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Soil Fertility Losses Under Missouri Conditions

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Soil Conservation and Soil Exhaustion

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SUMMARY

The data accumulated in this investigation indicate the following:

1. On non-erosive land which had been in cultivation for sixty years soil fertility decreased one-third.
2. The soil fertility losses as measured by soil nitrogen are shown to be accompanied by corresponding declines in corn production and land values.
3. Soil nitrogen falls off more rapidly during earlier periods of cultivation than during later ones. After several decades it tends to reach a more or less stable level.
4. The stable nitrogen level is much higher for good systems of soil management than for poor ones.



Fig. 1.—Sanborn Field Gives Its Different Yields As Evidence of the Effects by Cropping And Soil Treatments on the Fertility Level of the Soil During Fifty Years. (Photo May 30, 1938)

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INTRODUCTION

Many a farmer knows that the productivity of his land is not what it once was. Where his father grew forty bushels of corn he gets but twenty-five. The Missouri Agricultural Experiment Station can fully confirm this observation through its soil fertility studies on the old Sanborn Field at Columbia, Missouri. On an untreated plot corn has been grown continuously for over forty years and the average corn yield has dropped forty per cent from the ten-year period 1889-1898 to the ten-year period 1919-1928. The cause of these diminishing crop yields must be sought in the soil itself.

Why Soils Become Exhausted.—There is one outstanding factor which lowers the fertility of many Missouri soils and that is soil *erosion*. But this is by no means the only cause of soil impoverishment. Under the present system of exploitive soil management the amount of plant food in the soil is certain to be reduced because the crops are removed and little is returned. Few people realize how much plant food is annually removed from the soil by the major crops grown. Table 1 gives an estimate of such losses from Missouri soils for the year 1931. A total of 760,000 tons of nitrogen and mineral substances have been taken out by the plants, representing a value of 55 million dollars.

TABLE 1.—APPROXIMATE REMOVAL OF NITROGEN AND MINERAL SUBSTANCES FROM MISSOURI SOILS IN 1931

Crop	Production in bushels millions	Soil nitrogen		Total mineral substances	
		removed tons	value in dollars millions	removed tons	value of K, P, Ca in dollars millions
Corn	170	120,000	24.0	400,000	13.9
Oats	50	31,000	6.2	100,000	3.7
Wheat	30	24,000	4.8	85,000	2.5
Total	760,000 tons of "plant food" representing a value of \$55,000,000				

This amount of plant food, if loaded upon ordinary farm wagons, one ton on each, and lined up one after another, would make a continuous procession reaching from San Francisco to New York and back to Ohio. But erosion and cropping are not the only losses. Rain

water penetrates the soil, dissolves plant food and carries it away through deep seepage into rivers and finally into the ocean. It is not known how great these losses are for Missouri conditions.

Estimating the Actual Losses a Difficult Problem.—Since a considerable part of the crops produced is fed to farm animals and partly returned to the land as manure, and furthermore, since bacteria living in the soil are able to replace a part of the nitrogen lost, an exact calculation of the actual fertility losses is impossible. Only the analyses of the soil itself can provide definite information.

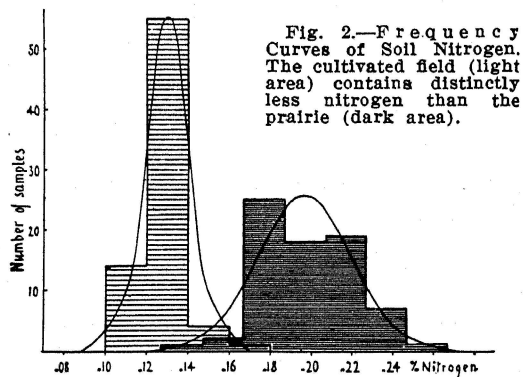
LOSSES FROM A SOIL CULTIVATED FOR SIXTY YEARS

In order to study the changes which take place under cultivation, two fields were selected. One had been in continuous cultivation for more than sixty years. Only corn, wheat, and oats had been grown and no manure or fertilizer had ever been added. The other field lay along side the first and on exactly the same type of soil, but it was a virgin prairie that had never been plowed, although it had been pastured and some hay removed. Both fields were nearly level so that practically no erosion took place. The losses were, therefore, limited primarily to those of cropping and leaching. They would, of course, have been greater if the land had been subject to erosion.

Nitrogen Drops Thirty-five Per Cent.—The average nitrogen content of the unplowed land (prairie) was found to be 0.197% or 3940 pounds in the surface seven inches of an acre. The cultivated land contained only 0.129% or 2580 pounds of nitrogen* in this same layer of soil. *In other words, a loss of 35% or 1360 pounds had occurred.* The effect of cultivation is undoubtedly greater than the variability of the fields, as evidenced from Figure 2, which represents a frequency distribution graph showing that the cultivated and the virgin fields now have very different nitrogen levels.

Organic Matter Also Disappears.—Determinations clearly indicate that the black vegetable matter in the soil (organic matter)

*0.197 ± 0.0027% and 0.129 ± 0.0013% N respectively.



also decreases at about the same rate as nitrogen, namely 38%.*

Although organic matter is not considered a plant food material, nevertheless it is exceedingly important in the maintenance of productive soils. It reduces soil erosion, increases the moisture retaining power of the soil and acts powerfully in retaining or holding within the soil the plant foods which otherwise might leach away.

Soil Structure is Altered Unfavorably.—Table 2 illustrates certain changes in the physical properties as a result of cultivation. Cropping has broken up the larger soil granules into smaller ones which consequently increase in number.

TABLE 2.—CHANGE IN THE SIZE OF SOIL GRANULES DUE TO CULTIVATION

Soil granules	Prairie	Cultivated field	Difference
Large ("sand" size)	39%	28%	decrease 28%
Fine ("clay" size)	14%	19.5%	Increase 39%

This alteration is of no advantage because it results in soil compaction which hampers air and water circulation, as well as tillage operations. Conditions for plant growth and soil management are thus made less favorable.

Water Economy Changed.—From 10 to 18 inches of rainfall are required to produce a 50-bushel corn crop. The more of the

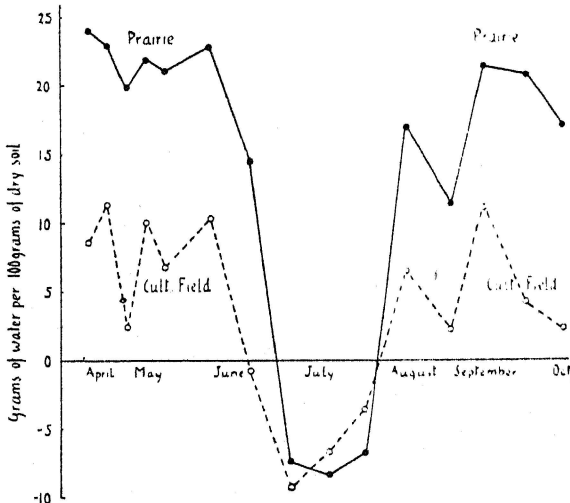


Fig. 3.—Cultivation Affects the Water Economy of the Soil. During most of the season the cultivated field contains less available growth water than the prairie.

rainfall is stored by the soil the better it is for the crop. Cultivation decidedly changes the moisture holding power of the soil. The graph in Figure 3 clearly demonstrates that throughout the growing season the prairie contains more available growth water in the surface soil than the cultivated field which had been planted in oats. Very similar curves are obtained for the subsoil.

*Prairie: $2.10 \pm 0.032\%$; Cultivated field: $1.30 \pm 0.014\%$ organic carbon.

Loss in Mineral Plant Food.—The so-called exchangeable bases which constitute an important part of mineral plant food also are subject to decided losses. The prairie contains an average of 10.64 units* of exchangeable bases while the cultivated field has only 7.10. The decline is 33%. The loss of 3.54 units corresponds to about 3500 pounds of limestone. In many localities prices should not be prohibitive for restoring the base content of the soil by adding limestone and some potassium fertilizer such as potassium chloride.

Increase in Soil Acidity.—About the only significant soil property which shows an increase, is acidity. Unfortunately, soil acidity is harmful to many plants, especially certain legumes. The cultivated field has become decidedly more acid; technically speaking the average pH changed from 5.34 to 5.01.

Application of lime on fields which have been long in cultivation has a double beneficial effect; it minimizes the harmful soil acidity and at the same time restores the depleted calcium level. The latter is as important as the former.

Summarizing the data secured it can be said that sixty years of cultivation have reduced the fertility of the soil about one-third. *It should be kept in mind that these results were obtained on non-erosive level land, and that on slopes or hilly land erosion may greatly increase these soil fertility losses.*

SOIL FERTILITY LOSSES MATERIALLY AFFECT CROP PRODUCTION AND LAND VALUES

Results of the outlying experiment fields of the Missouri Agricultural Experiment Station show that *for well drained upland soils of medium texture the nitrogen content of a soil is a pretty good index of its corn producing power* (see Figure 4). If a normal Missouri soil contains less than 2000 pounds of nitrogen per acre (surface soil, seven inches deep) the corn yield is likely to be below 20 bushels over a period of years, while in the case of soil with 3000 and 4000 pounds of nitrogen, the yields average between 25 and 40 bushels.

It is interesting to compare these data with the nitrogen losses observed. On the basis of the curve in Figure 4 the prairie would

*One "unit" defined as one milliequivalent of exchangeable bases per 100 grams of soil.

yield about 38 bushels of corn per acre and the cultivated field only about 22 bushels, a drop of 40%. In other words, the reduction in corn yields is about equal to the soil fertility losses.

Pastures Suffer.—Investigations indicate that in Missouri the important pasture plant *bluegrass* requires a definite level of mineral substances as exchangeable bases before it will grow satisfactorily.

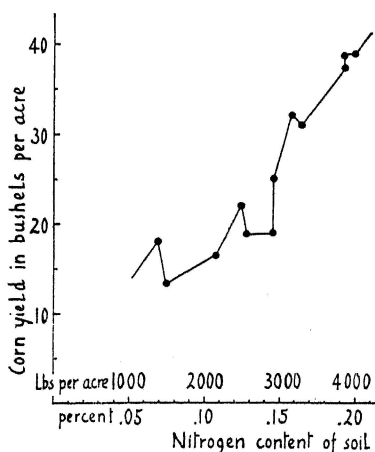


Fig. 4.—Corn Yields and Soil Fertility. In Missouri the more nitrogen there is in the soil the greater the corn yield per acre. Each point represents the nitrogen content of an experiment field (untreated plot) on a definite soil type.

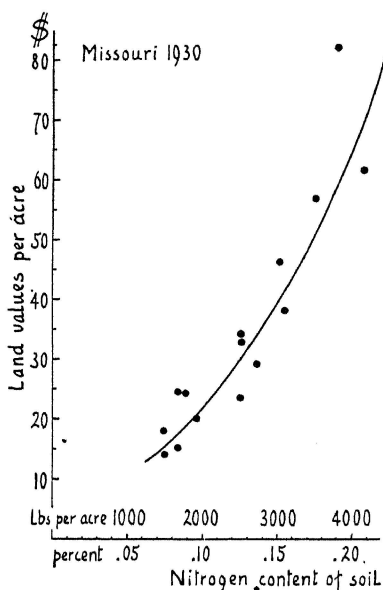


Fig. 5.—Land Values and Soil Fertility. The nitrogen content is a fairly good index of land values of normal upland soils in Missouri. Each point represents the nitrogen content of a soil type. (Census 1930; in cooperation with Department of Agricultural Economics.)

This level appears to be about eight units* of mineral bases such as calcium and potassium. The best Missouri bluegrass soils contain 16-20 units of basic mineral plant food. The soil investigated has dropped from 10.6 to 7.1 units and evidently has never represented excellent bluegrass pasture land. Through cultivation it has fallen, however, into a decidedly low grade bluegrass pasture.

Economic Aspects of Soil Fertility Losses.—It is commonly said that soil fertility represents the farmer's capital, a contention which is well illustrated in Figure 5. The graph shows that the

*One "unit" defined as one milliequivalent of exchangeable bases per 100 grams of soil.

sales value of the land (without buildings) is closely related to soil fertility. *The higher the nitrogen content of a normal upland soil in Missouri the higher the average price of the land.* In view of these relationships the reduction in land value due to continued cultivation speaks for itself. At a time when the original prairie would sell for 50-70 dollars per acre, the cultivated field would be worth only 25-35 dollars, a reduction of 50%.

Rebuilding Is Costly.—If a farmer would attempt to restore the fertility of the cultivated field to its original level by simply adding the lost nitrogen (1360 pounds per acre) in the form of com-

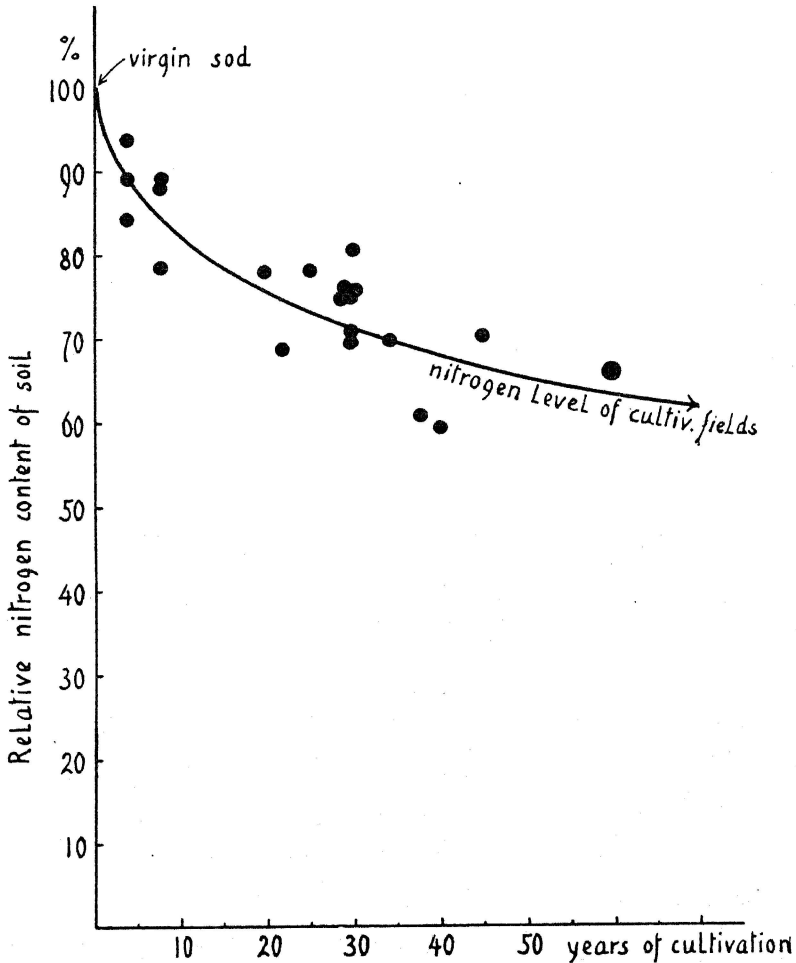


Fig. 6.—Decline of soil fertility with length of cultivation periods under average farming practices in the Middle West.

mercial fertilizer such as ammonium sulfate or sodium nitrate, he would have to spend over \$100 per acre or more than the land is worth. Evidently it is a much better policy to carefully preserve nature's cheap nitrogen than to waste it and then replace it by buying expensive substitutes.

THE FUTURE DECLINE OF SOIL FERTILITY

In view of these striking changes in soil fertility important questions arise. Have the losses occurred at any particular time or has the decrease been a gradual one? Is the fertility still further declining or is it now at a standstill?

If nitrogen is taken as a general index of fertility it is possible to answer these questions on the basis of results from various experiment stations. Figure 6 (on page 8) indicates the general trend of the decline of soil fertility with years of cultivation under common farming practices in the Middle West. It is interesting to note that the line does not fall evenly. The drop is more pronounced in earlier periods than at later ones as seen from the following groupings:

Nitrogen reduction in the first 20 years—25%

Nitrogen reduction in the second 20 years—10%

Nitrogen reduction in the third 20 years—7%

Half a century after the sod has been broken the relative changes are but slight and the nitrogen content apparently becomes stabilized at a level considerably below the original standard.

The Ultimate Soil Fertility Level.—The indication that soil fertility—as judged by soil nitrogen—does not necessarily decline indefinitely, but tends to reach a certain minimum level is supported by soil analyses from Sanborn Experiment Field. All experimental plots were analyzed in the years 1913 and 1928. Table 3

TABLE 3.—APPARENT PERMANENT SOIL NITROGEN LEVEL.
(Sanborn Field, Columbia, Mo.)

Plot No.	Treatment	Nitrogen content of soil 0-8 inches depth	
		1913	1928
13	6 year rotation: corn, oats, wheat, clover, timothy, timothy; no treatment	0.116%	0.117%
16	Continuous oats; no treatment	0.112%	0.119%
23	Continuous timothy; no treatment	0.142%	0.137%

gives the values for some typical systems of farming. It is clearly seen that during fifteen years the average nitrogen level has remained practically unchanged.

These Observations Offer Certain Hopeful Aspects.—Stable soil fertility reflects itself in relatively stable crop yields. That is to say, the yields cease to drop rapidly and reach a more or less constant level. However, not all soils will ultimately reach the same fertility standard. Soil type, climate, and particularly systems of farming and soil management greatly affect the permanent soil fertility conditions as illustrated in Table 4.

TABLE 4.—EFFECT OF SYSTEMS OF SOIL MANAGEMENT ON THE NITROGEN LEVEL OF THE SOIL.

(Sanborn Experiment Field, 40 years of cultivation)

Plot No.		Pounds of nitrogen per acre (0-8 inches)
	High nitrogen levels:	
14	Six year rotation, six tons of manure	3956
34	Four year rotation, six tons of manure	3772
	Medium nitrogen levels:	
39	Four year rotation, no treatment	2875
27	Six year rotation, no treatment	2691
	Low nitrogen levels:	
9	Continuous wheat, no treatment	2254
17	Continuous corn, no treatment	1840

These data suggest real opportunities to the progressive farmer. *Without question he has it in his power to check excessive soil exhaustion and keep the soil fertility at a satisfactory level.** Table 4 shows that continued grain farming, especially if corn is used, results in an unnecessary and excessive loss of soil fertility, while rotation systems, especially if supplied with manure, successfully maintain a relatively high nitrogen content.

*The level depends on climatic conditions. It is lower in the South and higher in the North.

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