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Effects of Erosion on the Productivity of Two Ustolls

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EFFECTS OF EROSION ON THE PRODUCTIVITY OF TWO USTOLLS

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

Soil productivity is defined as the capacity of a soil to produce a specified plant or sequence of plants under a particular management system (SSSA 1965). Soil erosion is a threat to our agricultural productivity. Soil loss seldom improves the capacity of the affected soil to produce crops and often reduces the long-term crop production potential of that soil.

It is estimated that 181 million acres of our nations 413 million acres of cropland are susceptible to erosion exceeding tolerable soil loss levels (T-values). This amount will continue to increase as more marginal land is put into production. However, the degree to which erosion reduces agricultural productivity varies with the type of soil, regional climatic conditions, management systems employed, and the type of crop grown. High rates of erosion on one soil may be detrimental to crop production whereas on another soil no significant yield reductions would be observed.

Although many studies since the early 1940's have shown that erosion reduces yields, not until recently has the need to determine the causes of these yield reductions been fully recognized. Difficulty exists in detecting productivity losses. One problem is that the reduction of soil productivity is often masked by increased fertilizer application and improved crop varieties. Another problem with detection is that productivity losses may proceed so slowly that yield reductions may not be recognized until the land is no longer capable of economically producing crops. (USDA-SEA 1981). The Joint Council on the Food and Agricultural Sciences lists a need to develop an understanding of the relationship between erosion and soil productivity as a research priority for 1985. A long range objective of the council is to promote the qualitative assessment of erosional impacts on cropland. According to the council, this can be accomplished by developing and validating quantitative models that will predict long-term changes of major soils in each region of the country due to soil erosion.

The objectives of this study were: (1) to determine the effects of erosion on soil properties; (2) to determine the effects of erosion on continuous corn yields; and (3) to develop a prediction model investigating the influence of soil properties and erosion on corn yields.

LITERATURE REVIEW

Effect of Erosion on Crop Yield

Extensive research to investigate the effects of erosion on crop production was begun in the early 1930's. This research was authorized by the 1928 Buchanan Amendment to the Agriculture Appropriations Bill. With this bill, erosion experiment stations were located in areas of the country where erosion was considered a potential problem. (USDA 1981). There has been great diversity in the soils and methods used in studies since 1930's but most of the research has indicated that soil loss does indeed have a negative impact on a soil's capability to produce crops.

In the mid-1940's, yields of corn on class II land were compared to class IV land on a Typic Hapludult, a 39.6% yield reduction was observed on class IV land when compared to class II land. This amounted to a 2.7 bu/acre decrease for each inch of soil lost. (Adams 1949).

Another study in the mid-1940's showed that for each inch of topsoil lost up to 12 inches. The yield of corn was reduced an average of 4 bu/acre. (Smith 1946).

At the Ohio Experiment Station, corn in a rotation with wheat and two years of alfalfa was reduced by 72% on eroded areas of a Typic Fragiudalf when compared to uneroded areas (Bauer 1950).

In an early Wisconsin study, corn was grown in rotation with small grain and one year of hay on moderately and severely eroded phases of a Typic Hapludalf. Corn yields on the moderately eroded areas exceeded yields on the severely eroded areas seven out of nine years. (Hayes et al. 1948).

More recent studies on naturally eroded areas have shown similar results as earlier studies. Corn yields of 36, 75, and 92 bu/acre were observed on severely, moderately, and noneroded phases of a Typic Hapludult in the Southern Piedmont. A close relationship was found between corn yields and depth to Bt horizon. The difference between yields on the moderately and severely eroded areas was greater during seasons with poor rainfall distribution. An estimated 2.34 bu/ac/yr was lost as each cm of topsoil was eroded. (Langdale et al. 1979).

In Kentucky, losses in soil productivity were quantified in eroded and noneroded areas of two Typic Paleudalfs. (Crider and Maury series). Over a four year period corn yields on the eroded phases were 12 % lower for the Maury soil and 21% lower for the Crider soil as compared to the noneroded phases of the same series. (Frye et al. 1982). The Crider soil was lower in natural fertility, and it appeared that erosion had a more detrimental effect on yields on it than on the Maury soil.

Many studies compared yields on uneroded land with yields on neighboring plots from which varying amounts of topsoil have been mechanically removed. One such study was done in eastern South Dakota on a Beadle silty clay loam (Typic Argiustoll). One plot had 12 inches of topsoil removed, the second had 18 inches removed and the third was left intact. Average corn yields over an eight year period showed that removing 12 inches of topsoil significantly reduced yields but removal of an additional 6 inches did not further decrease yields. (Olson, 1977).

In an earlier study, yields of corn were compared on a Marshall silt loam (Typic Hapludoll) with an artificially exposed subsoil of Marshall. Yields on the exposed subsoil plots were 45-50 bu/acre lower than from corresponding surface soil plots (Engelstad and Shrader 1961).

A similar trend was seen during a ten year period at Bethany, Missouri. The average corn yield on a desurfaced plot of Shelby silt loam (Typic Arguidoll) was 47% of the control plot (Smith and Whitt 1945). Similar results have occurred on numerous scalped and desurfaced plots (Ripley et al. 1961, Batchelder and Jones 1972, Eck and

Ford 1962, Heilman and Thomas 1961, Philips and Kamprath 1973, Reeves and Campell 1961, Thomas and Cassel 1979).

Within the past 20-25 years, some researchers have attempted to determine how much soil loss must occur before crops yields are reduced. Murdock and Frye (1980) quantified the loss in corn yield as topsoil is eroded on deep soils in Iowa with desirable subsoil characteristics. They found that a loss of 5 inches of topsoil by erosion resulted in a 16 bu/acre/year reduction in yield. This is an average loss of about 3 bu/acre/year per inch of soil lost.

Another study in Iowa related corn yields to topsoil depth on a medium textured soil. This study showed that reducing the topsoil depth from 22 to 12 inches had no effect on yield. However, with only 10 inches of topsoil present, corn yields were 6% less than with 12 inches of topsoil present. (Webb and Beer 1972).

On a sandier soil in eastern North Carolina, the yield effect of reducing topsoil was more apparent. As the topsoil depth decreased from 18 to 15 inches, a 20% yield decline occurred with an additional 20% decline as the topsoil depth was reduced from 15 to 10 inches. (Thomas and Cassel 1979).

In other studies, yields were measured for various crops when all of the topsoil was removed. A great amount of variability in yield reductions is shown not only for the same crops but also between crops. Soybean yields were reduced 20-40% on medium textured soils. Likewise, cotton yields were reduced from 12-20% and small grains 11-24%. Generally, greater yield declines were associated with sandier textured soils. (Langdale and Shrader 1981).

Although a majority of studies have shown that yield reductions occur as topsoil is removed, a study done in Guelph, Ontario has proven otherwise. Over a ten year period on a medium textured soil with 7% slope, no significant differences in corn yields were observed for plots which had greater soil loss. The researchers concluded that corn yields were not reduced by moderate amounts of erosion where good management practices are employed. (Ketcheson and Webber 1978)

Effect of Erosion on Soil Properties

Erosion reduces corn yields by altering many soil physical and chemical properties. The USDA position paper on erosion- productivity research lists four major ways in which erosion decreases soil productivity. These include a loss of plant available water, loss of plant nutrients, degradation of soil structure, and nonuniform removal of soil within a field. Other studies have shown that reduced rooting zone depth and undesirable subsoil properties such as low pH, aluminium toxicity, and high bulk density had adverse affects on crop yields. (Thomas and Cassel 1979, Langdale et al. 1979, Pierce et al. 1983)

Crosson and Stout (1983) stated that removal of topsoil by erosion threatened productivity by removing valuable nutrients and organic matter and by weakening the soil structure. The later effect diminishes the capacity of the soil to hold plant-available water, impedes drainage and movement of air through the soil, and reduces tilth. Over the long term, erosion may also reduce soil water holding capacity by reducing rooting zone depth.

Organic matter

In most upland soils, organic matter makes up 1 to 6% of the weight of the soil. Even though organic matter makes up a small proportion of total soil weight, its importance to soil physical and chemical properties cannot be overstressed. It is a natural source of nitrogen in our soil and also supplies phosphorus, sulfur and many micronutrients when decomposed. Organic matter promotes good soil structure which improves the tilth of the soil and infiltration and storage of water. However, Bauer (1974) states that the effect of organic matter on increasing the available water holding capacity of the soil is overstated by many researchers. He states that an increase in the plant available water by organic matter additions is slight. Thompson and Troeh (1973) also warn against concluding that soil water holding capacity can be readily increased by simply adding organic matter.

Several studies compared the relative amounts of organic matter across various eroded phases of a soil. In one study the humus content in the 0-10 cm layer of a noneroded, slightly eroded, moderately eroded, and severely eroded phases of a Mollisol were compared. The humus content in the slightly eroded soil was 79.6-89.0% of that in the noneroded soil, in the moderately eroded soil it was 61.0-61.1%, and in the severely eroded soil it was 34.5-38.9% of the noneroded soil. Also the humus content in the noneroded soil was 3 times the amount found in the severely eroded soil (Dzhadan 1975).

In another study, the differences in organic matter between uneroded and severely eroded Typic Paleudolfs were significant at the 0.05 level under cropped conditions (Frye et al. 1982). High organic matter contents in the soil was also correlated to high corn yields on Ultisols of the Atlantic Coastal Plain (Thomas and Cassel 1979).

Available-Water Holding Capacity

Available water is that portion of water in the soil that is readily absorbed by plants. It is defined as the water held between 0.03 MPa tension (field capacity) and 1.5 MPa tension (permanent wilting point). (Donahue, Miller, Shikluna, Fifth Ed.). Available water holding capacity directly influences yields by reducing the ability of a soil to store water for crop use between significant rainfalls. In Kentucky, there were highly significant differences in available water holding capacity between the uneroded and eroded phases of two Typic Paleudalfs to a depth of 15 cm (6 in.). The lower water holding capacity of the eroded soil was attributed to both a higher clay and lower organic matter content of the surface (Frye et al. 1982).

A Russian researcher determined that a decrease in soil productivity of a Mollisol in the Don Basin was primarily due to a decreased soil moisture capacity in soils with increased erosion. He found that the maximun amount of plant available water in the plowed layer of a severely eroded soil was 7.36% of the amount in the noneroded soil. (Shikula 1961).

Thomas and Cassel (1979) considered the available water holding capacity of the entire rooting zone of Ultisols on cut and fill plots in North Carolina. The available water holding capacity of the rooting zone was one of the most important physical properties affecting total dry matter production of corn in the developed prediction model.

A second study on cut and fill plots showed similar results. On a Pullman silty clay loam where fertility was not limiting, the soil water storage between the cut and fill plots was responsible for differences in yields between the plots. As the depth of cut increased and the depth of fill decreased there was a trend towards decreased stored water. Even though the relative decrease in water holding capacity was only 5.5% it was sufficient to reduce available water to the plant and a yield reduction resulted. (Eck 1969).

Plant Nutrients

The erosion process alters the fertility of a soil by redepositing water soluble constituents (primarily nitrates) and nutrients attached to sediment such as phosphorous, exchangeable cations, organic N, and sulfur. Loss of organic matter is of particular concern because it is a natural source of phosphorous and nitrogen in the soil (Logan 1982). Other ions such as potassium are fixed in illitic clays and may be carried away through the erosion process.

Early studies have shown that the eroded material contained much larger quantities of plant nutrients than would be expected on the basis of the original content of the soil. (Neal 1944). Losses may be especially serious for nitrogen and phosphorus (Mehring and Parks 1950).

Stoltenberg and White (1952) also found more plant nutrients in the runoff material than in the eroded soil. The nitrogen and phosphorus contents of the eroded material were almost double the amount in the surface soil while the potassium content of the eroded material was seven times that of the original soil. The greater loss of potassium suggests that the eroded material may contain more clay than the soil from which it was eroded. Research on Argiboroll soils in east-central South Dakota has shown that dissolved PO_4-P and NO_3-N losses from six individual cultivated watersheds and two groups of small runoff plots were highly correlated to the mean volume of runoff. The percent total N and organic matter were highly correlated and each is correlated with total P in the sediment. Both organic matter content and total N are correlated with the clay content as is the total P of the sediment. Although the significant correlation of clay and total P explains only 16% of the variation of the data, the high correlation of clay to organic matter may be influencing the relationship to total P. (White 1977).

Other researchers have attempted to quantify the loss of specific nutrients from erosion. For a medium textured soil, assuming the sediment contains the same amount of nutrients as the original topsoil, a loss of one metric ton/ha (0.5 tons/acre) will result in a 0.008 cm loss of topsoil and consquently a loss of one kg/ha nitrogen, 3.5 kg/ha phosphorus, and 13 kg/ha potassium. (Logan 1982). A soil loss of 5 tons/acre represents an average loss of 15 lbs of N/acre. The erosion of one-tenth inch of soil represents 16.6 tons soil/acre and 50 lbs. of N/acre. (Willis and Evans 1977).

The fertility balance is also influenced by subsoil conditions. Soil test values over 24 fields in Georgia showed that extractable P was high on slightly eroded and low on severely eroded sites. This was caused by high iron concentrations in the exposed B horizon that immobilized the phosphorus. Extractable K was found to be medium on slightly eroded but high on moderately and severely eroded sites. (White et al. 1983).

Fertilizer inputs can often mask the effects of erosion especially in soils with subsurface properties similar to surface properties. In this case, increased inputs maintains soil productivity without a corresponding decrease in the maximum yield potential of the soil. For example, application of 100 pounds of nitrogen fertilizer to a silt loam derived from Wisconsin loess in Iowa completely substituted for the A horizon in a year with favorable rainfall. (Engelstad and Shrader 1961). These same researchers found that equal yields can be obtained on either the surface or the artificially exposed subsoil of a silt loam provided that adequate N was supplied. The production of maximum corn yields on the subsoil required 35 more pounds of N/acre one year and 52 pounds N/acre in the second year. Other studies on exposed subsoils have also shown that topsoil loss can be adequately compensated for by additions of nitrogen and/or phosphorus fertilizer. (Reuss and Campbell 1961, Heilman and Thomas 1961, Eck and Ford 1962, Eck 1969, Olsen 1977).

In the case of soils which contain undesirable subsoil properties, increased inputs can not alleviate the reduction in maximum yield potential of the soil. For example, in a Pullman silty clay loam adding nitrogen did not restore yield potential under dry land conditions but did under irrigated conditions. (Eck 1969). On Coastal Plain soils Phillips and Kamprath (1973) had fertility problems associated with acid subsoil conditions. Adams (1949) reported reduced yields on heavy clay subsoils because of low fertility and poor physical conditions of the soil. On the other hand, Rosenberry (1980) suggested that yields generally will decline as a soil shifts from one erosion phase to another even with increased fertility.

Soil Structure

Soil structure is the combination or arrangement of primary soil particles into secondary particles, units, or peds. This occurs as a result of weathering, and chemical and biological processes of soil formation. (Donahue, Miller, Shickluna, 5th Ed.) Even though it is difficult to quantify the effects of erosion on soil structure the importance of structure in determining the capacity of a soil to infiltrate water and provide air for the growth of plants cannot be overemphasized (USDA 1975). Undesirable structure is likely to be more limiting to plant growth than nutrients, which can be increased by fertilizer additions. (Logan 1982). The degradation of soil structure results in surface sealing which promotes increased erosion, poorer tilth of soil resulting in poorer seedbed, and decreased soil water storage due to decreased infiltration. (USDA 1981).

The National Erosion-Productivity Planning Committee (1981) lists nonuniform removal of soil from a field as the last way in which erosion reduces productivity. Optimal production is impossible for all areas of an eroded field because applications of fertilizers and herbicides would be more appropriate for some areas than for others. Herbicide performance in particular varies with the amount of organic matter, pH, and CEC of a soil. Herbicides applied to an eroded field may kill the weeds in one area but not effectively control weeds in another part of the field. Also, farming operations are affected by erosion. Energy requirements would be greater in eroded areas because of increased energy requirement for tilling subsurface material and for filling and smoothing gullies. In addition, timing of field operations is upset because eroded parts of the field may be too wet when the rest of the field is dry enough for tillage operations.

The extent to which erosion reduces yield varies from soil to soil. The Soil Survey Staff (AH 436 1975) separates soils with respect to soil productivity as follows; Mollisols and Alfisols vs Ultisols. Initial crop yield reductions on exposed subsoils of most Mollisols-Alfisols are less than or equal to 50% those of Ultisols. (Langdale and Shrader 1982). Generally, the detrimental effects of erosion are greater on Ultisols because of the thinner solums and problems associated with subsoil acidity. A crop survey in Iowa shows that only the most erosive Mollisols and Entisols possess similar yield reductions trends as the Ultisols (Fenton 1971).

Shrader and his associates (1960) grouped Iowa soils according to the amount of damage to yield capacity and workability that corresponded with a loss of topsoil. They found that the finer textured the subsoil, the more damaging was erosion. Lastly, medium textured soils without clayey subsoils had lower yield reductions than coarser textured soils.

MATERIALS and METHODS

Plot Layout

In 1983, continuous corn plots were established on an Egan (fine-silty, mixed, mesic Udic Haplustolls) series at the USDA-ARS farm near Madison, South Dakota. (NW 1/4, Sec. 35. T107N, R35W). This soil is formed in silty glacial material overlying loamy glacial till. In 1984, plots were added on a Beadle (fine, montmorillonitic, mesic Typic Argiustolls) series which is formed in loamy glacial till. Both series occur within the Loess Uplands and Till Plains of the Central Feed Grain and Livestock Major Land Resource Area (102B).

Plots covering an area of approximately 0.07 hectares were selected on slightly eroded, moderately eroded, and severely eroded phases of both the Egan (1983, 1984) and Beadle (1984) series. All plots were located on backslope positions within the same landscape. The depth to calcium carbonate provided the basis for determining each erosion class. In the slightly eroded areas, calcium carbonate occurred at a depth greater than 46 cm. Carbonates were found between 30.5 cm and 46 cm. in the moderately eroded areas, and in the severely eroded plots, calcium carbonate was present on the soil surface. These criteria were based on observations of uncultivated pedons and established series information collected by the Soil Conservation Service. The slope percentages on the Egan site are 1%, 4%, and 6%, and on the Beadle series they are 2%, 7%, and 9% for slightly eroded, moderately eroded, and severely eroded phases, respectively.

Plot Management

In 1983, Pioneer 3965A corn was planted on June 3 in each plot which was subdivided into two tillage treatments; moldboard plow-disk, and chisel plow-disk. A plant population of 22,000 with a row width of 76 cm was used. Ammonium nitrate fertilizer (34-0-0) was applied at a rate to obtain a yield goal of 7526 kg/ha. Fertilizer recommendations were determined by soil test results of the Ap horizon. On the severely and slightly eroded Egan plots 508 kg/ha of ammonium nitrate was applied. On the moderately eroded plot, 469kg/ha was added. Lasso (34.3 L/ha), Bladex (27.1L/ha), and Ramrod (12.3 kg/ha) heribicides were used on each plot. The insecticide Furadan was applied at a rate of 13.4 kg/ha to each plot.

In 1984, each erosion plot was divided into three subplots on both the Egan and Beadle series. Pioneer 3732 corn was planted on May 16 into conventionally tilled plots at a population of 26,000. Fertilizer was applied at a rate to obtain a predicted yield of 8781 kg/ha. Starter fertilizer (13-33-13) was added to each plot at a rate of 140 kg/ha. The rate of ammonium nitrate used was 560 kg/ha. Sutan(31.5 L/ha), Bladex (27.1 L/ha), and Ramrod (28 L/ha) were the herbicides used. Dyfonate insecticide was applied at a rate of 8.4 kg/ha.

Soil and Plant Measurements

A pedon was described and sampled by horizon within each erosion plot. Particle-size analysis was done by the pipette method (Soil Survey Staff 1972); organic carbon by a modified Walkley-Black method (Allison, 1965); 0.03 and 1.5 MPa soil water measurements were made in a pressure membrane apparatus (Richards, 1965) on undisturbed samples of the Ap Horizon taken by a Uhland sampler, and on disturbed samples of the horizons below the Ap; pH of a 1:1 soil to water suspension was measured by an electronic pH meter; calcium carbonate equivalent was determined using the titrimetric method (Bundy, L.G.and J.M.Bremmer, 1972).

Separate samples were collected by a hydraulic probe for determination of bulk density. The Uhland sampler was used for determination of surface bulk density and hydraulic conductivity. Bulk density samples were taken at 15 cm increments to a depth of 150 cm on both the Egan and Beadle series (1984). Samples were dried at 100 degrees C for 24 hours to obtain oven-dry weights. Hydraulic conductivities of the Ap horizon were determined by the constant head method (Klute, 1965). Other field measurements included; residue cover found by the meterstick method (Hartwig, R.O., J.W. Loflen, 1978); soil temperature readings were taken with thermisters placed at 1 cm, 50 cm, and 100 cm depths on the Egan soil (1983) and by thermocouples at the same depths on both Egan and Beadle soils (1984); leaf area was found by a leaf area meter and soil roughness by a random roughness meter; albedo measurements were made on each erosion class using a pyranometer; soil moisture readings were recorded with a neutron probe taken at two week intervals throughout the growing season.

Each year, several fields in Lake County, South Dakota were selected for sampling. Within each cooperators' field, three areas representing slightly eroded, moderately eroded, and severely eroded conditions were selected within an Egan-Wentworth map unit according to the criteria used at the research farm. Soil samples from each erosion class were taken at the 0-15 cm depth for determination of nitrates and phosphorous by the Olsen P test on both calcareous samples and noncalcareous soils.

(Oslen, S.R. et al., 1954); potassium levels were found by extraction with 1 N ammonium acetate (Pratt, S.F., 1965); pH and organic carbon were analyzed by methods described earlier. Yield measurements at both the reasearch farm and cooperators' fields were made by sampling two-6.1 meter row segments within each erosion class. Yields were reported on a 15.5% moisture basis.

Differences between erosion classes for each parameter studied were analyzed with ANOVA and means comparisons were done using the Waller-Duncan k-ratio, t-test.

A stepwise regression method was used to determine the parameters having the most influence in predicting the variability in yields. The independent variables used were shallow nitrates (NO_3S), phosphorous, potassium, pH, and organic matter. Climatic variables found to have a significant influence on yields were also used (Kenefick 1983). These variables include June through September average monthly precipitation, June and September minimum temperature, and July and August maximum temperature. Each erosion class was used as a dummy variable.

The data included in the appendices will be used in the Nitrogen-Tillage-Residue-Management (NTRM) model developed by the Soil and Water Management Research Unit, USDA-St. Paul,Minnesota. This computer simulation model was designed to provide a comprehensive model of the soil environment and its effect on crop growth.

RESULTS and DISCUSSION

Physical Properties

The severely eroded Egan soil had a significantly lower surface hydraulic conductivity than both the slightly or moderately eroded phases (Table 1). The reduced permeability may be related to the higher surface clay content of the severely eroded phase (40%) as compared to 35% clay for both the slightly and moderately eroded phases. No significant differences existed however between the slightly and moderately eroded phases of the Egan soil. Permeability rates were moderately rapid, moderate, and moderately slow for the slight, moderate, and severe erosion classes, respectively. In comparison, the saturated hydraulic conductivity for each phase of the Beadle soil was moderate and no significant differences existed among the three erosion classes.

Surface bulk densities for both the Egan and Beadle soils were also examined. (Table 2). Bulk density values of the Ap horizon were not significantly different among the three erosion classes for either soil. Although the values for each erosion class are slightly higher on the Egan than on the Beadle soil, compaction is not great enough to limit normal plant growth.

TABLE 1. Effect of erosion on surface hydraulic conductivities of the Egan and Beadle soils.

Hydraulic Conductivity (cm/hr)

Soil	N	Slightly Eroded	Moderately Eroded	Severely Eroded
Egan	9	6.55 a	4.75 a	1.47 b
Beadle	9	5.32 a	3.64 a	4.21 a

Rates: Moderately slow: 0.50-2.0 cm/hr.
Moderate: 2.0-6.25 cm/hr.
Moderately rapid: 6.25-12.5 cm/hr.

Means with the same letter compared across erosion classes are nonsignificant. (0.05 level of significance)

TABLE 2. Effect of erosion on the surface bulk density of the Egan and Beadle soils.

Bulk Density (g/cm^3)

Soil	N	Slightly Eroded	Moderately Eroded	Severely Eroded
Egan	9	1.17 a	1.13 a	1.17 a
Beadle	9	1.08 a	1.07 a	1.08 a

Means with the same letter compared across erosion classes are non significant. (0.05 level of significance)

Available Water

Severe erosion plays on important role in reducing the available water holding capacity of the surface horizon. The severely eroded Egan had an available water holding capacity that was 18% lower than the slightly eroded and 30% lower on a volume basis than the moderately eroded phase. (Table 3). In the case of the Beadle soil, the same trend was observed. The available water holding capacity of the severely eroded phase was 37% and 39% lower on a volume basis than the slightly and moderately eroded phases, respectively. Values for the severely eroded sites were significantly lower than the slightly or moderately eroded sites for both soils. No significant differences were observed between the latter two erosion classes. The significantly lower plant available water holding capacities of the severely eroded soils are due to both the higher clay and lower organic matter content of the surface horizons. Higher available water holding capacities in the Beadle soil across erosion classes are a result of greater amounts of organic matter in the Ap horizon.

Table 4 compares the total centimeters of available water possible in the profile for each soil. less plant available water is held in the profile of the severely eroded phase than in the slightly or moderately eroded

TABLE 3. Effect of erosion on surface available water holding capacity (θv) of the Egan and Beadle soils.

		Available Water Holding Capacity (θv)		
Soil	N	Slightly Eroded	Moderately Eroded	Severely Eroded
			%	
Egan	9	17 a	20 a	14 b
Beadle	9	30 a	31 a	19 b

Means with the same letter compared across erosion classes are nonsignificant. (0.05 level of significance).

TABLE 4. Centimeters of available water by horizon for each phase of the Egan and Beadle Soils.

Egan Series
(150 cm depth)

Slightly Eroded	Moderately Eroded	Severely Eroded
Ap - 3.1 cm	Ap - 3.8 cm	Ap - 2.2 cm
Bw1 - 4.0 cm	Bw - 4.3 cm	Bk1 - 2.8 cm
Bw2 - 4.6 cm	Bk - 8.5 cm	Bk2 - 7.5 cm
Bk - 13.0 cm	C - 9.4 cm	C - 11.2 cm
C - 7.2 cm		
Total - 31.9 cm	Total - 26.0 cm	Total - 23.7 cm

Beadle Series

Slightly Eroded	Moderately Eroded	Severely Eroded
Ap - 6.3 cm	Ap - 7.1 cm	Ap - 4.2 cm
Bw - 2.8 cm	Bt - 3.4 cm	Bk - 6.0 cm
Bk1 - 4.6 cm	Bk - 7.7 cm	C1 - 9.8 cm
Bk2 - 3.7 cm	C - 11.9 cm	C2 - 4.4 cm
C1 - 2.6 cm		
C2 - 11.6 cm		
Total - 31.6 cm	Total - 30.1 cm	Total - 24.4 cm

phase of each soil. The severely eroded Egan holds 8.2 fewer centimeters than the slightly eroded Egan. In comparison, severely eroded Beadle soil holds 7.2 fewer centimeters of available water in 150 centimeters of soil than the slightly eroded Beadle. The lower available water holding capacity in the profile of the severely eroded soil probably has a more detrimental effect on yield during seasons when moisture is limiting than in years when adequate and timely rainfall occurs. This is especially true in eastern South Dakota where soil moisture is often a limiting factor to crop production. For this reason, the lower plant available water holding capacity is thought to have a negative influence on yields of the severely eroded Egan and Beadle soils.

Soil Fertility Status

Comparison of Egan and Beadle Soils

The shallow (NO_3S) and deep (NO_3D) nitrate soil test values are not significantly different for either soil when comparing across erosion classes. (Table 5). A concentration of nitrates in the deep sample is a result of past fertilzer management. Nitrogen levels in both soils exceed the plants needs and are not considered to be yield limiting. The phosphorous test levels are significantly lower on the severely eroded Egan but are not significantly different on the Beadle soil across erosion

TABLE 5. Effect of erosion on the soil fertility status of the Egan and Beadle soils.

Soil Fertility Parameters
N=3

Egan Series

Variable	Slightly Eroded	Moderately Eroded	Severely Eroded
NO3s(kg/ha)	50 a	32 a	41 a
NO3d(kg/ha)	138 a	124 a	209 a
P (kg/ha)	61 a	53 a	31 b
K (kg/ha)	568 a	411 b	362 c
pH	6.7 a	7.2 b	7.7 c
% OM	2.9 a	2.6 b	2.5 b

Beadle Series

Variable	Slightly Eroded	Moderately Eroded	Severely Eroded
NO3s (kg/ha)	46 a	44 a	38 a
NO3d (kg/ha)	149 a	127 a	186 a
P (kg/ha)	57 a	57 a	50 a
K (kg/ha)	496 a	435 ab	358 b
pH	7.2 a	6.6 b	7.7 a
% OM	3.6 a	3.2 ab	2.8 b

Means with the same letter compared across erosion classes are nonsignificant. (0.05 level of significance) classes. An explanation for this could be that more phosphorus is being mineralized in the severely eroded Beadle than in the severely eroded Egan due to higher amounts of organic matter in the former. Another reason could be that more phosphorous is being fixed in the Egan because of a higher percentage of $CaCO_3$ on the surface (10.10%) as compared to the Beadle (6.3%). Potassium values for both soils are very high as a result of potassium bearing minerals in the glacial till. One reason for the significantly lower potassium readings in the severely eroded phases of both soils may be related to differences in weathering of the exposed surfaces. Less weathering has occurred in the exposed subsoil of both the severely eroded soils than in the other two erosion classes, resulting in lower amounts of released potassium. The pH is significantly higher on the surface of the severely eroded Egan due to the free calcium carbonate present on the surface. Although the pH of the severely eroded Beadle is higher than the slightly eroded phase, there is no statistical difference because of the variability among pH values. In contrast to the pH values, the amount of organic matter decreases as erosion increases. This trend occurs in both soils. Significantly lower amounts of organic matter are present in the severely eroded phases of both soils as compared to the slightly eroded phases. The lower amounts of organic matter influenced the soil structure, available water holding capacity, and CEC of the surface horizons of the soils studied.

Corn Yields

Corn yields were also determined at the Madison Research Farm (Table 6). In 1983, yields on the slightly and moderately eroded Egan soil yielded higher than on the severely eroded site. However, no significant differences occurred between the slight and moderate erosion classes. The yield of the severely eroded site was 52% of the slightly eroded site and was significantly lower than the other two erosion classes. In 1984, yields on the slightly eroded phase of the Egan soil were not significantly different than on the severely eroded phase of the Egan. The low yields on the slightly eroded plot could be caused by inadequate root development and growth due to excess soil moisture present early in the growing season. Corn yields were also determined on the Beadle soil in 1984. No significant differences were found between the slight and moderately eroded phases but the 20% reduction in yields on the severely eroded site was significantly lower than on the other two erosion classes.

In summary, erosion had a similar effect on soil test and yield results of the Egan and Beadle soils. This may indicate that productivity changes as a result of erosion

TABLE 6. Effect of erosion on Madison corn yields

Yield Means (kg/ha)

Soil	Year	Slightly Eroded	Moderately Eroded	Severely Eroded
Egan	1983	5582 a	4892 a	2132 b
Egan	1984	5017 a	8279 b	5958 a
Beadle	1984	8593 a	8091 a	6899 b

bu/ac = kg/ha / 62.72

Means with the same letter across erosion classes are nonsignificant. (0.05 level of significance) are similar for soils that are closely related.

Survey Study of the Egan Soil

The differences observed in the shallow nitrate values are a result of differing rates of nitrogen fertilizer applied on each farm. (Table 7). The available phosphorous test values decreased as the amount of erosion increased, although no significant differences were observed between the slightly and moderately eroded areas. Significantly lower phosphorous levels on the severely eroded sites are probably caused by the formation of slowly soluble tricalcium phosphate compounds in the calcareous surface horizons. Potassium readings were high across all three erosion classes because of fertilizer additions and natural sources of potassium in the soil. No significant differences existed among erosion classes, however.

The pH values for the severely eroded phase is significantly higher than the slightly and moderately eroded values. The exposed calcareous horizon accounts for the high pH. The percent organic matter present in the Ap horizon decreased as erosion increases and is significantly different for each erosion class.

TABLE 7. Effect of erosion on the soil fertility status of the Egan soil. Average of 1983-1984.

Soil Fertility Parameters
N=29

Variable	Slightly Eroded	Moderately Eroded	Severely Eroded
NO3s (kg/ha)	37 a	30 b	31 ab
P (kg/ha)	41 a	38 a	29 b
K (kg/ha)	618 a	517 a	504 a
pH	7.0 a	7.0 a	7.6 b
% OM	3.4 a	3.1 b	2.6 c

lbs/ac = kg/ha / 1.12

Means with the same letter across erosion classes are nonsignificant. (0.05 level of significance)

TABLE 8. Effect of erosion on corn yields. Average of 1983-1984

Yield Means (kg/ha)

Year	N	Slightly Eroded	Moderately Eroded	Severely Eroded
1983	11	7526 a	6620 a	5069 b
1984	18	7544 a	7397 a	5826 b
Ave.	29	7535 a	7008 a	5447 b

bu/ac = kg/ha / 62.72

Means with the same letter across erosion classes are nonsignificant. (0.05 level of significance)

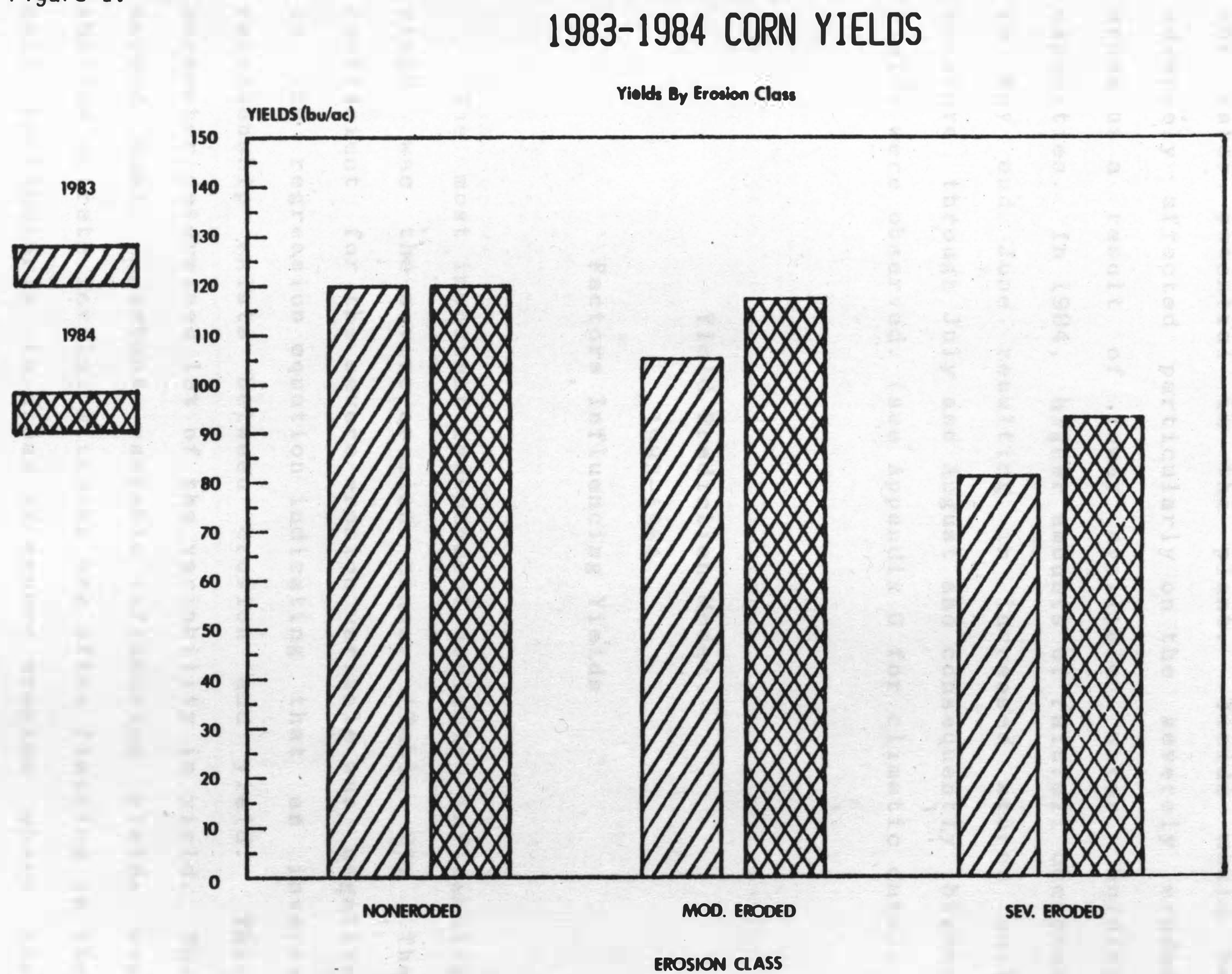
Effect of Erosion on Corn Yields

Survey Study

Corn yields in 1983 were reduced by 12% on the moderately eroded areas and 33% on the areas of severe erosion as compared to the slightly eroded sites. (Table 8). In 1984, yields on the moderately and severely eroded sites were reduced by 2% and 23%, respectively. Yields on the severely eroded Egan in both 1983 and 1984 are significantly lower than the yields on the slightly and moderately eroded phases of the Egan soil. No differences existed in yields between the slight and moderate erosion classes.(see Figure 1).

Comparing yield means between years for the same erosion class, yields averaged 0.3%, 10.5%, and 13% higher in 1984 for the slight, moderate, and severely eroded phases, respectively. The lower yield reductions across the three erosion classes and the higher average yields for each erosion class in 1984 are probably attributed to more favorable precipitaion and temperature conditions in 1984 than in 1983. Even though more rainfall occurred during critical growth stages (pollination and grain filling) in 1983 than in 1984, July and August average temperatures were higher in 1983. This resulted in increased evapotranspiration and less plant available water present in the root zone at these critical growth stages.

Figure 1.


1983-1984 CORN YIELDS
Yields By Erosion Class
YIELDS (bu/ac)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1983
1984
NONERODED
MOD. ERODED
SEV. ERODED
EROSION CLASS

The raised potential evapotranspiration could also lower the water potential in the plant. Yields would be adversely affected particularly on the severely eroded areas as a result of lower available water holding capacities. In 1984, higher amounts of rainfall occurred in May and June resulting in increased stored soil moisture through July and August and consequently higher yields were observed. (see Appendix G for climatic data).

Yield Prediction Model

1983-1984

Factors Influencing Yields

The most important independent variable influencing yield was the severe erosion class. (Table 9). The coefficient for the severe erosion variable was negative in the regression equation indicating that an inverse relationship exists between erosion and yield. This parameter determined 19% of the variability in yield. The second most important variable influencing yields was shallow nitrate levels. Nitrates are often limiting in the soil particularly in areas of severe erosion where the natural source of nitrogen, organic matter, is less abundant.

TABLE 9. Yield Prediction Model. 1983-1984

Step	Variable added	Influence	Coeff. of Deter.
1	SE (A)	-	0.19
2	NO3s (B)	+	0.22
3	JulyMaxTemp (C)	-	0.24

$$\hat{Y}\ (bu/ac) = 303.30 - 27.86(A) + 0.30(B) - 2.37(C)$$

kg/ha = bu/ac * 62.72

This variable has a positive effect on corn yields and along with the severe erosion parameter explains 22% of the variability in yields. July maximum temperature was the third variable entered into the model and increases the R^2 value by 2% . The three variables; severe erosion nitrate level, and July maximum temperature explain 24% of the variability in corn yields. Because the July maximum temperature variable has a negative influence on yield, high average July temperatures would have a detrimental effect on yield for reasons discussed previously relating to available water holding capacity and lower plant water potentials.

Low coefficient of determination (R^2) values are a result of the large variability of the data collected across many different management systems. Under a more controlled system, the R^2 values would probably be much higher.

Lastly, caution should be used in determining yields with this equation as only 24% of the variability in yield is being explained by this model. This model is more appropriately designed to determine significant factors that are influencing corn yields.

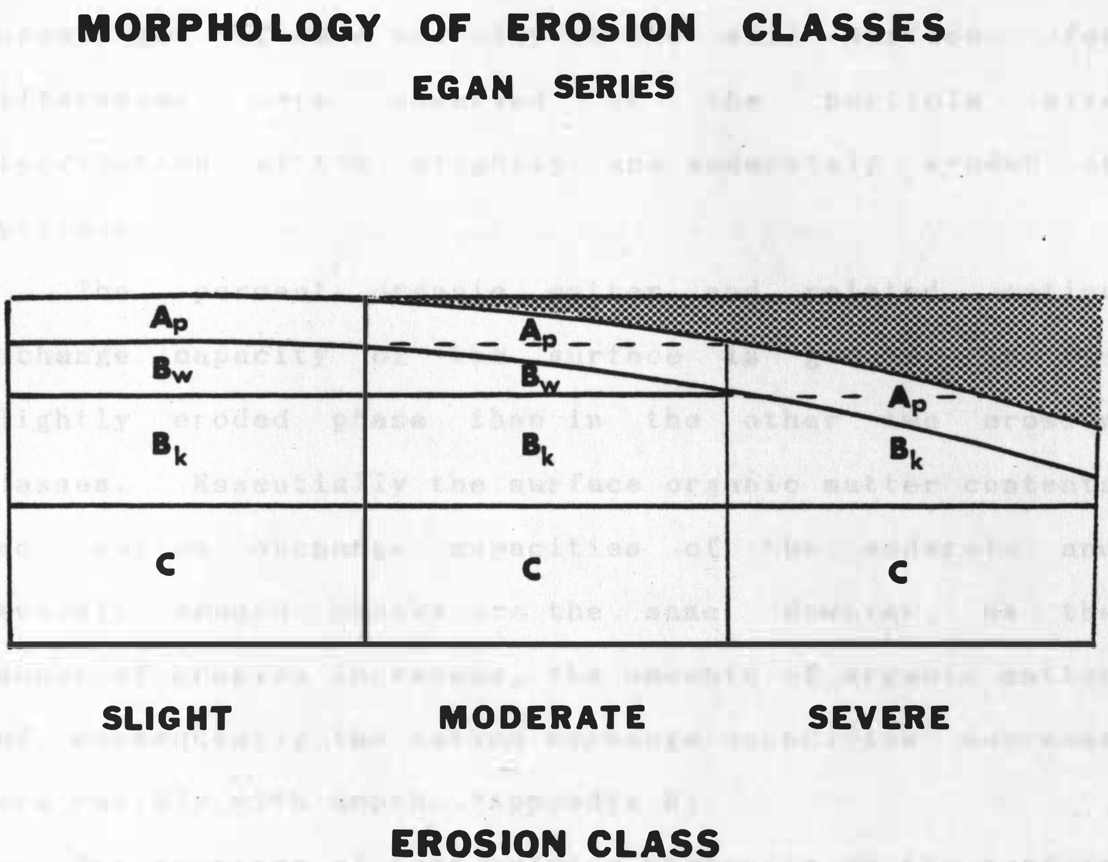
Pedon Characterization

Both the Egan and Beadle soils are susceptible to the erosional process primarily because of their position on the landscape, land-use, and surface soil texture. Each soil is found on an upland position commonly on slopes ranging from two to nine percent. Both are generally used for row crop production and have silty clay loam textured surfaces in the slightly eroded phase. Also, these soils have a shallower depth of desirable rooting material than a soil developed in loess, for example. As a result of the former factors, these two soils are susceptible to erosional damage over a short period of time. As more of the original A horizon is removed through sheet erosion, tillage mixes more and more undesirable subsoil material with the surface material imparting those characteristics to the A horizon.(see Figure 2).

Egan Soil

Erosion had an influence on the particle size distribution of the surface horizon of the Egan soil particularly in the severely eroded phase.(Appendix B). With respect to the slightly eroded phase, the severely eroded phase had a 5.1% increase in the clay fraction, a 14.3% increase in the sand fraction and a

Figure 2. Schematic diagram of morphological changes due to erosion.



19.4% decrease in the silt percentage. Silt-sized soil particles, being more susceptible to detachment by raindrop impact than clay and sand-sized particles, were easily carried away from the site. This increased the percentages of sand and clay on the soil surface. Few differences were observed in the particle size distribution of the slightly and moderately eroded Ap horizons.

The percent organic matter and related cation exchange capacity of the surface is greater in the slightly eroded phase than in the other two erosion classes. Essentially the surface organic matter contents and cation exchange capacities of the moderate and severely eroded phases are the same. However, as the amount of erosion increases, the amounts of organic matter and consequently the cation exchange capacities decrease more rapidly with depth. (Appendix B)

The presence of free calcium carbonate on the surface of the severely eroded Egan results in a higher pH value when compared to the other erosion phases. These high pH values may influence the availability of micronutrients such as iron, zinc, copper, and manganese. Also phosphorous becomes less available to the plant due to its precipitation in the soil solution by calcium. This calcareous surface horizon is thought to be the Bk horizon of the uneroded Egan exposed at the surface due to soil loss. Evidence to support this theory exists in the particle size data. In the slightly eroded Egan, a large increase in percentage of sand occurs in the C horizon at a depth beginning at 110 cm. In the moderately, eroded phase this increase in sand occurs in the Bk horizon at a depth of 48 cm. In the severely eroded phase, the properties of the Bk horizon are present on the surface. This supports the conclusion that this was once subsoil material which is now exposed due to soil loss through time.

Beadle Soil

The Beadle soil is formed in loamy glacial till and therefore has a higher content of sand and a lower percentage of silt in the solum than the Egan soil. The slightly eroded Beadle may be considered a taxadjunct due to the absence of an argillic horizon. The clay percentage increases slightly in the B horizon, but not the 1.2 times the amount of clay increase needed to designate this as an argillic horizon. (Appendix B). In the moderately eroded Beadle, the sand fraction of the surface increased with a corresponding decrease in the amount of silt compared to the slightly eroded Beadle. The clay percentage remained slightly lower. An argillic horizon is present in the moderately eroded Beadle. Both the CEC/clay and the 1.5 MPa/clay ratios of the argillic horizon are indicative of smectite-type clay mineralogy In the surface of the severely eroded Beadle a further increase in the amount of sand (6.1%) and clay (6.7%) and a corresponding decrease in the amount of silt (12.8%) over the moderately eroded Beadle occurs. The absence of an argillic horizon in the severely eroded Beadle may be a result of the erosion process and the subsequent exposure of the Bk horizon on the soil surface. In the C_2 horizon of this eroded phase a large decrease in the percent sand and a large increase in the percent clay indicates that this may be the contact with a different aged till. Also a slight increase in the organic matter content indicates that this once may have been surface material.

The organic matter content and cation exchange capacities of the surface horizons decrease as the amount of erosion increases. As seen in the Egan soil, these two properties also decrease considerably faster with depth as the erosion class shifted from slight to severe. (Appendix B). The pH of the surface horizon in the severely eroded phase is high because of the calcium carbonate present on the surface just as in the Egan soil.

SUMMARY and CONCLUSIONS

The effects of erosion on corn yields and soil properties were investigated over a two year period in Lake County, South Dakota. Two soils, a Udic Haplustoll (Egan series) and a Typic Argiustoll (Beadle series) were chosen for this study. Productivity is threatened in both soils as a result of highly erodable silty clay loam surface textures and relatively shallow depths of desirable rooting material. Soil physical and chemical properties, morphological data, and yields were compared across erosion classes for both soils.

Measurements of soil physical properties revealed no significant differences between the slightly and moderately eroded phases of each soil. Surface hydraulic conductivities were significantly lower on the severely eroded Egan, however no significant differences existed among all three erosion classes for the Beadle soil. Bulk densities of the surface horizon were also nonsignificant among erosion classes for both soils. Erosion had an adverse effect on the plant available water holding capacity of the entire profile. Surface available water holding capacities significantly decreased on the severely eroded phases of both soils. This could be a result of reduced organic matter and higher clay contents on the surface of the Egan and Beadle soils.

The fertility status of both soils was also examined. A comparison of the slightly and moderately eroded Egan to the severely eroded phase revealed significantly lower phosphorous, potassium, and organic matter test levels and significantly higher pH values in the severely eroded phase. Erosion had no influence on either shallow or deep nitrate levels. In the Beadle soil, significantly lower organic matter and potassium and a significantly higher pH was found in the severely eroded than in the slightly eroded class. No significant differences in available phosphorous contents occurred across erosion classes. As in the Egan soil, differences in nitrate levels were nonsignificant.

Average corn yields on the severely eroded Beadle were significantly lower than the yields on the slightly and moderately eroded phases. The same trend occurred on the Egan soil in 1983 but in 1984 the yields on the slightly and severely eroded phases were not significantly different from one another. In 1984, yields between the Egan and Beadle soils were comparable across erosion classes except for the slightly eroded Egan. Overall, the similarity of soil test data and yield results between the Egan and Beadle soils indicates that it may be possible to extrapolate data collected from one soil to another closely related soil given the same type of climate and management system.

Soil fertility data and yields were also collected on the Egan soil in fields throughout Lake County. The results showed that erosion significantly reduces available phosphorous and organic matter contents of the Ap horizon. Conversely, the pH was higher in the severely eroded phase of Egan than in both the slightly and moderately eroded phases. Nitrates showed no particular trends and were highly variable due to different rates of fertilizer applied from one field to another. Average corn yields in the two-year study were significantly lower on the severely eroded than on the other two erosion classes. Lower yields on severely eroded areas in 1983 compared to 1984 is probably related to lower stored soil moisture in 1983. Yields on slightly and moderately eroded areas are not affected as greatly as on the severely eroded sites because of higher plant available water holding capacities. The results obtained in this survey were similar to these found at the research farm.

Using a multiple regression technique, variability in yields were largely explained by the erosion class, nitrate levels, and July maximum temperature. Low coefficient of determination values (R^2) were a result of sampling across many different management systems. Under a more controlled management system, the three variables would probably explain a larger percentage of the variation in yields.

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APPENDICES

APPENDIX A

SITE INFORMATION

Site Information

Egan

Elevation; 1760

	SLIGHT	MODERATE	SEVERE
% Slope	0-1	4	6
Slope Length (m)	-	26	34
Aspect	W	N	W

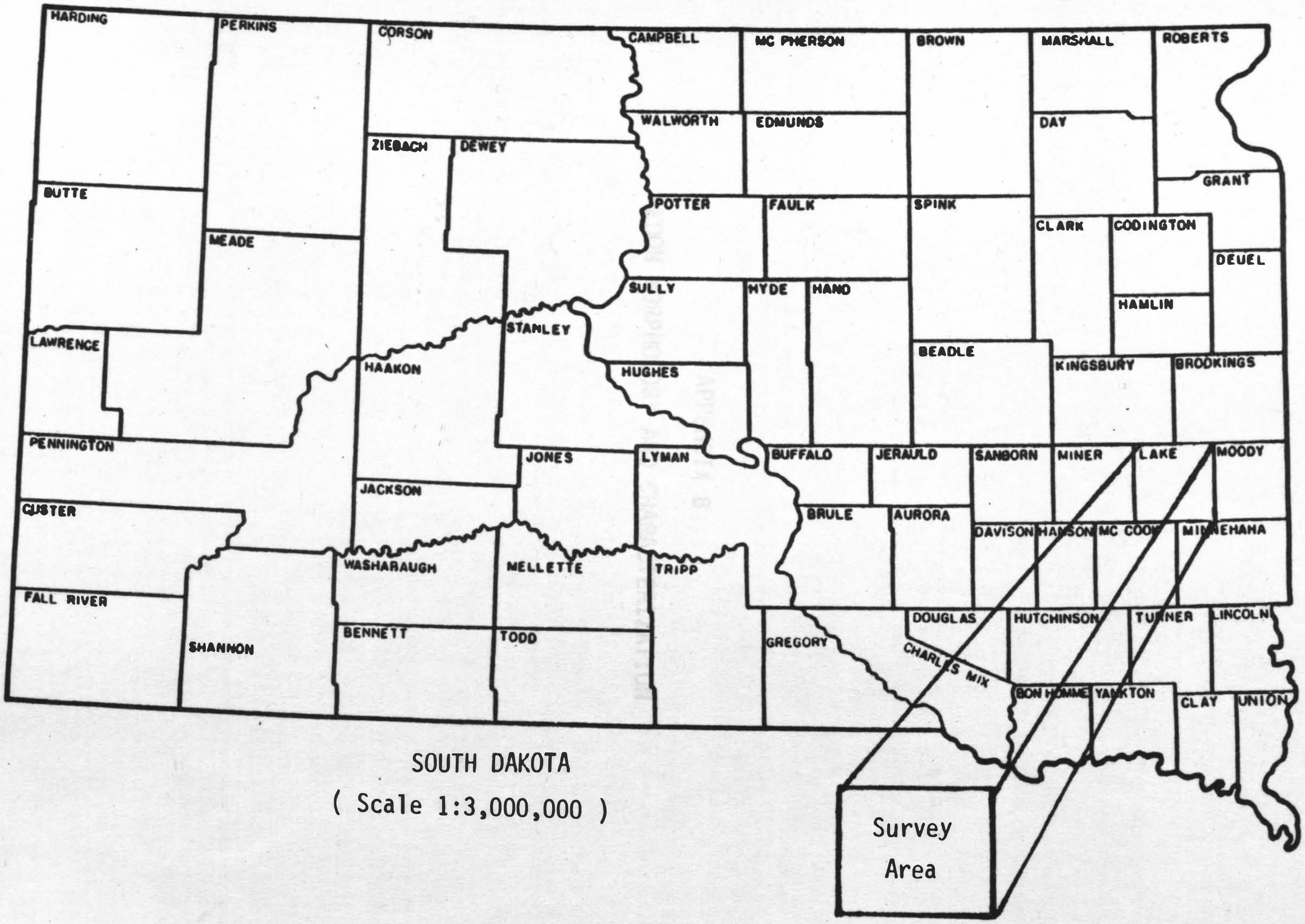
Beadle

Elevation; 1730

	SLIGHT	MODERATE	SEVERE
% Slope	0-1	7	10
Slope Length (m)	-	33	33
Aspect	SE	SE	SE

Latitude; $44^{\circ}02'$

Figure 3. Location of Farm Survey



SOUTH DAKOTA

(Scale 1:3,000,000)

APPENDIX B

PEDON MORPHOLOGY AND CHARACTERIZATION

SOIL	HORIZON	DEPTH (cm)	PARTICLE SIZE (% of TOTAL) TOTAL Sand	TOTAL Silt	TOTAL Clay	SAND FRACTION VC	SAND FRACTION C	SAND FRACTION M	SAND FRACTION F	SAND FRACTION VF	SILT FRACTION C	SILT FRACTION M	SILT FRACTION F
Egan-Slight	Ap	0-18	5.9	59.1	35.0	0.1	0.7	1.4	1.9	1.7	30.8	19.4	8.9
	Bw_1	18-37	5.1	59.0	35.9	0.1	0.5	1.3	1.7	1.5	33.2	20.0	5.8
	Bw_2	37-60	10.9	54.8	34.2	0.5	3.4	3.2	2.5	1.3	23.1	25.7	6.1
	Bk	60-110	5.4	58.5	36.1	0.6	1.3	1.4	1.4	0.7	21.6	29.0	7.9
	C	110-150	28.5	40.3	31.2	1.0	3.6	6.0	9.7	8.2	18.4	15.6	6.4
Egan-Moderate	Ap	0-19	6.1	58.9	35.0	0.3	0.6	1.3	2.1	1.8	30.8	21.7	6.5
	Bw	19-48	8.0	56.6	35.4	0.4	0.9	2.0	2.8	2.0	25.3	23.8	7.4
	Bk	48-98	29.5	34.0	36.5	1.2	3.0	6.7	11.8	6.8	11.5	13.5	9.0
	C	98-150	27.5	37.0	35.5	1.2	2.9	6.3	10.5	6.6	11.8	15.4	9.8
Egan-Severe	Ap	0-16	20.2	39.7	40.1	0.7	2.7	5.2	7.5	4.0	20.7	13.5	5.6
	Bk_1	16-36	29.7	29.8	40.6	0.7	3.9	7.7	11.3	6.2	10.9	14.3	4.6
	Bk_2	36-80	28.2	31.7	40.2	0.5	3.7	7.1	10.9	6.0	10.5	13.7	7.5
	C	80-150	28.0	29.4	42.6	1.2	4.1	6.9	10.1	5.8	8.1	12.9	8.4

SOIL	Horizon	EXTRACTABLE BASES Ca	Mg	Na	K	CEC NH_4OAC	pH (1:1)	OM %	$CaCO_3$ %	RATIO CEC/Clay	WATER CONENT .03 MPa	1.5 MPa	RATIO 1.5 MPa to Clay
		cmol $(p^+)kg^{-1}$									%		
Egan-Slight	Ap	24.7	7.7	0.3	1.9	28.7	6.6	2.9	1.70	0.82	35.4	20.6	0.59
	Bw_1	23.0	8.1	0.3	1.9	28.4	6.4	2.5	1.36	0.79	38.7	20.7	0.58
	Bw_2	17.5	9.9	0.3	1.3	23.7	6.6	0.94	0.92	0.69	34.4	19.0	0.55
	Bk	--	--	0.3	1.2	20.5	7.7	0.94	14.5	0.56	35.2	18.1	0.50
	C	--	--	0.7	1.4	17.9	7.8	0.49	18.2	0.57	27.6	15.9	0.51
Egan-Moderate	Ap	20.4	6.7	0.0	1.7	26.0	6.7	2.6	1.20	0.74	34.4	18.5	0.53
	Bw	19.2	6.9	0.3	1.3	24.0	6.8	1.25	2.22	0.68	30.0	18.1	0.51
	Bk	--	--	0.5	1.1	18.6	7.7	0.68	21.4	0.51	30.6	19.5	0.57
	C	--	--	0.5	1.3	18.7	7.8	0.57	21.3	0.53	30.2	19.1	0.54
Egan-Severe	Ap	--	--	0.3	1.4	25.4	7.7	2.6	10.10	0.63	32.4	19.6	0.49
	Bk_1	--	--	0.3	0.8	20.4	7.6	0.81	23.00	0.50	28.7	18.3	0.45
	Bk_2	--	--	0.3	0.6	19.3	7.9	0.71	23.30	0.48	30.6	18.7	0.47
	C	--	--	0.3	0.6	20.2	7.9	0.33	21.20	0.47	32.5	22.5	0.53

Egan Series - Slightly eroded

Ap - 0 to 18 cm; black (10 YR 2/1) moist; silty clay loam; moderate fine granular structure; friable; abrupt smooth boundary.

Bw1 - 18 to 37 cm; very dark grayish brown (10 YR 3/2) moist; silty clay loam; moderate medium prismatic structure parting to moderate, fine subangular blocky structure; firm; pressure faces present on ped faces; clear wavy boundary.

Bw2 - 37 to 60 cm; dark brown (10 YR 3/3) moist; silty clay boam; moderate medium prismatic structure parting to moderate fine subangular blocky structure; firm; pressure faces present on ped faces; clear wavy boundary.

Bk - 60 to 110 cm; grayish brown (2.5 Y 5/2) moist; silty clay loam; moderate medium prismatic structure parting to moderate medium subangular blocky structure; firm; many medium soft accumulations of carbonates; violent effervescence; clear wavy boundary.

2C - 110 to 150 cm; light olive brown (2.5 Y 5/4) moist; clay loam; common medium distinct gray (2.5 Y 5/0) and fine medium prominent reddish brown (5 YR 4/4) mottles; massive structure; firm; many medium soft accumulations of calcium carbonate; violent effervescence.

Egan Series - Moderately eroded

Ap - 0 to 19 cm; black (10 YR 2/1) moist; silty clay loam; moderate fine granular structure; very friable; abrupt smooth boundary.

Bw - 19 to 48 cm; dark brown (10 YR 3/3) moist; clay loam; moderate medium prismatic structure parting to moderate medium subangular blocky structure; friable; abrupt wavy boundary.

Bk - 48 to 98 cm; dark grayish brown (2.5 Y 4/2) moist; clay loam; common medium distinct gray (2.5 Y 5/0) mottles; moderate medium prismatic structure parting to moderate medium subangular blocky structure; firm; many medium soft accumulations of calcium carbonate; violent effervescence; clear wavy boundary.

2C - 98 to 150 cm; olive brown (2.5 Y 4/4) moist; clay loam; common medium distinct gray (2.5 Y 5/0) mottles, massive structure; firm; common fine soft accumulations of calcium carbonate; strong effervescence.

Egan Series - Severely eroded

Ap - 0 to 16 cm; very dark grayish brown (10 YR 3/2) moist; clay; weak fine granular structure; firm; strong effervescence; abrupt smooth boundary.

Bk1 - 16 to 36 cm; dark brown (10 YR 3/3) moist; clay; moderate medium prismatic structure parting to moderate medium subangular blocky structure; firm; many common soft accumulations of calcium carbonate; violent effervescence, clear wavy boundary.

Bk2 - 36 to 80 cm; dark grayish brown (2.5 Y 4/2) moist; clay; common fine distinct gray (2.5 Y 5/0) mottles; moderate medium prismatic structure parting to moderate medium subangular blocky structure; firm; many medium soft accumulations of calcium carbonte; violent effervescence; clear wavy boundary.

2C - 80 to 150 cm; light olive brown (2.5 Y 5/4) moist; clay; common medium distinct gray (2.5 Y 5/0) mottles; massive structure; firm; few fine accumulations of calcium carbonate; strong effervescence.

SOIL	HORIZON	DEPTH (cm)	PARTICLE SIZE (% of TOTAL) TOTAL Sand	Silt	Clay	SAND FRACTION VC	C	M	F	VF	SILT FRACTION C	M	F
Beadle-slight	Ap	0-21	14.3	49.5	36.2	0.3	1.5	3.1	5.2	4.2	25.6	20.5	3.4
	Bw	21-46	9.5	53.2	37.3	0.0	0.8	1.8	3.5	3.2	32.1	13.7	7.4
	Bk_1	46-57	6.7	55.8	37.5	0.0	0.6	1.2	2.7	2.3	26.7	25.4	3.7
	Bk_2	57-79	6.2	58.4	35.3	0.2	0.2	0.6	2.1	3.2	26.2	24.0	8.3
	C_1	79-92	26.5	41.4	32.1	0.2	0.3	1.7	13.8	10.5	23.0	0.0	18.4
	C_2	92-150	35.4	28.8	35.8	0.0	0.2	3.2	22.3	9.7	18.2	8.6	2.0
Beadle-Moder.	Ap	0-23	25.8	39.8	34.4	1.1	4.1	7.2	8.5	4.8	21.0	13.8	5.1
	Bt	23-41	27.9	30.3	41.8	0.4	3.4	7.3	10.5	6.3	13.3	14.2	2.8
	Bk	41-84	33.0	30.0	37.0	0.7	3.8	7.9	12.7	7.9	9.0	15.2	5.8
	C	84-150	34.0	27.8	38.2	0.9	3.6	8.0	13.1	8.4	7.3	13.8	6.7
Beadle-Severe	Ap	0-22	31.9	27.0	41.1	1.5	4.3	8.2	11.0	6.8	8.9	14.9	3.2
	Bk	22-68	30.2	27.4	42.4	0.6	4.0	7.6	11.2	6.8	3.3	18.3	5.8
	C_1	68-129	31.2	30.2	38.6	0.7	4.1	7.8	10.9	7.7	11.6	10.6	8.1
	C_2	129-150	17.6	27.8	54.5	0.4	1.9	4.5	6.8	4.1	6.4	15.3	6.2

SOIL	Horizon	EXTRACTABLE BASES Ca	Mg	Na	K	CEC NH_4OAC	pH (1:1)	OM %	$CaCO_3$ %	RATIO CEC/Clay	WATER CONENT .03 MPa	1.5 MPa	RATIO 1.5 MPa to Clay
		cmol $(p^+)kg^{-1}$									%		
Beadle-Slight	Ap	29.9	7.6	0.3	1.0	30.6	6.8	3.60	1.43	0.85	47.7	22.0	0.61
	Bw	28.9	8.7	0.3	1.4	27.8	7.3	2.43	1.45	0.75	36.2	21.9	0.59
	Bk_1	--	--	0.3	1.0	17.9	7.7	0.60	37.7	0.48	33.3	17.8	0.47
	Bk_2	--	--	0.3	1.2	17.5	7.9	0.97	30.6	0.50	30.9	20.0	0.57
	C_1	--	--	0.3	1.0	14.8	7.9	0.35	26.0	0.46	28.1	15.3	0.48
	C_2	--	--	0.3	0.8	12.6	7.8	0.31	20.3	0.35	24.2	11.6	0.32
Beadle-Moder.	Ap	20.8	6.1	0.2	1.8	27.2	6.6	3.20	1.1	0.79	42.4	19.0	0.55
	Bt	27.7	7.6	0.3	1.3	25.7	7.1	1.39	1.4	0.61	31.2	19.0	0.45
	Bk	--	--	0.3	1.0	18.5	7.7	1.00	24.5	0.50	28.7	17.2	0.46
	C	--	--	0.4	1.4	17.4	7.9	0.70	20.2	0.45	29.7	19.6	0.51
Beadle-Severe	Ap	--	--	0.3	1.8	25.3	7.5	2.80	6.3	0.62	35.3	20.5	0.50
	Bk	--	--	0.3	1.2	19.6	7.8	1.17	26.6	0.46	28.6	19.4	0.46
	C_1	--	--	1.7	1.3	19.6	7.8	0.19	20.1	0.50	31.6	21.0	0.54
	C_2	--	--	2.1	1.9	23.9	8.0	0.45	19.6	0.44	38.2	25.1	0.46

Beadle Series-Slightly eroded

Ap-0 to 21 cm; black (10 YR 2/1) moist; silty clay loam; moderate fine and very fine granular structure; friable; abrupt smooth boundary.

Bw-21 to 46 cm; very dark grayish brown (10 YR 3/2) moist; silty clay loam; weak medium prismatic structure parting to moderate medium and fine subangular blocky structure; friable; abrupt wavy boundary.

Bk1 - 46 to 57 cm; light olive brown (2.5 Y 5/4) moist; silty clay loam; weak medium prismatic structure parting to fine and moderate medium subangular blocky structure; friable; violent effervescence; clear wavy boundary.

Bk2 - 57 to 79 cm; olive brown (2.5 Y 4/4) moist; silty clay loam; weak coarse prismatic structure parting to moderate medium subangular blocky structure; fine; common medium soft accumulations of calcium carbonate; violent effervescence; clear wavy boundary.

C1 - 79 to 92 cm; light olive brown (2.5 Y 5/4) moist; clay loam; few fine distinct gray (2.5 Y 5/0) mottles; massive structure; few fine soft accumulations of calcium carbonate; violent effervescence.

C2 - 92 to 150 cm; light olive brown (2.5 Y 5/4) moist; clay loam; few fine distinct gray (2.5 Y 5/0) and common coarse prominent brown (7.5 YR 4/4) mottles; weak fine platy structure; friable; violent effervescence.

Beadle Series - Moderately eroded

Ap - 0 to 23 cm; black (10 YR 2/1) mixed with dark brown (10 YR 4/3) moist; clay loam; moderate fine and very fine granular structure; friable; abrupt smooth boundary.

Bt - 23 to 41 cm; dark brown (10 YR 4/3) moist; clay; moderate medium prismatic structure parting to moderate fine and medium subangular blocky structure; firm; very dark grayish brown (10 YR 3/2) coatings on ped faces; abrupt smooth boundary.

Bk - 41 to 84 cm; light olive brown (2.5 Y 5/4) moist; clay loam; weak medium prismatic structure parting to moderate medium subangular block structure; firm; common medium soft accumulations of calcium carbonate; violent effervescence; clear wavy boundary.

C - 84 to 150 cm; light olive brown (2.5 Y 5/4) moist; clay loam; common medium distinct gray (2.5 Y 5/0) mottles; firm; 2% coarse fragments; pressure faces on ped surfaces; violent effervescence.

Beadle Series - Severely eroded

Ap- 0 to 22 cm; black (10 YR 2/1) moist; clay loam; moderate medium subangular blocky structure and moderate fine granular structure; firm; strong effervescence; abrupt smooth boundary.

Bk - 22 to 68 cm; brown (10 YR 5/3) moist; clay loam; common fine distinct gray (2.5 Y 5/0) mottles; coarse medium prismatic structure; firm; 2% coarse fragments; some pressure faces on ped surfaces; common medium accumulations of calcium carbonate; violent effervescence; gradual wavy boundary.

C1 - 68 to 129 cm; olive brown (2.5 Y 4/4) moist; clay loam; common fine prominent yellowish red (5 YR 4/6) and common medium distinct gray (2.5 Y 5/0) mottles; massive structure; firm; 2% coarse fragments; violent effervescence; gradual wavy boundary.

C2 - 129 to 215 cm; olive brown (2.5 Y 4/4) moist; clay; few fine prominent yellowish red (5 YR 4/6) and common medium distinct brown (7.5 YR 5.6) and common medium distinct gray (2.5 Y 5/0) mottles; massive structure; firm; 2% coarse fragments; violent effervescence.

APPENDIX C

MADISON RESEARCH FARM BULK DENSITIES

Bulk Density
(g/cm^3)

Egan Series

Depth (cm)	Slightly Eroded	Moderately Eroded	Severely Eroded
0 - 15	1.16	1.32	1.23
15 - 30	1.26	1.36	1.32
30 - 45	1.37	1.48	1.35
45 - 60	1.49	1.54	1.48
60 - 75	1.55	1.63	1.53
75 - 90	1.59	1.60	1.55
90 - 105	1.57	1.61	1.52
105 - 120	1.56	1.60	1.61
120 - 135	1.53	1.59	1.65
135 - 150	1.70	1.62	1.61

Beadle Series

Depth (cm)	Slightly Eroded	Moderately Eroded	Severely Eroded
0 - 15	1.14	1.29	1.19
15 - 30	1.19	1.25	1.31
30 - 45	1.19	1.35	1.37
45 - 60	1.37	1.43	1.42
60 - 75	1.42	1.49	1.50
75 - 90	1.58	1.55	1.52
90 - 105	1.57	1.60	1.58
105 - 120	1.59	1.59	1.61
120 - 135	1.57	1.62	1.63
135 - 150	1.59	1.61	1.63

APPENDIX D

MADISON RESEARCH FARM

YIELD AND SOIL TEST DATA

Madison Farm Data

YEAR	SOIL	Rep	Erosion Class	Yield bu/ac	NO_3S lbs/ac	NO_3D lbs/ac	P lbs/ac	K lbs/ac	pH	% OM
1983	Egan	1	1	89	5	-	94	560	6.6	2.9
			2	78	12	-	62	400	7.3	2.6
			3	34	12	-	35	310	7.5	2.6
1984	Egan	1	1	80	46	158	65	480	7.0	3.0
			2	128	45	195	58	330	6.5	2.4
			3	90	20	51	20	320	7.7	2.6
		2	1	78	26	121	70	540	7.1	2.9
			2	146	19	100	60	410	6.8	2.7
			3	110	26	391	28	330	7.7	2.5
		3	1	82	64	90	70	500	7.5	2.8
			2	121	22	38	54	360	6.8	2.6
			3	85	65	119	35	320	7.6	2.6
1984	Beadle	1	1	139	43	84	62	410	6.8	3.3
			2	150	17	45	69	380	6.5	3.3
			3	115	56	253	53	320	7.5	3.2
		2	1	144	37	170	56	440	7.3	3.8
			2	121	53	135	63	390	6.9	3.6
			3	111	31	117	22	270	7.8	2.6
		3	1	127	42	146	69	480	7.5	3.6
			2	117	49	159	56	370	6.3	2.8
			3	104	14	128	59	370	7.7	2.7

Erosion Class: 1 = SLIGHT 2 = MODERATE 3 = SEVERE

APPENDIX E

FARM SURVEY-YIELD AND SOIL TEST DATA

1983 FARMS

Farmer	Location	Erosion class	Yield bu/ac	lbs/ac NO_3S	lbs/ac NO_3D	lbs/ac P	lbs/ac K	pH	% OM
G. Boer	NE¼, NE¼, Sec 31, R53W, T107N	1	154	36	--	116	770	6.6	3.6
		2	105	23	--	113	770	6.9	3.3
		3	108	22	--	44	410	7.3	2.6
L. Janke	SE¼, NE¼, Sec 8, R53W, T106N	1	110	68	--	80	710	6.6	3.9
		2	111	32	--	35	600	6.6	3.3
		3	70	41	--	30	380	7.3	2.2
D. Carper	W½, SE¼, Sec 8, R51W, T207N	1	183	15	--	19	540	6.7	3.7
		2	105	6	--	8	340	6.9	2.6
		3	57	31	--	30	370	7.3	2.9
R. Kasperson	S½, NW¼, Sec 10, R52W, T108N	1	150	73	--	94	720	7.1	3.5
		2	117	38	--	14	450	7.2	3.0
		3	106	38	--	8	380	7.5	2.4
D. Schroeder	NE¼ + NW¼, NE¼, Sec 8, R52W, T108N	1	84	80	--	17	820	7.2	3.6
		2	101	73	--	18	720	7.0	4.0
		3	88	84	--	26	960	7.5	2.7
V. Schroeder	SE¼, NE¼, Sec 17, R52W, T108N	1	86	20	--	180	960	6.9	3.4
		2	142	25	--	134	820	7.1	3.7
		3	91	32	--	88	680	7.4	3.3
J. Gross	NE¼, NW¼, Sec 28, R52W, T107N	1	94	33	--	12	650	7.0	3.7
		2	75	37	--	12	580	7.2	4.7
		3	50	37	--	24	440	7.4	3.4
J. Gross	S½, SW¼, Sec 9, R52W, T105N	1	121	13	--	14	380	6.9	3.2
		2	124	17	--	24	400	6.8	3.0
		3	99	15	--	20	380	7.5	2.6
G. Borgard	N½, SE¼, Sec 9, R51W, T108N	1	114	35	--	11	480	7.5	3.5
		2	85	20	--	24	510	7.5	2.2
		3	84	27	--	14	330	7.6	2.1
D. Hyland	SE¼, NE¼, Sec 1, R53W, T108N	1	144	22	--	30	840	7.2	3.4
		2	133	6	--	20	990	7.3	2.2
		3	109	12	--	20	570	7.6	1.9

Erosion Class: 1 = slight, 2 = moderate, 3 = severe

1984 FARMS

Farmer	Location	Erosion class	Yield bu/ac	lbs/ac NO_3S	lbs/ac NO_3D	lbs/ac P	lbs/ac K	pH	% OM
H. Bortnem	N½, SE¼, Sec 9, R51W, T108N	1	91	13	20	20	360	6.3	3.1
		2	54	16	18	13	260	7.2	3.5
		3	48	15	14	7	1180	7.8	2.7
V. Olson	S½, SW¼, Sec 26, R52W, T108N	1	132	31	19	28	500	7.0	3.0
		2	126	19	19	35	350	7.7	2.4
		3	92	17	18	35	370	7.9	1.9
W. Gehrels	NW¼, NE¼, Sec 27, R51W, T107N	1	167	37	53	14	330	7.7	3.0
		2	136	18	20	9	260	7.6	2.1
		3	164	26	62	8	280	7.7	2.4
L. Janke	SE¼, NE¼, Sec 8, R53W, T106N	1	107	24	35	16	310	7.1	2.9
		2	69	27	29	17	300	6.8	2.8
		3	31	23	30	18	260	7.6	2.0
H. Mechens	NE¼, NW¼, Sec 13, R54W, T106N	1	127	31	55	45	520	6.2	3.7
		2	108	33	64	60	440	6.2	3.3
		3	79	37	60	16	380	7.5	2.3
W. Gehrels	NW¼, NE¼, Sec 26, R51W, T107N	1	163	55	99	19	300	6.9	3.5
		2	138	28	36	12	270	7.1	3.6
		3	123	30	23	14	240	7.0	3.4
M. Molskness	NE¼, SW¼, Sec 24, R51W, T107N	1	155	35	41	34	300	6.6	4.2
		2	155	42	36	51	420	7.2	4.1
		3	106	27	49	20	380	7.8	2.3
E. Seten	NE¼, NW¼, Sec 18, R51W, T108N	1	129	14	46	22	1220	7.3	3.8
		2	122	22	39	11	490	7.1	3.2
		3	79	9	24	10	350	7.9	3.0
L. Steffen	S½, NW¼, Sec 8, R51W, T108N	1	103	17	19	30	390	7.5	3.0
		2	93	14	33	40	460	7.6	2.9
		3	66	12	22	12	380	7.9	2.5
D. Pederson	W½, SE¼, Sec 8, R51W, T108N	1	130	13	82	8	270	7.0	3.3
		2	125	21	35	9	370	6.9	3.1
		3	97	21	137	63	1870	7.8	3.1
E. Hanaman	NE¼, SE¼, Sec 9, R52W, T107N	1	98	14	26	20	920	7.6	2.9
		2	91	13	19	8	370	7.6	2.7
		3	83	8	19	8	350	7.8	2.2
H. Bortnem	SE¼, NE¼, Sec 4, R51W, T108N	1	113	8	12	12	310	7.8	2.6
		2	123	20	26	40	230	7.3	2.9
		3	89	14	15	10	220	7.8	2.6

Erosion Class: 1 = slight, 2 = moderate, 3 = severe

APPENDIX F

PLANT INFORMATION

Residue Cover (%)
1983

Egan Series

Tillage	Slightly Eroded	Moderately Eroded	Severely Eroded
Plow	0.9	0.8	0..9
Conservation	32	29	30

Forage Yields
(tons/ac)

	Slightly Eroded	Moderately Eroded	Severely Eroded
Egan 1983	1.06	1.28	1.32
Egan 1984	1.14	1.46	1.36
Beadle 1984	1.80	1.87	1.62

Egan
Stand Counts
(plants/10m)

	Slightly Eroded	Moderately Eroded	Severely Eroded
1983	36	38	40
1984	44	45	49

1983 Plant Population - 22.000
1984 Plant Population - 26,000

Volumetric Water Content At Silking

1983 vs 1984

Egan Series

Depth (cm)	Slightly Eroded 1983	Slightly Eroded 1984	Moderately Eroded 1983	Moderately Eroded 1984	Severely Eroded 1983	Severely Eroded 1984
23	43	35	34	33	33	27
46	33	38	27	35	31	33
76	34	40	30	40	35	35

Tissue Analysis

Egan Series

	Slightly Eroded 1983	Slightly Eroded 1984	Moderately Eroded 1983	Moderately Eroded 1984	Severely Eroded 1983	Severely Eroded 1984
% N	3.19	2.71	3.46	2.73	3.30	2.52
% P	.29	.22	.29	.24	.30	.22
% K	2.03	3.58	3.58	1.80	1.84	1.60

Leaf Area

(cm^2/plant)

Egan Series

Date	Slightly Eroded	Moderately Eroded	Severely Eroded
7/28/83	3821	4264	4095
6/26/84	648	757	438

APPENDIX G

CLIMATIC AND

SOIL TEMPERATURE DATA

CLIMATIC DATA

MONTHLY AVERAGES

1983

Month	Temperature °F Max.	Temperature °F Min.	Precipitation (in)	Pan Evaporation (in)	Wind (km)
May	64.1	42.3	1.75	-	5760
June	73.7	54.6	4.53	7.52	5130
July	84.8	63.5	4.02	9.53	3766
August	87.6	62.9	2.55	9.08	3046
September	72.4	48.2	1.96	5.48	3896

14.81

1984

Month	Temperature °F Max.	Temperature °F Min.	Precipitation (in)	Pan Evaporation (in)	Wind (km)	Solar Radiation ly/day
May	64.4	43.4	2.75	8.14	5973	-
June	75.6	57.1	9.57	8.17	4720	202
July	81.5	60.6	1.98	8.30	3485	178
August	82.9	60.5	1.35	7.56	2904	161
September	67.6	43.0	0.83	5.42	3691	125

16.48

Egan Series

Radiation
(ly/min)

	Slightly Eroded 1983	Slightly Eroded 1984	Moderately Eroded 1983	Moderately Eroded 1984	Severely Eroded 1983	Severely Eroded 1984
Incoming	1.57	1.64	1.36	1.58	1.57	1.68
Reflected	.22	.17	.27	.23	.29	.26

Solar Radiation
(langleys/day)

Month	Day	Total langleys/day
June	22	134
	23	133
	24	234
	25	214
	26	227
	27	231
	28	180
	29	232
	30	234
July	1	106
	2	217
	3	208
	4	212
	5	91
	6	234
	7	213
	8	213
	9	207
	10	103
	11	219
	12	219
	13	173
	14	109
	15	208
	16	139
	17	225
	18	224
	19	72
	20	218
	21	163
	22	197
	23	188
	24	140
	25	131
	26	206
	27	170
	28	201
	29	203
	30	188
	31	125

Month	Day	Total langleys/day
August	1	190
	2	146
	3	71
	4	94
	5	193
	6	181
	7	95
	8	204
	9	198
	10	197
	11	194
	12	196
	13	194
	14	179
	15	178
	16	45
	17	141
	18	192
	19	191
	20	72
	21	180
	22	188
	23	186
	24	153
	25	120
	26	161
	27	179
	28	176
	29	172
	30	160
	31	161
September	1	91
	2	125
	3	162
	4	162
	5	135
	6	76