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CHAPTER 13
USDA Soil Depletion Study of the Southern Iowa River Basin, USA

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13.1 INTRODUCTION

The soil depletion study (Rosenberry *et al*., 1980) used soil mapping units of the Soil Survey as the basis for extrapolation and the 1967 Iowa Conservation Needs Inventory as the initial data source. Three erosion phases were recognized: Phase 1 had no mixing of the surface and subsoils in the plough layer, phase 2 had some subsoil mixing in the plough layer, and phase 3 is where the plough layer is predominantly subsoil material. The sample data were sorted by county, land resource area, sub-basin and soil mapping unit. Crop land area was summed across all soil mapping units in each county and the totals were then adjusted to the crop areas reported in the 1974 Agricultural Statistics. Four land uses were reported: corn for grain, soy-beans, oats (includes all small grains) and hay (includes rotation pastures). The percentage of each soil mapping unit area in each land use was assumed to represent the rotation, i.e. 66% corn and 33% soy-beans represented a corn–corn–soy-beans rotation.

From the above information the gross erosion per unit area was computed for each production alternative by using the Universal Soil Loss Equation (Wischmeier and Smith, 1978). The individual soil losses were weighted to give an average soil loss for each mapping unit.

The tonnage of soil loss for each mapping unit was converted to depths of soil after adjusting for the bulk density of a partially compacted plough layer for each mapping unit.

The soil depletion study of the Southern Iowa Conservancy District covers 5.3 million acres (13.1 million hectares), with 3.5 million acres of crop land. The area is predominantly general grain and livestock farms and the topography is gently to strongly rolling with Wisconsinan loesses mantling earlier

Pleistocene tills. Soils are dominantly Mollisols with small areas of Alfisols. Surface horizons are silt loam, silty clay loam and loam, and the B horizons, if present, are fine silty, fine loamy and fine textures (Rosenberry *et al*., 1980).

The study was made to 'predict the effect that current levels of soil erosion, if continued, will have on individual soils in the Southern Iowa Conservancy District by the year 2020'. Production inputs and yields were estimated for each erosion phase of the soil. The study estimated the impact on productive potential and compared the productivity capacity in 1974 and 2020. The extra inputs required to keep yields at levels consistent with soil-test recommendations were estimated. A secondary goal was to examine six alternative methods of controlling erosion at tolerable levels and to determine the impacts of alternatives on land use and income. The authors defined tolerable erosion as: 'that amount of annual soil loss in tons per acre a soil mapping unit can lose and still be able to maintain its natural productivity and top soil over time'. No definition was given for natural productivity.

The logic used in computing soil degradation assumed a constant soil loss for each alternative between 1965 and 2020. The total tonnage eroded was converted to inches of soil and then the percentage of the soil mapping unit that degraded one erosional phase was estimated from a graph. The graph assumed an equal distribution of topsoil across each point on the scale from maximum to minimum topsoil for each phase. For example, 10% of the soil mapping unit would have the amount of topsoil allowed in the upper 10% of the erosional phase and 10% would have the amount allowed for the lower 10% of that phase. The other 80% would be evenly distributed throughout the remainder of the mapping unit.

Fuel requirements, fertilizer, pesticide and terrace costs were estimated for each mapping unit and adjusted when a soil changed from one erosional phase to another.

The conservation practices considered were rotations, contouring, terracing and residue management. The practices were combined so that soil loss was less than or equal to the tolerable soil loss that was assumed to prevent soil depletion. A total of six alternatives were examined:

(1) rotations alone with up-and-down the slope cropping and residue incorporated;
(2) rotations alone with up-and-down the slope cropping but 2500 pounds (1134 kg) of corn and 1000 pounds (454 kg) of bean residue left on the surface after planting;
(3) rotations and contouring, residues incorporated;
(4) rotations, contouring and residues on surface after planting;
(5) rotations and terracing with residues incorporated;
(6) rotations, terracing, and residue left on surface after planting.

Table 13.1 Harvested crop land (×1000 acres) by erosion phase, projected over time (Report Table 5)

Erosion phase[a]	1974	2000	2020
1	683	569	501
2	1217	1007	768
3	195	519	826
Totals	2095	2095	2095

[a]Erosion phase 1: no apparent or slight erosion, > 10 inches to B horizon: phase 2: moderate erosion, Ap may contain a mixture of A and B horizons, depth to B ranges from about 6 to 10 inches; phase 3: severely eroded, <3 inches of A horizon, the Ap is 50–100% B material.

13.2 RESULTS

About 1.4 million acres of crop land, nearly 40%, were within the tolerable soil loss limits in 1974. The authors assumed these soils would maintain their topsoil and their productivity. The other 60% of the soils were above the tolerable soil loss so, by the assumptions made, they would be degraded over time (Table 13.1).

The projected change in erosion classes requires 30% additional fertilizer to help counteract the depletion from erosion (Table 13.2). Yields are assumed to decrease as the soil is eroded from one phase to another (Table 13.3).

With the exception of alternative rotation (6), terracing and residue, the major impact of the alternative is to shift land from row crops to small grain and hay to bring all soils within the tolerable erosion levels. The decrease in projected income, averaged across all soils now exceeding the tolerable soil loss, is proportional to the area of row crops being taken out of production (Table 13.4).

Table 13.2 Increases in fertilizer needs (pounds/acre) as soil is depleted (Report Table 7)[a]

Change in erosion phase	Corn			Soy-beans			Oats		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
1–2	10	2	6		1	5	5	2	6
2–3	30	1	7		1	7	15	1	7

[a]From unpublished data, Iowa Agricultural Station, Ames, Iowa.
1 pound/acre = 1.12 kg/ha.

Table 13.3 Reduction in yield (per acre) as soil is depleted (Report Table 8)[a]

Change in erosion phase	Corn	Soy-beans	Oats	Hay
1–2	16	5	9 bu	0.6 ton
2–3	7	3 bu	4 bu	0.5 ton

[a]From Fenton *et al.* (1971); Soil Conservation Service, Iowa 2, US Dept. Agric., Feb 1969.
1 US bushel = 32.24 dm^3; 1 acre = 0.405 ha; 1 ton = 1.016 t.

13.3 CONCLUSIONS

The authors of the study concluded that the cost of reducing soil erosion to tolerable levels is three times as expensive as benefits. Farmers will be hard-pressed to finance erosion control without some form of assistance. The authors believed that the used surface residues with rotations and contouring can be an important and economically feasible method of controlling erosion. They also concluded that fertilizer can offset yield reductions for a short time, but cannot prevent a decrease in potential productivity.

13.4 CRITIQUE

The study of erosion's impact on the Southern Iowa Conservancy District used the best available information in its computations. Some refinement probably could be made, but it is doubtful if the results or conclusions would be changed significantly. We need to look at the basic assumptions of the study, however, some of which were:

(1) The Universal Soil Loss Equation is applicable to the study and can be used to predict rates of erosion and interpret the amount of soil degradation.
(2) There apparently was no allowance made for regeneration of the topsoil, although mixing of topsoil and B horizon were recognized.
(3) The tolerable level of erosion is the T value set for each mapping unit. This level of erosion, if not exceeded, will maintain the productivity of the soil, but degradation will start when the T value is exceeded. In other words, surface horizons are generated at a rate equal to the T value. If the tolerable annual soil loss is 5 tons per acre (12.6 t/ha), then 1 inch (25 mm) of surface horizon is produced every 30 years. Assumptions 2 and 3 are contradictory.
(4) The mapping or identification of erosion phases is accurate.
(5) The reduction in productivity with increasing erosion applies equally to all soils.

Table 13.4 Comparison of alternative methods of controlling soil erosion from water runoff (Report Table 10)

Alternative	Row crop	Close grown	Hay	Residue	Terraced	Net Income (lost dollars)
				(×1000 acres)		
(1) Rotation control	−1190	274	911	0	0	97 260
(2) Rotation and residue	−881	210	679	1727	0	66 043
(3) Rotation and contouring	−809	206m	603	0	0	59 388
(4) Rotation, contouring and residue	−623	244	379	1725	0	34 478
(5) Rotation and terracing	−243	128	116	0	2009	99 216
(6) Rotation, terracing and residue	401	−168	−233	1586	2009	49 473

The Universal Soil Loss Equation was specifically designed and field tested to predict the average annual soil movement from a given field slope under specified land use and management conditions and to estimate the reduction in soil loss from various changes in cropping systems and cultural practices (4). The question is whether the equation can be used effectively in estimating soil loss from county-wide mapping units, since it was designed primarily for a single field application. Rosenberry *et al*. defined *L*, the slope-length factor, as the distance from the top of the hill to the sediment fan at the bottom of the slope. Yet Wischmeier and Smith (1965) defined effective slope length as: 'the distance from the point of origin of overland flow to the point where either the slope decreases enough that deposition begins or runoff water enters a well defined channel'. Few details were given by Rosenberry *et al*. on how an average slope length or percentage slope was derived for each mapping unit. However, they stated that if two mapping units were on one slope, the soil at the bottom would have the entire slope length for *L*.

Most mapping units subject to erosion have an uneven topography that varies from convex to concave, and most have first- and probably second-order stream channels to route the runoff. The delineations are irregular in shape and a sloping unit may occupy narrow spur ridges as well as valley slopes. The uneven or irregular slopes need to be divided into relatively uniform segments but may or may not be treated as independent units (Wischmeier, 1977). Establishing an average slope length and percentage slope would require many measurements for each mapping unit. The slope length from the ridge crest to depositional footslope ignores the converging water flow in the concave areas, potential depositional areas, and the diverging or straight flow, usually eroding segments, in other areas. It is also possible for slope length to be made longer and shorter than normal by cultivation patterns. Thus, the slope-length factor, which is very important in determining soil loss for slopes above 3% (Williams and Berndt, 1977), is probably overestimated by Rosenberry *et al*. on slopes over 3% where most of the erosion occurs. The question that needs to be carefully examined is how one applies the Universal Soil Loss Equation to predict erosion from large areas when each delineation is a special problem unto itself.

Although it was not directly stated, apparently no allowance was made for regeneration of the surface or A horizon in mapping units where erosion exceeded the tolerable limit. If topsoil and productivity can be maintained at a *T* value of 5 tons per acre per year, with the inference that this is the rate of regeneration (McCormack *et al*., 19??), why should not 6 or 8 tons per acre per year erosion be the equivalent loss of only 1 or 3 tons when computing topsoil or productivity losses for that soil? A 6-ton soil loss should be an effective loss of 1 inch of surface soil in 150 years. This means that a 6-inch plough layer or surface horizon would still be 5 inches thick at the end of 150 years, not lost completely at the end of 150 years (based on 150 tons/acre/

Table 13.5 Guide for assigning soil-loss tolerance values *T* to soils having different rooting depths

Rooting depth (inches)	(cm)	Soil-loss tolerance values (Annual soil loss, tons/acre) Favourable substrata[a]	Unfavourable substrata[b]
0–10	0–25	1	1
10–20	25–51	2	1
20–40	51–102	3	2
40–60	102–152	4	3
60+	152+	5	5

[a]Can be renewed by cultural and management practices.
[b]Substrata such as rock or soft rock that cannot be renewed by economical means.
1 ton/acre = 2.51 t/ha.

inch) as apparently as assumed by Rosenberry *et al*. If any consideration is given to regeneration of the A horizon it would decrease the rate of topsoil loss so the interval between changes from one erosion class to another would increase and the computed loss of soil productivity would be much less. There, of course, must be an upper limit; i.e. if erosion is 40 tons per acre per year it is doubtful there would be any regeneration of the surface horizon.

Soil-loss tolerance is defined as the maximum rate of annual soil erosion that will permit an economically high level of crop productivity to be maintained indefinitely (McCormack *et al.*, 1982). Guidelines for soil-loss tolerance were formulated in the early 1960s after years of discussion by soil scientists, agronomists and others. During 1961 and 1962 the Soil Conservation Service held regional workshops where the guidelines for establishing soil-loss tolerances and the *T* values were set for the major soils. A maximum of 5 tons/acre (12.6 t/ha) per year was established. Current Soil Conservation Service guidelines are (*Guide*, 1973):

(1) An adequate rooting depth must be maintained.
(2) Soils that have significant yield reduction when the surface layer is removed by erosion are given lower soil-loss tolerance values than those where erosion effects yields very little.

A maximum of 5 tons soil loss per acre per year was selected for use with the Universal Soil Loss Equation for the following reasons:

(1) Soil loss in excess of this value affects the maintenance, cost and effectiveness of water control structures affected by sediment.

(2) Gully erosion accompanies excessive sheet erosion in many places.
(3) The loss of plant nutrients is excessive with greater soil losses.
(4) Numerous practices can keep soil losses below this value.

The prevention of off-site damages by sediment was also used to limit the maximum soil loss to 5 tons per acre per year. The guidelines used by the Soil Conservation Service do not document the supporting data for establishing the allowable soil loss. Such documentation is difficult to find, and when presented is often of questionable value. For example, Browning *et al*. (1948, 1949) were among the first papers to establish a maximum allowable soil loss. They stated that: 'all known conservation practices may be needed if soil losses are to be reduced to an allowed minimum and the productivity is to be maintained over a period of time'. In a paper published while the 1948 paper was in press, Browning *et al*. stated that soil loss should be reduced so that productivity will be maintained over a period of time. To accomplish the above, gully formation must be prevented and loss of fertility by erosion, leaching and crop removal should not exceed that which is being replaced or built up from the lower soil by management practices. They developed a table showing permissible soil loss for a number of Iowa soils but gave no details in either paper on criteria used and what evidence supported the figures given.

Smith and Stamey (1965), in a discussion on determining tolerable erosion rates, quoted Chamberlin's remark (1908) that a foot (30.5 cm) of soil developed in 10 000 years as a mean rate of soil formation. Chamberlin's ideas were based on observations of the Mid-west Pleistocene in the period before radio-carbon dating drastically shortened the time intervals between deposits and increased the rates of soil formation. After citing Jenny's (1941) review of rates of soil formation, Smith and Stamey (1965) used a renewal rate of 0.2 tons for weathering of the average rock and between 0.1 and 0.6 tons from adjusted erosion under close-growing vegetation if a balance were assumed between erosion and renewal. These renewal rates from Smith and Stamey are for weathering of parent material, not development of surface horizons from B horizon material.

Van Doren and Bartelli (1956) maintained that the rate of weathering of soil material, the soil-building potential of the material under the surface soil, the texture of the subsoil, the climate, and a host of other factors should be considered when assigning a permissible soil-loss value. These authors used crop yield data and its variation with surface depth to help establish permissible soil-loss rates. The assumption was made that the Tama soil could lose 4.5 tons per acre (11.3 t/ha) per year without materially affecting crop yields. The 1 inch (25 cm) of soil lost about every 35 years would be compensated for by the management practices used so that crop production would be maintained. There was no evidence presented that supported the assumption that 1 inch of topsoil could be formed every 35 years, but it probably came from

Bennett's (1939, pp. 8, 95) ideas on how fast topsoil forms under natural conditions and Hudson's (1971, p. 36) inference that modern agriculture could build surface soil at about this rate.

Although the allowable erosion rates have been used for many years, the rates apparently are based upon the experience of a large number of individuals and have been arrived at more or less by committee vote. Hard evidence to support the decision is scarce. As Smith and Wischmeier (1962) stated: 'establishing the tolerance values (for allowable soil loss) has been largely a matter of judgment'. It remains so today. But no better alternative exists because research has not established the hard data, nor is it likely to in the near future.

Major criticism of attempts to establish allowable erosion rates by most authors or organizations were not documented, or the documentation is difficult to obtain so that someone else can logically reconstruct the information used and arrive at a similar conclusion.

The unstated assumption by Rosenberry *et al*., that soil erosion maps are accurate, must also be challenged. There are few uniform areas of moderate or severe erosion. Most delineations of erosional map units, especially at scales of 1:20 000 to 1:24 000, have areas of phase 2 and 3 erosion because the landscape within the delineation is not uniform and has areas of erosion and deposition. The minimum size delineation on the small-scale maps is about 5 to 10 acres, so micro landscapes can occur within each delineation.

Dideriksen (1966) summarized the plot data from various mapping units in Iowa and evaluated the correctness of mapping series, slope, and erosion based upon concepts and criteria used at that time. These data are summarized by series and slope group in Table 13.6. The plots were drawn randomly from a 2% statistical study used in the Conservation Needs study. A point was located by drawing random numbers to determine the corner of the quarter section and distance along the X and Y axes. From Table 13.6 it is evident that erosion was mapped correctly most of the time, especially on the lesser slopes. These data are somewhat surprising because most studies have indicated wide variability within mapping units (McCormack and Wilding, 1969; Amos and Whiteside, 1975). When only phase-3 map units are considered, erosion was mapped correctly on 28 out of 34 plots studied, or about the same percentage as shown for all erosion phases in Table 13.6. But it must be recognized that these data are from loess soils and the uniformity under these conditions is probably much greater than in more complex parent materials and landscapes.

If Dideriksen's summary is correct, erosion on about 70–80% of the severely eroded map units is correctly classified. But this also means that about 20–30% of the map unit is less severely eroded and can produce from 7 to 23 bushels more corn per acre (Table 13.3). At a minimum this is a productivity under-estimation of 1.5–3 bushels of corn per acre if yields are

Table 13.6 Summary of corn yield sites—testing series slope, erosion groups (Dideriksen, 1966)

Series	Slope (%)	Number of sites	Average percentage correctly mapped		
			Series	Slope	Erosion
Ida	5–9	12	91	100	91
	9–14	10	80	70	60
	14–20	7	71	100	86
Monona	0–2	3	66	100	100
	2–5	10	60	100	90
	5–9	13	69	100	69
9–14	9–14	16	100	100	94
	14–20	7	57	86	71
Marshall	0–2	5	76	98	84
	2–5	12	83	66	83
	5–9	14	79	100	71
	9–14	10	70	80	80
Sharpsburg	0–2	2	100	100	100
	2–5	9	63	100	78
	5–9	11	55	90	73
Tama	0–2	2	100	100	100
	2–5	2	100	100	100
	5–9	4	100	100	75
Shelby	5–9	1	100	100	100
	9–14	9	77	89	100
	14–18	2	75	92	100

near 100 bushels per acre, or well within the experimental error. But the apparent high accuracy of mapping erosion shown by Dideriksen's data may be an artifact of a small number of plots located in the more complex landscapes of the severely eroded phase-3 units. Final judgement should be withheld until yield data for individual delineations are available, especially in the more complex landscapes.

The areal extent of other erosion phases within a mapping unit needs to be known to predict the changes in productivity with continued erosion. For example, if all convex areas in the mapping unit have the B horizon as the plough layer, will continued erosion increase the area of severely eroded soils significantly? Will continued erosion remove the surface horizon from the straight and concave slopes so the entire map unit is severely eroded? If the area of severely eroded soil within the map unit does not expand significantly with continued erosion, productivity should stabilize, providing unfavourable horizons are not exposed on the eroding areas.

Rosenberry *et al*. assumed the same reduction in yield for all soils when changing from one erosion phase to another (Table 13.3). Yet in the original publication, Fenton *et al*. (1971) recognized that the decrease in yield was greater for some soils than others as erosion phases changed. The use of a constant decrease in yield for each phase change may have changed the overall results very little, but for the individual mapping units the change can be considerable.

Much of the work cited by Rosenberry *et al*. to support their productivity analyses is unpublished yield data from Iowa State University. These data were collected from plot studies where each plot was classified by an experienced soil scientist. Thus the change in productivity with increasing erosion shown in Table 13.3 should be an accurate prediction for the area of a mapping unit within a specific erosion phase. But if more than one erosion phase is included within a mapping unit, the map units' productivity would be over-estimated or under-estimated by assuming that the area was all one erosion phase. Considering the normal inclusions within various mapping units, it is probable that Rosenberry *et al*.'s analysis over-estimated the decrease in productivity with continuing erosion.

13.5 SUMMARY

The study by Rosenberry *et al*. used the best available information to compute the impact of erosion on productivity. Procedural changes are probably not warranted in most cases, except the method for determining slope length, and some allowance should be made for regeneration of the surface horizons. The major problem is that the assumptions used—such as (i) that regional erosion can be computed by the Universal Soil Loss Equation, (ii) that erosion rates equal to or less than the T values will permit long-time production by maintaining the surface horizon, or if the T value is exceeded production will decrease; (iii) that A horizons or surface soil can be generated at a rate of 1 inch per 30–35 years under modern cultural practices—are not supported by adequate data or rigorous field testing. The stated and unstated assumptions used in the study have been accepted and used for 20 years or more. While unsupported by data in many cases, the judgements were made by knowledgeable individuals using the best available information at that time. It is doubtful that we could do any better if it had to be done today with current information. It is also doubtful that additional research could give better data for a considerable period because how do you approach the problem except through inference based on past history, including the Holocene? However, this still does not excuse us for blindly accepting assumptions that have questionable validity, or for not documenting how decisions were reached so that others can evaluate their validity as new evidence becomes available.

13.6 CHANGES IN SOIL PROPERTIES PRODUCED BY CULTIVATION

Soil degradation, if defined as the changes from a virgin profile, is easy to prove in Mollisols or other soils with thick dark A horizons, because a large

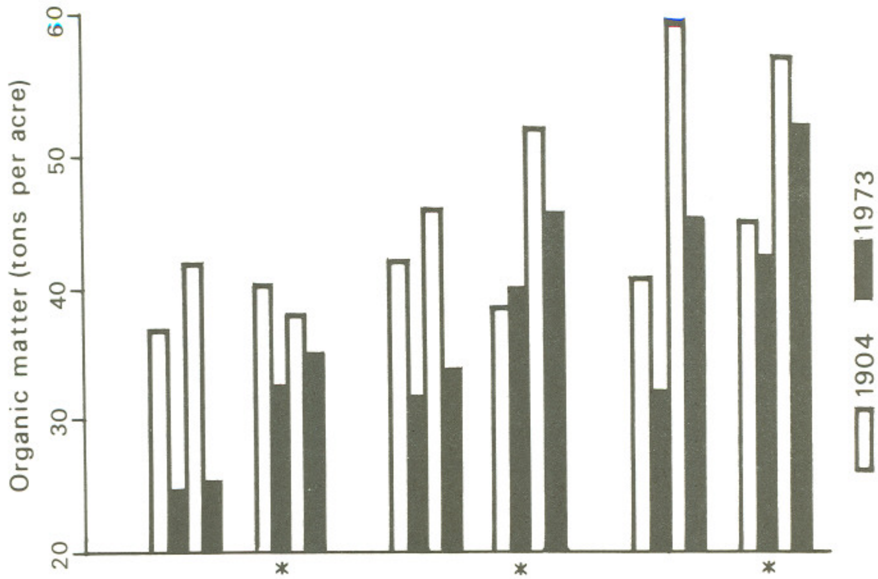

Figure 13.1 Organic matter content in the surface soils of selected sub-plots of the Morrow Plots in 1904 and 1973 (Welch, 1981, unpublished data)

decrease in organic matter usually occurs within a short time (Guernsey *et al*., 1969). Other changes are more difficult to document because many of the measurements required were not developed until recently, or the data are not available on virgin pedons.

Probably the best source for changes in Mollisols is the Morrow Plots in Illinois. These plots were established in 1876 on a nearly level Flannigan silt loam, a fine, montmorillonitic, mesic aquic Argiudoll, with about 18 inches (46 cm) or more of A1 horizon. Cultivation has produced some marked changes depending upon the treatment (Figure 13.1). The amount of organic matter has decreased from 1904 to 1973 in all plots, although at different rates (Figure 13.2—sample dates were 1904, 1913, 1923, 1933, 1944, 1953, 1955, 1961, 1967 and 1973). The two interesting points about Figures 13.1 and 13.2 are that a rotation of corn–oats–clover retained a relatively high organic matter status, and lime, nitrogen, phosphorus and potassium additions on continuous corn after 1954 increased the organic matter content by 1973 by about 5 tons per acre. The rotation corn–oats–clover rotation with manure, lime and phosphate was able to retain >85% of the original organic matter and nitrogen (Table 13.7).

Guernsey *et al*. (1969) found a higher total root weight of corn in the corn–oats–clover rotation plot than in the untreated continuous corn sub-plot. The A horizon averaged about 8 inches (20 cm) thicker and was more

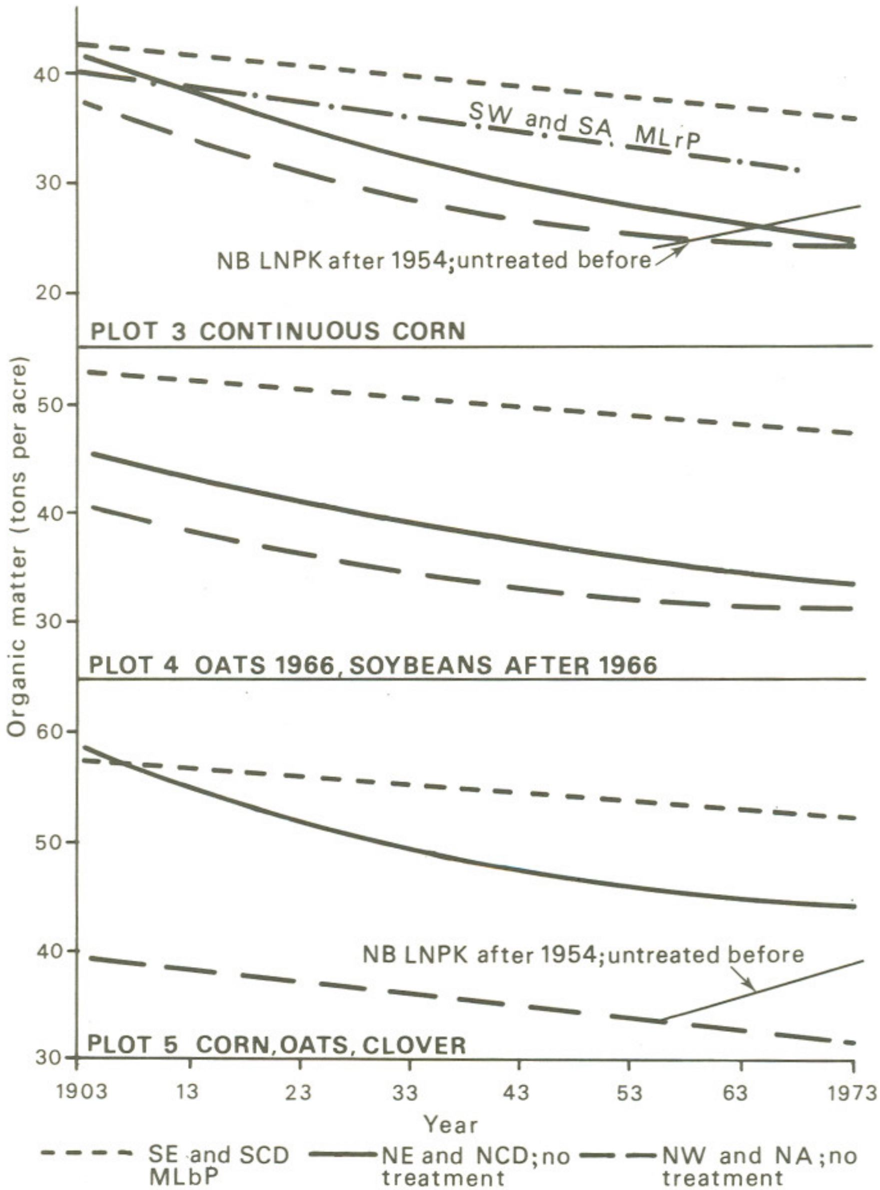

Figure 13.2 Trends in organic matter content of surface soils on the Morrow Plots, 1904–73 (Welch, 1981, unpublished data)

Table 13.7 Data from the Morrow Plots (see Figures 13.1, 13.2 and the text) (Welch, 1981, unpublished data)

Crop history and soil treatment	Organic matter		Nitrogen	
	(tons/acre)	(%)	(lb/acre)	(%)
Sod border; no treatment	60.1	100	5237	100
Corn–oats–clover; MLP treatment	53.7	89	4550	87
Continuous corn; no treatment	28.7	48	2640	50

From L. F. Welch, 1981, Univ. Ill.—unpublished data.

porous on the rotation plot than on the continuous corn plot. Stauffer *et al.* (1940) found similar trends in the Morrow Plots in 1940 and that only the corn–oats–clover fertilized rotation materially increased the amount of large aggregates in the upper 6 inches compared with the continuous unfertilized corn plots.

Similar changes have probably taken place in other Mollisols. Very little data are available from specific plots on the changes in bulk density, aggregation, water-release curves and moisture retention produced by cultivating a virgin Mollisol. Most comparisons are made from adjacent fence rows or 'similar' soils. Such data will be difficult to obtain because there are few virgin sites left—probably not even enough to characterize the natural variability within the same soil. But comparing soil properties on virgin and cultivated soils is, in part, a negative academic exercise. It is nearly impossible using present technology not to 'degrade' or change some soil property. Maintaining a 'virgin' level of organic matter in Mollisols is not economically feasible or even desirable in most cultivated soils. The very act of cultivation to produce the desired seed-bed will areate the soil, oxidize more organic matter, and change the aggregation. Drainage, necessary to produce crops on wet soils, also increases the rate of organic matter oxidation. What is important is what has happened to the productivity of the soil using present technology—has it decreased, remained the same or increased? What can be done with what soil is remaining?

The best measure of productivity is yield, and in Iowa that means corn yields. Tables 13.8 and 13.9 are the average corn yields for counties within the Southern Iowa Conservancy district. Adair County is in the Shelby–Sharpsburg–Macksburg soil association area, Page County is about evenly split between the Marshall and Shelby–Sharpsburg–Macksburg soil association areas, and Wayne County is in the Adair–Grundy–Haig soil association (Fenton *et al.*, 1971). Estimated obtainable yields for the major

Table 13.8 Corn for grain: areas harvested and yield[a]

	Adair		Page		Wayne	
Year	(acres)	(bu/acre)	(acres)	(bu/acre)	(acres)	bu/acre)
1879	80 008	39.4	133 631	47.1	88 081	39.5
1890	91 581	40.9	112 591	47.8	67 560	40.8
1899	112 723	42.7	132 601	43.2	71 908	26.9
1909	98 366	33.3	109 725	38.5	76 911	25.3
1919	101 898	41.0	96 646	36.8	69 267	31.0
1924	90 838	25.6	108 180	31.5	67 186	24.8
1925	98 050	34.9	102 165	36.0	66 338	27.6
1934	5 616	5.3	14 805	7.3	6 794	4.5
1940	89 010	39.9	96 411	43.9	45 651	36.1
1945	92 941	37.4	115 039	46.4	77 836	24.7
1954	87 574	42.3	95 333	28.9	54 178	26.3
1959	94 783	62.6	105 404	56.8	57 239	47.8
1964	82 554	73.6	85 124	64.1	46 820	67.3
1969	75 405	87.9	86 155	90.7	45 504	75.6
1974	97 636	57.3	98 864	44.1	–	69.4
1978	102 997	103.7	103 380	97.2	57 227	100.9

[a]Source: US Census of Agriculture.
1 US bushel = 35.24 dm^3; 1 acre = 0.405 ha.

soils for each county are given in Table 13.10. The corn yields were relatively steady from about 1879 until 1900 when a slight decrease occurred from 1900 to 1929. The changes may not be statistically significant. The abrupt drop in areas harvested and yield in 1934 is the result of an extremely hot and dry summer. In most counties the area harvested for grain remained relatively high with the maximum area being in the late 1800s. Starting in the mid 1950s, the corn yields increased dramatically, and while fluctuating considerably have continued to increase until 1980. In 1979, the county average yields in all three counties were higher than the estimated attainable yield predicted by Fenton *et al.* in 1971. Page County, with an average yield of 133.4 bushels per acre in 1979, was about 20 bushels greater than the predicted attainable yield for the major soil (Table 13.10). Nineteen seventy-nine was an almost perfect year for corn production, but the average yields obtained in the above counties (Table 13.9) illustrates how rapidly corn yields have been increasing.

What has been responsible for the increase in corn yields? Thompson (1969) and Thompson and Troeh (1978) believe that the increases in corn yields have been due to improved technology (increased fertility level, better varieties, hybrid corn, higher plant populations, better weed control, and timely operations) and favourable weather. The cooler-than-normal weather and above-normal precipitation favoured high corn yields during the 1960s

Table 13.9 Corn yields (bushels/acre), Southern Iowa Conservancy District, 1942–80[a]

Year	County			Year	County		
	Adair	Page	Wayne		Adair	Page	Wayne
1942	51.4	47.6	48.1	1962	74.6	71.3	57.7
1943	50.6	52.3	35.4	1963	83.4	84.0	73.0
1944	43.0	49.4	33.9	1964	73.6	64.1	67.3
1945	37.4	46.4	24.7	1965	76.0	82.8	68.2
1946	56.8	51.9	43.3	1966	82.8	83.5	79.6
1947	20.8	31.9	15.7	1967	78.0	80.4	67.9
1948	59.3	54.3	46.1	1968	83.2	59.3	84.6
1949	45.0	45.3	44.0	1969	87.9	90.7	75.6
1950	49.4	55.0	42.0	1970	83.9	75.6	79.1
1951	36.4	34.1	29.1	1971	95.0	97.0	94.0
1952	58.2	56.7	46.8	1972	104.0	106.0	104.0
1953	46.1	50.0	37.1	1973	104.1	102.1	94.9
1954	42.3	28.9	26.3	1974	57.3	44.1	69.4
1955	40.8	32.8	36.5	1975	65.6	70.7	75.2
1956	50.4	42.2	46.3	1976	99.0	98.5	93.2
1957	52.2	50.8	48.0	1977	50.1	66.6	53.7
1958	64.6	61.6	54.3	1978	103.7	97.2	100.9
1959	62.6	56.8	47.8	1979	114.7	133.4	111.5
1960	62.0	63.3	49.6	1980	89.7	73.5	95.3
1961	69.1	64.7	57.3				

[a]Source: Iowa Statistical Reporting Service.
1 US bushel = 35.24 dm^3; 1 acre = 0.405 ha.

Table 13.10 Estimated obtainable yields (bushels/acre) for corn (Fenton *et al.*, 1971)

Adair County		Page County		Wayne County	
Soil series	Corn yield	Soil series	Corn yield	Soil series	Corn yield
Shelby	81–90[a]	Marshal	99–107	Adair	65
Sharpsburg	113–105	Sharpsburg	113–105	Grundy	87–107
Macksburg	121	Shelby	81–90	Haig	105

[a]Range for slope and erosion phases.
1 US bushel = 35.24 dm^3; 1 acre = 0.405 ha.

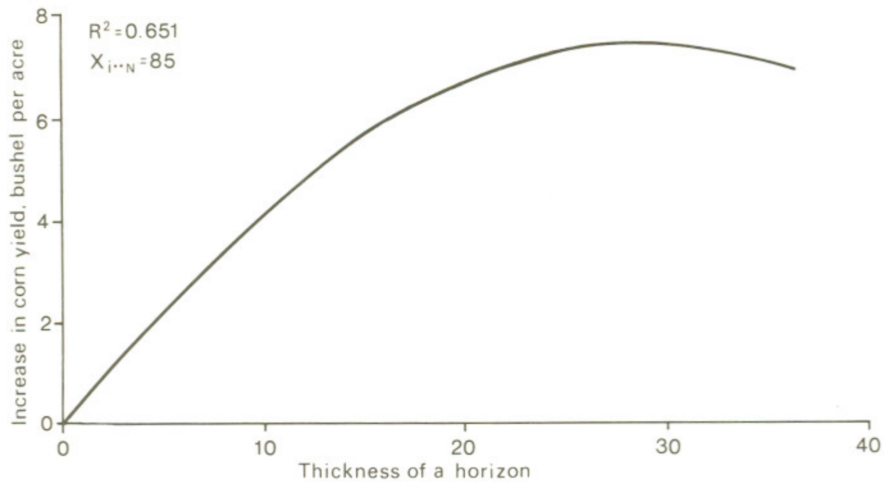

Figure 13.3 Correlation between the thickness of A horizon and increase in corn yield in Iowa (Dumenil, 1976, unpublished data)

(Thompson and Troeh, 1978; Shaw and Duorset, 1965; Hendricks and Scholl, 1943). Thompson (1973) also believes that heating and cooling cycles last about 10 years, i.e. cool summers in the 1940s and 60s, and warm summers in the 1930s, 50s and 70s relate to corn yields. Some of the yield variability, especially in the 1970s (Table 13.9), may be explained by temperature and moisture variations.

The high corn yields have been produced regardless of the degradation or changes in soils since they were first cultivated. Unpublished work by Dumenil at Iowa State University (Figures 13.3, 13.4, 13.5) show the correlation between thickness of A horizon, erosion class, the amount of organic carbon and corn yields in Iowa. The figures shown are summarized from several years' plot data taken in farmers' fields on some of the major soils in Iowa. Even under improved technology and rising yields, any decrease in organic carbon below about 4%, or decreased thickness of the A horizon below about 25 inches (63 cm), results in a loss of corn yield. The same applies when erosion class is changed to one of greater severity.

Dumenil's data require a cautious interpretation because there is not a simple relation between corn yield and A horizon thickness: several interactions need to be considered. Not all soils initially had the same thickness and organic carbon content of the A1 horizon and the same productivity capacity. The micro-environment such as drainage, runon or runoff, aspect, slope gradient, etc., can have a considerable effect on yields in any year. The temperature regimes and moisture-supplying capacity of the soil during the

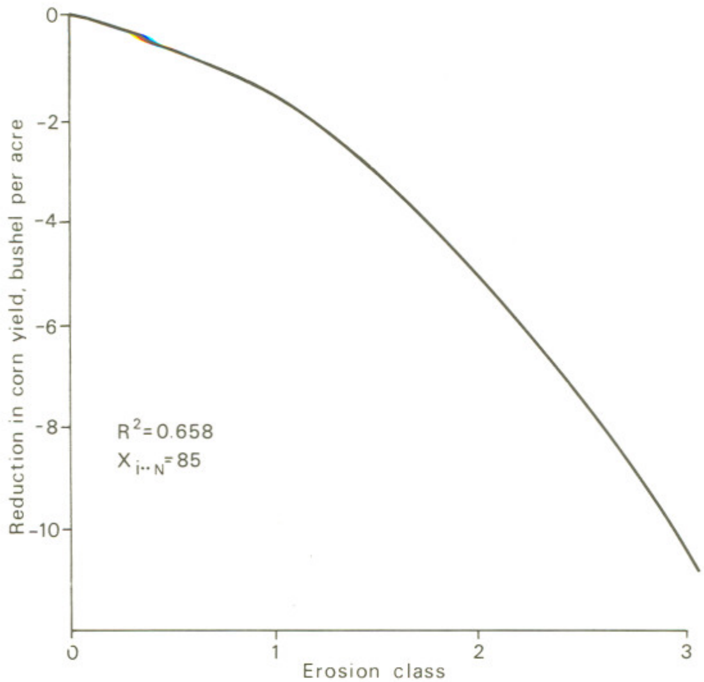

Figure 13.4 Correlation between erosion class and reduction in corn yield in Iowa (Dumenil, 1976, unpublished data)

critical periods of crop growth are very important, especially in high-management rain-fed agriculture. A soil on a level surface or a slight depressional area with 25 inches of A1 horizon has a much different environment from a soil in similar materials on a 10% convex nose slope with only 5 or 6 inches of A1 horizons. The productivity capacity also has to be different, especially when moisture and temperature regimes are different. To illustrate, Sopher *et al.*'s (1973) data from North Carolina indicate that corn yields on wet soils are improved by spring drought but decreased on well-drained soils. Cold, wet springs favoured yields on the well-drained soils compared with their wetter counterparts. Corn yields on wet soils commonly are reduced under conservation or no-till compared to ploughed soil, apparently because lower temperatures and damp conditions lead to a wide variety of processes unfavourable to maximum yields (Van Dorin *et al.*, 1976; Griffith *et al.*, 1973; Unger and McCalls, 1980). There is a lot more to high yields than organic matter or A1 horizon thickness, although this is part of it. Simple correlations of yields with organic matter combine several micro-environmental features that are equally as important as the organic matter.

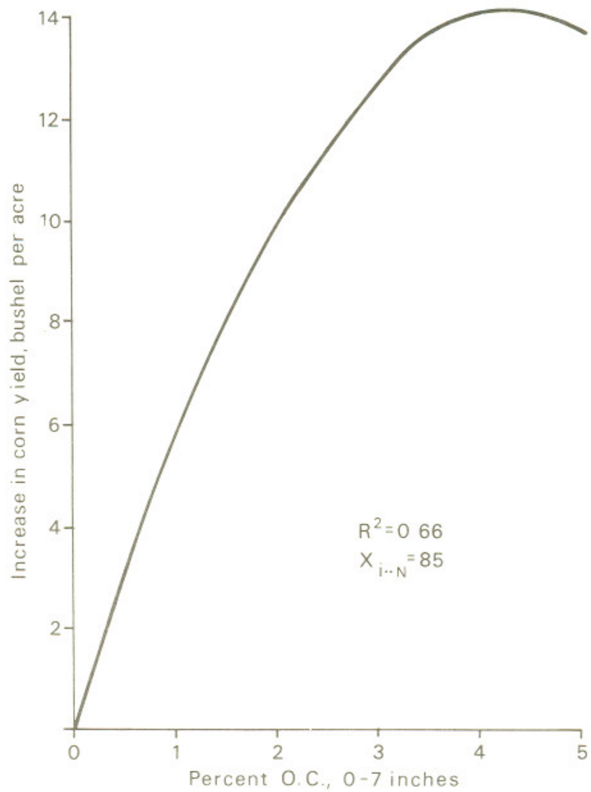

Figure 13.5 Correlation between amount of organic carbon and increase in corn yield in Iowa (Dumenil, 1976, unpublished data)

Every manipulation of the soil changes some soil property, but not always for the worse. The carbon content of a soil in the Morrow Plots that had been under continuous corn for nearly 100 years increased considerably when lime, nitrogen, phosphorus and potash were added (Moldenhauer, *et al*., 1967; Barnhart, *et al*., 1978; Figure 13.2). The increase was about five tons of organic matter in about 20 years. Tables 13.11 and 13.12 are from the Morrow Plots in Illinois and show the changes in treated and untreated plots across three rotations. The base data are not available for the condition of the plots in 1876, but Tables 13.11 and 13.12 do indicate that management can easily alter the nutrient status and pH of the soil surface. There is also some unpublished data indicating that the nutrient status of the B horizons of many soils are increasing with continued cultivation and addition of amendments.

Although certain changes have taken place in the soils of the Southern

Table 13.11 Summary of surface soil tests for the Morrow Plots during selected years, 1955–77[a] (Welch, 1981, unpublished data)

			pH						P_1						K	
Plot	Cropping system	Soil treatment	No. of obs.	Mean (lb/acre)	R^2	Coef. of var.	Inter-cept a	Reg. coef. b	No. of obs.	Mean (lb/acre)	R^2	Coef. of var.	Inter-cept a	Reg. coef. b	No. of obs.	Mean (lb/acre)
						(%)						(%)				
3NACD	Continuous corn	Not treated	7	5.2	0.947	1.3	4.8	0.030[e]	7	15	0.785	12.0	19.1	−0.373[e]	7	206
3NB[b]	Continuous corn	LNPK after 1954; untreated before	6	6.0					6	40					6	246
3SCD	Continuous corn	MLbP	7	6.5					7	79					7	273
3SB[b]	Continuous corn	MLrP 1904–54 + LNPK after 1954	7	6.3					6	55					6	271
3SA[c]	Continuous corn	MLrP 1904–66	3	6.6					3	73					3	277
3SA[d]	Continuous corn	MLrP 1904–66 + Hi LNPK after 1966	4	6.2					4	108					4	346
4NACD	Corn Oats through 1966 S.B. after 1966	Not treated	7	5.3	0.788	2.7	5.0	0.030[e]	7	13	0.910	9.0	17.9	−0.416[e]	7	206
4NB[b]	Corn " " "	LNPK after 1954; untreated before	6	6.1					6	50					6	251
4SCD	Corn " " "	MLbP	7	6.4					7	47					7	274
4SB[b]	Corn " " "	MLrP 1904–54 + LNPK after 1954	7	6.4					6	51					6	297
4SA[c]	Corn–oats	MLrP 1904–66	3	6.6					3	41					3	252
4SA[d]	Corn-soybeans	MLrP 1904–66 + Hi LNPK after 1966	4	6.4					4	112					4	362
5NACD	Corn–oats–clover	Not treated	7	5.2	0.784	2.5	4.9	0.026[e]	7	10	0.913	15.0	16.4	−0.549[e]	7	214
5NB[b]	Corn–oats–clover	LNPK after 1954; untreated before	6	6.0					6	39					6	246
5SCD	Corn–oats–clover	MLbP	7	6.5					7	45					7	234
5SB[b]	Corn–oats–clover	MLrP 1904–54 + LNPK after 1954	7	6.6					6	90					6	280
5SA[c]	Corn–oats–clover	MLrP 1904–66	3	6.8					3	35					3	236
5SA[a]	Corn–oats–clover	MLrP 1904–66 + LNPK after 1966	4	6.7					4	96					4	321

[a]Soil tests were studied for the years 1955, 1957, 1961, 1967, 1970, 1974 and 1977.
[b]Soil samples were collected in April 1955 before new treatments were applied in May 1955 on sub-plots 3, 4 and 5NB and 3, 4 and 5SB. Therefore, the results of 1955 soil tests for plots 3, 4 and 5NB and the P_1 and K tests in 1955 for sub-plots 3, 4 and 5SB were not included in the analysis.
[c]1966 and before.
[d]After 1966.
[e]Highly significant.

Table 13.12 Interpretation of soil tests for the Morrow Plots (Welch, 1981, unpublished data)

		Available nutrients (lb/acre)	
pH	Soil reaction	P_1	K
5.1–5.5	Strongly acid	0–12 (very low)	0–90
5.6–6.0	Medium acid	12–20 (low)	90–135
		20–30 (slight)	135–180
6.1–6.5	Slightly acid		
6.6–7.3	Neutral	30–45 (medium)	180–300
		45–65 (high)	300–400
7.4–7.8	Mildly alkaline	>65 (very high)	>400

Conservancy District that have lowered corn yields under specific levels of management and weather conditions, improved technology has increased the total yield per acre considerably. There are many unanswered questions; but Figures 13.3 and 13.4 indicate that, even under the most severe conditions of removal or loss of the A horizon, the decrease in production will be about 10 bushels per acre, or about 10–12% of the maximum 'attainable' yield for the soils tested. Ninety plus bushels of corn per acre is not as good as 100 plus, but it is still much better than the 40 bushels or less grown during the last part of the 1800s when the soils were first broken from the prairie sod (Table 13.9). It is difficult to argue with success when the apparent productivity is still rising. However, 30 years is a short time and it has not been proven that technology can economically increase or even hold the current level of yields. Fifty years from now we may have some answers.

If the changes in soil properties and the decrease in productivity potential produced by cultivation and erosion are thought to indicate a steadily worsening condition, the reader should look to the geological past for an indication of the recuperative powers of the soil system. Data from western and south-western Iowa show that, within the last 1500 to 500 years, so-called 'geological' erosion has removed, at a minimum, three feet (>90 cm—the entire soil profile) from the surrounding landscape (Ruhe and Daniels, 1963). Yet these geologically eroded areas recuperated rapidly enough, so they became the 'rich' virgin soils that were first cultivated about 130 years ago. There will always be a soil, but within the next few hundred years what kind of soil exists will be strongly influenced by the manipulations of man. The Southern Iowa Conservancy study and the above critique show that erosion does not have the same effect under all conditions. The deep, favourable soil material in much of the conservancy district lowers the impact of erosion on the soils of the area, but care must be used when extrapolating to other areas.

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