JANUARY, 1949 BULLETIN 522

UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION

J. H. LONGWELL, *Director*

Evaluating Annual Changes In Soil Productivity

A. W. KLEMME and O. T. COLEMAN

COLUMBIA, MISSOURI

(Revision of Bulletin 405)

FOREWORD

In the farming business, the soil is the raw material from which the more valuable, finished products for the markets are made. As such a manufacturing process, agriculture has been exhausting its stock of the raw (soil) materials to the point where declining crop yields and mounting costs are crowding out the margin of security. Special land classifications and many types of economic adjustments are deemed necessary mainly (a) because our soils are declining in productivity, and (b) because in determining costs of agricultural production we make no charge for the raw materials which the soil contributes to the final products.

In the face of these conditions we need now to know how rapidly our soil resources are declining, or increasing, under our different methods of handling the land. We need to know whether these methods, even under a larger interest in soil conservation, are going to perpetuate significant productivity in the land. Since the nitrogen in the soil must be applied as commercial fertilizer or built into the soil from the air by means of legumes grown there as green manures, and since these crops will function as nitrogen-fixers only when the soil is fertile in other respects, the level of the nitrogen as organic matter becomes a good guide for the productivity of our soils. This publication is an attempt to provide helps in judging the effectiveness of our efforts in keeping our soils productive. Acknowledgment is gladly made to M. F. Miller, Dean Emeritus of the College of Agriculture, who instigated this study and lent his encouragement and help during the preparation of the material.

WM. A. ALBRECHT,
Chairman, Department of Soils.

Evaluating Annual Changes in Soil Productivity

A. W. KLEMME and O. T. COLEMAN

A method for evaluating in approximate terms the annual fertility and erosion losses from soils under the main crop and cropping systems used in Missouri has been developed from data taken from the experiments of the Department of Soils of the Missouri Agricultural Experiment Station and from various other sources. Through the use of this method, farmers and other agricultural workers can plan cropping systems more effectively, provide the necessary soil treatments, and give thought to the soil conservation measures which offset the fertility and erosion losses brought about by crop removal, leaching, and erosion.

ORGANIC MATTER AND NITROGEN—IMPORTANT FACTORS IN PRODUCTIVITY

This method of evaluating soil productivity changes is based upon the annual gain or loss of nitrogen in the surface seven inches of soil. Since nitrogen is consumed in comparatively large quantities by all crops, its annual gain or loss is large in relation to the available supply. Consequently, from the standpoint of soil composition, it is a good indicator of soil productivity. In order to economically maintain a proper nitrogen turnover under Missouri conditions, legumes must be used frequently in the cropping system. To grow these crops successfully, lime and other mineral plant nutrients must be kept at such a level as is suitable for biological activities and which will provide a sufficient amount of those available mineral nutrients for optimum growth.

In the final analysis, crop yields normally serve as the best measure of the productivity on silt and silt loam soils which make up the greater part of the soils of Missouri. They are closely related to its total organic matter and nitrogen content. The close relationship between the total organic matter or nitrogen content of soils and crop yields is shown in Table 1. This table gives the average total nitrogen content of the surface seven inches of soil, and the average yields of corn from untreated plots of experimental fields on some of the principal soil types of the state.

TABLE 1.—THE RELATION OF TOTAL NITROGEN CONTENT TO CORN YIELDS*

Soil Type	Total Nitrogen (in lbs. per A. 7 in. deep)	Av. Yield of Corn in Bushels per Acre
Marshall Silt Loam	3630	38.6
Grundy Silt Loam	3370	32.0
Eldon Silt Loam	3160	31.2
Crawford Silt Loam	2840	25.4
Cherokee Silt Loam	1950	22.5
Gerald Silt Loam	1890	19.0
Union Silt Loam	1600	16.0
Average	2634	26.4

*Missouri Agricultural Experiment Station Bulletin #238, and #264.

These data indicate that, in general on upland silt loam soils, corn yields vary with the total nitrogen content of the soil. According to the table, about 10 bushels of corn may be expected for each 1000 pounds of total nitrogen contained in an acre plowed to a depth of 7 inches. Yields of other crops usually vary with the corn yields.

DECREASING ORGANIC MATTER MEANS DECLINING CROP YIELDS

The cropping systems and methods of tillage used in the past have hastened the destruction of organic matter with the consequent liberation of nitrogen. The magnitude of this loss is shown in Table 2, which compares the total nitrogen content of virgin areas of various soil types with that of adjacent cultivated areas.

TABLE 2.—THE EFFECTS OF CROPPING ON THE TOTAL NITROGEN CONTENT OF SOIL

Soil Type	County in which samples were collected	Lbs. Nitrogen in Surface 7 inches			Percentage loss in Nitrogen
		Virgin	Cultivated	Loss of N. in lbs. per A.	
Baxter Silt Loam	Lawrence	3020	1820	1200	39.7
Crawford Gravelly Loam	Greene	2580	1640	940	36.4
Eldon Silt Loam	Lawrence	4270	2720	1550	36.3
Grundy Silt Loam	Caldwell	5200	3340	1860	35.7
Marshall Silt Loam	Saline	5980	3530	2450	41.1
Putnam* Silt Loam	Callaway	3940	2580	1360	35.0
Shelby Loam	Worth	4630	3100	1530	33.0
Summit Silt Loam	Lafayette	4590	3520	1070	23.3
AVERAGE		4276.2	2781	1495	34.9

*Missouri Agricultural Experiment Station Bulletin #324.

The analyses were made of soil samples representing the surface seven inches of comparatively level virgin areas of native prairies, of virgin timber land, and other undisturbed areas, and from the nearly level adjoining cultivated fields where little or no erosion had taken place.

The average total nitrogen content in the surface seven inches of the virgin soils representing these eight soil types was 4,276 pounds per acre. The adjacent cultivated soils averaged but 2,781 pounds per acre. This represents an average loss of 1,495 pounds of nitrogen per acre or a total decree of approximately 35 per cent in this element since this land was first put into cultivated crops.

A comparison of the yields of corn, oats, wheat, and hay in Missouri over a 60-year period, as shown in Table 3, indicates that there has been a slight decline in the yield of all these crops except wheat. The yield of this crop has remained about the same through this whole period. These data indicate clearly that improved varieties have not on the average compensated for the decline in soil productivity through erosion, crop removal and leaching.

TABLE 3.—THE AVERAGE YIELDS OF THE PRINCIPAL CEREALS AND HAY CROPS GROWN IN MISSOURI FOR SIX TEN-YEAR PERIODS

			Six 10-Year Periods			
Crop	1868-1877	1878-1888	1888-1897	1898-1907	1908-1917	1918-1927
Corn	30 bu.	27.4	28.6	27.5	28.9	27.7
Wheat	12.5	11.8	12	12.9	13.7	13.0
Oats	28.7	26.5	21.8	22.9	26.6	23.6
Hay	1.37 T.	1.2 T.	1.18 T.	1.2 T.	1.1 T.	1.2 T.

The Department of Field Crops of the Missouri Experiment Station estimates that 60 per cent of the total wheat acreage of the state is grown from varieties developed or improved by the Experiment Station. Experimental tests made by this station show that these improved varieties out-yield by about four bushels per acre the ordinary varieties which were used during this earlier period. Similar tests show that as a general average fertilizer increases the average yield of wheat by four or more bushels per acre. The extent of the use of these two practices in the state should have increased average wheat yields by at least two bushels per acre. Improved cultural practices, such as better tillage methods, drainage of bottom lands, and new land being brought into cultivation should give an estimated additional yield of two bushels per acre or a total of four bushels. This would represent a total increase of not less than 30 per cent.

Prior to the drouth in 1934, 90 per cent of the corn acreage grown in the state was of improved varieties. It is estimated that the use of such varieties should have increased corn yields at least two bushels per acre. It is further estimated by the Department of Field Crops that 80 per cent of the total oat acreage now grown in Missouri consists of varieties developed by the Experiment Station. These varieties in Experiment Station tests out yielded other varieties from six to eight bushels per acre. The use of these improved oat varieties alone should have increased the state oat yield at least five bushels per acre, or approximately 25 per cent. These estimates indicate that improved varieties and cultural practices have been offsetting the decline in soil productivity and that these should have brought about from 20 to 30 per cent increase in yields.

LENGTH OF TIME MISSOURI LAND HAS BEEN CROPPED AND THE EFFECT ON PRODUCTIVITY

The approximate length of time that Missouri land has been in cultivation can be determined from a study of the following United States Census Bureau records:

Year	Bu. Cereals	Year	Bu. Cereals
1850	44,551,820	1900	252,772,272
1860	81,504,832	1909	246,665,000
1870	97,793,338	1919	233,365,000
1880	248,768,095	1928-32	207,320,000
1890	267,305,096		

These figures show that the production of cereal crops increased more than 500 per cent between the years 1850 and 1880.

Further evidence that large areas of land were brought into cultivation sometime following the close of the Civil War is supplied by additional Census Bureau records, which show a total of 2,193,964 acres in corn, wheat, oats, and tame hay in 1866; 7,058,812 acres in 1876; 13,685,954 acres in 1886; while in 1936 there were approximately 12,000,000 acres in these crops or a total of 13,141,600 acres in all crops.

These records show that approximately five-sixths of the acreage now used for crop production was broken out of sod, or cleared of timber, and first cultivated between 1866-1886 or slightly less than 70 years ago. The data presented in Table 2 show that during this short period more than one-third of the total organic matter and nitrogen content of the virgin soil has been destroyed by cropping. This represents an average loss equivalent to about one-half of one per cent yearly.

CROPS VARY IN THEIR CONSUMPTION OF NITROGEN

It has long been known that some crops use, and require more nitrogen than others for satisfactory yields. The difference in the amounts and the percentages of total nitrogen removed from the surface 7 inches of soil by the three important cereal crops grown in Missouri, is indicated in Table 4.

TABLE 4.—PER CENT OF TOTAL NITROGEN REMOVED ANNUALLY FROM MISSOURI SOILS BY DIFFERENT CEREAL CROPS*

Crop	Average Yields in Bu. per Acre	Pounds Nitrogen Removed by Crop Grain and Forage	Average Nitrogen Content in Lbs. per Acre for surface 7 inches	Per Cent of Total Nitrogen Removed Annually by Crops
Corn	24.15	40.3	2480	1.63
Oats	26.8	23.4	2480	.94
Wheat	10.0	17.7	2480	.71

*Computed from Missouri Experiment Station Bulletins #238 and #264 and from unpublished data of the Missouri College of Agriculture.

These data show that corn removes, on the average, about twice as much nitrogen as do the small grains. Since, as shown in Table 1, crop yields correspond roughly to the amount of organic matter and nitrogen present, the removal of nitrogen from the soil will correspond to the kind and size of the crop. This is especially true on soils well supplied with these constituents. On the poor soils, the organic matter and nitrogen will likely not be removed so rapidly by cropping, because as the soil fertility declines, the absolute loss becomes proportionately less and its decline less noticeable. Erosion, however, takes a higher percentage of soil and plant food from the thinner soils since they produce less vegetative growth and therefore less cover to protect them. Consequently on average or better soils, in evaluating the effects of the crop itself on soil productivity, intertilled crops are considered about twice as destructive as small grains.

EFFECTS OF CROPPING SYSTEMS ON TOTAL NITROGEN CONTENT OF SOIL

Additional information regarding the effects by different crops and cropping systems on soil productivity may be gained from a study of the total nitrogen content of the soil after 25 and after 50 years of cropping on Sanborn Field at Columbia, Missouri. The land on which this experimental field was started was cleared of timber and brush in 1884, and would be considered as in a virgin state of fertility when the experiment field was established in 1888. The soil type is a slightly rolling phase of Putnam silt loam. While no chemical analyses of any of the plots were made at the time the field was established, they were made after 25 and after 50 years of cropping. From analyses made on soil samples collected from the adjoining virgin areas, it has been estimated that the total nitrogen content of these plots at the beginning of the experiment was about 3,250 pounds per acre.

Table 5 gives the nitrogen content of some untreated plots on Sanborn Field at the end of the 25 and the 50 year periods in contrast to the calculated nitrogen content of the field at the beginning of the investigation.

TABLE 5.—NITROGEN CONTENT OF SURFACE 7 INCHES OF SOIL ON UNTREATED SANBORN FIELD PLOTS AT COLUMBIA, MISSOURI*

Plot No.	Cropping System	Total Nitrogen in Pounds per Acre in Surface 7 Inches of Soil			Percentage of Total Nitrogen Depleted		Percentage of Nitrogen Depleted Annually	
		Calculated for Beginning of Experiment†	After 25 years of cropping	After 50 years of cropping	1st 25 years	50-year period	1st 25 years	50-year period
17	Corn Continuously	†3250.	1575	1420	51.5	56.3	2.06	1.13
9	Wheat Continuously	3250	2040	1750	37.2	46.1	1.48	.92
23	Timothy Continuously	3250	2485	2363	23.5	27.3	.94	.54
39	Corn, Oats, Wheat, Clover	3250	2573	1917	20.8	41.0	.83	.83
13	Corn, Oats, Wheat, Clover, Tim. 2 Yrs.	3250	2037	1943	37.3	40.2	1.49	0.82

*Unpublished data on Sanborn field—Missouri Experiment Station.
†Average Nitrogen content for beginning of experiment was determined from average nitrogen analyses of samples taken from adjacent virgin areas.

These data substantiate further the close relationship of crop yields to total nitrogen and organic matter content as explained in Table 1. For example, where corn was grown continuously on the same plot for 50 years, the total nitrogen content decreased 56.3 per cent,* and corn yields† declined from an average of 28.4 bushels per acre for the 10-year period 1889-1898 to 12.7 bushels per acre for the ten-year period 1928-1937, or a decrease of 55.2 per cent. The major part of this loss of organic matter and nitrogen occurred during the first 25 years. The continuous corn plot lost 51.5 per cent of its original nitrogen during the first 25 years of cropping. Average corn yields for the third 10-year period of the 50 years were 40 per cent below the average of the first 10 years.

*Unpublished data—Missouri College of Agriculture.
†Missouri Agricultural Experiment Station Bulletin #182.

Fig. 1.—Corn and other row crops deplete soil productivity most rapidly of all cultivated crops. (Courtesy, U. S. Department of Agriculture).

Fig. 2.—Small grains deplete soil productivity less rapidly than does corn and other row crops.

Plots in continuous timothy lost 23.8 per cent of their original nitrogen content during the first 25 years. In the third 10 year period of the 50 years, the average hay yields had declined 30 per cent. At the end of 50 years, this plot had declined 27.3 per cent in total nitrogen while the average hay yields remained about the same as they were in the third ten year period. The losses in the total nitrogen after 25 years and after 50 years of cropping on the continuous wheat plot were 37.1 and 46.1 per cent respectively. Wheat yields which were exceedingly low during the first 10 years of the period were maintained or slightly increased during the 50 year period. In this case, in all probability, improved varieties and better cultural practices more than offset the effects of declining fertility.

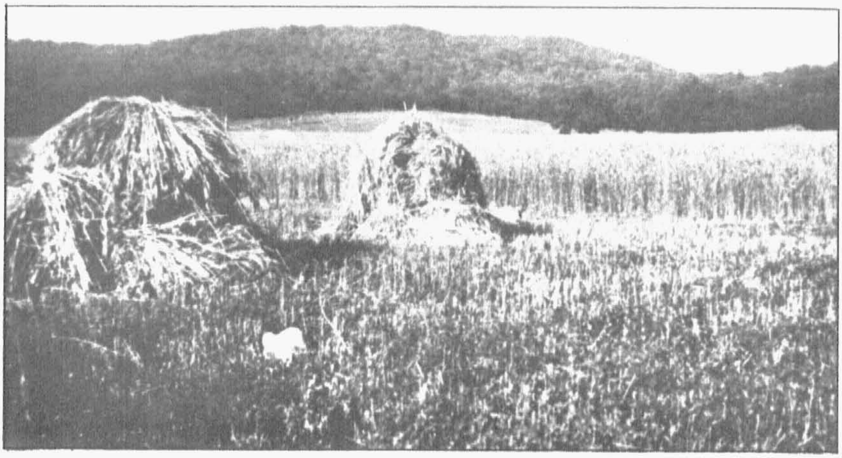

Fig. 3.—Clovers or lespedeza growing in the small grain will reduce erosion and help to maintain soil productivity.

A study of the untreated plots show that for the first 25 year period corn was also much more destructive of organic matter and nitrogen than were the small grains and timothy crops. The plot in continuous corn lost annually more than two per cent of its total organic matter or nitrogen. The plot in continuous wheat lost annually 1.4 per cent. The continuous timothy plot lost annually but .9 per cent of its original nitrogen content. During the second 25 year period, there was little difference between corn and wheat in their destruction of nitrogen. The annual decline in nitrogen for the continuous timothy plot over the 50 year period was slightly more than one-half of one per cent. In no case on the untreated plots, where all crops were removed, was the total nitrogen content maintained.

Effects of Frequency of Plowing on Productivity Changes

Rotations in which plowing was required once every three, four or six years were compared with the continuous timothy meadow which required plowing and reseeding only occasionally. The ni-

Fig. 4.—Controlled grazing of well established permanent pasture will about maintain productivity.

trogen losses in each case were more or less directly related to the frequency of plowing. Plowing and cultivation apparently hastened the destruction of organic matter and the decline in productivity.

Efficiency of Different Legumes in Restoring Nitrogen to the Soil

Another experiment conducted by the Department of Soils of the Missouri Experiment Station which continued for a 20-year period, provides additional information on the effects of different crops and cropping systems on the total nitrogen content of the soil. This experiment indicates that land kept in continuous bluegrass pasture or alfalfa, even when the alfalfa hay is removed, will, in the climate of central Missouri, gain slightly in total nitrogen and organic matter. Cowpeas grown in combination with rye and all crops returned to the land increased the total nitrogen content about one-half of one per cent annually, or to approximately the same extent as alfalfa where all alfalfa hay crops were removed. The rye-cowpea combination, however, had provided, according to analyses, an annual nitrogen turnover of about one per cent of the total nitrogen content of the soil where grown. Where rye was grown alone continuously and plowed under, there was a consistent loss of total nitrogen. In this experiment, sweet clover grown continuously and all crops returned to the soil increased the total nitrogen content approximately two per cent annually.

Fig. 5.—Soil productivity may be maintained with legume-grass mixtures when removed for hay, if 50 per cent or more of the mixture is legumes.

The increase in the nitrogen content of the sod and alfalfa plots, and the approximate maintenance of the nitrogen content of these plots in a rotation of corn, wheat, and clover was probably due to the greater amount of almost continuous vegetative cover provided by the closely growing crops. The vegetative cover allowed a minimum of leaching by its extensive annual growth and decay of roots, and other residues such as leaves and stubble.

It has been estimated that legume crops secure approximately one-third of the nitrogen in their roots and tops from the soil, and two-thirds from the air. These conditions naturally vary with conditions of growth. Soybeans, according to experiments at the Missouri Experiment Station when well inoculated, obtained only about one-half of their nitrogen from the air and one-half from the soil.

Further information on the ability of legumes in providing nitrogen turnover to the soil can be ascertained from a study of the yields and composition of legumes on the experiment fields of the Missouri College of Agriculture, and of other experiment stations.

Average yields of full second year crops of red clover grown on nine soil experiment station fields of the Missouri College of Agriculture show that if all growth had been returned to the land, they would have provided a nitrogen turnover of two to three per cent of the total nitrogen content of the land upon which these crops were grown. Full crops were obtained only on land well adapted to the clovers or made suitable by lime and phosphate treatments. First year or stubble growth crops were from one-fourth to one-half of the second year crops, and consequently, would have provided a corresponding additional amount of nitrogen.

Fig. 6.—Alfalfa, even when all crops are removed, is generally soil conserving.

Sweet clover makes more growth and has a higher concentration of nitrogen in both tops and roots than is the case for red clover. Consequently, it will provide a greater nitrogen turnover when plowed under than does red clover. It has been estimated that a full second year sweet clover crop, when plowed under in late April or May will provide a nitrogen gain, or turnover, equal to three per cent of the total nitrogen content of the soil upon which it is grown. A vigorous stubble growth of sweet clover will be around one-fourth to one-half as effective as the crop of the second year.

The average yields of soybeans obtained from untreated plots at the Missouri Experiment Station indicate that if all the crop had been returned to the soil, it would have provided a nitrogen gain or turnover of approximately one per cent of the total nitrogen content of the soil. Other annual legume crops, such as cowpeas, and crimson clover, which have a root and top growth similar to soybeans, would be expected to provide about the same nitrogen gain or turnover to the soil as soybeans.

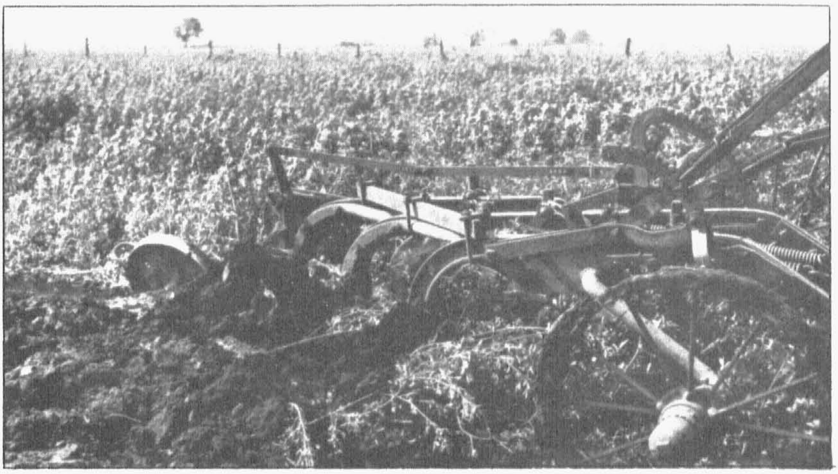

Fig. 7.—Sweet clover, when used as green manure, will return more nitrogen to the soil than is removed by a corn crop.

Observations indicate that well established Korean lespedeza on good land can be expected to yield only slightly less hay than good stands of red clover. Investigations at the Missouri Experiment Station indicate that the ratio of roots and stubble to tops of this crop is not far different from that of red clover. Consequently, as

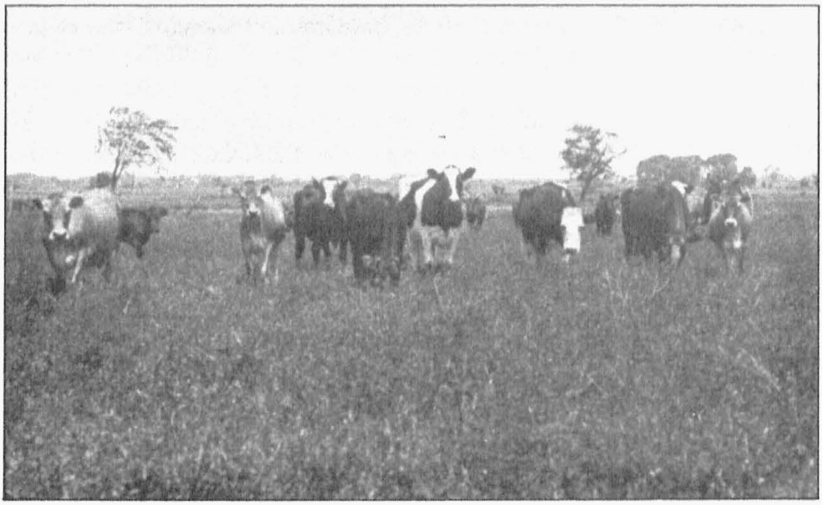

Fig. 8.—Sweet clover and other crops, when grazed with livestock, will return about three-fourths as much nitrogen as when plowed under as green manure.

a means of providing a turnover of nitrogen to the soil, Korean lespedeza ranks only slightly under red clover. On soils where red clover is not well adapted, it may be superior. Recorded yields of hay from established stands on various experiment fields when based on the average nitrogen content as determined by analyses, indicate that when all of the crop is returned to the land, it may be sufficient to increase the nitrogen content of the soil upon which it is grown in an amount equivalent to 1.5 to 2 per cent of the total.

Fig. 9.—Grazing lespedeza and other legumes with livestock increases the productivity of most soils.

Experiments indicate that when forages of any kind are utilized as pasture, or fed where the droppings will fall directly on arable land, it is possible to return about three-fourths of their total nitrogen content to the soil. This figure was used in calculating the annual gain or loss in nitrogen for legumes and grasses used for pasture.

These data show that where sufficient legumes are grown in the cropping system, soil exhaustion can be checked, and soil productivity may even be increased.

EFFECTS OF SOIL TREATMENTS ON THE TOTAL NITROGEN CONTENT OR PRODUCTIVITY OF THE SOIL.

On the Sanborn field plots at Columbia, heavy applications of manure have been applied annually for 50 years to duplicates of all plots receiving no treatments. The average, effects on the total nitrogen content by applications of manure on the plots cropped to corn continuously, timothy continuously, rotations of corn-wheat-clover, corn-oats-wheat-clover, and corn-oats-wheat-clover-timothy are shown in Table 6.

TABLE 6.—AVERAGE TOTAL NITROGEN CONTENT OF SIX MANURED AND SIX UNMANURED PLOTS AT END OF 50-YEAR PERIOD*

Manured Soil—6 tons annually for 50 years	2698 lbs. per acre
Unmanured Soil	1912 lbs. per acre
Increase in total nitrogen by use of manure	786 lbs. per acre
Increase in total nitrogen	41.1 per cent
Increase in nitrogen per ton of manure	0.137 " "

*Unpublished data covering 50 years results at Sanborn Field, Columbia.

Where manure was used over a 50-year period, the total nitrogen content of the soil was almost 0.14 per cent greater for each ton of manure applied than where no manure was used. This increase probably represents the nitrogen in the more slowly acting forms of the manure, and from the increased growth of roots and other vegetative materials accumulating in the soil as a result of the application. From these data together with the consideration of the average analyses of farm manure, the annual nitrogen turnover per ton of applied manure could be taken as .15 per cent of the total nitrogen content of the average Missouri soil.

Fig. 10.—The return of all manure and other crop residues to the land helps maintain soil productivity.

Fertilizers used in crop rotations at the Ohio Experiment Station* increased the total nitrogen content of the soil .15 per cent for each 36-40 units of plant food applied, or an increase equivalent to that from a ton of manure. An application of 200 pounds per acre of twenty per cent superphosphate would be expected to have the

*Ohio Agricultural Extension Service Bulletin #175.

Fig. 11.—On most Missouri soils, lime and phosphate fertilizers are essential to establish clovers or alfalfa.

Fig. 12.—Commercial fertilizers will increase vegetative growth, crop yields, and also reduce erosion on most Missouri soils.

same effect on the total nitrogen content as an application of one ton of manure. This effect is also probably due to the increased vegetative legume growth brought about by the use of the fertilizer.

At least three-fourths of the soils of Missouri are deficient in lime. Applications of limestone are essential in order to grow red clover, sweet clover, and alfalfa successfully on such soils. Limestone can be expected to improve the quality of forage. By making possible the growth of legumes in the rotation, it increases the yields of all crops in the cropping system either directly or indirectly.

SOIL PRODUCTIVITY INDEXES BY CROPS

The data from the Missouri and other Experiment Stations show that the effects of different crops on soil productivity vary with the kind of crop, with its position in the cropping system, and with the use made of it. For example, corn is twice as destructive as are small grains. Legumes restore soil productivity in proportion to their total top and root growth. The method of utilizing legumes as well as other crops will also determine to a large extent their effect upon the soil. Legumes like sweet clover, red clover, and alfalfa produce more root and top growth and restore more nitrogen to the soil than do annual legumes such as cowpeas and soybeans. Where any crop is pastured, it is less destructive to the soil than when harvested and removed from the land.

From these available data, productivity indexes have been calculated for the various crops and cropping systems. These indexes measure approximately the annual beneficial or destructive effects by crops or types of crops on the soil productivity. They may be either positive or negative depending on whether there is an annual gain or loss in nitrogen. They are expressed as the annual percentage gain or loss in the productive capacity of the soil resulting from the production of a given crop under definite conditions. They may also be used to measure the nitrogen turnover required for most satisfactory crop yields. The productivity indexes assigned to the more important crops grown in Missouri and to the various methods of handling or utilizing them are assembled in Table 7.

EFFECTS OF EROSION ON PRODUCTIVITY

Soil erosion is even more devastating of productivity in Missouri than is cropping. In the removal of soil by sheet erosion, organic matter, nitrogen and other plant nutrients are removed in large quantities. In the erosion experiments* conducted by the Department of Soils of the Missouri Experiment Station, where corn was grown continuously, 19.7 tons of soil per acre containing 66 pounds of nitrogen were removed annually by erosion. Where

*Missouri Agricultural Experiment Station Research Bul. # 177.

wheat was grown continuously, 10 tons of soil per acre containing 33 pounds of nitrogen were lost annually. Similar plots in good bluegrass sod lost but .3 ton of soil containing less than a pound of nitrogen per acre.

The loss of organic matter and nitrogen through erosion causes large declines in crop yields. An experiment conducted by the Missouri Experiment Station comparing the normal surface soil, and the desurfaced or subsoil plots, show significant results. The exposed subsoil produced an average of 12.9 bushels of wheat per acre while the normal surface soil produced 30.6 bushels of wheat per acre. In a similar experiment at Bethany, Missouri, the normal soil produced 23.2 bushels of oats per acre while the subsoil produced but 5.9 bushels per acre without treatment. In this case the cultivated subsoil produced but slightly more than half as much hay as did the surface soil. At the same location oats which received fertilizer and lime yielded 40.2 bushels on surface soil and 22.8 bushels on subsoil.

TABLE 7.—PER CENT OF TOTAL NITROGEN GAINED OR LOST ANNUALLY FOR THE VARIOUS CROPS AND METHODS OF UTILIZING THEM

Crops: Productivity Indexes Given are for Full Stand and Normal Growth. One-half Full Crop Means One-half the Index Listed, etc.	All Turned Under or Left on Land	Grazed off or the Grain or Seed Only Removed	Whole Crop Removed or Burned
1. Grasses			
Permanent Pastures	0.00	0.00	—0.50
Perennial Grasses	0.00	0.00	—0.50
Perennial Grasses + 50% Legumes	+0.50	+0.35	0.00
Sudan Grass	0.00	—0.50	—2.00
2. Intertilled Crops			
*Corn, Tobacco, Sorghums, etc.	0.00	—1.35	—2.00
Cotton	0.00	Lint & Seed—1.35	—2.00
3. Legumes—When Well Inoculated			
Alfalfa—Over 1 year old	+3.00	+2.25	+0.50
Alfalfa—Under 1 year old	+1.00	+0.75	0.00
Clover, Alsike—1st year	+0.75	+0.50	0.00
Clover, Alsike—2nd year	+1.75	+1.30	0.00
Clover, Crimson—Spring after seeding	+1.50	+1.00	0.00
Clover, Red—1st year	+1.00	+0.75	0.00
Clover, Red—2nd year—1st crop	+2.00	+1.50	+0.25
Clover, Red—2nd year—2nd crop	+0.50	+0.35	0.00
Clover, Sweet—1st year	+1.00	+0.75	0.00
Clover, Sweet—2nd year	+3.00	+2.25	+0.50
Clover, White or Hop	+1.00	+0.75	0.00
Crotalaria	+2.50	+1.85	0.00
Lespedeza—Crop growth to Aug. 1	+1.00	+0.75	0.00
Lespedeza—Crop growth after Aug. 1	+0.75	+0.50	0.00
Lespedeza—Total season crop	+1.75	+1.30	0.00
Soybeans, Cowpeas, etc.	+1.00	+0.75	—0.50
Vetch, Winter	+1.50	+1.00	—0.50
4. Small Grains			
Wheat, Oats, Rye, Barley, Flax, Etc.	0.00	Combined—.65 Grazed—0.25	—1.00
5. Soil Treatments			
Barnyard or straw manure per ton applied			+0.15
Commercial Fertilizer—For each 40 lbs. available Plant food applied			+0.15

All Crops turned under, grazed or removed from the land during the season should receive consideration.

Heavy applications of straw or other organic matter low in protein without the growth of legumes on the land or the use of chemical treatments, may cause a temporary reduction in available nitrogen.

6. Each ton of feed hauled to the farm and fed in the fields and not otherwise given credit as manure should be given positive credits as follows:

Small grain straw or silage, .075. Timothy, orchard grass, red top, sorghums, corn fodder, etc. (air dry), .225. Legumes, grains, grain mixtures and supplementary feeds, .45.

*Corn all hogged down should be given a factor of —.50.

Total and Annual Erosion Losses on Missouri Farms

An estimate of the amount of erosion which has occurred on Missouri farms was made by the Missouri College of Agriculture and the Soil Conservation Service in 1934. This survey shows that one-half and more of the top soil on fully half of the land area of the State has eroded away, while one-fourth of the top soil has been lost on another quarter of the area. On the gentle slopes of one to four per cent, about two-fifths of the top seven inches have eroded away, while on slopes of over 5 per cent, slightly over half of the surface soil has been lost by erosion. During 70 years of cropping, the more gentle slopes of one to four per cent have lost annually about one-half of one per cent of their surface seven inches of soil; the steeper slopes of 5 per cent or more have lost annually approximately three-fourths of one per cent or more of their surface seven inches of soil.

THE EFFECTS OF SLOPE, CROPS, AND CROPPING SYSTEMS ON EROSION

The annual effects of erosion are shown in the erosion experiments conducted by the Missouri Experiment Station at Columbia over a 10 to 15 year period. The percentages of the surface seven inches of soil lost annually under individual crops and different cropping systems on increasing degrees of slope are given in Table 8.

TABLE 8.—PERCENTAGES OF SURFACE SEVEN INCHES OF SOIL LOST ANNUALLY FOR DIFFERENT CROPS AND CROPPING SYSTEMS FOR SLOPES 90 FT. LONG
Columbia, Missouri

	Degree of Slope in Per Cent		
	3.68%	6%	8%
Crop	Per Cent of Surface Seven Inches Removed Annually	Per Cent of Surface Seven Inches Removed Annually	Per Cent of Surface Seven Inches Removed Annually
Corn Continuous	1.97	5.10	9.40
Wheat Continuous	1.00	...	...
Corn After Clover in Rotation of Corn-Wheat-Clover	.46	1.80	3.70
Wheat After Corn in Rotation of Corn-Wheat-Clover	.38	1.00	3.40
Clover in Rotation of Corn-Wheat-Clover	.17	0.22	...
Meadow Grasses Well Established	.03	...	.04

According to these results, the corn crop, which requires the most cultivation of all crops on the list, and which provides little or no vegetative cover on the land during the months of heaviest rainfall, permits the most erosion. Other intertilled crops which occupy the land at the same season of the year would be expected to permit about the same amount of erosion. Small grains which require less cultivation than corn and which in turn furnish more vegetative cover on the land during the months of heaviest rainfall permit much less erosion than the intertilled crops. Grasses and legumes permit the least erosion. They provide efficient vegetative cover and root development which helps to anchor the soil in place. In general the legumes are less effective in checking erosion than is grass sod.

The erosion losses from corn grown in a rotation of corn, wheat, clover on the 3.68% slope were but slightly more than one-fifth as much as when corn was grown continuously on this same slope. On the six and eight per cent slopes the erosion losses from corn in a rotation were but slightly more than one-third of what they were when corn was grown continuously.

Erosion losses increase with the increase in degree of slope. On land in continuous corn on a slope of 3.68 per cent, the loss per acre was 1.97 per cent of the surface seven inches annually. On 6 per cent slope in the same crop, the loss per acre was 5.1 per cent of the surface 7 inches annually, while on an 8 per cent slope the loss was 9.4 per cent or nearly 5 times the loss of the 3.68 per cent slope.

Where there is a good grass sod, such as bluegrass or timothy, little or no erosion occurs. Where pasture land is closely grazed and the land is left nearly bare, it will erode to some extent. The erosion, however, will be chiefly gullying. The amount of sheet erosion that may occur is indicated by some work by Weaver of the University of Nebraska. He reports that an over-grazed mixed bluestem and bluegrass pasture on a 10 per cent slope almost bare of grass lost 5.08 tons of soil per acre in a period of 15 months.

Contour Farming Checks Erosion

Results of investigations* conducted by the Soil Conservation Service research units and state agricultural experiment stations to determine the effectiveness of contouring in checking soil losses varied as follows: On the open, porous Marshall silt loam at Clarinda, Iowa, contour listing of corn on short slopes was 80 per cent effective in reducing erosion from corn on a 9.0 per cent slope. At Bethany, Missouri, on Shelby loam, contouring with contour ridges between draws and depressions that were well sodded reduced erosion 89 per

*Missouri Experiment Station Bulletin #400, p. 7.

cent under that where no mechanical control measures were used. On plots 270 feet long without sodded waterways the reduction was 52 per cent.

On a very fine sandy loam on a 6.9 per cent slope at Guthrie, Oklahoma, contouring reduced the soil losses from cotton rows about 63 per cent under that from cotton rows running up and down the slope. At LaCrosse, Wisconsin, on a 16 per cent slope of river hill soil, contouring reduced soil loss 20 per cent. At Urbana, Illinois, on a 2 per cent Carrington silt loam slope, contouring reduced soil loss 40 per cent. At Temple, Texas*, on a black Houston clay with a 3½ per cent slope, the annual loss of soil from cotton rows across the slope was only 56 per cent as much as from rows planted up and down the slope.

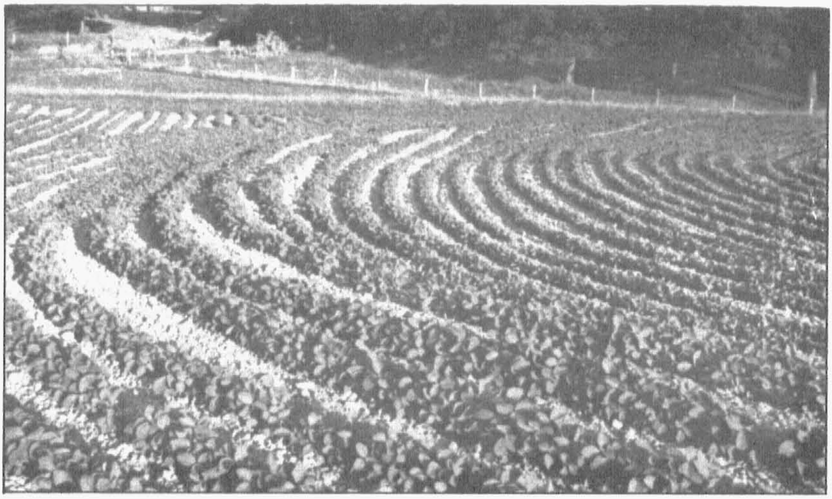

Fig. 13.—Contour farming, where draws and depressions are well sodded, should reduce erosion around 50 per cent. (Photo by courtesy of the Soil Conservation Service).

While the above data have, in the main, dealt with intertilled crops, field studies conducted by Dodge† in Iowa show that wheat planted across the slope was about twice as effective in holding soil and one-fourth more effective in holding water than wheat planted up and down the slope.

The experimental evidence, therefore, indicates that contour farming with well sodded waterways used in combination with

*Soils and Men—U. S. Year Book of Agriculture—1938—p. 638.
†Ayres Quincey Claude—Soil Erosion and Its Control—pp. 49-51.

recommended soil treatments and crop rotations, will reduce erosion from 20 to 90 per cent. In computing the erosion factors listed in Table 9, it was estimated that this combination of practices would reduce erosion from the field at least 40 per cent.

Terraces Reduce Soil Losses

On Shelby loam at the Soil Conservation Experiment Station* at Bethany, the annual losses from terraced areas in a rotation of corn, oats, wheat and clover were but 2.2 per cent of those from unterraced areas. These results are similar to those from experiments conducted at five other Soil Conservation Experiment Stations† where soil losses from terraced and unterraced areas with similar cropping systems were compared.

Fig. 14.—Contouring and terracing with protected waterways, in rotations including legumes and grasses should reduce erosion at least 80 per cent.

The Erosion Factors

From the data presented and the unpublished data regarding length of slope collected by the Department of Soils of the Missouri College of Agriculture‡ together with interpolation and calculations, erosion factors for different types of crops, crop sequences and different methods of crop utilization on the various degrees and lengths of slope were computed. These erosion factors are given in Table 9 and are based upon average annual rainfall.

*Missouri Experiment Station Bulletin #400, p. 7.
†U. S. D. A. Farmers Bulletin #1789, p. 10.
‡Data collected by H. H. Krusekopf, Professor of Soils, Missouri College of Agriculture.

TABLE 9.--EROSION FACTORS OR PER CENT OF SURFACE 7 INCHES OF SOIL LOST ANNUALLY FROM WATER EROSION FOR DIFFERENT CROPS OR CROPPING SYSTEMS ON DIFFERENT DEGREES AND LENGTHS OF SLOPE

Crop and Sequence	Slope length Feet	Crop or rotation without control measures						Crop or rotation plus contouring						Crop or rotation plus terraces and contouring					
		Per Cent Slope																	
		2	4	6	8	10	12	2	4	6	8	10	12	2	4	6	8	10	12
Intertilled crop; after intertilled crops for 3 or more years.	200	1.8	3.6	6.0	8.9	11.8	15.0	1.1	1.8	3.1	4.7	6.7	9.4	.8	1.5	2.6	4.0	5.7	7.8
	400	2.7	5.4	9.0	13.3	17.6	22.5	1.6	2.7	4.6	7.1	10.0	14.1	.8	1.5	2.6	4.0	5.7	7.8
	600	3.4	6.9	11.3	16.9	22.4	28.5	2.1	3.4	5.8	8.9	12.7	17.9	.8	1.5	2.6	4.0	5.7	7.8
	800	4.2	8.3	13.7	20.4	27.1	34.5	2.5	4.2	7.1	10.8	15.4	21.6	.8	1.5	2.6	4.0	5.7	7.8
	1000	4.7	9.4	15.5	23.0	30.6	39.1	2.8	4.7	8.0	12.2	17.4	24.5	.8	1.5	2.6	4.0	5.7	7.8
Intertilled crop; after small grain or lespedeza hay; or 1 year of intertilled following grass or legume crops.	200	0.9	1.7	2.9	4.3	5.7	7.2	0.5	0.9	1.5	2.3	3.2	4.5	.2	.6	1.1	1.8	2.6	3.6
	400	1.3	2.6	4.3	6.4	8.5	10.8	.8	1.3	2.2	3.4	4.8	6.8	.2	.6	1.1	1.8	2.6	3.6
	600	1.7	3.3	5.5	8.1	10.7	13.7	1.0	1.7	2.8	4.3	6.1	8.6	.2	.6	1.1	1.8	2.6	3.6
	800	2.0	4.0	6.6	9.8	13.0	16.6	1.2	2.0	3.4	5.2	7.4	14.4	.2	.6	1.1	1.8	2.6	3.6
	1000	2.3	4.5	7.5	11.1	14.7	18.8	1.4	2.3	3.9	5.9	8.4	11.8	.2	.6	1.1	1.8	2.6	3.6
Intertilled crop; after clover, green manure, or full growth lespedeza turned under or worked in soil.	200	.4	.9	1.5	2.2	2.9	3.7	.3	.4	.7	1.1	1.6	2.3	0	.1	.4	.8	1.2	1.7
	400	.7	1.3	2.2	3.2	4.3	5.5	.4	.7	1.1	1.7	2.4	3.4	0	.1	.4	.8	1.2	1.7
	600	.8	1.7	2.8	4.1	5.5	6.9	.5	.8	1.4	2.2	3.1	4.3	0	.1	.4	.8	1.2	1.7
	800	1.0	2.0	3.3	5.0	6.6	8.4	.6	1.0	1.7	2.6	3.8	5.3	0	.1	.4	.8	1.2	1.7
	1000	1.1	2.3	3.8	5.6	7.4	9.5	.7	1.1	2.0	3.0	4.2	6.0	0	.1	.4	.8	1.2	1.7
Intertilled crop; after meadow or pasture in which grass predominates.	200	.3	.6	.9	1.4	1.8	2.3	.2	.3	.5	.7	1.0	1.5	0	0	.1	.4	.6	1.0
	400	.4	.8	1.4	2.1	2.7	3.5	.3	.4	.7	1.1	1.6	2.2	0	0	.1	.4	.6	1.0
	600	.5	1.1	1.8	2.6	3.5	4.4	.3	.5	.9	1.4	2.0	2.8	0	0	.1	.4	.6	1.0
	800	.6	1.3	2.1	3.2	4.2	5.3	.4	.6	1.1	1.7	2.4	3.4	0	0	.1	.4	.6	1.0
	1000	.7	1.5	2.4	3.6	4.7	6.0	.4	.7	1.3	1.9	2.7	3.8	0	0	.1	.4	.6	1.0
Spring grain, without meadow seeding; after intertilled, small grain, or other annual drilled crop.	200	.6	1.2	1.9	2.9	3.8	4.9	.4	.6	1.0	1.5	2.2	3.1	.1	.4	.6	1.1	1.6	2.4
	400	.9	1.8	2.9	4.3	5.8	7.3	.5	.9	1.5	2.3	3.3	4.6	.1	.4	.6	1.1	1.6	2.4
	600	1.1	2.2	3.7	5.5	7.3	9.3	.7	1.1	1.9	2.9	4.1	5.8	.1	.4	.6	1.1	1.6	2.4
	800	1.4	2.7	4.5	6.6	8.8	11.3	.8	1.4	2.3	3.5	5.0	7.1	.1	.4	.6	1.1	1.6	2.4
	1000	1.5	3.1	5.1	7.5	10.0	12.7	.9	1.5	2.6	4.0	5.7	8.0	.1	.4	.6	1.1	1.6	2.4
Fall grain, without meadow seeding; after intertilled, small grain, or other annual drilled crop. Spring grain with meadow seeding; after small grain or other annual drilled crop.	200	.4	.8	1.4	2.1	2.7	3.5	.3	.4	.7	1.1	1.6	2.2	0	.1	.4	.7	1.1	1.6
	400	.6	1.3	2.1	3.1	4.1	5.2	.4	.6	1.1	1.6	2.3	3.3	0	.1	.4	.7	1.1	1.6
	600	.8	1.6	2.6	3.9	5.2	6.6	.5	.8	1.4	2.1	3.0	4.1	0	.1	.4	.7	1.1	1.6
	800	1.0	1.9	3.2	4.7	6.3	8.0	.6	1.0	1.6	2.5	3.6	5.0	0	.1	.4	.7	1.1	1.6
	1000	1.1	2.2	3.6	5.4	7.1	9.1	.7	1.1	1.9	2.8	4.0	5.7	0	.1	.4	.7	1.1	1.6

Crop and Sequence	Slope length Feet	Crop or rotation without control measures						Crop or rotation plus contouring						Crop or rotation plus terraces and contouring					
		Per Cent Slope																	
		2	4	6	8	10	12	2	4	6	8	10	12	2	4	6	8	10	12
Spring grain with meadow seeding; after intertilled crops. Fall grain with meadow seeding; after small grain or other annual drilled crop.	200	.3	.6	1.0	1.5	2.0	2.6	.2	.3	.5	.8	1.1	1.6	0	0	.2	.4	.7	1.1
	400	.5	.9	1.4	2.3	3.0	3.9	.3	.5	.8	1.2	1.7	2.4	0	0	.2	.4	.7	1.1
	600	.6	1.2	1.8	2.9	3.8	4.9	.4	.6	1.0	1.5	2.2	3.1	0	0	.2	.4	.7	1.1
	800	.7	1.4	2.2	3.5	4.6	5.9	.4	.7	1.2	1.9	2.6	3.7	0	0	.2	.4	.7	1.1
	1000	.8	1.6	2.5	4.0	5.2	6.7	.5	.8	1.4	2.1	3.0	4.2	0	0	.2	.4	.7	1.1
Fall grain with meadow seeding; after intertilled crops. Small grain and Korean lespedeza, one-year rotations.	200	.2	.5	.8	1.2	1.6	2.1	.2	.2	.4	.7	.9	1.3	0	0	.1	.3	.5	.8
	400	.4	.8	1.2	1.8	2.4	3.1	.2	.4	.6	1.0	1.4	2.0	0	0	.1	.3	.5	.8
	600	.5	1.0	1.6	2.3	3.1	3.9	.3	.5	.8	1.2	1.8	2.5	0	0	.1	.3	.5	.8
	800	.6	1.2	1.9	2.8	3.7	4.8	.3	.6	1.0	1.5	2.1	3.0	0	0	.1	.3	.5	.8
	1000	.7	1.3	2.2	3.2	4.2	5.4	.4	.7	1.1	1.7	2.4	3.4	0	0	.1	.3	.5	.8
Small grain with meadow seeding; after sod crops.	200	.2	.3	.6	.8	1.1	1.4	.1	.2	.3	.4	.6	.9	0	0	0	.1	.3	.5
	400	.3	.5	.8	1.2	1.7	2.1	.2	.3	.4	.7	.9	1.3	0	0	0	.1	.3	.5
	600	.3	.6	1.1	1.6	2.1	2.7	.2	.3	.5	.8	1.2	1.7	0	0	0	.1	.3	.5
	800	.4	.8	1.3	1.9	2.5	3.3	.2	.4	.7	1.0	1.5	2.0	0	0	0	.1	.3	.5
	1000	.4	.9	1.5	2.2	2.9	3.7	.3	.4	.8	1.2	1.6	2.3	0	0	0	.1	.3	.5
Grass and legume meadows and pastures.	200	0	.1	.2	.2	.3	.4	0	0	.1	.2	.2	.2	0	0	0	0	0	0
	400	.1	.1	.2	.4	.5	.6	0	.1	.1	.2	.3	.4	0	0	0	0	0	0
	600	.1	.2	.3	.4	.6	.8	.1	.1	.2	.2	.3	.5	0	0	0	0	0	0
	800	.1	.2	.4	.5	.7	.9	.1	.1	.2	.3	.4	.6	0	0	0	0	0	0
	1000	.1	.2	.4	.6	.8	1.0	.1	.1	.2	.3	.5	.7	0	0	0	0	0	0
Well-sodded, but overgrazed pastures and meadows.	Entire Slope	.1	.2	.3	.4	.6	.7	0	0	0	0	0	0	0	0	0	0	0	0

1. Bare or fallow land free of vegetation will have erosion factors about double those given for intertilled crops. Idle land covered with weeds, erodes about one-fourth to one-half as much as continuous intertilled crops.
2. The erosion factors in Table 9 for terraced land, are based on experimental evidence which shows that properly constructed terraces with stable outlets can be expected to reduce erosion an average of about 80 per cent. On short gentle slopes, terraces will not reach this degree of effectiveness, while on longer slopes their effectiveness will approach 100 per cent. With upslope plowing the effectiveness of terracing is near 100% for most rotations.
3. The erosion factors for contouring are also based on experimental evidence which shows that this practice when considered for the entire year (on the average Missouri soil) can be expected to reduce erosion at least 40 per cent under that of the crop rotation alone.
4. Where slopes are over 12 per cent or longer than 1000 feet, the factors should be increased in the same ratio as those listed for the more moderate or shorter slopes.

Grateful acknowledgement of help in computing the erosion factors in above table is given to Marion B. Clark, extension professor of agricultural engineering, Dwight D. Smith and Darrell M. Whitt, research associates in soils and crops respectively.

THE USE OF THE PRODUCTIVITY INDEXES AND EROSION FACTORS

Through the use of these tabulated productivity indexes in Table 7 and the erosion factors in Table 9, it is possible to determine the approximate annual gain or loss in productivity for field, farm, township, county or state. Before these factors can be used and the annual gain or loss in productivity determined, the following factors must be considered: The average length and degree of slope, acreage, mechanical control measures used, the influence of the present crop as well as that of the crop preceding, the use made of the present crop for each field and the soil treatments applied.

The determination of the degree of slope can be made most accurately with a farm level. Individuals, however, who have had considerable experience may estimate it accurately enough for this purpose. Length of slope may be determined by pacing or measuring the distance. After an individual has had some practice, estimates may be made quite accurately.

In a given field, the length of slope should be considered as the distance in the general direction which run-off water will follow from the top of the slope to a well-defined natural drain which has a grade appreciably less than that of the adjacent slope. This is usually a waterway or perhaps a small draw which leads to a larger waterway or gully where the water changes its general direction of flow at approximately right angles to the adjoining slopes. In those cases where row crops are planted up and down the slopes so that each row carries its own water, the length of slope may be the full length of the rows. If only the upper part of a slope is in cultivation and runoff spreads from this area to a lower sodded slope, only the part of the slope of the cultivated area exposed to active erosion should be considered. If the lower part of a long slope is in cultivation and water from the upper slope does not become well confined into main draws before it passes on to the lower part of the field, the total average length of the whole slope, including the upper part, should be used in determining the erosion factor.

It will be noted that where contour farming is practiced with rotations, the erosion factors are given as one-half to two-thirds of those without contouring. Similarly where contouring is combined with terracing the erosion factors are reduced to about one-fifth of those where neither contouring nor terracing is used. Where contouring alone is practiced, it is assumed that draws and depressions are seeded to sod or close growing crops, and where terracing is practiced it is assumed that stable outlets are provided.

The productivity value for each field is calculated for the crop on the land by multiplying the acreage in the field by both the productivity index and erosion factor as given in Tables 7 and 9 respectively. In some instances the crop which was grown on the field the previous year will materially influence the erosion factor. For instance, this factor will be much greater where corn follows corn than where the corn follows a legume or grass sod.

AN ILLUSTRATION OF HOW THE PRODUCTIVITY BALANCE MAY BE CALCULATED FOR A GIVEN FARM

An example of how the productivity indexes and erosion factors given in Tables 7 and 9 respectively, can be used in calculating the productivity balance for a 160-acre farm is shown in Table 10. The methods of computation for each field are given below.

Field A consists of 35 acres of well-sodded permanent pasture. Its slopes average 8 per cent with an average length of 400 feet. During the year, 40 tons of manure were spread on this pasture. Table 7 shows that the productivity index for well-sodded pasture is zero, while Table 9 shows the erosion factor is 0.4 per cent. The productivity value for this well-sodded permanent pasture would, therefore, be 35 x 0 or zero. The total erosion would be 35 x 0.4 or 14, which is recorded in the negative column 12B.

According to Table 7, manure has a positive productivity value of 0.15 per cent per ton. The total positive value for the manure applied to the pasture would, therefore, be 40 x .15 or 6 which is recorded in the positive column 12A of Table 10.

The terraced field B, consists of 20 acres, has an average slope of 4 per cent with an average length of 700 feet. It was in wheat last year with first year sweet clover growing in it. This year the sweet clover was plowed under and the field was planted on the contour to corn. Both the fodder and grain will be removed. Table 7 shows that sweet clover as green manure has a positive productivity index of 3. The total positive productivity value for sweet clover for this field would then be 20 x 3 or 60. This is recorded in positive column 12A of Table 10.

Table 7 shows that a corn crop, when both grain and fodder are removed, has a negative productivity index of 2. The total negative productivity value for the crop itself would then be 20 x 2 or 40, which is recorded in negative column 12B of Table 10. Table 9 shows that corn planted on clover sod on the contour with terraces with the degree and length of slope of field B has an erosion factor of only 0.1. The total negative productivity value for this field,

TABLE 10.--SHOWING THE USE OF THE PRODUCTIVITY INDEXES AND EROSION FACTORS ON 160A FARM

1	2	3	4	5	6	7	8	9		10	11	12	
								Soil Treatments		Productivity Index		Productivity Values	
Field No. or Letter	Acres in Field	Av. Slope %	Av. Length of Slope in Feet	Mechanical Erosion Control Measures	Crops Last Year	Crops This Year	This Year's Crop Use	Kind	Total Used on[1] Field	for Crops or Soil Treatments	Erosion Factors	(A) Positive	(B) Negative
A	35	8	400	None	Permanent	Permanent	Grazed			0.00	0.40		14.00
					Pasture	Pasture		Manure	40 tons	+ 0.15		6.00	
B	20	4	700	Terraced	Wheat & 1st	2nd Yr. Sw.	Green Manure	None		+ 3.00		60.00	
				& Contoured	Yr. Sw. Clover	Clover, Corn	All Removed			- 2.00			40.00
											0.10		2.00
C	20	6	500	Contoured	Wheat &	Oats &	All Removed	None		- 1.00			20.00
					Lespedeza	Lespedeza	Hay			0.00	0.70		14.00
D	20	4	800	None	Oats &	Wheat &	Combined			- 0.65			13.00
					Lespedeza	Lespedeza	Grazed			+ 1.30	1.20	26.00	24.00
								4-16-4	4000 lbs.			3.60	
E	20	6	600	None	Wheat & 1st	2nd Yr. Tim-	Hay			0.00	0.30		6.00
					Yr. Timothy &	othy & 50%		Manure	50 tons	+ 0.15		7.50	
					Red Clover	Red Clover							
F	10	6	500	None	Alfalfa	Alfalfa	Hay			+ 0.50	0.25	5.00	2.50
								0-20-0	2000 lbs.			1.50	
G	10	6	800	Terraced	Barley & 1st	2nd Yr. Sweet	Grazed	None		+ 2.25	0.00	22.50	
					Yr. Sw. Clover	Clover							
H	20	4	400	Contoured	Corn after	Wheat	Combined			- 0.65			13.00
					Sw. Clover	1st Yr. Sw.							8.00
						Clover	Left on Land			+ 1.00	0.40	20.00	
								0-20-0	4000 lbs.			3.00	
								Manure	40 tons	+ 0.15	0.40	6.00	
I	5	4	300	None	Garden, Lots	Garden, Lots	Garden, Lots	None		0.00	0.00	0.00	0.00
					& Buildings	& Buildings	& Buildings						
Total	160	X	XX	XX	XX	XX	XX	XX	XX	XX	XX	161.10	156.50

Productivity and erosion balance equals total positive of 161.1 and total negative of 156.5 or a positive of 4.6 for the whole 160 acres. Per cent gain or loss in productivity equals $\frac{\text{total positive or negative}}{\text{Total acres}}$ for this farm for the year $\frac{4.6}{160}$ or 0.03 per cent positive.

[1]Each ton of manure is credited with a positive productivity factor of 0.15. Each 40 pounds of available plant food is credited with a positive productivity factor of 0.15.

due to erosion, would therefore be 20 x 0.1 or 2, which is also recorded in the negative column 12B of Table 10.

Field C consists of 20 acres and has an average degree and length of slope of 6 per cent and 500 feet respectively. Last year this field was in wheat and Korean lespedeza; this year it is in a 1-year rotation of oats drilled on the contour with volunteer Korean lespedeza following. Both the grain and straw from the oats will be removed, and the Korean lespedeza removed for hay. According to Table 7 the productivity index for oats, where both the straw and grain are removed, is negative 1.00. The total negative productivity value for the oats crop would, therefore, be 20 x 1 or 20 and recorded in negative column 12B of Table 10. The erosion factor for small grain contoured after lespedeza is not given in Table 9 for a field of this length and degree of slope, but this can easily be ascertained by interpolation. Thus, the erosion factor for small grain drilled on contour after lespedeza on a 6 per cent slope 400 feet long is 0.6. It is 0.8 for the same degree of slope 600 feet long. Thus the erosion factor for a slope 500 feet long would be midway between that of a 400 foot and a 600 foot slope or one-half the sum of these two factors $\left(\frac{0.6+0.8}{2}\right)$, which is 0.7 as recorded in column 11 of Table 10.

Erosion will cause a total decline in the productivity value for field C of 20 x 0.7 or 14, which is recorded in column 12B. A full stand of Korean lespedeza when removed for hay has a productivity index of zero. Therefore, there will be no positive values credited to field C.

Field D, which consists of 20 acres, has an average slope of 4 per cent and an average length of slope of 800 feet. This field was in oats and lespedeza last year, and is in wheat and lespedeza this year. The wheat will be harvested with a combine and the straw left on the ground. The lespedeza will be grazed. An application of 200 pounds per acre or a total of 4000 pounds of a 4-16-4 fertilizer was applied to this field with wheat. Table 7 shows that combined small grain has a negative productivity index of 0.65. The total negative productivity value due to the wheat crop for this field would be 20 x 0.65 or 13, which is recorded in negative column 12B of Table 10. The erosion factor as given in Table 9 for one-year rotations of small grain and lespedeza on the degree of slope recorded for this field, without the aid of mechanical control measures, is 1.2. Therefore, the negative productivity value for the field due to erosion would be 20 x 1.2 or 24, which is shown in column 12B of Table 10. Table 7 credits each 40 pounds of plant food used as commercial fertilizer with a positive productivity of .15 per cent. The positive value for the use of fertilizer for this field would, therefore, be

$\frac{40 \times 24 \times .15}{40}$ which is recorded in positive column 12A of Table 10.

According to Table 7, the lespedeza crop, when grazed, has a positive productivity index of 1.3. Therefore, the total productivity for the Korean lespedeza on this field would be 20 x 1.3 or 26, which is recorded in the positive column 12A of Table 10.

In the illustration in Table 10, the productivity and erosion values for all the remaining fields of the farm have been calculated in the same manner as above indicated.

Field E is an illustration of how the calculations are made for a timothy-red clover meadow which received an application of manure. Field F shows how calculations are made for an alfalfa field on a 6 per cent slope 500 feet long where all crops are removed for hay. Field G furnishes an illustration of what occurs when a terraced second-year sweet clover field on a 6 per cent slope 800 feet in length is used for pasture. Field H shows the effect of contouring a field seeded to wheat and first year sweet clover which received an application of manure. No loss of productivity was assumed from crops or erosion on the garden, lots, building spots, etc. as represented by I in Table 10.

The total positive and negative values are added for all the fields on the farm. The smaller of these two total values is subtracted from the larger, and is expressed accordingly as a positive or negative value. This net positive or negative figure divided by the acres in the farm will give the annual per cent gain or loss per acre in productivity for the farm.

According to the method here illustrated, this 160-acre farm has a total positive value of 161.1 and a total negative value of 156.5, leaving a total net productivity value of 161.1 — 156.5 or 4.6 positive. The annual per cent gain or loss in productivity for the farm is obtained by dividing 4.6 by the 160 acres of the farm, which gives an annual gain in productivity of about 0.03 per cent. In this illustration, it is thus seen that the cropping system and the mechanical conservation measures used, along with the soil treatments applied, made it possible to slightly more than maintain the soil productivity.

SUMMARY AND CONCLUSIONS

1. The total organic matter and nitrogen content of a silt loam soil were taken as a guide to soil productivity and crop yields. Accordingly, a yield of about 10 bushels of corn per acre can be expected for each 1000 pounds of total nitrogen in the surface 7 inches of an acre.

2. Analyses of soil from virgin and cultivated areas where no erosion has occurred show that cropping alone has been responsible for a decline of about 35 per cent of the organic matter and nitrogen.

3. United States Census Bureau records for Missouri for six 10-year periods show that there has been a slight decline in yields of corn, oats and hay, while wheat yields have remained about the same over the entire period.

4. Experiments of the Department of Field Crops show that improved crop practices such as improved varieties, use of commercial fertilizers, bringing in of new land and better cultural methods, had soil fertility been maintained, should have increased crop yields 20 to 30 per cent. These practices, therefore, have been compensating for the declining soil productivity.

5. From the yields of the principal crops on the outlying experiment fields where the total nitrogen content of the soil has been ascertained, the annual withdrawal of nitrogen supply of the soil was estimated for the different crops. From the yields of legumes on the outlying experimental fields the nitrogen turnover provided by them on the soil they were grown was estimated.

6. The per cent gain or loss of the total nitrogen supply of the surface 7 inches of the soil from different crops, cropping systems and soil treatments was considered as the productivity index. The per cent of the total nitrogen and organic matter lost by sheet erosion when in different crops and cropping systems was taken as the erosion factor.

7. Through the combined use of the productivity and erosion factors it is possible to determine approximately the annual gain or loss in productivity for a field, farm or county.

8. These productivity indexes and erosion factors provide an approximate measurement of the annual gain or loss in the pro-

ductivity of the soil under the land use or soil farm management program of the farm. They may be used specifically to:

a. Estimate the effectiveness of individual soil improvement or conservation practices;

b. Measure the progress on individual farms towards a balanced productivity program;

c. Ascertain the need for additional conservation measures;

d. Make farm inventories of productivity changes brought about by individual farm operators; and

e. Formulate a farm and soil management program which will maintain productivity for the individual fields or the farm as a whole.