Soil Productivity and Erosion of Iowa Loess Soils

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R. G. Spomer, R. F. Piest
MEMBER ASAE MEMBER ASAE

ABSTRACT

SOIL and plant nutrients are being rapidly removed from inadequately-protected rowcrop fields in Iowa (Spomer et al., 1981), but increased use of fertilizer and adoption of other technology have masked the effect of erosion on crop yields. Prior to the adoption of hybrid seed corn in 1932 and increased use of commercial fertilizer beginning in the early 40's, Iowa average corn yields (1866-1931) remained nearly constant at 2.3 t/ha (37 bu/ac). Pottawattamie County corn yields averaged 2.9 t/ha (45.6 bu/ac), 1929 through 1953, with a small but steady annual increase of 0.037 t/ha (0.59 bu/ac). The most rapid increase in corn yields, highly correlated with fertilizer use, occurred during the decade of the 60's. Concurrently, we show that soil erosion rates from unprotected cornfields in the region greatly exceeded acceptable soil loss tolerances. Measured sediment yields from a 33.6 ha (83 ac) research watershed since 1964 were 30.4 t/ha/yr (13.6 t/ac/yr), and the effective denudation of the watershed is occurring at a minimum rate of 40 cm (16 in.) per century. Average annual nitrogen and phosphorus movement during a recent 5-year period of minimal runoff and erosion was 20 kg/ha (18 lb/ac) and 3.0 kg/ha (2.7 lb/ac), respectively.

INTRODUCTION

The U.S. is losing soil from agricultural lands at excessive rates (U.S.D.A., 1980). At our research station near Treynor in Pottawattamie County, Iowa, sediment yields have averaged 30.4 t/ha/yr (13.6 t/ac/yr) with contour corn. Continued excessive erosion must have an adverse effect on crop yields, although it is often difficult to show in the short term because of favorable soil depth, use of fertilizer, and adoption of new technologies.

Shrader (1980) describes many of the detrimental effects of erosion on soil properties. The complicated interaction of organic matter and soil productivity is also discussed. In calcareous soils, he states that yields of large-seeded crops such as corn and soybeans are not related to organic matter content, because good soil structure is maintained in calcareous loess soils even as organic matter decreases. This finding has been substantiated by Moldenhauer and Onstad (1975). Another confounding factor in assessing the impact of soil erosion on crop yield is that farmers have rapidly adopted advances in technology since World War II. Larson (1981) states that yield increases nation-wide have averaged 1.6 percent annually over the past several decades. He suggests that it may be difficult to sustain this productivity increase in the future with continued erosion of our soil resource. Future productivity increases will be limited by rising fertilizer costs, loss of prime agricultural land to other uses, and the availability and cost of irrigation water. Yield increases have occurred even though erosion rates have exceeded soil loss tolerance values judged to be the upper limit of soil loss without deterioration of the soil resource. The U.S. Department of Agriculture (1980) reported soil resource, excluding wind and gully erosion, exceeded soil loss tolerance values on more than 97 million acres nationwide, or 23 percent of total cropland.

In a recent study of erosion in the Southern Piedmont soils, Langdale et al. (1979) concluded that current corn yields are reduced 147 kg/ha/yr (2.9 by/ac/yr) for every centimeter (0.4 in.) of soil removed by erosion. Depth of topsoil above the argillic horizon was their measure of past erosion. Krauss and Allmaras (1981) separated soil productivity decreases from technology-increased winter wheat yields in a highly erosive Palouse landscape. Among other sources of information, they used 90 paired measurements of winter wheat yield and associated topsoil thickness over a period of 5 years. Based on an average soil loss of 13.4 cm (5.3 in.) for Whitman County, Washington, productivity decreased 724 kg/ha (10.8 bu/ac) while technology increased wheat yields by 1,446 kg/ha (21.5 bu/ac) over the same 90-year period. The productivity gains attributed to land capability subclasses IIe and IIIe (severely eroded, moderate to steep slopes) were enough to project a net productivity gain of 722 kg/ha (10.7 bu/ac) for Whitman County. The importance of these results is emphasized by the steep topography where the original loess soils have been removed and subsoils have been exposed. This separation of the soil productivity change by land capability subclass showed that the net increase in yield on IIe and IIIe land has masked a significant productivity decline on subclasses IVe and VIe (severely eroded, steeply sloping) land during the 90-year period of intensive cultivation.

Topsoil removal and impact on crops yields have been investigated by numerous researchers. Eck et al. (1967) reported that most land-forming studies have shown that deficiencies of nitrogen, phosphorus, and potassium were principally responsible for reduced yields from subsoils. Eck also referred to others who have shown that organic amendments or zinc were required before yields on subsoils approached those on topsoils.

A national soil erosion-soil productivity research planning committee (1981) presented a thorough review of

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The authors are: R. G. SPOMER, Agricultural Engineer, USDA-ARS, Council Bluffs IA; R. F. PIEST, Hydraulic Engineer (retired), USDA-ARS, Columbia, MO.

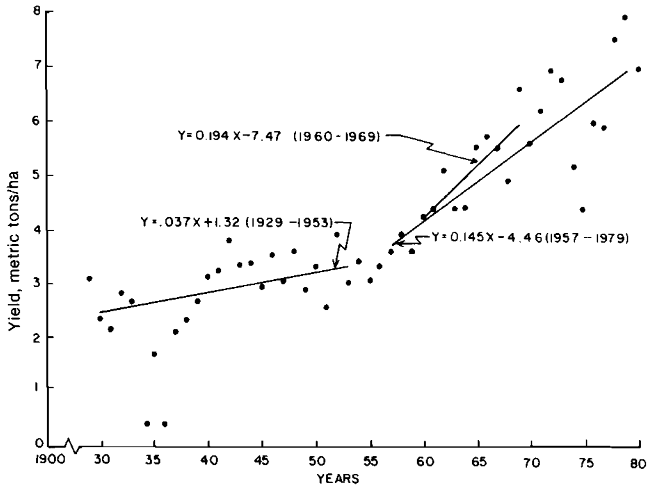

FIG. 1 Pottawattamie County average annual corn yield.

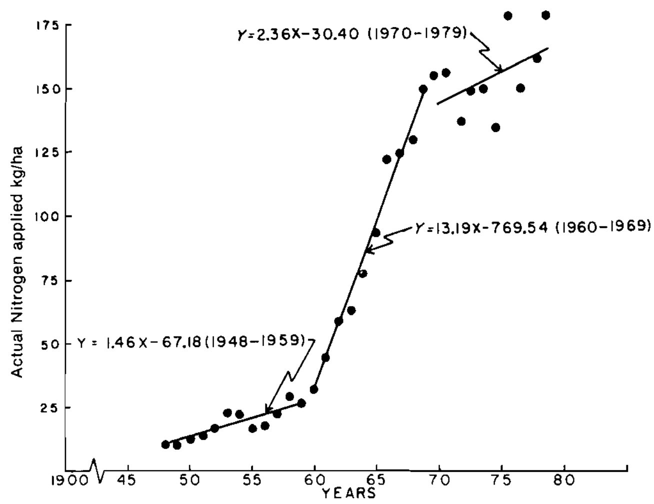

FIG. 2 Average annual nitrogen application for the state of Iowa—source National Agricultural Statistics.

erosion and soil productivity problems, past and current research, and research approaches to define the relationship between erosion and soil productivity. Numerous researchers are quoted who have found that when topsoil is removed, yields are reduced 20 to 75 percent compared with check plots. In addition, they note that erosion reduces crop yields slowly and may escape detection until crop production is not economical.

The objective herein was to study the effect of erosion on soil productivity in the deep loess soils region adjacent to the Missouri River Valley. Resource data for the study include historical corn yield and fertility records for Iowa, Pottawattamie County, and research data from ARS Watershed 2 near Treynor, Iowa.

CORN YIELDS AND FERTILIZER USE

Historical Data

Corn yields for Pottawattamie County, provided by Iowa Agricultural Statistics, are presented in Fig. 1. The average annual crop yield from 1929 through 1953 was 2.9 t/ha (45.6 bu/ac) and the average yearly increase was 0.037 t/ha (0.59 bu/ac). Drouthy periods in the 30's and mid-50's were omitted in the regression. The modest increase in corn yields can probably be attributed to a gradual adoption of hybrid seed beginning in 1932*, application of modest rates of phosphorus (P) and the use of legumes in the crop rotation. In Fig. 2, the average application of fertilizer nitrogen (N) per acre is given for the State of Iowa and a steady increase is evident beginning in the late 1940's. State soil testing laboratories were instrumental in increasing fertilizer use, recommending application rates to farmers. Not all farms were using fertilizer; according to USDA Statistical Bulletin 348 (1964) the percentages of Iowa farm acres receiving fertilizer were 41 and 37 percent in 1954 and 1959, respectively. Therefore, the application rates on less than half the total state corn acres were higher than shown in Fig. 2 for the years 1948 through 1959. Since specific statistics for areas fertilized are not available for all years, averages were used to show trends. The data in Table 1 indicate that use of phosphorus and potassium fertilizers increased steadily, until the decade of the 70's.

*Personal communication with Clifford Johnson, retired Pottawattamie County, Iowa, Extension Agent.

Recent fertilizer and yield trends

The decade of the sixties was one of increased technology on the farm. Fig. 2 shows that the average annual increase of N in Iowa was 13.2 kg/ha (11.8 lb/ac) and Table 1 indicates a rapid increase in application of P and K.

Pottawattamie County corn yields show a corresponding yield response and in Fig. 1 the average annual yield increase of 0.194 t/ha (3.1 bu/ac) is shown by the linear regression for 1960 through 1969. The yield increase con-

TABLE 1. STATE OF IOWA, AREA PLANTED, CROP YIELD AND AVERAGE ANNUAL ELEMENTAL FERTILIZER APPLICATION*

Year	Corn hectares† x 1,000	Corn yield, t/ha‡	N	P	K
			--------kg/ha§	-------	
1940-44	4,033	3.30	<1	<1	<1
1948	4,541	3.80	3.4	4.6	3.0
1949	4,677	2.95	2.7	4.5	2.5
1950	3,984	3.04	4.6	5.8	3.8
1951	4,206	2.73	6.2	5.9	4.3
1952	4,367	3.92	9.3	7.5	6.2
1953	4,541	3.33	15.2	8.0	7.5
1954	4,269	3.42	14.8	9.2	8.7
1955	4,374	3.04	9.1	7.3	7.7
1956	4,286	3.33	10.6	7.4	8.2
1957	4,151	3.89	14.3	8.7	9.4
1958	4,105	4.14	20.8	11.2	12.2
1959	5,086	4.08	18.4	8.8	9.6
1960	5,126	3.99	23.7	9.1	9.6
1961	4,191	4.74	35.6	12.9	13.1
1962	4,112	4.83	50.6	16.1	17.4
1963	4,518	5.02	55.3	17.7	19.9
1964	4,161	4.86	69.0	21.2	25.2
1965	4,239	5.15	85.2	25.8	31.6
1966	4,324	5.59	114.0	31.4	46.7
1967	4,929	5.56	116.5	28.6	45.7
1968	4,190	5.84	120.5	35.5	55.8
1969	4,232	6.21	141.5	37.9	61.8
1970	4,358	5.40	146.0	37.9	60.9
1971	4,944	6.40	145.4	31.7	55.9
1972	4,558	7.28	128.1	32.5	64.5
1973	4,848	6.72	140.4	31.9	71.5
1974	5,346	5.02	140.4	31.9	71.5
1975	5,407	5.65	125.3	30.6	61.7
1976	5,650	5.71	167.4	32.0	66.2
1977	5,468	5.40	141.3	29.8	65.9
1978	5,468	7.22	152.8	30.2	63.2
1979	5,468	7.97	168.9	33.6	86.0

*USDA National Agricultural statistics
†Hectares x 2.471 = acres
‡t/ha x 15.935 = bu/acre
§kg/ha x 0.892 = lb/acre

TABLE 2. POTTAWATTAMIE COUNTY, AREA PLANTED, CORN YIELD AND AVERAGE ANNUAL ELEMENTAL FERTILIZER APPLIED

Year	Hectares*	Corn yield t/ha†	N	P	K
			------- kg/ha‡		-------
1958	79,785	3.86	23.5	5.9	1.1
1967§	99,346	5.45	102.0	22.1	7.9
1970	82,660	5.57	141.9	26.4	35.1
1971	96,674	6.15	127.9	23.7	31.0
1972	91,408	6.90	148.1	28.8	30.7
1973	90,801	6.74	166.7	28.9	37.3
1974	113,278	2.44	163.7	25.6	45.7
1975	95,985	4.36	117.8	20.3	31.2
1976	96,674	5.94	156.5	21.8	26.7
1977	99,914	5.42	151.4	24.8	40.7
1978‖	97,605	7.47	168.9	33.7	39.2
1979	90,315	7.90	213.9	39.5	65.6
1980	90,315		148.1	19.7	25.8

*Hectares x 2.471 = acres
†t/ha x 15.935 = bu/acre
‡kg/ha x 0.892 = lb/acre
§July 1, 1966 through June 30, 1967 (second half-year data not available)
‖1978 data is for first 6 months only (second half-year data not available)

tinued through the decade of the 70's. It correlates well with the rapid fertilizer increase for this period. Total fertilizer use for Iowa from the US Department of Agriculture, (Agricultural Statistics, 1940-1978), Table 1, and Pottawattamie County fertilizer use from the Iowa Department of Agriculture (1958-1980), Table 2, includes N used for all crops and obviously overestimates N used on corn, but they are the best records available. This bias partially explains the smaller than expected corn yield response (Fig. 1) during the sixties for Pottawattamie County.

The limited fertilizer data available for Pottawattamie County is summarized in Table 2. Nitrogen use, 1958-1980, averaged 1.07 times that in the state and was the basis for comparing state fertilizer data with corn yields in Pottawattamie County. The constantly increasing application rate of N slowed during the decade of the 70's (Fig. 2). Increased cost has probably been one factor; also, application rates are approaching the maximum plant response per unit of nitrogen (Voss et al., 1974).

TREYNOR WATERSHED 2

Agronomic and soil factors

Watershed 2 near Treynor is an instrumented 33.6 ha (82.8 ac) field planted since 1964 to continuous clean-tilled corn with rows on approximate contours. Because most agronomic practices have been consistent through 1980 and represent typical farming operations in the area, it is a suitable field to evaluate corn yield/soil loss relationships. It is representative of the deep loess soils adjacent to the Missouri River Valley in Iowa, Kansas, Missouri and Nebraska. Depth of the loess varies from 25 m (80 ft) on the ridges to 5 m (15 ft) in the valleys. The silt-loam soils on this watershed are classified as *Typic Hapludolls, Typic Haplorthents,* and *Cumulic Hapludolls* (USDA Soil Conservation Service, 1975). All of these soils are fine-silty, mixed mesics and have moderate to moderately rapid permeability. The area-weighted land slope of the study watershed is 8 percent, and the maximum slope is about 14 percent. A more complete description of the watershed and instrumentation is given by Saxton et al. (1971).

TABLE 3. HARVESTED CORN YIELDS, ELEMENTAL FERTILIZER APPLIED, AND SEDIMENT YIELD, WATERSHED 2, TREYNOR, IOWA

Year	Corn yield t/ha*	Fertilizer application N	P	K	Sediment yield from sheet-rill erosion source t/ha‡
		------	kg/ha†	------	
1964	4.43	106.1	30.9	13.7	56.0
1965	5.10	139.3	17.4	16.5	81.6
1966	5.71	146.5	35.2	13.2	19.3
1967	6.71	163.0	38.1	13.7	168.6
1968	5.98	141.7	38.3	14.4	9.2
1969	7.61	184.7	43.3	31.5	2.2
1970	6.31	150.1	38.9	28.0	16.6
1971	7.60	180.8	39.8	29.3	29.8
1972	7.65	181.1	39.6	29.2	17.7
1973	7.10	175.7	38.9	29.1	1.1
1974	drouth	158.1	39.1	28.3	0.7
1975	4.47	110.9	39.8	28.6	1.8
1976	5.16	180.1	41.9	30.9	<0.2
1977	5.56	234.5	41.2	28.2	18.2
1978	7.70	192.1	42.7	53.8	9.2
1979	8.07	185.2	40.1	28.7	4.3
1980		180.7	29.5	29.2	
Average for 16 years 1964-1979					27.3

*t/ha x 15.935 = bu/acre
†kg/ha x 0.892 = lb/acre
‡t/ha x 0.446 = t/acre

Fertilizer applications and corn yields

Fertilizer applications and corn yields on the Treynor watershed increased rapidly from 1964 through 1969 (Table 3). Fertilizer applications, statewide and for the research watershed, increased at rates of 13.2 (11.8) and 11.9 kg/ha (10.6 lb/ac), respectively, during the decade of the sixties as defined by regressions in Figs. 2 and 3. There was a concurrent annual corn yield increase for Pottawattamie County and Watershed 2 of 0.194 (3.1) and 0.560 t/ha (8.9 bu/ac), respectively, as depicted in Figs. 1 and 4. The larger yield response on Watershed 2 probably reflects an initial plant nutrient deficiency greater than the county average. (Harvested yields from Watershed 2 were determined on the basis of sample plot yields from adjacent Watersheds 1 and 2 and the weighed total field harvest from both watersheds.)

The corn yield increase appears to be continuing for Pottawattamie County, Fig. 1, through 1973, whereas yield increases appear to be diminishing on Watershed 2,

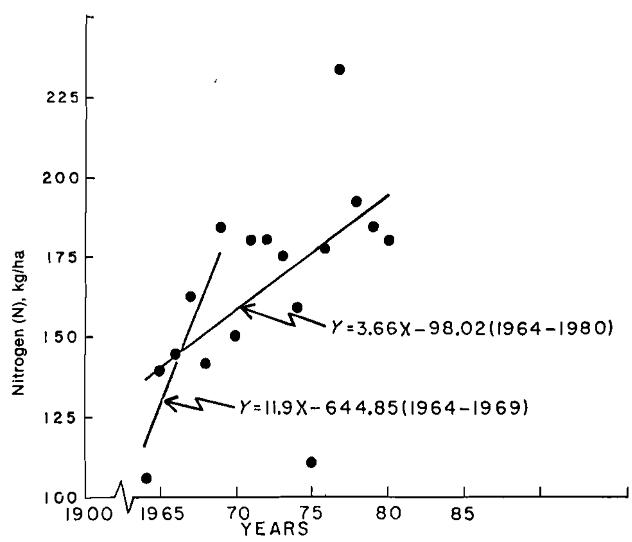

FIG. 3 Elemental nitrogen applied annually to Watershed 2, Treynor, Iowa.

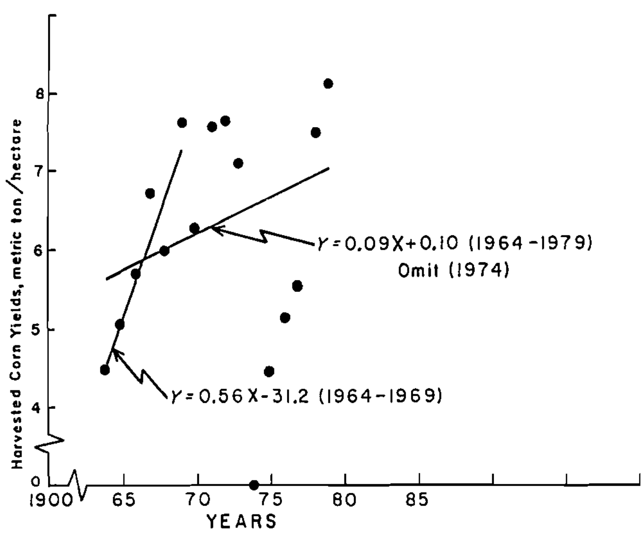

FIG. 4 Adjusted harvested corn yields, Watershed 2, Treynor, Iowa.

Fig. 4. The correlation coefficient for the county yields, Fig. 1 (1957-1979) is significant at the 1-percent level while the correlation coefficient for Watershed 2 yields, Fig. 4 (1964-1979) is not significant at the 5-percent level or the slope of the regression does not differ from horizontal. This indication of a yield plateau on Watershed 2 may be the result of several factors: (a) Fertilizer rates have been at high levels since 1964 and optimum fertility levels may have been reached; (b) continuous corn for 16 years has resulted in insect and weed problems, especially volunteer corn; and (c) severe erosion has removed valuable topsoil, especially on steep hillsides.

Sampled yields by slope position, ridge, mid-slope and lower slope, are available for 16 years. Statistical analyses showed that yields were significantly affected by slope position at the 0.01 level, $r^2 = 0.98$. The ridge and mid-slope positions both had a lower yield than the lower slope, but there was no yield difference between ridge and mid-slope locations. The mean values for crop yield by slope position were: ridge 6.7 (107.3), mid-slope 6.7 (106.1), and lower slope 7.3 t/ha (116.9 bu/ac). The lower slope position benefits from deposition of soil, organic matter and nutrients from the upslope areas, and additional run-on moisture.

EROSION

Denudation rates

The deep loess soils of southwest Iowa are being rapidly eroded wherever clean tillage and continuous rowcropping are practiced. The measured annual sediment yield from Watershed 2 has averaged 27.3 t/ha (12.2 t/ac) for 16 years of record, Table 3. We also measured 3.1 t/ha (1.4 t/ac) average annual sediment trapped in the main waterway so that the average annual sediment yield to this outlet section has been 30.4 t/ha (13.6 t/ac). Applying a sediment delivery ratio of 55 percent (derived from Universal Soil Loss Equation calculations, precise topographic surveys, and measured sediment yields), the annual sheet-rill erosion rate is estimated to be 55.3 t/ha (24.6 t/ac) which amounts to 40 cm (16 in.) of topsoil per century.

Another method for estimating the soil movement along the steeply sloping loess terrain involved measurement of Cs 137 remaining in the soil profile after deposition from the atmospheric nuclear tests in the late 1950's and early 1960's. Soil samples for CS 137 analysis were taken at six sites along a sidehill transect. Sampling was repeated and additional sidehill sites were sampled to confirm erosion and deposition. Analysis by Piest et al. (1980) shows that about 45 percent of the original level of Cs 137 remained in the steeply sloping loess profile in 1979; the balance has been removed by erosion. A mixing depth of 14.2 cm (5.6 in.) was derived for 16 years of plowing at a depth of 18 cm (7 in.) and a 10.2 cm (4 in.) disking depth for 4 years. In order to reduce the Cs-137 level to 45 percent in 17 years of erosion, 5 percent of the 14.2 cm (5.6 in.) mixing depth would have to be removed every year or 90 t/ha/yr (40 t/ac/yr) of topsoil moved downhill. This amounts to 70 cm (28 in.) per century. We can, therefore, conclude that continuation of row cropping without conservation practices except contouring will result in about 55 cm (22 in.) of topsoil removal per century. This extremely rapid denudation rate implies some serious consequences for the future of agriculture in the loess soils region.

Erosion-related problems

Unacceptable rates of erosion forebode problems for agriculture that we cannot fully anticipate. Some items of concern are loss of organic matter, plant nutrients, deteriorating soil structure, increasing cost of fertilizer to maintain soil fertility, and farmability of the land, plus the loss of the soil itself and downstream pollution-sedimentation problems.

A short-term problem already encountered is the serious rilling and gullying of side-hill fields that impede farming operations and result in machinery damage. This field erosion especially impedes the movement of combines and trucks during harvest. When rills or gullies prevent passage through the field much time is lost in harvesting; in addition, the cost of repairing machinery damanged in crossing rills is expensive.

Another short-term problem is the maintenance of grass waterways. Large quantities of soil are deposited in the waterways. This causes waterways to build up and results in water flowing down one or both sides of the waterway with one or two large rills dveloping. The reshaping and reseeding of waterways is an ongoing maintenance cost. There is also the cost of repairing sidehill areas dissected by rills and gullies. Waterway and rill maintenance and repair on Watershed 2 has averaged $4.60/ha/yr ($1.86/ac/yr) for 16 years. Most farmers use front-end loaders or front-end blades and plows to repair these areas, all of which are expensive when machinery, time, and energy are considered. Gullies become too large to repair and productive land is lost. Machinery efficiency decreases because smaller, irregular fields must be farmed.

Plant nutrients

Results of a comprehensive study of chemical movement for the loess soils were reported by Burwell et al. (1977). Their data for N and P movement for the 5 years of this study are given in Table 4. As previously noted, the period 1969-1974 was one of low surface runoff, with 1971 the only year of significant runoff events. The data in Table 4 show that in 1971 there were 41.3 kg/ha (37 lb/ac) of N carried out of the watershed with the sediment or the equivalent of 23 percent of the N applied. In addition, another 2.4 kg/ha (2.1 lb/ac) of N as NO_3 and NH_4 were dissolved in the runoff water. The 5-year

TABLE 4. ANNUAL DISCHARGES OF N AND P IN SURFACE RUNOFF, WATERSHED 2, TREYNOR, IOWA, 1969-1974*

Year	Nitrogen, kg/ha† Sediment N	Soluble N NO_3-N runoff	Soluble N NH_4-N runoff	Total N	Phosphorus, kg/ha† Sediment P	Soluble P Runoff	Total P
1969‡	2.56	0.32	0.03	2.91	0.17	0.09	0.26
1970	25.16	0.53	0.35	26.04	0.48	0.04	0.52
1971	41.31	0.94	1.46	43.71	1.10	0.19	1.29
1972	26.68	0.49	0.17	27.34	0.43	0.03	0.46
1973	3.90	0.59	0.21	4.70	0.09	0.22	0.31
1974§	0	0.08	0.03	0.11	0	0.01	0.01
60-month total	99.61	2.95	2.25	104.81	2.27	0.58	2.85
Average annual	19.92	0.59	0.45	20.96	0.45	0.12	0.57

*Burwell et al., 1977
†kg/ha x 0.892 = lb/acre
‡Measurements include April through December
§Measurements include January through March

average was 20 kg/ha (18 lb/ac) of N lost with the sediment and another 1.04 kg/ha (0.9 lb/ac) in solution. The 5-year loss of N was 12 percent of the total N applied, a significant loss of plant nutrients. The 3.0 kg/ha (2.7 lb/ac) of P lost was only 1.5 percent of the total applied and surprisingly small compared to the N loss. The average sediment yield was about one-half of the 1964 through 1979 sediment yield, indicating that much larger losses of N and P are likely to occur than was recorded during the study.

CONCLUSIONS

Sediment yields are two and one half times the soil loss tolerance value on Iowa loess soils with continuous cropping and clean tillage. Plant nutrients are also removed with the soil and in runoff water. In the long term, soil erosion must have a detrimental effect on crop yield and efficient fertilizer utilization. Obviously, present crop yields would be higher if soil erosion had not been excessive since farming began and the landscape would not be dissected with rills and gullies. The continued mining of soil fertility through excessive erosion will probably require increased additions of increasingly expensive fertilizer amendments.

It is not possible at this time to define the relationship between soil erosion and crop yield because crop yields without fertilizer additions are not available. The effect of erosion has been masked by the use of fertilizer, pesticides, hybrid seed, improved implements and climatic variations.

Specific studies are needed to determine the effect of technology on yield. A study to evaluate the effect of nitrogen on crop yield on eroded and slightly eroded soil will be initiated on the loess watershed. It is obvious that additional studies to assess the impact of all recent technological practices are needed to determine the effect of erosion on yield. Research is needed to measure the productivity of non-eroded (virgin prairie) loess soil over a 10-year period with no soil loss, while replenishing nutrients at present-day rates. This would provide a yield potential for comparison. These data are required to improve present programs to predict crop yield reduction related to erosion.

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