.

In order to keep the soil supplied with organic matter, careful conservation of all farm wastes such as crop residues and manures is necessary. In addition to thrifty management, the cropping system should include the use of sod and sod-like crops on the tillable land for definite periods (2). These crops wherever possible should be legumes. Where grasses can be readily established, they may be used to advantage in recreating a desirable soil structure. Plantings of sweet clover, either broadcast or in rows, (Figure 15), has proved to be a desirable practice in eastern and central Oklahoma (24). Lime and/or phosphorus are quite essential in this practice should the soil show a deficiency in either or both. Failure will result when the lime and phosphate are not applied to soil deficient in these constituents. This necessitates testing the soil for its soluble phosphorus and lime content and making the necessary corrections before planting the sweet clover.

Figure 15. Sweet clover in rows produced over 2,000 pounds of forage per acre on poor shallow soil where light applications of lime and phosphorus were applied at the Red Plains Conservation Experiment Station in 1935.

Methods of Conserving Soil Resources

Terraces properly constructed and maintained have long been recognized as the basic mechanical method of preventing erosion (47) on cultivated land. In western Oklahoma, the primary function of terraces is generally to conserve moisture, while in the central and eastern parts, it is to shorten length of slope over which water must pass and reduce velocity of run-off from fields. The structure of the soil profile, however, and especially the density, porosity, and other agents of the sub-soil which influence the rate of infiltration or its water holding capacity, are very important factors in determining the type of terrace to construct in any area. In other words, terraces in a field only constitute a system of drainage and the design must be worked out to meet the particular soil condition.

Properly constructed terraces are helpful in erosion control, but their usefulness will be increased by good soil management practices (13) such as crop rotations and contour cultivation. Soils are found to be in better physical condition after growing a crop of grass or grass-legume mixture for a few years (7). For generations, farmers have known that cultivated crops grew better following such crops, and the data in

Table IX show that the rotation of crops is very important in controlling erosion. The average annual soil loss since 1929 from the area farmed to continuous cotton was 4.4 times more than that from land in the 3-year rotation of cotton, wheat and sweet clover. The effect of the individual crops of cotton, wheat and sweet clover on soil and water losses may also be observed from Figure 16 and the data.

Even under the best combination of erosion-control practices, it is practically impossible to prevent all erosion from

Table IX.—Average Effect of a Crop Rotation on Run-off and Soil Loss at the Red Plains Conservation Experiment Station from 1930 to 1941, Inclusive.

Crop[1]	Run-off in percent of rainfall	Soil loss per acre-tons
Rotation:		
Cotton	10.74	8.81
Wheat	11.08	1.59
Sweet clover	5.95	0.49
Average	9.26	3.64
Continuous co*ton	12.03	16.06

[1] Plot 1/100 acre in size; all cultivation with the slope; land slope 7.70 percent; soil Stephensville fine sandy loam.

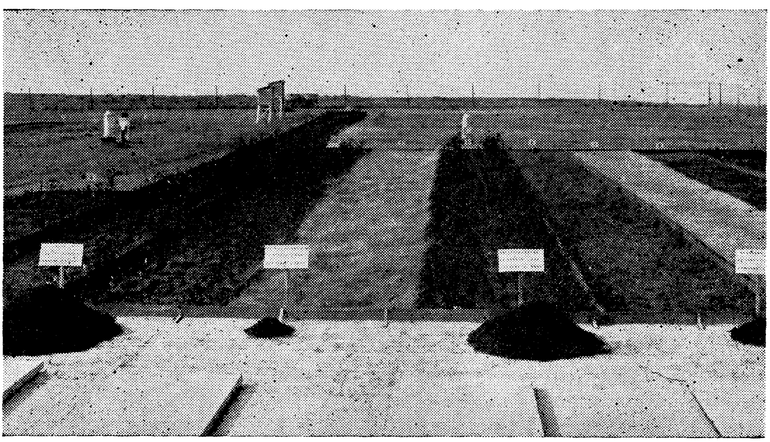

Figure 16. Another part of the control plots shown in Figure 9. This experiment was started in 1929 and shows the effect of a crop rotation on erosion. The piles of soil represent the average annual soil loss from the respective areas since 1930. Pile 1, on the left, was from continuous cotton, while piles 2, 3 and 4 were from the respective crops of sweet clover, cotton and wheat in the rotation.

cultivated lands. Table X gives calculations from the measurements at the end of terraces with different grades at the Red Plains Conservation Experiment Station, on heavy soils similar to that shown in Figure 17. The land was planted on the contour in a rotation of cotton, oats, and darso, with oats followed by a green manure crop of cowpeas and the cotton by a winter cover crop. The results show that the steeper the grade, the greater the erosion and that top-soil was lost at the rate of 1 inch in 132 years from the level terrace. Water moved very slowly from the level terraces (13) and the eroded land and the compact soils on which they were placed often could not absorb the water (Figure 18) they were able to retain fast enough to prevent damage to crops. When crop yield was considered, the terrace with the grade of 2 inches per 100 feet on compact, impervious soil was the most satisfactory. It lost top-soil, however, at the rate of 1 inch in 55 years. Top-soil was lost at the rate of 1 inch in 2 years from an unterraced area planted in a rotation of cotton and cowpeas, with rows

Table X.—Estimated Period of Time During Which a Given Amount of Soil Is Lost from Terraced and Unterraced Land at the Red Plains Conservation Experiment Station, 1930-38.

	Size (Acres)	Land slope percent	Annual soil loss per acre (Tons)[1]	Estimated time in which one inch of top soil is lost[2] (years)
Plot 13[3]				
Unterraced	3.23	5.13	83.72	2
Terraces[4]				
3C—6 inches fall per 100 feet	2.85	4.33	9.30	19
4C—4 inches fall per 100 feet	2.77	4.41	5.92	30
5C—2 inches fall per 100 feet	2.58	4.72	3.17	55
6C—Level	2.06	5.51	1.33	132

[1] Soil loss measurements determined at end of terraces.

[2] Computed from weight of actual losses from the different areas and the weight of an acre-inch of the soil of the station as determined by Middleton, Slater, and Byers (34).

[3] Unterraced badly eroded land on Zaneis, Chickasha, and Stephensville fine sandy loam Rotation of cotton and cowpeas and cultivated across gullies.

[4] Terraces all 1,500 feet long, on Zaneis and Chickasha fine sandy loam, with 1,000 feet of virgin soil and the other slightly eroded and in a rotation of cotton, oats and darso. The oats were followed by cowpeas and the cotton by a winter cover crop.

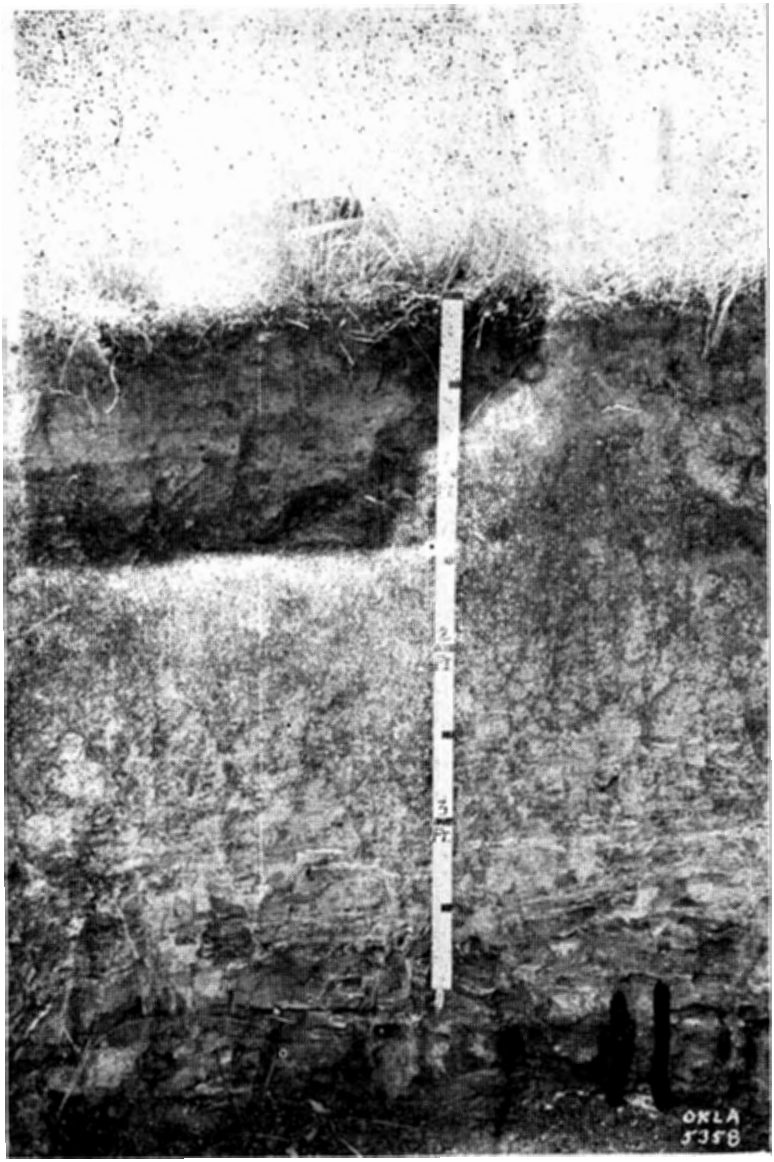

Figure 17. This soil profile is quite representative of a large amount of the soils at the Red Plains Conservation Experiment Station. The surface soil is about 12 to 14 inches in depth and is immediately underlaid with clay, sandstone and shale at a depth of about 30 inches. Such a soil absorbs water rather slowly.

across the gullies. This information definitely shows that any time muddy water leaves a field, it probably contains some soil, but that the slower it moves the less soil it carries.

At the Panhandle Agricultural Experiment Station at Goodwell, Oklahoma (10) on deep fertile soil, the average annual grain yield of wheat and milo for a 10-year period was increased 3 bushels per acre by conserving water with level, closed-end terraces. Similar results were obtained at the

Figure 18. Water moves slowly from level terraces; and on heavy soils where the absorption of water is retarded, crops are often damaged.

Texas Agricultural Experiment Sub-Station at Spur (17) where closed, level terraces increased the annual yield of lint cotton an average of 68 pounds per acre in a 12-year period.

For these reasons the water storage capacity of the soil should be determined as nearly as possible before deciding what type of terrace to construct. Level terraces may be used satisfactorily on sandy soil or soils with deep, permeable profiles (Figure 19), where rate of infiltration is rapid; (13) but graded terraces, not exceeding 2 inches per 100 feet, are the most satisfactory type on the medium and fine-textured soils

Figure 19. This particular soil has a deep, permeable profile which will absorb water readily.

underlaid with compact clay sub-soil. Although no water is lost in run-off from level, closed terraces, this practice is recommended for arable soils only in regions where moisture is the limiting factor for crop production and wind erosion is usually the problem.

SOME DESIRABLE LAND USES

Man must adopt a system of farming which will, in so far as possible, maintain a productive soil for the continued support of a healthy and permanent civilization. There are many areas of sandy and shallow soils throughout Oklahoma which were put into cultivation during periods of abnormally high prices and favorable rainfall. Much of this land is sub-marginal for cultivation and is often the source of much erosion. In general, the deep soils are the most suitable for cultivation but many soils are unproductive due to the physical, chemical, and biological properties of the profile aside from plant nutrient requirements. The experiment stations are demonstrating (13, 20, 21) that land may be sub-marginal for cultivation, but more stable and greater returns obtained when put to its most desirable or best known use. As a result the shallow, highly erodible soils which have suffered seriously from erosion, as well as others unsuited for cultivation in various parts of the state, might be more useful if retired to some type of dense vegetative cover. In the eastern part, where the rainfall is highest, some of this land may be reforested; while in central and western Oklahoma regrassing is probably the most feasible.

There will, no doubt, be periods and seasons with more rainfall than others, and the time to secure a cover for the land sub-marginal for cultivation is during a series of wet years. If some permanent means of land use is not in force in the wind eroded area during years of sufficient rainfall (51), the extra moisture might postpone the destructive process, yet in the end accelerate it by raising false hopes and by encouraging mistaken agricultural practices. When this land is returned to grass, it will be a long time before there is a perfect sod, but with proper range management and careful planning, soil which contains some natural fertility should still produce good pasture. In the sand hills and black jack areas of central Oklahoma, it might be profitable to remove some of the scrubby timber, sagebrush and other woody vegetation (21) for grass development in order to remove the heavy grazing requirements from other pastures. In order to maintain a protective cover on all land covered by grass, timber, stubble mulch, and other dense vegetation (22), burning and over-utilization should be discouraged.

There is great need for further research, demonstrations, short courses, and extensive education in order to maintain agricultural production and obtain the most efficient use of the land. The present information, however, indicates in general that for the deeper lands suitable for arable farming in eastern and central Oklahoma the most desirable erosion-control practice is probably a well planned system of terraces designed to reduce the amount and velocity of run-off from fields, supplemented with crop rotations (13). It is also advisable for all cultivation to be conducted on the contour and the cropping system to include as many close-growing sod crops of legumes and better grasses as possible. In addition to the conservation of crop residues and manure, the use of lime and mineral fertilizer is recommended, when needed.

The maintenance of soil fertility is important in the wind eroded area (33) but not nearly so immediately important as the conservation of soil and water. In selecting crops to be planted in a rotation (14), stress must be placed on the soil-moisture relations and their value in maintaining a vegetative cover at those critical periods of the year when wind erosion is most severe, rather than on their effects on soil fertility. In such areas raw organic matter, particularly in the form of crop residue (Figure 20) is a helpful factor in successful crop production. These residues influence the physical properties of the soil; and if sufficient quantities are present they also have a mechanical effect in controlling soil and water losses (14, 18) provided decomposition has not occurred to such an extent that the organic matter has lost its identity in the soil. Due to the importance of moisture (10) for crop production on deep medium and fine textured soils in the arid section of the state, terraces may be designed to conserve moisture, and the cultivation and cropping systems be such (Figures 21 and 22) as to uniformly distribute and economically use the rainfall to produce crops and maintain a protective cover.

SUMMARY

There are wide variations in types of farming in Oklahoma, but the agricultural interests are about equally divided between cropland farming, and livestock industries which are dependent largely upon pastures. Notable variations oc-

Figure 20. Stubble mulch of wheat straw on the Wheat-land Conservation Experiment Station, Cherokee, Oklahoma.

cur in climate, rainfall, topography, soil and vegetation from east to west. Even though there were great variations in the type of original plant cover, the soil was always protected by vegetation.

The state was opened for settlement about 1889, and with the type of land use practices adopted, much of the land has suffered from erosion. The cultivated soils have lost an average of 26.8 percent of their original organic matter, and retain only about 80 percent as much available water for plant growth as did the virgin soil. Considerable variation occurs in the quantity of total ash, lime, phosphorus acid and potash removed per acre by various crops, but alfalfa removes the largest amount and grain sorghum the smallest.

The average total nitrogen content for the state is 2,092 pounds per acre (to a depth of 6⅔ inches) and the total phosphorus 568 pounds per acre. Laboratory tests have shown that from 54 to 83 percent of the samples studied from different soil areas of eastern Oklahoma were probably deficient or had a low content of available phosphorus, while only 3.6 percent of those from the western prairies and none from the high plains were low in this constituent. Although these

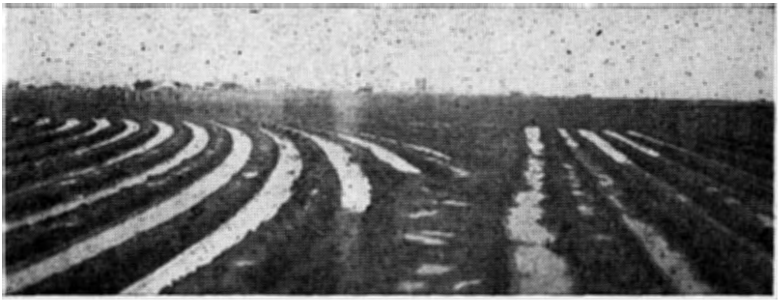

Figure 21. Contour furrows holding water after a rain at Goodwell, Oklahoma. See Figure 22.

western soils are not deficient in minerals now, if they are farmed continuously to wheat, cotton, grain sorghum, alfalfa and other cash crops without careful consideration being given to the conservation of soil and minerals there is a great danger of a large amount of these soils becoming deficient in phosphorus within one hundred years. Chemical analyses of cropped and virgin soil profiles showed that available phosphorus, organic matter and total nitrogen content of the subsurface layers was much lower than that of the surface soil. The surface virgin soil produced an average of 1.59 times more

Figure 22. The effects of moisture conservation by terraces and contour cultivation, as shown in Figure 21, on the growth of plants at Goodwell, Oklahoma. The plots on the left were terraced and contour cultivated and those on the right were unterraced and cultivated with the land slope. Although the land slope was less than one percent, the terraced and contoured plots produced 194 pounds per acre more Tepary bean hay in 1935 than the unterraced land.

total forage than that of the same layer of cropped soil, while the average yield from this layer of both the cropped and virgin soil produced 1.92 times more forage than the second 1-foot layer of these soils. Regardless of the depth of soil, erosion removed soil fertility and rapidly decreased crop yields. Badly eroded land lost soil 1.67 times faster than virgin land.

The most effective method of controlling erosion was with thick growing vegetation, and of this, grass was the best erosion resistant cover. Native prairie grasses re-establish themselves on eroded land slowly, but this process can be greatly accelerated in central Oklahoma by the use of legumes such as sweet clover and lespedeza sericea lightly fertilized. Grazing experiments during the last three years indicated that the production of beef, on formerly useless, abandoned, scrubby oak land, compares favorably with that produced on the range land of the area.

Three systems of farming; namely, a livestock system, a grain system and a commercial fertilizer system, were studied and the best results were obtained where all crops except lint cotton were fed to livestock and the manure produced returned to the land with an additional application of lime and phosphorus. Other experiments are demonstrating that land may be sub-marginal for cultivation, but more stable and greater returns obtained when put to its most desirable or best known use. As a result, the shallow, sloping, highly erodible soils which have suffered seriously from erosion as well as others unsuited for cultivation in various parts of the state might be more useful if retired to some type of dense vegetative cover.

The present information indicates that, in general, a well planned system of terraces, designed to reduce the amount and velocity of run-off from fields which are supplemented with crop rotations, is probably the most desirable erosion control practice for the deeper lands suitable for arable farming in eastern and central Oklahoma. It is also advisable for all culitvation to be conducted on the contour and the cropping system to include as many close growing sod crops of legumes and better grasses as possible. In addition to the conservation of crop residues and manure, the use of lime and mineral fertilizers is recommended when needed.

The maintenance of soil fertility is important in the wind-eroded area, but not nearly so immediately important as the conservation of soil and water. In such areas, raw organic matter, particularly in the form of crop residue, is a helpful factor in successful crop production. In the arid section of the state, terraces may be designed to conserve moisture and the cultivation and cropping system such as to uniformly distribute and economically use the rainfall to produce crops and maintain a protective cover.

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