OUR . . . HERITAGE, *The* SOIL

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Our Heritage - the Soil

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THE NEED for conservation of the soil resources of America is not a recent discovery. In 1859 Baron Justus von Liebig, famous German chemist and agriculturist, made the following none too complimentary statement about the then prevailing methods of handling farm lands in this country:

> "The American farmer despoils his farm without the least attempt at method in the process. When it ceases to yield him sufficiently abundant crops, he simply quits it, and with his seed and plants, betakes himself to a fresh farm; for there is plenty of good land to be had in America; and it would not be worth his while to work the same farm to absolute exhaustion."

For many years our own soil and crop scientists have deplored the ruinous exploitation of farm land in America. The farmer has been charged with squandering the birthright of future generations. Abandoned farms, dotting the landscapes of many of America's older areas, are the omens of what is to come elsewhere if this process of soil robbery continues.

Public consciousness has been awakened during the past 5 years to the vicious force of soil erosion, but other destructive agencies, often the forerunners of erosion, are also rapidly wasting our soil resources. We are told that, in the United States, farm lands equal to five times the cropped area of Ohio already are ruined beyond hope of redemption, and that a vastly larger area is rapidly approaching this unhappy state. Truly, this is a dismal picture, and, if true, a damaging indictment of the system that has permitted the exploitation of the nation's most valuable material heritage, the soil.

But does this dismal portrayal apply in a region of progressive, enlightened farmers such as Ohio?

We all know of farmers who are "skinning" the land, but we also know some who are following excellent methods. An examination of some of the evidence should show us if there is any basis for believing that the farm lands in Ohio are actually being despoiled.

The Evidence of Crop Yields

What does the evidence of crop yields show? If our soils are deteriorating, we would at first assume that acre yields of crops would necessarily show the same trend.

Table 1 shows the average acre yields of the four most important crops in Ohio for four 10-year periods beginning with the decade of 60 years ago. Corn yields have shown no significant change in 60 years, being just about 37 bushels for the decade of 60 years ago and the same for the last 10-year period. Oats and wheat yields actually increased appreciably up to the decade of 1910-19, but dropped slightly in the next 10 years. Hay yields show a slight tendency to increase from each decade to the next.

Superficially at least, with all yields equal to or above what they were 60 years ago, the evidence for soil deterioration is not alarming. Perhaps, after all, soil scientists have just been crying "wolf, wolf" to attract attention. *But is it possible that crop yields could be holding their own or even increasing slightly and, at the same time, the soil itself be deteriorating?*

Table 1.—Acre Yields of Crops in Ohio by 10-Year Periods

Period	Corn	Oats	Wheat	Hay
	Bushels	*Bushels*	*Bushels*	*Tons*
60 years ago, 1870-79	36.9	27.7	13.3	1.03
40 years ago, 1890-99	34.3	29.1	14.6	1.07
20 years ago, 1910-19	37.0	36.4	17.5	1.10
10 years ago, 1920-29	37.2	35.1	16.5	1.15

Improved Practices Should Have Given Large Yield Increases.—Most farmers will admit that they are doing a little better job of farming than their fathers or their grandfathers did. Many improved methods have been developed and at least partially adopted within the past half century. The most important are along the following lines:

1. Tiling.—Thousands of miles of tile have been buried beneath the surface of formerly wet lands in Ohio. This improvement alone should more than account for the previously noted yield changes with oats and wheat.

2. Improved Varieties.—The crop varieties grown by our grandfathers have been largely, if not wholly, displaced by better adapted, higher yielding varieties developed by our experiment stations and other crop breeders.

3. More Lime and Fertilizers.—The whole usage of lime and fertilizers has grown up within the last three or four decades. Farmers have learned to appreciate the value of manure and to take better care of it—at least they no longer purposely dump it in the creek.

4. Growing Legumes in Rotation.—The soil improving values of alfalfa, sweet clover, and the true clovers are better understood. The pioneer practice of growing corn several years in succession on the same land is no longer looked upon with favor.

5. Use of Improved Machinery.—The machines employed for tilling the soil and for seeding and harvesting crops have been wonderfully improved, and should be doing more efficient jobs than the clumsy tools of a generation or two ago.

6. Seasonal Planting and Harvesting.—We have learned much about how and when to plant and harvest crops for greater yields.

7. Pests and Diseases.—Extensive research has shown how to control or avoid many of the diseases and insects that formerly preyed upon crops.

Worn-out Areas Discarded for More Productive Land.—Another important factor in maintaining the yield level in Ohio has been the trading of good land for poor land. Thousands of acres of poor land in eastern Ohio, once cropped, are now in grass or timber, whereas equally large areas of highly productive land in western Ohio have been reclaimed from the swamp by drainage, even within the past 30 and 40 years.

Why Are Yields Not Greater?—Certainly, taken together, all of these changes and improvements should have raised acre yields considerably—how much, it is difficult to say exactly, but we believe an increase of 40 to 60 per cent would have been conservative (Figure 1).

For example, wheat yields were only 3.2 bushels more during the decade of 1920-1929 than in the "seventies." Four-fifths of Ohio's wheat acreage is now planted to improved varieties which yield, according to hundreds of field tests and thousands of threshermen's records, 3 or 4 bushels more per acre than the varieties they displaced. From 1920 to 1929, the average acre of wheat in Ohio annually received about 180 pounds of fertilizer, and we know from hundreds of field tests that this alone should have increased the yield at least 7 bushels. Taken together, fertilizers and better varieties should have increased the yield 10 bushels, as against an actual increase of only 3 bushels.

There can be but one explanation for the stubbornness with which acre yields have resisted the farmer's efforts to improve them. *The natural productive capacity*[1] *of the land has been deteriorating at a rate almost fast enough to offset all of these improvements in soil and crop management* (Figure 1). With every step ahead we have slipped back almost if not quite as far.

Chemical and Physical Evidences of Change in Ohio Soils

Direct chemical and physical examinations of soils indicate several ways in which soils may deteriorate under the average systems of tillage and cropping followed in Ohio.

Cropped Lands Show Heavy Loss in Soil Nitrogen.—J. W. Ames, chemist at the Ohio Agricultural Experiment Station, obtained at several locations samples from comparable virgin and cropped soils; he took a sample of virgin forest or grass land, then climbed the fence and took a comparable sample from cropped land on the same type of soil. These samples were analyzed, and in Table 2 are shown the results for the important element nitrogen, which is contained in the soil organic matter.

Nitrogen forms such a constant part of the organic matter that it serves as a criterion of the amount of organic matter present in the soil. As an average for seven virgin soils in Ohio, there were present 4,214 pounds of nitrogen in one acre of surface soils, whereas the average for comparable cultivated soils was 2,744 pounds, a loss of 1,470 pounds or just about one-third. Most of these cultivated soils had been farmed only for a period of from

[1] Throughout this bulletin "productive capacity" refers to the inherent potential capacity of a soil to produce. It depends upon characteristics which can be modified only slowly, several years being required for major changes to take place. A soil of given productive capacity may produce relatively high or low crop yields, depending upon the particular methods of soil management followed. A soil of low "productive capacity" with good soil management—thorough cultivation, generous use of fertilizers, manure, green manure crops, etc.—may produce as high yields as a soil of high "productive capacity" under poor management. With equally good management the yields on the latter soil will be superior and the unit cost of production will be lower.

50 to 75 years; really a very short time, even when compared with the age of our young nation.

Table 2.—Nitrogen Content of Comparable Virgin and Cropped Soils in Ohio

Soil Type	County	Nitrogen contained in 1 acre of surface soil			
		Virgin	Cultivated	Loss	
		Pounds	*Pounds*	*Pounds*	*Per Cent*
Toledo silty clay	Fulton	5900	3330	2570	43.6
Brookston silty clay loam	Miami	7750	4050	3700	47.8
Miami silty clay loam	Auglaize	3620	2420	1200	33.2
Crosby silt loam	Miami	3330	2760	570	17.2
Clermont silt loam	Hamilton	2725	1960	765	28.1
Wooster silt loam	Ashland	3250	2386	864	26.8
Wooster loam	Summit	2925	1600	1325	45.4
Average		4214	2744	1470	34.8

Soil Tilth Impaired by Cropping Systems.—Loss of organic matter and nutrient elements is only one of several ways in which soils may deteriorate under cropping. Associated with these effects is often found a deterioration in the physical properties or tilth of a soil, particularly on the heavier types of land. For some time, farmers on the heavier clay and silty clay loam soils of northwestern Ohio have been telling us that their land is getting heavier, that it doesn't drain as well as it once did, that it is more difficult to work down into a good seedbed, that it cracks worse in dry weather, and that satisfactory legume seedings are more difficult to obtain. All of these happenings indicate that these soils are losing their granular structure and becoming compact and impervious.

Our soil physicist, Richard Bradfield, started in 1935 to see if any evidence existed that such changes are actually taking place. In Paulding County, he sampled several comparable pairs of virgin and cropped soils, taking these samples to successive 1-foot depths down to 3 or 4 feet. Among other things, he determined the weight of a cubic foot of each of these samples. In the field a given volume of soil is made up partly of solid soil material and partly of pore space, filled with air and water. Obviously, the more a soil weighs per cubic foot, the greater the volume occupied by solid material, the less the amount of pore space through which air and water can move, and the harder it will be for roots to penetrate.

A part of what Dr. Bradfield found in answer to the farmers' statements is shown, for a typical Paulding County silty clay loam, in Table 3.

The virgin soil was grass land that had been plowed for the first time and put into corn. The cultivated land was of the same soil type, just across the fence, and had been cropped for 40 years, mostly to corn and oats. This field was also in corn. The soil of the virgin field was so loose one could scoop it up with his hands; that of the cultivated field, so hard one could scarcely dent it with his heel. On the virgin field, the corn was expected to yield 75 to 80 bushels per acre, but 20 bushels was about the expectation for the previously cultivated field.

Table 3.—Effect of 40 Years' Cropping on Physical Properties and Organic Matter Content of Nappanee Silty Clay Loam in Paulding County, Ohio

(Unpublished Data of R. Bradfield)

Depth	Weight of soil per cubic foot		Pore space as per cent of total volume		Organic matter content	
	Virgin	Cultivated	Virgin	Cultivated	Virgin	Cultivated
Feet	*Pounds*	*Pounds*	*Per Cent*	*Per Cent*	*Lbs. per acre*	*Lbs. per acre*
0–1	65.5	81.7	60.3	50.5	132,000	89,400
1–2	70.3	86.7	58.1	47.6		
2–3	76.6	91.0	53.5	44.8		
Average 0–3	70.8	86.5	57.3	47.6		

In Table 3 we note that for each foot of depth, the soil of the cultivated field was much heavier than at a corresponding depth in the virgin soil. In the upper 3 feet there was 16 pounds more solid soil material in each cubic foot of volume. The cultivated soil contained only about four-fifths as much pore space as the virgin soil. This loss of pore space is disastrous because much of that loss is of the larger pores through which soil air and water move most readily.

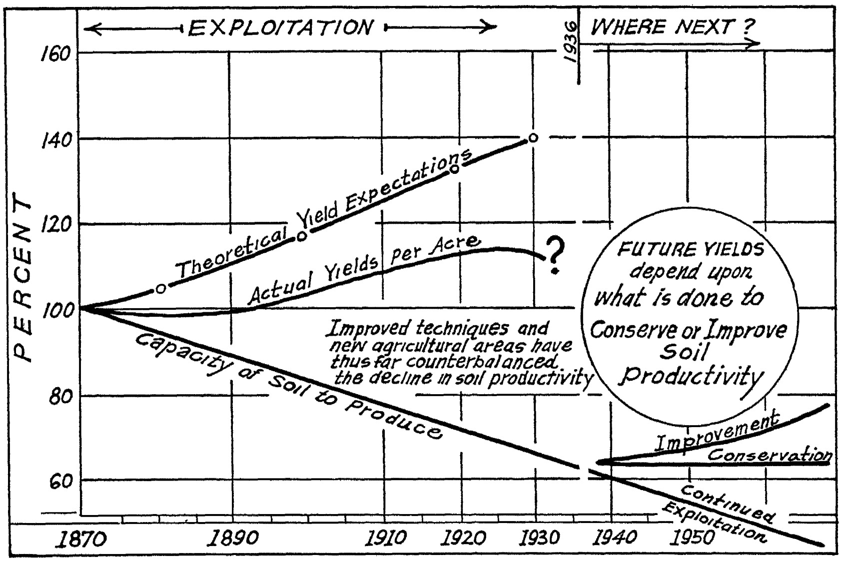

Figure 1.—Improved farm practices in Ohio since 1870-79 should have resulted in 40 to 60 per cent higher yields per acre; but the aggregate yield has increased less than 15 per cent; improved practices have thus only slightly more than counterbalanced the decline in the ability of the soil to produce. With continued soil exploitation, average yields per acre must soon trend downward; yields can be maintained only if programs of soil conservation and soil improvement are generally adopted.

Apparently, the happenings the farmers have been telling us about such lands are actually taking place.

Evidence of Soil Deterioration is Conclusive.—From such evidence as we have been discussing, there seems no escape from the *conclusion that our soils are deteriorating, that they have a lower productive capacity today than they had a generation ago* (Figure 1). We can only speculate on what they will be like a generation hence when our children take them over (page 16). Unless significant changes soon occur in the average systems of soil and crop management, yields per acre will probably start a downward trend. Of course, we have been talking in terms of the average situation. There are in Ohio many farms that are improving with age under careful management. The unfortunate fact, not without its tragic aspects, is that for each farm on the up-grade there must be several on the down-grade.

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Factors Involved in Soil Deterioration and Improvement

SOIL deterioration and its opposite, soil improvement, are not simple processes. Many practices of soil and crop management are involved. However, among these, the cropping system appears to be of dominant importance. Liming is of special importance on acid soils, since it determines the type of legume crops that can be grown. Other factors that must be evaluated are the use of manure and fertilizers, and special management practices for controlling soil erosion. To evaluate these factors, standards have been established.

STANDARDS FOR MEASURING SOIL PRODUCTIVITY

There exists at several agricultural experiment stations in the United States field experiments that afford a rich opportunity for studying the effects of certain long continued cropping systems and soil management practices upon the soil. Such effects are measurable both in the chemical and physical properties of the soil itself and in the crop yields produced, as explained on pages 3 to 8.

On the Main Farm of the Ohio Station at Wooster, certain experiments have been in progress for 42 years, others nearly as long. From time to time the plots involved in these experiments have been sampled and subjected to chemical analyses. One of the most complete studies has been made on samples taken in 1925, after the oldest of these experiments had been in progress 32 years. The results of the laboratory studies of these soils, compared with crop yields, indicate a close relationship between changes in the organic matter and nitrogen content of a given type of soil and its capacity to produce.

To be sure, there is really nothing new in this, since farmers have long associated the productivity of soils with their humus content as shown by their darkness in color. By way of illustration, however, data from the untreated check plots in an experiment in which corn has been grown continuously since 1894 are presented in Table 4.

Table 4.—Relative Nitrogen Content and Yield of Continuous Corn Plots at Wooster, Ohio

Year	Relative nitrogen content of soil	Years	Relative corn yield
	Per Cent		*Per Cent*
1896.......	100.0	1894–1898	100.0
1913........	51.6	1911–1915	59.6
1925........	41.2	1923–1927	45.6

The nitrogen content and the yield of corn, both stated on a relative basis, are compared at three different periods. With the continuous cropping to corn, the nitrogen content of the soil has decreased markedly, and simultaneously the yield of corn has declined almost in proportion. It is believed that this relationship is sufficiently exact to permit the use of changes in the nitrogen or organic matter content of the soil as an approximate measure of the effect of a cropping system or management practice upon the productivity of a given type of soil.

Effects of Cropping Systems on Soil Organic Matter and Nitrogen

In Table 5 are shown the amount of organic matter and nitrogen in this soil at the beginning, as shown by the plots of the 5-year Rotation Experiment in 1894. In comparison are the amounts of the same constituents in these plots in 1925, after 32 years of cropping, and also in similar land cropped continuously to corn, wheat, or oats for the same period of time. Corresponding data are shown for a 3-year rotation of corn, wheat, and clover after 29 years of cropping. All of these soils have been limed regularly since about 1900, but no fertilizers or manure have been applied in any case.

Table 5.—Organic Matter and Nitrogen Content of Unfertilized Plots at Wooster, Ohio

Crop rotation	Begun	Analyzed	Organic matter	Nitrogen
	Year	*Year*	*Pounds per acre*	*Pounds per acre*
Corn, oats, wheat, clover, timothy	1894	1894	35,050	2,176
Corn, oats, wheat, clover, timothy	1894	1925	26,700	1,546
Continuous corn	1894	1925	12,730	840
Continuous oats..............	1894	1925	22,800	1,425
Continuous wheat	1894	1925	22,050	1,315
Corn, wheat, clover	1897	1925	29,500	1,780

Corn is outstandingly destructive in its effect on the soil organic matter and nitrogen, as shown by the loss under continuous corn of almost two-thirds of both constituents in the 32-year period. Wheat and oats appear to have been about half as destructive as corn. When the grain crops have been combined with hay crops in rotation, the losses of organic matter and nitrogen have been materially decreased, indicating that the hay crops exert a conserving or accumulative effect. That clover is particularly effective in overcoming losses caused by growing corn and small grain is shown by the larger amounts of organic matter and nitrogen in the 3-year rotation where clover is grown every third year.

Cultural Practices an Important Factor.—The growing of any crop results in some favorable and some unfavorable effects on soil productivity. The final effect of any single crop is the net result of these opposing tendencies. Cultural practices, chiefly the amount of soil tillage, are most important in determining the degree of destruction occasioned by growing a crop. Any stirring of the soil speeds up the destruction of soil organic matter and increases the liability of erosion. With a given type of crop culture, losses will be roughly proportional to the store of organic matter present. The actual removal of soil nutrients by the crop also contributes to soil deterioration. This loss will vary with the size of the crop and this, in turn, with the productivity of the soil.

Crop Residues Beneficial.—The favorable or positive effects of a crop depend upon the amount and composition of the root and stubble residues left in and on the soil after harvest. The sod crops—alfalfa, sweet clover, the common clovers, and timothy—leave abundant residues. Willard, of the Ohio Station, reports nearly 2 tons dry weight of roots per acre left by alfalfa as an average of six tests. Annual crops leave relatively small residues, those from corn and soybeans being especially meagre. As a 4-year average, Thatcher at Wooster found less than ¼ ton of roots left by soybeans yielding about 2 tons of hay per acre.

From a given weight of residues, the humus left after decay is about in proportion to the nitrogen content of the residues. The final effect of a ton of alfalfa residues is probably two to three times that of an equal weight of corn, small grain, or grass residues. With any single crop the amount of residues will be roughly proportional to the size of the crop, and the latter will depend, of course, upon the productivity of the soil.

Soil Productivity Indexes

An analysis of the data we have been discussing, together with those from other experiments in Ohio and in other states, has made it possible to assign to various individual crops indexes which represent approximately their effects upon the productivity of the soil. These indexes may be either negative or positive, depending upon whether a particular crop has a soil deteriorating or a soil improving effect. They are conveniently stated as the percentage change in productive capacity of the soil caused by growing each crop for a single year. The soil productivity index for a given crop is an approximate measure of the balance between the favorable and unfavorable effects of that crop on the capacity of the soil to produce. The magnitude of the index will obviously vary with differences in climate.

The soil productivity indexes assigned to the more important crops grown in Ohio are shown in Table 6.[1]

Table 6.—Soil Productivity Indexes for Individual Crops in Ohio

Crop	Soil productivity index
	Points in Per Cent
Corn	—2.0
Potatoes, tobacco, sugar beets	—2.0
Oats, wheat, barley, rye, buckwheat	—1.0
Soybeans — Hay	—0.5
Seed—straw and leaves left on field	0.0
Timothy and other grass sods	0.0
Red and alsike clovers	+2.0
Alfalfa (1 year)	+2.5
Alfalfa (2 years or more)	+3.0 (total)
Mixed meadows	According to type of sod*
Sweet clover (green manure)	+2.5
Rotation pastures	According to type of sod*
Additions to or subtractions from these indexes are also made to account for the use of manures, fertilizers, and the degree of erosion (see pages 14 and 15)	

* A weighted index is calculated from the estimated percentages of different plants in the herbage.

The intertilled crops — corn, potatoes, tobacco, and sugar beets — are all given a negative factor of —2 per cent, indicating that each time one of these crops is grown there is a loss of about 2 per cent in the productive capacity of the soil. The small grains, requiring the preparation of a seedbed but no cultivation, are given a factor of —1 per cent. That is, they are ranked as about one-half as destructive as the intertilled crops. Soybeans harvested for hay are rated as —0.5 per cent, but, if harvested for seed with straw and leaves left on the field, they are given an index of zero. Timothy is also given a zero rating, indicating neither loss nor gain from growing this crop. Some data indicate that it should have a small negative rating.

The biennial and perennial legumes all have positive factors. For red clover, this is +2 per cent; one crop of red clover being sufficient to offset the effect of one crop of corn. Alfalfa and sweet clover are given higher

[1] This method of analysis has been in process of formulation over a period of 4 years. In 1932 the need for indexes, evaluating the effects of individual crops, was pointed out in extension-research conferences at the Ohio State University. In December, 1932, Robert M. Salter and T. C. Green presented a paper at the meetings of the American Association for the Advancement of Science, analyzing the effects of crops on soil organic matter and nitrogen in terms of annual percentage changes (See Jour. Amer. Soc. Agron. 25:622-630, 1933). In April, 1933, tentative productivity indexes were proposed by the authors as one basis for payments on contracted acres under the AAA. In March and April of 1934 the indexes suggested in 1933 were again used in appraisal schools for the corn-hog committeemen in 25 to 30 counties of Ohio. In 1935 they were refined and published in "A Basis for Regional Agricultural Adjustments in Ohio." (Mimeograph Bulletin, Agricultural Extension Service, Ohio State University and Ohio Agricultural Experiment Station, September, 1935). During the winter of 1935-1936 these same crop indexes, appropriately modified to allow for such factors as soil erosion, use of manure and fertilizer, etc., have been employed in county agricultural planning studies throughout the state.

positive values than the common clovers, in line with their larger soil improving effects (see Table 12 for illustrations of the use of these indexes).

Type of Evidence Supporting the Use of Soil Productivity Indexes.—To illustrate how these factors may be employed in predicting the effect of any particular cropping system upon the productivity of the soil, let us examine the data in Table 7, taken from a crop rotation experiment in which fifty different crop rotations have been compared over a 20-year period at Wooster. The data shown are for two 5-year rotations, one a rotation of corn, oats, and three years of alfalfa; the other, three years of corn followed by wheat and clover. The figures show the amount of nitrogen in corresponding plots of these two rotations on five different sections of land after 20 years' continuous cropping.

Table 7.—Effects of Two 5-Year Rotations on Soil Nitrogen Content Over 20-Year Period at Wooster

Rotation	Nitrogen in surface soil after 20 years Pounds per acre					
	Sec. V	Sec. W	Sec. X	Sec. Y	Sec. Z	Average
Corn, oats, alfalfa 3 years	2800	2460	2440	2520	2320	2508
Corn 3 years, wheat, clover	2380	2060	2000	2060	1920	2084
Difference	420	400	440	460	400	424

Employing the soil productivity indexes previously discussed for the individual crops in the first rotation we have −2 per cent for corn, −1 per cent for oats, and +3 per cent for three years of alfalfa, making a total of zero per cent change for the rotation as a whole. Similarly, for the second rotation we would have −6 per cent for the three corn crops, −1 per cent for the wheat crop, and +2 per cent for clover, making a total of −5 per cent for the rotation as a whole, equal to an average loss of 1 per cent in soil productivity each year. A 1-per cent annual loss, compounded over 20 years, gives a total loss of about 18 per cent. Observe the almost constant difference in the nitrogen content between plots of the two rotations on each of the five sections of the experiment. As an average for all sections, the soil in the second rotation contains 17 per cent less nitrogen than that in the first rotation.

If we use the yield of the corn in these rotations as a measure of soil productivity, we find that the yield in the first rotation has averaged 81 bushels per acre without any evidence of its either increasing or decreasing from the beginning to the end of the 20-year period. On the other hand, the yield of the first corn crop in the second rotation has declined steadily. The trend of the fluctuating annual yields starts at 77 bushels and drops to 61 bushels at the end of the 20-year period, a decline of 21.6 per cent. Thus, we have for this rotation a decrease in productivity of 18 per cent, calculated from the crop soil producing indexes; an actual loss of 17 per cent in the nitrogen content of the soil; and a decline of 21.6 per cent in the yield of corn. This is about as good a verification of the method of calculating the effect of a given cropping system on soil productivity from the individual crop indexes as could be expected.[1]

Lime — A Basic Factor in Soil Conservation

In Ohio, any program of soil conservation and improvement must sooner or later fail unless some method is devised for enormously increasing the amount of lime applied to the soil. By far the most effective method for overcoming soil deterioration, brought about by erosion or due to chemical and biological forces, consists in expanding the acreage devoted to the soil building sod legumes. The successful establishment of these legume crops requires a fair abundance of lime in the soil. The so-called "acid tolerant" legumes offer little promise for purposes of soil conservation. Only by liming acid soils can they be made to grow the more efficient soil improving legumes.

Liming Increases Crop Returns.—The immediate economic benefits of soil liming from the improvement in quality of forage and the increase in yield of all crops of the rotation is indicated by the results of a 7-year experiment at Wooster. An expenditure for limestone of $5.13 per rotation raised the reaction of the Canfield silt loam soil from pH 5.0 to pH 6.8, and made possible the substitution of alfalfa for timothy in a 3-year rotation of corn, small grain, meadow. As a result of the use of lime and the shift to alfalfa, the total value of the crops per rotation was raised from $34.97 to $86.46 — or a net gain of $46.36 in crop values.

Limed Crops Leave Larger Residues.—In addition to the immediate crop benefits from lime, there is also an important contribution to soil capital in the form of residues from the legumes. The effect of lime as a factor in soil conservation is thus intimately connected with the nature of the legumes whose growth is made possible by its use. Since the comparative values of the different hay crops for soil improvement are reflected in the productivity indexes assigned to them (Table 6), no further allowance need be made for lime additions in analyzing the effects of cropping systems on soil productivity.

Greater Quantities of Lime Necessary.—A summary of several thousand soil tests indicates that two-thirds of the cropped land of Ohio is too acid to produce satisfactory clover and only one-fourth is in shape to grow either alfalfa or sweet clover well. Moreover, the soils of the state are becoming increasingly acid, since the amount of lime used (the peak tonnage was 233,000 tons in 1929) is estimated to be less than one-fifth that needed to maintain the soils at their present reaction status. It is estimated that to put the cropped land of Ohio in condition to grow red clover and alfalfa within a 25-year period, and at the same time compensate for annual losses of lime through crops and drainage, would require the yearly application of around 2,000,000 tons of limestone. This is a serious problem, of such fundamental

[1] It is recognized that a cropping system which yields a positive soil productivity balance, if followed continuously, will not continue indefinitely to increase soil productivity. Instead, the effect will be to stabilize at a relatively high maximum. Similarly, the use of a destructive cropping system will deplete the soil only to a certain low minimum of productivity, where crop yields will remain relatively constant. Practically, most land will lie well within these two extremes. In this intermediate region the destructive or constructive effects of different crops and management practices will be roughly proportional to the existing level of soil productivity, thus justifying the use of productivity indexes stated as percentages.

importance as to warrant cooperative action by all agencies interested in the welfare of the agriculture of the state.

Adjustments for Manure and Fertilizers

Fertilizers and manure, by increasing the size of the crops and hence the amount of residues left, tend to lessen the effect of destructive crops and to increase the effect of accumulative crops. Manure also contributes directly to the humus content of the soil, since it supplies both organic matter and nitrogen. For a given amount of plant nutrients supplied, manure adds about twice as much to the humus content of the soil as do chemical fertilizers. This indicates that about half of the conservation effect of manure arises from the increased residues from the larger crops grown, whereas the other half represents the direct contribution from the organic matter supplied in the manure itself.

Although the effect of a given amount of fertilizer or manure depends somewhat upon the soil type and to a larger extent upon the cropping system, results obtained in 3-year and 5-year rotation experiments at Wooster indicate that a fair allowance is +0.125 per cent for each 200 pounds of ordinary strength fertilizer (18 to 20 per cent total plant food nutrients) or for each 1 ton of manure applied (see Table 8). On this basis, 8 tons of manure per acre has half as much effect on soil productivity as a crop of clover (compare Table 6).

Table 8.—Soil Productivity Indexes for Manure and Fertilizers

Annual treatment per rotated acre	Soil productivity index
	Points in per cent
For each ton of manure applied	+0.125
For each 200 pounds average commercial fertilizer applied	+0.125

Adjustments for Soil Erosion

Our discussions so far have been concerned with soil deterioration or improvement which takes place wherever land is cropped. On sloping land, an additional destructive factor, soil erosion, must be given proper consideration. Here again the nature of the cropping system is of vital importance. Table 9 shows the losses of soil and water under different cropping systems over a 14-year period at the Missouri Station. Again, continuous cropping to corn leads to most serious losses. Intertillage and leaving the ground bare over winter both favor loss by erosion. Continuous wheat, requiring the annual preparation of a seedbed but no further cultivation, and providing soil cover during the winter, shows only half as much soil loss as under corn. Continuous bluegrass shows negligible loss of soil, reflecting the absence of any soil tillage whatever and the presence of a year-around vegetative cover. In the corn-wheat-clover rotation the soil loss is comparatively low. This rotation requires plowing only once in three years, keeps the soil covered in winter, and the extensive clover residues probably reduce the erosion loss during the growth of the corn crop. A crop rotation providing for a fairly high proportion of the land in sod crops is, under Ohio conditions, the one most effective method for controlling erosion on rotated land. Other devices for controlling erosion include (1) contour farming, in which the small grains and row crops are planted on the contour; (2) strip cropping, in which the several crops of the rotation are grown in narrow strips of land running on the contour; and (3) terracing, adapted chiefly to long, gentle slopes.

Table 9.—Relation of Cropping System to Erosion Losses, Missouri, 1918-1931.
Shelby Loam Soil, 3.68 Per Cent Slope
(Mo. Agr. Exp. Sta. Res. Bul. 177)

Cropping system	Average yearly loss	
	Soil	Rainfall
	Tons	*Per Cent*
Fallow, plowed 8 inches..	41.0	30.3
Continuous corn........	19.7	29.4
Continuous wheat	10.1	23.3
Continuous bluegrass	0.3	12.0
Corn, wheat, clover.....	2.8	13.8

A proper allowance for soil erosion in combination with the effects of the individual crops and of manure and fertilizer treatment, previously discussed, would require more basic experimental information than now exists. A simple and reasonably satisfactory procedure is to multiply the sum of all negative crop productivity values by an erosion factor which increases with the slope and erosiveness of the soil, and decreases with the application of such practices as contour farming, strip cropping, and terracing. A tentative schedule of erosion factors is suggested in Table 10.

Table 10.—Factors for Calculating the Effects of Erosion on Soil Productivity

Erosion class[1]	Degree of erosion	Modifying factor for erosion[2]		
		No special control methods	Farmed on contour	Strip cropped or terraced
1	Little or none	0.00	0.00	0.00
2	Slight	— 0.25	— 0.125	0.00
3	Moderate	— 0.50	— 0.25	— 0.125
4	Severe	— 1.00	— 0.75	— 0.25
5	Very severe	— 2.00	— 1.75	— 1.00

[1] Classes correspond to those recognized by the Soil Conservation Service in its erosion surveys.
[2] To apply this factor: multiply it by the sum of the negative crop productivity values.

Soil Deterioration Not Inevitable

That the decline in productive capacity of the average Ohio soil is not inevitable is forcibly demonstrated by the 29-year average results obtained on the 45-acre variety test field of the Experiment Station (corn, 73.6 bu.; oats, 62.0 bu.; wheat, 34.6 bu.; hay, 3.00 tons). With an annual cash outlay of about $3.50 for lime and fertilizer, the prompt return of manure, and high type legume sods, the yields have averaged practically twice those for the average farm of the county and state (compare Table 1). It is significant that the hay yield has been nearly three times the state average. At the start the soil on this tract was poorer than the average for the county.

Using the Soil Productivity Balance in Evaluating and Adjusting Farming Systems

Calculations of "Annual Soil Productivity Balance"

Examples will now be given showing the method for calculating the "Annual Soil Productivity Balance." This is expressed as the percentage change in productive capacity of the soil that may be expected to occur annually under a given cropping system, using known amounts of fertilizer and manure, and on land belonging to a particular erosion class, with or without special erosion control methods. Two types of approach are illustrated: (1) calculation of the productivity balance for a given area for which the cropping pattern is expressed in percentage of the total annual rotated area; and (2) calculation of the productivity balance for a specific crop rotation.

The first approach may be applied either to an individual farm or to larger areas such as a township, county, or state. In Table 11 are presented data showing the calculation of the annual soil productivity balance for the state of Ohio, based upon statistics of crop acreage and manure and fertilizer used in 1929. It is estimated that for the state as a whole the average soil erosion effect is equivalent to that for "Erosion Class 2" with no special control methods (see Table 10). Note that the "productivity value," shown in two right hand columns for a given crop, is the same percentage of the productivity index for the crop that the acreage of the crop forms of the total rotated area.

Table 11.—Data Showing Method of Calculating Annual Soil Productivity Balance as Applied to the State of Ohio. (Based on the Situation in 1929.)

Type of crop	Per cent of Rotated area	Productivity index	Productivity value	
			Positive	Negative
Corn, tobacco, potatoes, sugar beets	33.5	— 2.0		— 0.67
Small grains	30.7	— 1.0		— 0.31
Soybeans for seed	0.1	0.0		0.00
Hay and rotation pasture	35.7	+ 1.04[1]	+ 0.37	
Total	100.0		+ 0.37	— 0.98
Balance due to crop factor (+0.37 —0.98)				— 0.61
Reduction in balance for erosion (0.25 × —0.98[2])				— 0.24
Gain in balance for manure (1.6 × 0.125[3])			+ 0.20	
Gain in balance for fertilizer (60 divided by 200 × 0.125[4])			+ 0.04	
Total			+ 0.24	— 0.85
Annual Soil Productivity Balance				— 0.61

[1] Weighted index based upon the following proportion of hay crops: alfalfa, 7.7%; clovers, 26.0%; clover-timothy, 30.5%; timothy, 32.4%; soybeans, 3.0%.
[2] Assumes slight erosion, no special control methods, modifying erosion factor equals 0.25.
[3] Estimated manure application equals 1.6 tons annually per rotated acre.
[4] Fertilizer applied in state equivalent to 60 pounds per rotated acre.

From Table 11, it is indicated that soil productivity in Ohio is declining at an average rate of about 0.6 per cent annually. A better understanding of the significance of this figure is obtained by translating it into terms of a 50-year period. An annual loss of 0.6 per cent, compounded over 50 years, results in a total loss of soil productivity amounting to 26 per cent. In other words, if the present rate of loss continues unabated, the soils of Ohio will possess by 1986 a productive capacity only three-fourths as large as at present.

In Table 12 are shown data illustrating the calculation of the annual soil productivity balance for two crop rotations, both on land belonging to the same erosion class, but receiving different amounts of manure and fertilizer, and with no special erosion control methods in one case and strip cropping practiced in the other.

In Table 12, "Situation I" is fairly typical of that existing on much acid, slightly erosive land in Ohio. Such land must be declining rapidly in soil productivity, as indicated by its negative annual productivity balance of −1 per cent. "Situation II" represents a desirable and practical method for handling land of this character. The shift from Situation I to Situation II involves: (1) using sufficient lime to permit substituting alfalfa or alfalfa-grass mixtures for timothy, (2) increasing the length of rotation to provide two years of hay or rotation pasture, (3) doubling the amount of fertilizer, (4) taking better care of the manure, and (5) adopting the practice of strip cropping.

We call attention to a frequent pitfall in planning farming systems. On paper, a corn-wheat-clover rotation may conserve soil productivity; but in average practice the one constructive crop (clover) in this rotation does not regularly materialize. To gain a true picture of what is happening to the capacity of the soil to produce, the analysis must be made on the basis of crops actually obtained, not those hoped for!

Necessary Adjustments in Cropping Systems

Throughout the foregoing analyses, the influence of various soil and crop management procedures in modifying the capacities of our soils to produce have been noted. The soil of the average farm in Ohio is on the downward trend. What, then, are the general adjustments in cropping systems involved in staying the trend toward deterioration on rotated acres?

1. A reduction in the proportion of the rotated area planted to intertilled crops, particularly corn, and to small grains.
2. An increase in the proportion of the rotated area in sod crops.
3. An increased use of biennial and perennial legume sod crops — more clover, sweet clover, alfalfa, and mixtures containing alfalfa.

Not all three of these shifts will be required on every farm. For instance, the conservation balance may be reached or exceeded on some farms by procedures 1 and 2; on other farms by procedure 3 alone; while many farms will require all three.

Even before these adjustments are made, there are areas on which some of the present farm land should be removed from agricultural use. In other cases some of the rotated area should be transferred to permanent pasture.

Table 12.—Data Showing Method of Calculating Annual Soil Productivity Balance as Applied to Two Different Crop Rotations

Situation I

Rotation: Corn, wheat, timothy.
Manure applied during the rotation equals 5 tons per rotated acre.
Fertilizer applied in rotation equals 200 pounds per rotated acre.
Class 2 erosion, no special control measures.

Crop	Productivity value	
	Positive	Negative
Corn		— 2.0
Wheat		— 1.0
Timothy	0.0	0.0
Total	0.0	— 3.0
Balance due to crop factor		— 3.0
Reduction in balance for erosion (0.25 × — 3.0)		— 0.75
Gain in balance for manure (5 × 0.125)	+ 0.63	
Gain in balance for fertilizer (200 div. by 200 × 0.125)	+ 0.12	
Total	+ 0.75	— 3.75
Soil Productivity Balance		
(a) For Rotation		— 3.00
(b) Annual (— 3.00 div. by 3)		— 1.00

Situation II

Rotation: Corn, wheat, alfalfa, alfalfa.
Manure applied during the rotation equals 10 tons per rotated acre.
Fertilizer applied in rotation equals 400 pounds per rotated acre.
Class 2 erosion, strip cropping practiced.

Crop	Productivity value	
	Positive	Negative
Corn		— 2.0
Wheat		— 1.0
Alfalfa (2 yrs.)	+ 3.0	
Total	+ 3.0	— 3.0
Balance due to crop factor	0.0	0.0
Reduction in balance for erosion (0 × — 3.0)		0.0
Gain in balance for manure (10 × 0.125)	+ 1.25	
Gain in balance for fertilizer (400 div. by 200 × 0.125)	+ 0.25	
Total	+ 1.50	0.0
Soil Productivity Balance		
(a) For Rotation	+ 1.50	
(b) Annual (+ 1.50 div. by 4)	+ 0.38	

Important Practices Regulating the Adjustments

These adjustments in acreages and types of forage will not be made to a satisfactory extent, unless certain farm practices are considerably altered:

1. *Lime Applications.*—Concentrated, cooperative attacks on the problems of obtaining, applying, and financing lime are required. For soil conservation the annual usage of lime in Ohio should be increased to at least five times the maximum yet applied (see p. 13). On most farms, lime rather than fertilizer should be assigned the first dollars used toward soil improvement.

2. *Erosion Control Practices* — In addition to the increase in acreage of sod crops, and the improvement in quality of the sod, large areas of Ohio farm lands require additional erostion control programs (see page 14) involving: (a) rearrangement of fields, (b) contour farming, (c) strip cropping, (d) occasional terracing, and (e) reforestation.

3. *Conservation of Manure* — Wastage of the crop producing values in manure is unnecessarily high on the average farm. Its value in soil building programs is very definite and highly constructive (see page 14).

4. *More Success in Obtaining Grass and Legume Seedings* — Undoubtedly the difficulties in securing satisfactory stands of forage crops have discouraged and retarded shifts toward a greater proportion of sod crops. But these difficulties can be largely overcome by applications of proven systems of seeding to meet particular situations. When farmers definitely plan the making of seedings, successes are the rule. In the past, the seedings have been a by-product, rather than an objective, of our farming systems.

5. *Higher Quality Forage* — With large acreages in sod crops, attention will be directed toward their wider utilization as hay, silage, and pasture. Hays of high feeding values, capable of replacing appreciable portions of the grains formerly fed, can be obtained by observing proven rules on times of cutting and methods of curing.

How Can Farmers Use More Forage?

Great concern is sometimes expressed over what is to be done with the forage from the greater acreages of hay and rotation pasture. Again experience and experiments are in agreement. Underproduction rather than overproduction of forage has prevailed on Ohio farms. More forage may be used on most Ohio farms in one or more of the following ways:

1. Additional forage crops may be used for soil improvement only, with no or only partial removal of crops as hay or pasture.

2. Pasturing productive meadows is the best known solution to the critical shortages on permanent pastures in July, August, and early September. Adequate rotation pastures could also be used more generally for wintering sheep and cattle. At the present time, overgrazing of rotation pastures results in thin sods of reduced soil improvement value.

3. Rations for farm animals can be modified to include more hay, if it be of high quality, with a consequent reduction in feed grains, and an accompanying reduction in the cost of producing animal products. Health and length of life of livestock will be improved by greater use of high quality forage.

4. Some of the increased forage acreage may well be used for production of seed. More locally grown, well adapted seed will be required.

Would Higher Acre Yields Result?

A higher yield level almost invariably results in a lowered cost of producing a pound, a bushel, or a ton of a crop. Would the placing of Ohio farms on bases of conservation and improvement raise the existing yield level? This question has been answered practically and positively on many Ohio farms. For instance, a reduced acreage of corn, accompanied by an increase in the acreage of forage and the use of higher types of sod, would lead to higher acre yields of corn, for:

1. There would be more selectivity of the land put to corn,
2. Legume sods have a positive effect on yields of succeeding crops.
3. Soil preparation and cultivation can be done more thoroughly and more nearly on time, if there are less acres of corn.

Similarly, the cost of producing a bushel of corn or small grains on the more efficiently managed reduced acreage, could be further lowered by the more general application of moderate amounts of fertilizer.

Varieties of farm crops, more dependable in yield and quality, are being rapidly developed. The new corn hybrids, for instance, have a constructive and encouraging place in soil conservation programs, for they are more dependable in yield and less subject to seasonal influences than the open pollinated corn varieties. If adapted hybrids be used, reductions of 20 to 25 per cent in the intertilled corn acreages may be made with an expectation of the same total amount of corn.

Soil Productivity Indexes in Relation to Farm Inventories and Appraisals

No farm inventory or income statements, known to the authors, have evaluated the gain or loss in productivity of the soil during the year. The usual farm income statements may therefore deceive one, unless they contain debit or credit items for the productivity changes in the soil, just as depreciation or improvement of buildings and equipment are considered. We believe that applications of the soil productivity indexes may profitably be made both in determination of real farm incomes and in the making of accurate appraisals.

Many difficulties of landlord-tenant relationships may be eliminated by an appreciation and application of these same indexes. The foresighted landlord would no longer approve the mining of the soil if he realized that many of the usual cropping procedures waste the capital structure — the soil.

Soil Productivity — The Concern of All

Soil productivity is not a temporary asset nor is it of concern to a limited portion of the nation. It is a heritage affecting the farmer, the manufacturer, and the consumer. Over a period of years, farmers should profit by adopting methods that improve the soil. Ohio already has many far-seeing, successful farmers who are operating their farms with no loss in soil productivity — some are making gains. Apparent overproduction and potential future lack cannot be solved without a sensible program of conservation of soil resources. The adoption of soil management practices and cropping systems that provide for soil conservation and improvement are necessary to the permanent economic welfare of the nation.