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# The Effects of Erosion and Desurfacing on Soil Properties and Productivity of a Typic Haplustoll

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# THE EFFECTS OF EROSION AND DESURFACING ON SOIL PROPERTIES AND PRODUCTIVITY OF A TYPIC HAPLUSTOLL

By

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# THE EFFECTS OF EROSION AND DESURFACING ON SOIL PROPERTIES AND PRODUCTIVITY OF A TYPIC HAPLUSTOLL

<u>This thesis is approved as a creditable and independent investigation</u> by a candidate for the degree, Master of Science, and is acceptable as 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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# TABLE OF CONTENTS

# LIST OF TABLES

page

## LIST OF TABLES (cont.)

## List of Figures

Page

# I. INTRODUCTION

Topsoil is a valuable resource to humankind. Current food production can not be continued without this resource. Topsoil protection efforts must be continued or increased to meet future demands of mankind.

The soil erosion/productivity relationship involves complex physical processes. Erosion reduces productivity but losses may not be detected until land is no longer suitable to produce crops economically, furthermore, other variables may mask the relationship (Williams et al., 1981). Technology advancement including improved seed varieties, modern fertilizer, and herbicide have doubled or tripled many North American crop yields in the past 50 years. However the improved management practices have not offset the negative impacts of topsoil removal on crop production (Young et al., 1985).

The impact of topsoil removal is largely determined by subsoil properties as they affect root growth, soil available water and nutrient availability in the soil. A new soil environment is encountered when topsoil is removed either by natural or artificial erosion. This new environment in most cases is less suited for plant growth than original topsoil. Germination and emergence are often poor because of less than ideal soil physical properties. Topsoil loss may alter root system growth (Craft et al., 1985). The potential for nutrient and water uptake consequently depends on the new level of soil nutrients and available water surrounding the root system, and the morphology of the root system.

Topsoil removal may change resistance of surface aggregates to the beating action of raindrops. The stability of surface aggregates is important because aggregates below the surface are protected from rapid wetting by those above. Unstable surface aggregates are easily broken down and transported in suspension (El-Hassanin, 1983). This can lead to the formation of crusts that inhibit the movement of water and air into the soil. Maridasan and Chibber (1971) obtained a significant negative correlation between aggregate stability and the erosion ratio. Furthermore, aggregate stability influences plant growth indirectly through its relationship to the maintenance of a porosity suitable for air, water, and root movement (Greenland, 1965b).

Recently, researchers have devoted considerable effort to quantify the relationship between topsoil removal and soil productivity, principally on the basis of data from the North Central Region of the United States (Pierce et al., 1983; Pierce et al., 1984). The objectives of this study were: (1) to determine the effects of erosion and desurfacing on soil physical and chemical properties. (2) to examine the relationships of aggregate stability (a measure of soil structural stability) with soil properties which result from the erosion and desurfacing of a Beadle Taxadjunct (Fine, montmorillonitic, mesic Typic

Haplustoll). (3) to assess and compare the effect of erosion and desurfacing on continuous corn yield for this soil in eastern South Dakota.

Soil erosion is a conservation problem on about half of the cultivated land in the United States (Larson, 1981). The United States is losing soil from its agricultural lands at excessive rates, averaging nearly 10.75 tons of soil per hectare per year by water erosion and 7.4 tons per hectare per year by wind erosion from cultivated cropland (Lee, 1984). Such soil losses can alter the inherent soil properties and potential soil productivity for many crops.

## Soil Erosion and Soil Productivity

Soil productivity has been defined as "the capacity of a soil for producing a specified plant or sequences of plants under a physically defined set of management practices" (Larson et al., 1985).

For many years considerable effort has gone into researching most important processes involved in soil erosion. However, limited research has been devoted to the soil erosion and soil productivity relationships. This may be because erosion is generally a slow process, and years of data are needed to evaluate the effects on soil or productivity, and other variables may mask the relationships. Moreover, because crop production has been adequate in the past, there has been little incentive for investment in this type of research (Williams et al., 1981).

Soil erosion is typically measured in terms of centimeters or tons of topsoil removed from a particular field by wind or water erosion. Topsoil is defined as a "living entity, with chemical, physical characteristics that differentiate one soil from another" (Sampson, 1985). Loss of topsoil and the impact or damage associated with this loss in relationship to the plant are typically measured as either degradation of soil properties or as effects on crop yields.

A simple quantitative relationship between soil erosion and crop production applicable for all soils is not possible. The use of simulation models as tools for assessing soil erosion-soil productivity relationships are essential. Currently, the Erosion - Productivity Impact Calculator (EPIC), (Williams et al., 1983) and the Nitrogen-Tillage-Residue-Management (NTRM) Model (Shaffer et al., 1982), are the most notable of those models which are being developed, and show promise of developing detailed relationships between quantities related to the erosion.

When research further validates these complex models, they may provide good estimates of the effect of erosion on productivity (Gantzer and McCarty, 1985). Perhaps, new techniques may be suggested based on simulated and long term results.

Another approach is being used to evaluate the potential effect of soil erosion on soil productivity in the Midwestern United States. This approach is the Productivity Index (PI), which provides an estimate of the relative impact of erosion on productivity and the effect of erosion and sediment accumulation in water bodies. The PI is based on the assumption that soil is a major determinant of crop yield. The suitability of a particular soil for root growth is indexed for each soil layer in a profile based on soil characteristics that influence root growth (Rijsberman and Wolman, 1985). However, the relationship between crop production and soil condition depends on other variables as well such as crop species, stage of plant growth, and climate (Letey, 1985).

Significant linear relationships between crop yield and soil erosion for wheat, barley, sweet corn, dry bean, alfalfa and sugar beets were developed by Carter (1985). He indicated that wheat, dry bean and sweet corn yields were reduced most, alfalfa and barley yields were reduced some what less, and sugar beet yields were least affected by topsoil loss from erosion.

Frye et al. (1982) attributed lower yields of 17, 27, 30, 36% for rye, hairy vetch, crimson clover and big flower to erosion. These studies indicate that plant species respond differently to soil erosion.

In the eastern United States, grain yields declined 30 to 40 percent while forage yield declined 20 to 30 percent when the Ap horizon eroded away (Latham, 1940; Langdale and Shrader, 1982; Langdale et al., 1979). Furthermore, the difference between yield was greater during a season with poor rainfall distribution (Langdale et al., 1979; Frye et al., 1982). These studies indicate that corn stover yields are less sensitive than grain to soil erosion.

Erosion on some soils may cause little or no damage in productivity, while erosion on other soils can cause great damage in productivity. The effect of soil erosion depends on the original thickness and quality of the topsoil, the degree of the profile development, and the nature of the subsoil (Shaffer, 1985; Busacca et al., 1985).

Loss of topsoil is believed to reduce soil productivity, however this relationship is inadequately documented to reflect the tremendous variability in soils across the United States. Several studies have related yield of certain crops to topsoil depth (Uhland, 1949; Langdale et al., 1979; Langdale et al., 1982; Krauss et al., 1982; Hoag and Young, 1983). Only a few studies have been made to relate crop yields to topsoil thickness for a limited range of soils and climate. Uhland (1949) reported a 47% reduction in corn yield on a field where erosion reduced the thickness of topsoil from 33 to 2.5 centimeters. Langdale et al. (1979) estimated that for each centimeter of eroded topsoil the reduction in corn will be 147 kilograms of grain per hectare per year.

The higher productivity of topsoil compared to subsoil has been widely recognized. In rare cases the subsoil is more productive than topsoil if it is composed of buried topsoil. Latham (1940) showed that under conditions of desurfacing the A horizon was more than 3 times as productive as the B horizon and 11 times as productive as the C horizon.

Many studies have been done to compare yield on uneroded land with an artificially exposed subsoil. In South Carolina, on a Cecil sandy loam (Clayey, Kaolinitic, thermic Typic Hapludults) where erosion was simulated by exposing different horizons, the four year average yields were 1052, 340, and 91 kg/ha for seed cotton on the A, B, and C horizons, respectively (Latham, 1940).

Another study by Engelstad and Shrader (1961), using an artificially exposed subsoil of a Marshall silt loam (Fine-silty, mixed, mesic Typic Hapludolls), indicated that the corn yield on the exposed subsoil yielded approximately 3136 kg/ha less than the corresponding unaltered surface.

Ripley et al. (1961) reported that removal of 7.5 cm of topsoil caused on average 21% reduction in barley yield over a 10 year period, on unfertilized soil. The reduction in barley yield was 19% with fertilization. The removal of 15 cm topsoil caused a 58% and 46% reduction in barley yield with and without fertilization, respectively.

In eastern South Dakota, removing 30 centimeter of topsoil on a Beadle series (Fine, montmorillonitic, mesic Typic Haplustoll) significantly decreased yield, but an additional 15 cm did not further decrease yields. The differences were greatest in the year with the highest yields (Olson, 1977).

Average corn yield for three years, on a Cecil sandy loam (Clayey, Kaolinitic, thermic Typic Hapludults) were 4674 and 2226 kg/ha on moderately eroded, and severely eroded soil, respectively (Langdale et al., 1979).

Williams et al. (1985) reported that yield was positively correlated with silt and clay content of eroded soil, and negatively correlated with sand content. Langdale et al. (1985) observed that deep medium textured soils generally showed less crop yield reduction from soil erosion than with a medium to coarse textured surface overlying clayey subsoils. The reduction of the topsoil depth from 55 centimeter to 30 centimeter had no effect on yield in Iowa, on a medium textured soil. An additional 5 centimeter topsoil loss resulted in a corn yield reduction of 6% (Weeb and Beer, 1972). In Eastern North Carolina, the yield reduction was more apparent on a sandier soil than a finer texture soil (Thomas and Cassel, 1979). A 20% yield decline occured as 8 centimeters of topsoil were lost.

Continuous corn yield on a desurfaced plot averaged 20% of that on a check plot during a 4 year period, at Bethany Missouri Valley loess region (Williams et al., 1981). While the 10 year average corn yield on a desurfaced plot of Shelby silt loam (Fine-loamy, mixed, mesic Typic Argiudolls) was 47% of that on a control plot (Smith et al., 1945).

In other studies, the effect of various amounts of topsoil replacement have been studied. One such study was done in northeastern Nebraska, when topsoil was added to an eroded C horizon of a loess soil. The results showed that thicknesses of 0, 10, and 20 centimeter, corn grain yields were decreased by more than 11% for no topsoil compared to plots with 10 centimeter or more topsoil. Oat grain yields were decreased by 16 and 41% for no topsoil compared to 10cm and 20cm topsoil thickness, respectively (Mielke et al., 1984). A similar trend was seen in a four year study by Dunker et al. (1984). In this study, topsoil replacement resulted in higher yield for both corn and soybeans than unreplaced topsoil. Soybean yield on the A/B and A/spoil were not different, while the A/B treatment produced higher corn yields than the A/spoil.

Fosberg et al. (1983) demonstrated that although there was a significant general relationship between yield of a wheat-pea or wheat-lentil rotation, and topsoil depth, the exact nature and sensitivity of the relationship was different for each soil series or phase. Furthermore, in a study in Kentucky on two soil series of (Fine-silty, mixed, mesic Typic Paleudalfs), a 12% lower corn yield was reported as compared to the noneroded phase of the Maury soil series, which has formed in residuum from phosphatic limestone, while on the Crider soil, which has formed in thin loess parent material over residuum from limestone, a 21% lower corn yield was reported (Frye et al., 1982). These studies point out a significant effect of soil series on the relationship between soil erosion and productivity.

Frye et al. (1982) reported that erosion substantially decreases the productivity of soils with strongly developed pedons. Langdale et al. (1985) indicated that soil order affects the relationships of soil erosion to productivity. The yield reductions on severely eroded Ultisols averaged 38% for soybeans and 37% for corn, while during the same period, yield reductions averaged 16% for soybeans and 17% for corn on Alfisols. Generally, the impact of erosion is more detrimental on Ultisols than Alfisols, because of the thinner solums. Initial crop yield reductions on exposed subsoils of Ultisols were about twice as great as of most Mollisols and Alfisols (Langdale and Shrader, 1982).

This indicate that topsoil loss has more impact on crop yeild on Ultisols than Mollisols and Alfisols.

Productivity is more influenced by soil erosion, in the Southeastern United States, because of chemical and physical conditions associated with acid subsoils (Peterson, 1964; Thomas and Cassel, 1979). In a 17 year study by Spomer (1985) results showed that corn yields, from well-managed deep and nonstratified loess soils, are not affected by topsoil loss from natural erosion, because of their favorable physical and chemical properties and the lack of a restrictive horizon in the profile. These studies indicate that subsoil horizons can cause significant variation in the specific relationship of crop yield to topsoil depth, and consequently can account more directly for the long-term effects of erosion on soil productivity.

Field observations in the Piedmont area of North Carolina indicate that certain landscape positions tend to be associated with certain erosion classes (Daniels et al., 1985). This association can affect soil erosion-soil productivity relationships. Both landscape position and erosion have been shown to influence soil productivity (Sinai et al., 1981; Ciha, 1984; Stone et al., 1985). Lower slope positions have been found to contain more available water than those at higher positions on the same slope (Hanna et al., 1982).

Corn yields are significantly lower on severely eroded sites (Adams, 1949; Langdale et al., 1979). In both studies, the moderately eroded sites were approximately 3% while the slope of the severely eroded sites was approximately 11%. Such great differences in slope can modify the soil water regime through runoff and internal drainage and affect yield.

## Impact of Erosion and Desurfacing on Soil Properties

Crop yields vary among and within fields due to difference in physical and chemical properties (Costigan et al., 1983; Costigan and McBurney, 1983). Soil erosion or desurfacing can alter physical and chemical soil properties and consequently affect productivity. The National Soil Erosion-Soil Productivity Research Planning Committee of the USDA listed degradation of soil structure, loss of plant available soil water, loss of plant nutrients and non-uniform removal of soil within a field as ways in which erosion decreases soil productivity (Williams et al., 1981).

### Impact of Soil Erosion and Desurfacing on Soil Physical Properties.

Infiltration rate, pore size distribution, available water holding capacity, texture, aggregation and aggregate stability, bulk density, and hydraulic conductivity are important soil physical properties that are most likely to be altered by topsoil loss.

Water infiltration has a major influence on yield. Surface sealing and crusting on eroded soil reduces infiltration (Williams et al., 1981). Soil water recharge data on eroded soils indicated that the soil was not completely recharged by rainfall, this was attributed to a slower infiltration rate (White et al., 1985). However, Busacca et al. (1985) reported that infiltration rates for both A and B horizons of Palouse (Fine-silty, mixed, mesic Pachic Ultic Haploxerolls) and Walla Walla (Coarse-silty, mixed, mesic Typic Haploxerolls) soil series were similar and that progressive erosion does not have a strong effect on runoff/infiltration ratios of these loess derived soils.

Plant available soil water can be reduced by changing the soil water holding characteristics or by reducing the depth of the rooting zone (Williams et al., 1981). Many studies have indicated that erosion reduces available water holding capacity (Olson, 1985; Stone et al., 1985). A National Soil Erosion-Soil Productivity Research Planning Committee referred to plant available soil water capacity as the major reason that erosion reduces productivity (Williams et al., 1981). The water-holding characteristics of the root zone almost always change when topsoil is removed, because topsoil usually has a higher plant available-water capacity than subsoil.

The reduction of corn growth on (Fine-silty, mixed, mesic Typic Paleudalfs) in Kentucky was attributed primarily to a decrease in available water holding capacity. Available water holding capacity averaged 4% to 5% lower in the surface layer of eroded soils. The lower water holding capacity of the eroded soil was attributed to both lower organic matter and a higher clay content of the surface soil (Frye et al., 1982). Furthermore, in a study by Shikula (1962), the maximum amount of plant available water in the plowed layer of a severely eroded soil was 7.4% lower than noneroded soil on a Mollisol in the Don Basin (USSR).

Sadler (1984) reported that removal of 7.5 or 15 cm of the original 20 cm thick Ap horizon reduced the soil's capacity to store plant available water within the rooting zone above the Bt horizon, by 1.3 and 3.4 cm of water respectively, from 9.8 cm for the control. Removal of the surface 10, 20, 30, and 40 cm of soil decreased yield due to differences in water storage and use (Reuss and Campbell, 1961). The decrease in the quantity of available water was attributed to the deterioration of surface soil structure and the reduction of total soil porosity (Battiston et al., 1985).

Dormaar and Lindwall (1985) indicated that the water holding capacity did not seem to differ greatly on cut and fill treatments on a Typic Haploboroll in Alberta. However, water use decreased as the amount of topsoil removal increased. Buntley and Bell (1976) attributed reduction in plant available water to the lower volume of soil. However Rhoton and Meyer (1985) reported an increase in water holding capacity with topsoil removal for a fragipan soil.

Another impact of erosion which can be important to crop production is the influence on bulk density. Frye et al. (1982) indicated that the Ap horizon of eroded compared to uneroded soils had higher bulk density. The increase in bulk density was attributed to higher clay content and lower organic matter content. Furthermore, Bramble-Brodahl et al. (1985) reported an increase in bulk densities as topsoil depth decreased in Argixeroll and Haploxeroll soils. No soil physical restrictions due to bulk density were found on (Fine-silty, siliceous, thermic Aquic Paleudalfs) in a study by Pettry et al. (1985).

Mechanical compaction of the soil can decrease aeration and consequently crop growth can be inhibited (Hillel, 1980). In a study by Indorante et al. (1981) newly reconstructed soil on surface mined land was compared with the nearby undisturbed soils. The constructed soils had higher bulk densities and packed structure. Sadler (1984) reported that when the top 7.5 or 15 cm of the original 20 cm thick Ap horizon was removed from plots on either side of a control plot, bulk density, porosity, saturated hydraulic conductivity and texture did not differ significantly due to soil removal.

There are indications that erosion or desurfacing in some soils affect Ap horizon texture. Shrader et al. (1960) pointed out that the finer the texture of the subsoils the more damaging was topsoil removal. In a study on the Cecil or Pacolet series (clayey, kaolinitic, thermic, Typic Hapludults) in Georgia, an increase in clay content and redder hues were observed where the erosion were more severe and the surface horizon was thinner (White et al., 1985). Also an increase in clay content due to surface soil removal has been reported by other researchers for (Fine-silty, mixed, mesic Typic Paleudalfs; Fine-loamy, mixed, mesic Typic Argiudoll; and Fine-loamy, mixed, mesic Hapludalf)

(Frye et al., 1982; Schertz et al., 1985). Moreover, Stone et al. (1985) reported that erosion increased clay content approximately 10% for each erosion class change from slight to moderate to severe for a Cecil series (Clayey, kaolinitic, thermic Typic Hapludults).

Midkiff et al. (1985) reported a clay content increase of 7 to 22% on desurfaced treatment. Furthermore, the subsoil exposed by removing the top 30 to 45 cm had higher clay content than topsoil on a Beadle series (Fine, montmorillonitic, mesic Typic Haplustoll) (Olson, 1977). Sadler (1984) indicated that desurfacing had no effect on the Ap horizon texture, but he suggested that 15 cm topsoil removal decreased aggregate stability of Ap horizon.

## Impact of Erosion and Desurfacing on Soil Chemical Properties.

Removal of topsoil not only enhances degradation of soil physical properties but also causes deterioration in the soil chemical properties. Soil nutrient loss may occur during erosion depending on the subsoil characteristics. Eroded soil particles carry attached nutrients from fields into streams and lakes (Williams et al., 1981). These plant nutrient losses due to erosion contribute to a reduction in productivity especially on soils with unfavorable subsoil properties.

There are indications that as surface soil erodes and subsoils are mixed into the Ap horizon by tillage operations, mixing imparts undesirable characteristics of the subsoil to the surface. Increasing fertilizer can not substitute for the reduction in maximum yield potential on soils with undesirable subsoil properties. On Coastal Plain soils with acid subsoil conditions, fertilizer was not sufficient to restore productivity (Phillips and Kamprath, 1973). Furthermore, Eck (1969) reported that nitrogen fertilizer did not restore yield potential under dry land conditions in a Pullman silty clay loam soil (Fine, mixed, thermic Torrertic Paleustolls). However, under irrigated conditions N fertilizer restored yield potential. On heavy clay subsoils reduced yield was attributed to low fertility and poor physical condition of the soil (Adams, 1949). In addition, subsoils with higher clay content than the topsoil tends to transform applied phosphorus more quickly into forms not readily available to plants (Williams et al., 1981).

Erosion will have a large effect on productivity if the plow layer soil fertility is not restored (Craft et al, 1985). Several studies reported that intensive nitrogen and phosphorous fertilization were necessary to restore crop production on soils that have lost their topsoil (Englestad et al., 1961; Englestad and Shrader, 1961; Reuss and Campbell, 1961; Heilman and Thomas, 1961; Eck and Ford, 1962; Eck, 1969; Olson, 1977). Topsoil removal frequently removes a large portion of plant available nutrients including micronutrients (Henning and Khalaf, 1985). Lower fertility status of Ap horizon of eroded compared to uneroded soil was reported by Frye et al. (1982).

Plant nutrient losses associated with soil erosion is recognized as a problem (Langdale et al., 1979). The eroded material contains much larger quantities of plant nutrients than the original soil (Neal, 1944). Stoltenberg and White (1952) found that the nitrogen and phosphorus content of the eroded material were about double the amount in the surface soil, and the potassium content of the eroded material was seven times that of the original soil.

Soil erosion is a selective process (Alberts et al., 1978; Monke et al., 1981). Erosion removes some soil constituents more than others. The selectiveness of the erosion process are in the order of organic matter, organic and ammonia nitrogen, available phosphorus and exchangeable potassium (Massey and Jackson, 1952).

Many researchers have attempted to quantify the loss of particular nutrients from erosion. Nitrogen availability in the unfertilized surface soil exceeded that in the unfertilized subsoil by the equivalent of about 178-190 grams of fertilizer nitrogen per acre per year (Englestad and Shrader, 1961). Nitrogen losses from grassed watersheds in western North Carolina were estimated to represent 6-10% of the applied nitrogen fertilizer (Kilmer et al., 1974). Alberts et al. (1978) reported that the average sediment-N losses was about 57 kg/ha while the soluble-N losses were less than 3 kg/ha. Total-N losses increase as the total solids removed in the runoff increase (Munn et al., 1973). Furthermore, most of the soluble inorganic nitrogen is lost in the nitrate form. Burwell et al. (1976) reported that nitrate in subsurface discharge accounted for 84-95% of the total annual soluble nitrogen discharged in stream flow.

A series of experiments at Fort Collins, Colorado (Gardner, 1941) indicated that the major factor limiting crop production on desurfaced soils is the lack of adequate nitrogen and phosphorus. Tanaka and Aase (1985) reported that nitrogen and phosphorus fertilizer on 6 cm removal plots of a (Fine-loamy, mixed Typic Argiborolls) resulted in in yields equivalent to the yields on the non-fertilized control plots, while none of the fertilizer combination restored yield reduction on the 12 and 18 cm desurfaced plots. Reuss and Campbell (1961) suggested that nitrogen and phosphorus are the major factors limiting crop production on desurfaced soils. However, Carlson and Grunes (1958), in a growth chamber experiment were unable to attain yields on the fertilized C horizon as high as those on the well fertilized A horizon. Furthermore, Aina and Egolum (1980) observed that additions of N, P, and K alone did not restore the productivity of an Alfisol in western Nigeria.

Batchelder and Jones (1972) reported that using fertilizer and supplemental irrigation restored yield capacity on desurfaced plots of a Typic Hapludult to almost that of the original soil. They concluded that soil water was the major yield limiting factor after soil fertility was restored.

Phosphorus availability is markedly influenced by erosion severity. As surface soil thickness decreased, available soil phosphorus decreased sharply (Pettry, 1985; Stone et al., 1985; Gilliam et al, 1985).

Neal (1943) estimated that the phosphorus content of eroded material to be 1.5 times that of phosphorus in the remaining material. The highest annual total P loss was 1.93 kg/ha on the Missouri Valley loess, this represents about 6% of the recommended annual P fertilizer rate, and sediment-P losses accounted for 90% of the total phosphorus discharged (Alberts et al., 1978). Also, Menzel et al. (1978) estimated the maximum annual phosphorus discharges as 11 kg/ha of total phosphorus and 2 kg/ha of soluble phosphorus, from six watersheds in Chickasha, Ok.

Schuman et al. (1973) found that the solution phosphorus lost was less than sediment phosphorus. A large portion of the phosphorus was sorbed by the suspended material in the runoff. Phosphorus sorption was observed to be more related to the sorptive capacity of the sediment in the surface runoff than to that of the surface soil material (Sharpley et al., 1981a).

White et al. (1985) showed differences in some of the available nutrients for a (Clayey, Kaolinitic, thermic Typic Hapludults) as influenced by severity of erosion. Extractable phosphorus was very low on severely eroded soils, while potassium and magnesium showed higher levels with increased degree of erosion. However, erosion had no significant effects on soil pH or total carbon. In Kentucky, the soil test potassium level was higher for eroded than for the uneroded Maury soil (Fine-silty, mixed, mesic Typic Paleudalfs) (Frye et al., 1982).

A loss of one metric ton/ha of topsoil will result in loss of 0.08 mm topsoil and consequently a loss of one kg/ha nitrogen, 3.5 kg/ha phosphorus and 13 kg/ha potassium, for medium textured soil (Logan, 1982). A ratio of nutrients in particles to those in parent aggregates were found to be 3.11, 2.25, 1.67 and 1.91 for N, P, K and organic, respectively (Hagen and Lyles, 1985)

Losses of K have been reported in a few studies. Neal (1943) found that the total K content of the eroded material was 1.4 times greater than the content of the remaining material. Furthermore, available K of eroded material was about 5.5 times greater than the content of the original material (Neal, 1944).

Knoblauch et al. (1942) reported an annual loss of 477 kg/ha calcium from Collington sand loam (Fine-loamy, mixed, mesic Typic Hapludults) soil. He suggested that calcium losses in the eroded material are related to the percentage of the finer soil fractions removed by soil erosion. Also Neal (1943) estimated that the calcium content of the eroded material averaged 8.3 times that in the original soil material on which the erosion occurred.

Carlson et al. (1961) indicated that where the topsoil had been removed the most deficient element was N followed by P and then Zn. It was necessary to apply N, P, Zn, and manure to restore yields on the subsoil to those on the surface soil. Bramble-Brodahl, et al. (1985) reported that Zn, Mn and Fe increased as topsoil depth increased in a (Fine-silty, mixed, mesic Ultic Argixeroll) soil while only Mn increased in a (Fine-silty, mixed, mesic Pachic Ultic Haploxeroll) soil.

Soil organic matter is selectively carried away with runoff because of its higher concentration in the surface soil, also because of its low specific gravity as compared to that of the inorganic fraction. Organic matter is a natural source for many macro and micro-nutrients. A study by Barrows and Kilmer (1963) indicated that nitrogen and phosphorus loss due to erosion was associated with a significant loss of organic matter. Erosion decreased organic matter and phosphorus in the upper 15 cm (Schertz et al., 1985). Organic matter promotes good soil structure which improves soil tilth, infiltration, and water retention. Peterson (1964) reported that high amounts of organic matter resulted in an increase in soil aggregation and in a decrease in bulk density from 1.3 to 1.1 gm/cm. High organic matter in the soil was also correlated to high corn yields on Ultisols (Thomas and Cassel, 1979).

As soil erosion reduced organic matter and nutrients, the soil left behind became less productive and even more erodible because of changes in its physical properties (Dormaar and Lindwall, 1985). Additions of organic matter in the form of stable manure to the desurfaced horizons resulted in increased yields on all horizons, however the beneficial effect of manure on the C horizon was relatively greater than on the other horizons (Latham, 1940).

Schertz et al. (1985) indicated that organic matter levels were reduced significantly in the upper 15 cm as erosion phase changed from slight to severe. During a 9 year period, erosion decreased soil organic matter from 2 to 0.5% at Zanesville, Ohio (Black and Siddoway, 1979). Furthermore, Hayes et al. (1948) estimated an annual loss of 1065 kg/ha organic matter from moderately eroded Fayette silt loam (Fine-silty, mixed, mesic Typic Hapludalfs).

Neal (1943) found that the eroded material from Collington sandy loam (Fine-loamy, mixed, mesic Typic Hapludults) averaged four times higher in organic matter than the remaining material. Moreover, the eroded material from Honeoye sand loam contained 30% higher (Fine-loamy, mixed, mesic durixerollic Haplargids) contained 30% higher organic matter than the remaining soil (Free, 1956).

## B. Soil Aggregates and Aggregate Stability

Soil aggregates are the basic units of soil structure. A soil aggregate has been defined as " a naturally occurring cluster or group of soil particles in which the forces holding particles together are much stronger than the forces between adjacent aggregates" (Lynch and Bragg, 1985).

Soil aggregation influences soil erosion, crusting, and infiltration (Lutz, 1934; Mazurak and Mosher, 1968; Moldenhauer and Koswara, 1968; Moldenhauer and Kemper, 1969; Moldenhauer, 1970; El-Hassanin, 1983; Young, 1984). Aggregation, also influences plant growth through its relationship to the maintenance of porosity. Air and water movement will be less desirable for plant growth if large proportions of the aggregates are less than a diameter of 0.5-2 mm (Greenland, 1965b).

Two sets of factors are important in soil aggregation, (a) those responsible for aggregate formation, and (b) those which give the aggregates stability once they are formed. The two processes of aggregate formation and stabilization can be concurrent in the soil, and the various stabilizing agents may act in conjunction with each other (Lynch and Bragg, 1985).

The forces involved in aggregate formation include Van der Waal's forces, H-bonding and coulombic attraction from clay domains (Tisdall and Oades, 1982).

## Forces Involved in Soil Aggregation

Several models have been proposed to describe the way in which individual mineral particles are held together to form soil aggregates. Investigators have indicated that the most important variable controlling the organization of soil aggregates is the clay fraction of the soil.

Russell (1934) proposed the cation-dipole linkage theory. According to this view, the exchangeable ions and charges on the surface of clay particles interact with water molecules between the surfaces. The removal of water results in an increase in attractive forces and reorientation of clay particles (Taylor, 1972). Martin et al. (1955) proposed that clay is the predominant binding agent in soil aggregation. According to this view, cohesiveness between clay particles is the binding force. It was suggested that the cohesive forces operating between clay particles may involve (1) linkage by chains of water dipoles (2) bridging between clay particles by polar long-chain organic molecules and (3) cross-bridging and sharing of intercrystalline ionic forces and interactions of exchangeable cations between oriented clay plates (Harris et al., 1966).

The domain theory of Emerson (1959), which is an extension of Russell's theory, explains the mechanisms of aggregation in accordance with the properties of the diffuse double layer (Taylor, 1972). Emerson (1959) defined a clay domain as "a group of clay crystals which are oriented and sufficiently close together to behave in water as a single unit". The forces causing the clay particles to bond together in a domain are a function of the double layer, which in turn is a function of the exchangeable cations. Both quartz and clay are held together by electrostatic forces. Stabilization of the quartz-clay bonds involves the linkage of organic polymers between the quartz crystals and the external edges of the clay domains.

Kohl and Taylor (1961) demonstrated that hydrogen bonding occurred between the carboxyl groups on organic molecules and clay. This may be due to binding with polyvalent cations. Emerson (1963) showed that bonds can be formed between polyanion carboxyl groups and polyvalent cations on the exchange complex. Three basic mechanisms were proposed as controlling polyanion clay linkage (a) bond formation between negatively charged carboxyls of the polymer and positively charged clay edges, (b) hydrogen-bond formation between polymer carboxyls or hydroxyls and free hydroxyls or oxygen atoms of the clay, and (c) cationic bridge formation between the polymer carboxyls and the negatively charged clay surfaces (Harris et al., 1966).

Greenland (1965a) emphasized the importance of Van der Waal's forces in adsorption of organic matter to inorganic colloids in the soil. He also indicated that the organic matter is distributed around clay domains rather than being spread uniformly over the surface of individual clay particles. Drying and aging of the materials surrounding clay domains may lead to the formation of films which can only be removed by extensive treatments (Greenland, 1965a). Clapp and Emerson (1965b) suggested that the aggregation of soils from Minnesota were due to two kinds of polymers, one coordinated with exchangeable cations and the other with H-bonds. Sideri (1936; 1938a; 1938b) observed that soluble humates are oriented on clay particles, forming films on dehydration, these films cement particles together to form microaggregates.

Most theories concerning the role of organic matter in soil aggregation involve the concept that organic compounds form bonds between domains. Organic matter appears to primarily form bonds between domains rather than forming a matrix around primary soil particles.

Evidence for the role of polyvalent ions in binding organic polymers in soil comes from the work of Martin and Richards (1963). They found that the binding action of some microbial and plant organic polymers were reduced if they were allowed to react with iron and aluminum ions before being added to soil. They suggested that when the active sites on the polymer are already occupied by these ions, they can not participate in binding through polyvalent cations.

Other studies seem to confirm the importance of polyvalent cations in soil aggregation. Weldon and Hide (1942) proposed that free iron oxides are important aggregating agents in prairie soils. A highly significant correlation between soil aggregation and the content of clay sized iron oxide was found by McIntyre (1956). Moreover, only the finest of particles (30-100 um) affected soil aggregation. Deshpande et al. (1964; 1968) indicated that minor amounts of iron oxide may be present as "active" bonding agents. However, they suggested that the role of iron oxides is of secondary importance and may play some part in enhancing the stability of micro and macroaggregates.

Harris et al. (1966) proposed that reducing conditions may cause re-solution of binding agents such as organic colloids and active iron oxide. Anaerobic decomposition of organic matter, causes a reduction of ferric iron. Reoxidation occurs on drying with the formation of protective iron oxide coatings on the aggregates. Sesquioxide coatings on quartz grains increase the strength of clay-quartz bonds (Emerson, 1954). Iron and aluminum oxides form a continuous matrix which bind soil particles into aggregates (Kroth and Page, 1946).

Calcium-saturated humus is less effective in aggregation compared to hydrogen or sesquioxide-saturated humus (Jesse and Lutz, 1940). Sharma and Tunny (1978) concluded that aggregation was completely independent of the level of calcium carbonate in the soils they examined. Furthermore, calcium carbonate had no significant effects on aggregate cementation in a study by Shanmuganthan and Oades (1983). However, Hadas and Wolf (1984) suggested that under air-dry conditions aggregates are bonded by calcium carbonate bonds.

The basic structural units in most soils consist largely of clay-polyvalent metal-organic matter complexes ( C-P-OM ). Bonds of ( C-P-C ) and ( OM-P-OM ), and aluminium, iron oxide or H-bonds may occur (Edwards and Bremner, 1967a; 1967b). Furthermore, fragments of humified organic matter may be bonded to a single clay particle, and a single fragment of humified organic matter may be bonded to more than one clay particle.

The domains function as a single unit (<2 um) as a result of particle orientation and electrostatic attraction. The domains are bonded to the surface of the quartz grains and firmly to each other by various cements. Crystalline oxides and persistent organic colloids cement domains together, to form microaggregates (2-250 um). Microaggregates and sand particles are held together mainly by a fine network of roots and hyphae to form macroaggregates (>250 um), (Greenland, 1971; Tisdall and Oades, 1982).

Aggregates in the field environment also encounter external forces in addition to internal forces. These forces include: the weight force of the particle itself; forces transmitted by the medium in pore spaces; forces transmitted by the solid phase; and forces from contacting interfaces (Hartage, 1978). When all these forces are in equilibrium the particles are at zero motion with respect to each other and the aggregate is stable.

## Factors Affecting Aggregation and Aggregate Stability

There are three key factors affecting soil aggregates: (a) type and condition of the organic matter; (b) the relative amount and activity of the soil colloids; (c) the kind of exchangeable ions connected with soil colloids. Other environmental factors, (water content, temperature, plant and associated microorganisms), appear to operate through an influence on one or the more of these three key factors. Water has a marked effect upon soil aggregates. The interaction of a soil aggregate with water is a complex process which depends on a number of factors, such as the amount and distribution of the organic matter, clay content, clay mineralogy, the rate of wetting, and pore-size distribution within the aggregate (Panabokke and Quirk, 1957). Surface aggregates may disperse under mechanical force of raindrop or as a result of osmotic stress. Osmotic stress arises between the clay particles as result of soluble salts diffusing out into a wetting solution of low electrolyte concentration (Emerson, 1977). Slaking can also occur as a result of differential expansion and pressure from entrapped air (Yoder, 1936).

The rapid intake of water into a dry aggregate causes unequal swelling throughout the aggregate, which produces fractures and fragmentation along the cleavage planes (Baver et al., 1972). Kolodny and Joffe (1939) indicated that when an air dry aggregate is immersed in water, the water penetrates the aggregate at the highest rate along cracks. This process compresses entrapped air which finally causes a series of miniature explosions which continue until the aggregate is shattered into its water-stable aggregates (Yoder, 1936). The importance of entrapped air in the disruption of macroaggregates and microaggregates during the wetting process is supported by the fact that wetting in a vacuum or slow wetting by capillarity does not cause violent disruption (Yoder, 1936). Aggregates which are slowly wetted, simply soften and retain their form.

Two major forces are involved in the effects of water on dry cohesive systems, matric potential and the attractive forces between particles. The driving force for water entry is capillary potential. Resistance to the disrupting action of water is strongly dependent on the kind and the arrangement of cementing substances. Baver et al. (1972) proposed that fats, resins, and waxes may arrest slaking by making the aggregates hydrophobic and therefore increasing their stability. Water content and total surface area were related to the susceptibility to disruption in swelling clay soils in a study by Coughlan et al. (1973)

Aggregate stability refers to the resistance of soil aggregates to the disintegrating influence of water and mechanical forces (Baver, 1972). The stability of aggregates is of great practical importance. Aggregate stability influences the process of erosion (Lutz, 1934; Mazurak and Mosher, 1968; Young and Onstad, 1978; El-Hassanin, 1983; Young, 1984). The stability of surface aggregates is most important because aggregates below the surface are protected from rapid wetting by those above. Unstable surface aggregates can slake and disperse under rainfall impact. Detached microaggregates or even clay particles, may be carried into pores and a crust is developed upon drying (Lal and Greenland, 1979; Stewart, 1985). Surface crusting reduces infiltration (Duley, 1939), increases runoff and consequent erosion.

Aggregate stability changes in response to factors affecting particle bonding. An increase in aggregate stability was reported by Reid and Goss (1982) following a drying period of the soil under maize. Harris et al. (1966) suggested that localized drying around the root as the result of water uptake may cause shrinkage and stabilization of aggregating bonds by dehydration. Deleenheer and Kirkham (1961) noted that air-dryed aggregates in the laboratory develop an abnormally high stability. The exact mechanisms to explain this increase in aggregate stability with excessive drying are not known. However, Harris et al. (1966) proposed that "irreversible or slowly reversible dehydration of organic or inorganic colloidal substances is probably a major factor".

Many investigators have observed the influence of drying temperature on aggregation. McCall (1944) reported that aggregate stability decreased as the temperature of the system increased. Water stability of soil aggregates tended to increase as the drying temperature increased (Slater and Hopp, 1955). Evidence of an inverse relationship of aggregate stability with temperature was illustrated by Alderfer (1950). Rao and Ramacharlu (1957) confirmed that aggregate stability increased as drying temperature was raised above $60^{o}$C and at $360^{o}$C the aggregates were completely water stable.

Type and condition of organic matter rather than the amount has a greater influence on aggregate stability. Swaby (1950a) mixed various humus extracts with soil and determined aggregation. He found that the aggregating power was humic acid > ferrohumates > calcium humates > fluvic acids. Phenolic or alcoholic $OH^-$ groups, and lignin-like colloidal substances were found to be important in aggregation, while $COOH^-$ groups of proteins or polyuronides were of only small importance in bonding (Baver et al., 1972). Colloidal substances containing amino, carboxyl and hydroxyl groups were partly responsible for the cementing action (Harris et al., 1966).

Microscopic examination showed that the humus was either present as films around the microaggregates or as particles of precipitated humus. Numerous investigators have attributed the major role of soil aggregate stabilization to the cementation action of polysaccharides (Greenland, 1965b). When polysaccharides are added to the soil, they are strongly adsorbed on the surfaces and on the edges of clay crystals, resulting in an increase in the amount and stability of aggregates (Baver et al., 1972).

Hide and Metzger (1939) reported that organic material with relatively high carbon, high total nitrogen content, and a wide carbon-nitrogen ratio increased aggregate stability. Lower carbon-nitrogen ratio maintained in the nitrogen treated soils favored rapid decomposition of microbially synthesized soil-binding materials. Addition of nitrogen with cellulose caused a greater and more rapid increase in the stability of aggregates (Tisdall et al., 1978).

Vegetation has a significant influence on aggregation through a combined effect of physical, chemical, and biological properties. Arable crops affect soil aggregate stability to a different degree. Difference between species probably reflect qualitative differences in the organic materials released by the roots. The proportion of lateral roots, could influence aggregate stability since the release of organic materials occurs mainly near the root tip (Reid and Goss, 1981). Crops which produce extensive root systems, a continuous supply of organic matter, and efficient protective coverage, improve soil aggregation (Harris et al., 1966). Low (1972) reported that old arable land had resistance to flowing water.

Negative effects of soybean and corn on aggregation have been observed by many investigators (Browning et al., 1942; Wilson and Browning, 1946; Page and Willard, 1946; Fahad et al., 1982). Fahad et al. (1982) ranked soybean rotation sequences according to their negative effect on aggregation as follows: continuous soybean > soybean after corn > soybean after sorghum > soybean after fallow.

Jesse and Lutz (1940) concluded that different amounts and kinds of organic matter added by the different crops caused a difference in microflora of the soil. The difference in microorganism populations apparently affected aggregate stability directly or indirectly by modifying the soil humus. Residues released by roots in the form of fine roots, root hairs, dead cells, mucilages affect aggregation by providing nutrients for soil flora and fauna.

Aggregate formation around roots involves the adherence of fine particles to living root hairs, and soil microorganisms by microbial gums. Chesters et al. (1957) found microbial gums to be an important aggregating factor. McCall (1946) found that the order of aggregating effectiveness of microorganisms was fungi > streptomycetes >certain bacteria > certain rhizobia > yeast > other bacteria. Hubbell and Staten (1951) reported that the aggregates which formed by the action of the fungial threads were spongy and resistant to crushing and the sizes were generally larger than 2 mm. While bacteria produced aggregates were fragile and crushed easily, the actinomycetes-type aggregates were resistant to crushing, and fairly compact.

# III. AGGREGATE STABILITY

## ABSTRACT

Considerable variation in the aggregate stability results due to analytical pretreatment led us to several studies to select the proper pretreatment for aggregate stability measurements. Also studies were conducted to determine factors affecting aggregate stability.

These studies were designed to determine: (1) the effects of pretreatments on aggregate stability; (2) the influence of water content at the time of sample collection on aggregate stability; (3) the relationship of aggregate stability to selected soil properties of a (Fine, montmorillonitic, mesic Typic Haplustoll).

In general, pretreatments of air-drying, humidification and storage have a significant effect on the aggregate stability. We found a significant difference in aggregate stability between air dried samples and fresh samples treated alike. Air drying increased mean aggregate stability by 19% and 15% during the first and the second week of storage, respectively. Increase in aggregate stability due to storage for one week were 2% and 4% for air-dry and fresh samples, respectively. This increase in aggregate stability was not significant statistically ($P > 0.05$). However the increase indicates that longer period of storage can be a problem particularly for fresh samples.

Our data showed a very significant influence of water content at the time of sample collection on the aggregate stability even when the samples were prehumidified to saturation.

Prediction equations that explain up to 72% aggregate stability variance for the Ap horizon were developed. The predicted equation suggests that organic matter, clay content, calcium carbonate content, and initial water content are important variables controlling aggregate stability in this soil. Coefficients associated with the regression equation and the entry of the independent variables into the equation indicates that organic matter was the most important of the independent variables, followed by water content at the time of sample collection. Total organic matter was insufficient to explain the variation in the aggregate stability. Arrangement and condition of the organic matter rather than absolute quantity may be more important.

# INTRODUCTION

The measurement of aggregate stability has received considerable attention during the last 50 years. However, uniformity in measurement and reporting of data has been limited. This problem has been recognized by many scientists and extensive studies have been made to standardize testing techniques. The standardization of aggregate stability analysis has included air drying and premoistening treatments to saturate air dry aggregates before analyzing for stability (Yoder, 1936; Kolodny and Joffe, 1939; Low, 1954; Kemper and Koch, 1966; Kemper and Rosenau, 1984). However air drying aggregates can result in irreversible changes in bonding between aggregate constituents (Harris et al, 1966). Premoistening and analyzing soil aggregates immediately after field sampling would be expected to preclude effects from air-drying and storage.

Preliminary studies examining aggregate stabilities of samples from eroded, noneroded and desurfaced treatments indicated differences due to treatment. However, these differences were time dependent and did not always conform to predictions based on measurements of other soil properties.

This study was conducted to examine the role of various soil constituents in the stabilization of aggregates which were analyzed immediately after field collection and pretreated by humidifying to saturation.

Extensive studies have been made on the importance of clay, organic matter and polyvalent ions as key factors in aggregate stability. Clay is important in controlling the organization of soil aggregates. According to Abruna and Smith (1953), microaggregates are more dependent on clay content than clay mineralogy. Clay content and aggregate stability were observed to be closely correlated (Chesters et al., 1957). Furthermore, the effect of clay content has been found to be more significant in soils containing small amounts of organic matter (Acton et al., 1963).

Experimental evidence of the effectiveness of organic matter on aggregate stability has been indicated by many investigators. However, many studies have indicated that certain fractions of the organic matter may be more important than others.

Calcium carbonate can exert important effects on aggregate stability (Greenland, 1971). Allison (1968) indicated that calcium carbonate may favor domain formation and also act as a substitute for organic matter as stabilizing agent. Sharma and Tunny (1978) on the other hand concluded that there was a complete independence of aggregation on amount of calcium carbonate in the soils which they examined.

A few investigators (Cernuda et al., 1954; Low, 1954; Kemper and Rosenau, 1984; Kemper et al., 1985) have examined the effect of initial moisture content of the soil on the stability of air dry microaggregates. Kolodny and Joffe (1939) noted an increase in the stability of microaggregates as the initial water content was decreased. Moreover, Francis and Cruse (1983) indicated that small changes in matric potentials near saturation had a large effect on aggregate stability. These studies primarily examined the effects of moisture content on air dry aggregates.

The objectives of this study were to determine (1) the effect of pretreatments (air-drying, storage, and prehumidification) on aggregate stability, (2) the influence of initial water content at the time of sample collection on aggregate stability, and (3) the relationship of aggregate stability to selected soil properties on eroded, noneroded and desurfaced plots of a Beadle soil (Typic Haplustoll).

# MATERIALS AND METHODS

All soil samples were collected from a Beadle soil series (Fine, montmorillonitic, mesic Typic Haplustoll) located at Madison, SD. Samples were collected from a series of experiments examining the influence of erosion and desurfacing on soil productivity. The plots were in continuous corn for at least 3 years before sampling. A small hand spade was used to carefully remove the soil from the plots so as to minimize disturbance in aggregation due to sampling. The samples were sieved to obtain 1-2 mm aggregates. The aggregates then were either air-dried in the laboratory, kept in sealed plastic bags in the refrigerator, or analyzed immediately after collection.

## Aggregate Stability Determination

Aggregate stabilities for humidified samples were determined in the laboratory by a modification of a method described by Kemper (1965, 1984). Four grams of the aggregates were loaded onto a 60-mesh sieve (holes 0.25 mm in diameter). At the same time subsamples were taken for moisture content determination. The sieves were then carefully placed into a humidified chamber (Hankscraft). The aggregates were slowly humidified until the soil reached saturation (30-35% water content by weight). After humidification, the sieves with soil aggregates were transfered onto a sieve holder. The sieves were slowly raised and lowered mechanically, into distilled water contained in preweighed aluminum cans. The samples were sieved in distilled water at 22-25 °C for

5 minutes at 42 cycles per minute. Then the sieves with the remaining aggregates were transfered to another set of preweighed aluminum cans. The remaining aggregates (stable aggregates) were destroyed by ultrasonic vibration with a sonifier (Bronwill Model BP-II). The sonifier was set to 30 watts first and gradually increased to 120 watts for 30 seconds. Persistent soil aggregates were broken down with a rubber tipped plastic policeman. The sand remaining on the screen was washed with a jet of water from a wash bottle. The aluminum cans and the screens were oven dried at 110$^{o}$ C. The oven dry materials were weighed and the aggregate stability was calculated as follows.

$$\%AS = \frac{\left((\text{weight of aggregates} + \text{sand}) - (\text{weight of sand})\right)}{(\ (\text{weight of sample}) - (\text{weight of sand})\ )} \times 100$$

## Study on the Effect of Pretreatments

Samples were collected during 1984 from 12 plots (eroded, noneroded, and desurfaced) at the USDA research farm. Aggregates ranging in size from 1-2 mm were prepared in the same way as mentioned previously. Several studies were conducted to determine the effects of pretreatments on aggregate stability.

Pretreatments consisted of air-drying samples after sieving, humidifying samples to saturation, and examination of the effects of short period of storage on air dry and moist aggregate samples.

Samples were divided into two groups after sieving. One group was air-dried in the laboratory for 3 days at 25$^{o}$C, while the second group was kept in plastic bags in a refrigerator (fresh sample) at 1-4$^{o}$ C.

Ten subsamples were taken from each fresh samples a day after sampling. Subsample were divided into two groups to determine if humidification affects aggregate stability. Aggregate stability determination for 4 of the subsamples were carried out as described previously. The second set of 4 subsamples were transfered onto a sieve holder without going through the humidification process. Gravimetric moisture content was determined for a subsample from each group.

The above described procedures were repeated on air-dried samples 36 and 96 hours after sampling.

One week after sample collection, fresh and air-dried aggregates were again analyzed for aggregate stability with and without humidification pretreatments.

### Determination of the Effects of Initial Water Content

An area was selected on the control plots at the same field during 1985, to determine whether aggregate stability is affected by moisture content at the time of sample collection. Two test plots were isolated within this area by a 1 meter square frame. Samples were also collected in a non wetted area immediately outside of the marked area. Test plots inside the two frames were covered by cubic sponges, to avoid disturbance. Water was added to the soil with an overhead sprinkling infiltrometer at a rate of 10 cm/hr until the soil was saturated and runoff occurred. The surface soil in each plot was sampled at the 0-3 cm depth after 24 hours. A small spatula was used to carefully remove the soil to minimize the disturbance in aggregation due to sampling. Aggregate stabilities were determined immediately after removing the sample from the field. Duplicate subsamples were run with and without prehumidification treatments. Gravimetric moisture contents were determined for each sample at the same time. Samples were taken every 24 hours, for a 96 hour period .

## Aggregate Stabilities in Relation to Selected Soil Properties

Seventy-eight soil samples comprising different horizons, from six soil profiles (eroded, noneroded, and desurfaced) of a Beadle series were evaluated for aggregate stability, organic matter, texture, calcium carbonate, initial water content and pH . Samples, from each horizon of the six profiles were sieved to obtain the 1-2 mm aggregates. The aggregates were kept at 1-4 °C and aggregate stability determinations were carried out for all the samples beginning immediately after the time of sample collection and continuing for a one week period. Aggregate stabilities were determined for prehumidified samples in triple subsamples as described previously. Moisture content was determined for each sample at the time of sampling.

Organic matter was determined by a modified Walkley-Black method (Allison, 1965); particle-size analysis was determined by the pipette method (Soil survey staff, 1972); calcium carbonate equivalent was determined by using the titrimetric method (Bundy and Bremer, 1972); soil pH values were obtained in a 1:1 soil water suspension with pH meter (HACH Model A1700) (Richards, 1954).

## Statistical Methods

The Statistical Analysis System, SAS, was used for all statistical analysis generated in this study. Statistics for each experiment were generated by Analysis of Variance (ANOVA) procedures, using the proc ANOVA in SAS (Goodnight and Spector, 1985). The Least Significant Difference (FLSD) mean comparison tests were used to determine significant difference between pretreatments if the (F) test for the pretreatment factor(s) were significant. Linear regression methods (Sall, 1985), were used to correlate aggregate stability to initial water content. A Stepwise Regression program in conjunction with Regression by Leaps and Bounds (Furnival and Wilson, 1985) was used to compute the best fit multiple regression equation for the variables having the most influence in predicting aggregate stability. The routine introduces independent variables successively, entering first the independent variable that is most closely correlated with the dependent variable. Other independent variables were added in decreasing order of importance, as long as they were within the 0.05 level of significance.

# RESULTS AND DISCUSSION

## Pretreatment Experiments:

Air-drying field soil samples before determining aggregate stability has been a common pretreatment. This may be because it was recognized that aggregate stability varied at least to some degree with soil moisture content. Therefore, it seemed logical to bring all of the samples to a common moisture content, which was quite generally the air-dry condition. Air-drying in the laboratory has a marked effect on aggregate stability results compared to aggregate stability of the soil at actual field moisture content. Air dry aggregates are very stable because they contain several types of binding agents whose effects are additive (Tisdall and Oades, 1982).

The higher aggregate stabilities of air-dried aggregates (Table 1) may be due to coatings of precipitated and irreversibley dehydrated organic or inorganic colloids, preventing direct contact of water (Harris et al., 1966). Increased hydrophobicity reduce the rate of water entry as well as strengthen the aggregating bonds against water attack, resulting in higher aggregate stability. Furthermore air-dried samples increased solid phase cohesion (Kemper and Rosenau, 1984).

Aggregate stability increased slightly after one week of storage time, however it was not significant statisically. The storage period in this study was relatively short. However, a significant increase in aggregate stability for a storage period of a month to 11 years were reported in several studies (Kemper and Koch, 1966; Kemper and Rosenau, 1984).

**Table 1. Effect of air-drying and storage on aggregate stabilty for prehumidified treatments.**

**Aggregate Stability (%)**

| Time | N | Air-dry | θm | Fresh | θm |
|---|---|---|---|---|---|
| First week | 24 | 94b | 5 | 75a | 15 |
| Second week | 24 | 96b | 5 | 79a | 15 |

Means with same letter are not significant at the (0.05) level.

**Table 2. Effect of prehumidifying on aggregate stability for air-dry samples.**

| Pretretment | N | Aggregate stability (%) | θm |
|---|---|---|---|
| Non-humidified | 24 | 56b | 10 |
| Humidified | 24 | 92a | 10 |

Means with same letter are not significant at the (0.05) level.

I found a significant difference in aggregate stability due to humidification (Table 2). Non-humidified aggregates have lower stabilities due to rapid wetting of the aggregate. Differential hydration of the aggregate results in uneven strains throughout the aggregate because of non uniform wetting and swelling. The outside of the aggregate wets first and expands, while the inside initially remains dry and does not swell. Cohesion between solid particles is reduced with increased moisture content. Compression of entrapped air by water that fills the outside pores, may exceed the attractive forces of cohesion between particles (Baver et al., 1972; Taylor, 1972; Marshall and Holmes, 1979). The force of water entry is much greater in non-humidified aggregate and can occur from all sides. Dry aggregates may literally explode and breakdown into small pieces upon wetting by immersion.

When aggregates are slowly moistened by humidification air will first escape from the larger pores. This allows the smaller pores to absorb water by capillary action. The effect of entrapped air is much less severe when samples are prehumidified.

## Initial Water Content Effect:

Paradoxically drying and wetting can both cause an increase and a decrease in aggregate stability, depending on pretreatment (Fig. 1). Pretreatment in conjunction with the initial moisture content and past history of the aggregates determine to a large extent the stability of the aggregates.

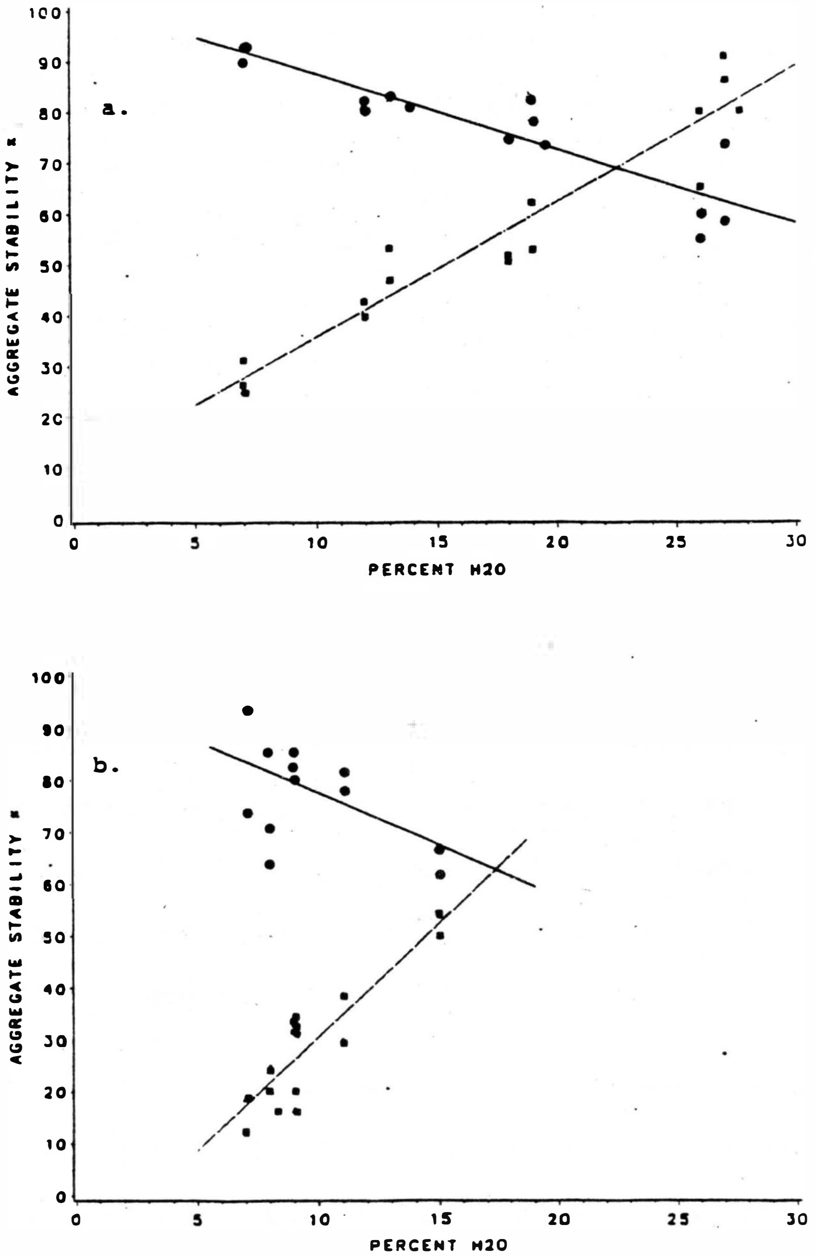


**Fig. 1 Aggregagate stability and moisture content relationship**

a. Soil initially saturated 24 hr before first measurement. ••••• Prehumidified sample (A.S.= 102.09 - 1.47 $H_2O$, $r^2$ = 0.84), ••••• Non humidified sample (A.S. = 9.11 + 2.66 $H_2O$, $r^2$ = 0.91).

b. Soil at field moisture sampled at the same time as (a). •••• Prehumidified sample (A.S. = 97.57 - 2.00 $H_2O$, $r^2$ =0.30), •••••• Non humidified sample (A.S. = -13.16 + 4.38 $H_2O$, $r^2$ = 0.80).

Treatments where the soil was initially saturated in the field and and allowed to dry had a high aggregate stability after prehumidification (Fig. 1a). As moisture content at the time of sample collection increased aggregate stability for this treatment decreased.

Wet aggregates in the field are fragile and easily crushed into smaller aggregates under external forces such as rainfall impact. This has being confirmed in a study by Alderfer (1946), who indicated that water stability of soil aggregates was at a maximum during the dry period of late summer and a minimum in the wet period of each spring.

The decrease in aggregate stability as moisture content increased may be due to (1) a softening and dispersion of the cementing materials, such as calcium carbonate, (2) a reduction in cohesion force with increased moisture due to hydration, (3) bond formation between water dipole and organic polymers within the aggregate (Baver et al., 1972; Marshall and Holmes, 1979).

Treatments where the soil was at field moisture and the aggregates were prehumidified (Fig. 1b), was similar to the treatment where the soil was initially saturated, however the curve shifted downward, as indicated by the intercept. This shift may be due to a different soil moisture history and soil water hysteresis. The increase in water stability associated with long duration of premoisting has been attributed to hydration of clay. Small cracks swell together and reduce planes of weakness in soils with high clay content (Evans, 1954). This may be a reason for the upward shift in aggregate stability in the saturated treatment, since this soil is a fine montmorillonitic soil.

The treatments where the soil was initially saturated in the field, but not prehumidified, gave results which were similar to the treatment where the soil was at field moisture content and not prehumidified (Fig. 1).

Both curves have a high coefficient of determination, 91% and 80% respectively, nevertheless they have different slopes. This change in slope may be due to the dehydration history. Perhaps the effect of organic matter has increased upon wetting through bond formation between water and organic polymers within the aggregate. Wetting might have increased inherent strength of the aggregate, resulting in less aggregate break down (Robinson and Page, 1950).

Aggregate stability for the non-humidified treatments decreased as water content decreased (Figures 1a and b). This finding is in agreement with Yoder's results (1936). Yoder indicated that, when the soil has been allowed to closely approach an air-dried condition, the aggregates will slake completely upon immersion in water due to compression of entrapped air.

## Relationship of Aggregate Stability to Selected Soil Properties:

This study was designed to evaluate selected soil properties in relationship to aggregate stability. Seventy eight soil samples comprising different texture, organic matter, calcium carbonate, pH, cation exchange capacity and initial water content were used to develop a regression equation specific for the Beadle soil series, which predicts the aggregate stability of this soil series. The soil properties fall into the following ranges; organic matter percent of 0.15 to 3.50, clay percentage of 12 to 50, calcium carbonate percentage of 0.30 to 25, and percent water content of 14 to 28 percent by weight. The equation obtained from multiple regression analysis was:

$$A.S.=160.9 +.73(clay-33.37) -.04(clay-33.37)^{2} +1.68(OM-.9099)$$
$$-26.0(OM-.9099)^{2}+ 13.82(OM-.9099)^{3} -3.20H_2O -.69CaCO_3$$

where A.S.= Aggregate stability, OM= Organic matter, aggregate stability and all constituents are given in percent. The coefficient of determination value ($R^2$) of this equation was 67%. This indicates that only 33% of variation in aggregate stability has not been explained. This variation may be due to some other variables not considered in the regression, such as microbial gum and sesquioxides.

The equation indicated that variables controlling aggregate stability of this soil are; initial water content at the time of sample collection, organic matter, clay content, and calcium carbonate content. The entry of the independent variables into the regression equation and the coefficients of the equation indicated that organic matter was the most important of the independent variables, followed by the water content at the time of sample collection.

## Aggregate Stability in Relation to Initial Water Content:

The initial moisture content of the aggregates is of importance in determining the extent of aggregate stability even when the aggregate is prehumidified. As our previous data indicated, initial water content had a highly significant influence ($p< 0.01$) on aggregate stability. The prediction equation confirmed the importance of initial water content, even when the aggregates were prehumidified, as indicated by coefficients associated with the regression equation. In addition, water was the second independant variable after organic matter to enter the regression equation.

The relationship of aggregate stability to water content was generated from the prediction equation for the Ap horizon (Figure 2a). This graph indicates the important of water content at the time of sample collection in the Ap horizon which has 5.5% calcium carbonate content, and 31% clay content. This relationship indicates that at low organic matter content (<2.5%), aggregate stability decreased with increased initial water content. Increased water content may have affected colloidal binding or linkage, with resulting weakening of these bounds upon hydration. Bond formation between water dipole and organic polymers within the aggregate decreases aggregate stability (Baver et al., 1972; Marshall and Holmes, 1979).

Aggregates with more than 2.5% organic matter are less affected by moisture content (Figure 1a). This may be due to more particle-to-particle bonding (Robinson and Page, 1950).

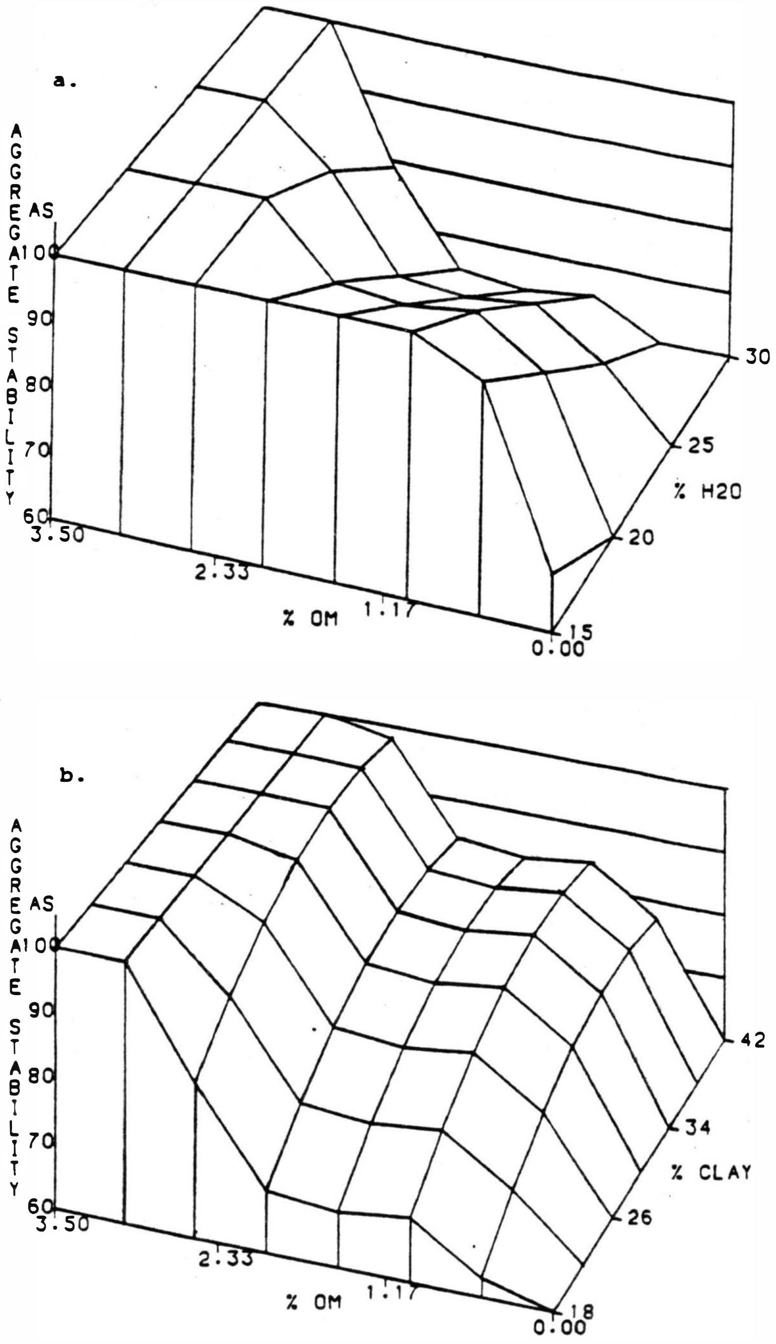


**Fig. 2 Aggregate stability relationships**

$$A.S.=136.24+0.30(Clay-32.99)-0.05(Clay-32.99)^2+18.7(OM-.6565)-31.64(OM-.6565)^2+14.38(OM-.6565)^3-2.45H_2O$$

a. Organic matter and water content for Ap horizon at 5.5% calcium carbonate and 31% clay content.

b. Organic matter and clay content for Ap horizon at 5.5% calcium carbonate and 22% water content.

## Aggregate Stability in Relation to Organic Matter:

Soil aggregate stability and organic matter relationships are a dynamic process. Aggregate stability is continually changing as organic matter is added and decomposed. The prediction equation indicates that organic matter play a major role in the aggregate stability of this soil. The role of organic matter in stabilizing aggregates is not yet completely understood (Aringhieri and Sequi, 1978). The importance of organic matter depends not only on the chemical nature of the organic matter, but also on its arrangement with respect to the mineral constituents (Dormaar, 1983).

Aggregate stability in relation to organic matter is illustrated in Figures (2a and b). Figure (2a) was generated from a prediction equation for the Ap horizon, at 5.5% calcium carbonate and 31% clay content. Figure (2b) was generated from a prediction equation for the Ap horizon, at 22% water content and 5.5% calcium carbonate content.

Figure (2a) indicates a significant influence of organic matter on aggregate stability. Organic matter content becomes increasingly more important as the gravimetric water content at the sampling time increases.

Figure (2b) illustrates a significant influence of organic matter on the aggregate stability of the Ap horizon. An increase in organic matter, for aggregates with contents less than 1% organic matter increased aggregate stability, while an increase in organic matter from 1.1 to 2.1% did not affect aggregate stability.

The organic matter content-aggregate stability relationships below 1.1% organic matter represent the aggregate stability of the Ap horizon of the 45 cm desurfaced plots. I found that this range of organic matter-aggregate stability relationships were associated with the organic matter content of the C horizons of the profiles. While the organic matter content-aggregate stability relationships between 1.1 and 2.2% organic content are associated with aggregate stability of the B horizons of the profiles.

The type of organic matter may be more important than the total amount of organic matter. Previous studies have indicated that certain fractions of organic matter are more important than others (Jesse and Lutz, 1940; Chaney and Swift, 1984; Aringhieri and Sequi, 1978; Tisdall and Oades, 1982). Tisdall and Oades (1982) grouped organic matter according to decomposition in the soil as follows: 1) transient, decomposition occurs rapidly resulting in an increase in aggregate stability for several weeks; 2) temporary, less readily decomposed material which leads to a gradual increase in aggregate stability which persists for several months; and 3) persistent material, which results in limited aggregate stability.

The percentage of organic matter in the soil may only be grossly correlated with soil structural stability. Organic materials that are slower to decompose require a longer time to exert their binding effect (Browning and Milam, 1944). Our finding of little influence of organic matter on aggregate stability in the range of 1.1 to 2.2% oxidizeable organic matter may reflect this possibility.

Arrangement of the organic matter rather than the quantity of the organic matter may influence binding abilities within the aggregate (Dormaar, 1983). Organic matter may be predominantly located in the center of the aggregate with particles of fine clay sorbed onto it (Foster, 1978; Turchenek and Oades, 1978), or found in greater quantities on the outside of the aggregate (Emerson, 1959; Greenland, 1965a). Aggregates which persist under ultrasonic vibration appear to have their organic matter sorbed onto clay surfaces. This arrangement with ageing can lead to the formation of films which can not be removed with ultrasonic vibration (Greenland et al., 1962).

Aggregate stability increases sharply with increasing amounts of organic matter after about 2% (Figure 2b). This effect is enhanced at low clay percentages. The steep increase in aggregate stability corresponds to the organic matter contents found in the Ap horizon of the control plots. This indicates that organic matter content at this range is more effective in causing aggregate stability, which may be due to additive effects of different fractions of organic matter. Soil with high organic matter have slower decomposition rates, thus there will be different fraction of organic matter present at different stages of decomposition. Materials that are readily decomposeable increase aggregate stability for a short period of time, while the materials that are slower to decompose increase aggregate stability over a long period of time and continue to be effective over a longer time (Browning and Milam, 1944).

### Aggregate Stability in Relation to Clay Content:

Clay has a significant effect on aggregate stability through electrostatic and Van der Waals attractive forces in clay domains. The relationship of clay content with aggregate stability is shown in Figure (2b). The hyperbolic curve indicates a quadratic relationship between aggregate stability and clay content for this soil. This is in agreement with the findings of Kemper and Koch (1966).

### Aggregate Stability in Relation to Calcium Carbonate:

Calcium carbonate had little effect on aggregate stability. All the prediction equations (Table 3) indicate a negative effect of calcium carbonate content on the aggregate stability for this soil. Since most of the calcium carbonate was present as soft lime accumulations (weakly cohering masses) throughout the profile, the negative effect may be due to the dispersion of these cementing material upon wetting (Marshall and Holmes, 1979). Consequently the aggregate disintegrates upon wetting as bonding due to calcium carbonate is disrupted.

Table 3. Prediction Equations for Each Horizon.

| Horizon | Equation |
|---|---|
| Ap | $A.S.=136.24+0.30(Clay-32.99)-0.05(Clay-32.99)^2+18.7(OM-.6565)-31.64(OM-.6565)^2+14.38(OM-.6565)^3-2.45H_2O$<br>$(R^2= 0.72)$ |
| Bw | $A.S.=150.59+0.79(Clay-32.79)-0.30(Clay-32.79)^2+8.18(OM-.8077)-30.09(OM-.8077)^2+12.67(OM-.8077)^3-2.46H_2O-0.86CaCO_3$<br>$(R^2= 0.58)$ |
| Bk | $A.S.=145.52+0.59(Clay-31.48)-0.03(Clay-31.48)^2+2.83(OM-.9726)-20.84(OM-.9726)^2+12.30(OM-.9726)^3-2.41H_2O-0.19Silt$<br>$(R^2= 0.71)$ |
| C1 | $A.S.=170.28+0.81(Clay-32.98)-0.04(Clay-32.98)^2+2.21(OM-1.009)-24.86(OM-1.009)^2+15.23(OM-1.009)^3-3.62H_2O-0.76CaCO_3$<br>$(R^2= 0.70)$ |
| C2 | $A.S.=164.54+0.68(Clay-33.69)-0.07(Clay-33.69)^2-3.17(OM-.9755)-18.99(OM-.9755)^2+12.10(OM-.9755)^3-3.39H_2O-0.72CaCO_3$<br>$(R^2= 0.75)$ |

A.S.= Aggregate stability (%).  OM = Organic matter (%).

# SUMMARY

In summary, air-drying in the laboratory had a marked effect on aggregate stabilities compared with soil samples at actual field moisture content. Air-drying increased aggregate stability significantly. Prehumidifying modified aggregate stability results. The data indicates that the moisture content at the time of sample collection is a critical factor in aggregate stability measurements even with a prehumidification treatment. It also indicates that storage can be a problem, if the objective is a determination of aggregate stability in the field. Samples should then be run immediately after collection on freshly collected samples. An alternative is the development of equations for the soil of interest which include field moisture content as a variable in aggregate stability prediction.

The prediction equations indicate that initial water content, organic matter, clay content, and calcium carbonate content are the variables that control aggregate stability in this soil. Total organic matter alone is insufficient to explain variation in aggregate stability. This conclusion also has been drawn by Greenland (1971) and Chesters et al. (1957). The stability of soil aggregates could be related to the arrangement and condition of the organic matter, rather than to the absolute quantity.

# IV. EROSION AND DESURFACING

## ABSTRACT

Field studies were conducted over a two year period on a Beadle taxadjunct (Fine, montmorillonitic, mesic Typic Haplustoll) series, to compare the impact of erosion and desurfacing on soil properties and corn yield. Plots were established on a site consisting of three erosion classes (slight, moderate and severe). Plots were also established on adjacent desurfaced land (0, 30, and 45 cm of topsoil were removed) of the same soil series. Soil physical properties, soil chemical properties and plant growth parameters were compared across the erosion classes and the desurfaced treatments.

Soil erosion and desurfacing altered some soil physical and chemical properties of this soil while others were unaffected. There was not a significant difference in the surface bulk densities and aggregate stabilities between erosion classes. However, there was a significant increase in the bulk densities and a decline in the aggregate stabilities as the result of desurfacing. Erosion decreased volumetric water content in the upper 45 cm of the profiles, while desurfacing increased volumetric water content in the root zone. Saturated hydraulic conductivities were not affected by topsoil thickness. Significantly higher calcium carbonate content and pH values in the Ap horizon were

obtained due to the topsoil lost. Generally, available water holding capacity, and organic matter were significantly reduced as topsoil thickness decreased, however the reduction was more pronounced on the desurfaced plots. Tissue analysis indicated significantly lower potassium content of the ear leaf on the severely eroded soil. Plant growth and development were delayed as topsoil thickness decreased, however the delay was more pronounced on the desurfaced plots. Consequently yield reductions of 6% and 14% were obtained on the moderately and severely eroded classes, respectively. While the yield reductions were 13% and 19% on the 30 and 45 cm removal, respectively.

# INTRODUCTION

Continuing loss of topsoil from erosion is a major concern for row crop production on many glacial till soils in the Western Corn Belt (Henning and Khalaf, 1985). The removal of topsoil on many glacial till soils expose dense clay or clay loam subsoils that may be infertile and poorly suited for growing crops (Olson, 1977).

Measurements from erosion plots, desurfaced plots and predictions from productivity models have been used to study productivity-erosion relationships (Meyer et al., 1984). Considerable research has been conducted on desurfaced land (Latham, 1940; Daniel et al., 1943; Odel, 1950; Englestad and Shrader, 1961; Reuss and Campbell, 1961; Shrader et al., 1963; Batchelder et al., 1966; Eck, 1969; Batchelder and Jones, 1972; Olson, 1977; Dormaar, 1983; Bruce et al., 1984; Sadler, 1984; Tanaka and Aase, 1985). Researchers have generally favored the closely controlled experiment where erosion is simulated by desurfacing the soil. Although research on naturally occuring erosion are more like those in the actual field situations. Topsoil removal due to desurfacing may be analogous to loss of topsoil by natural erosion in some aspects (Williams et al., 1981). However, the abrupt loss due to desurfacing generally affects immediate productivity more than the gradual loss due to erosion.

Topsoil removal and the associated changes in productivity are measured by soil physical and chemical relationships and their subsequent impacts on crop yield (Lee and McElyea, 1985). The objectives

# MATERIALS AND METHODS

## Site Establishment and Experimental Design

Field trials were established during two consecutive growing seasons (1984-1985), on a Beadle Taxadjunct (Fine, montmorillonitic, mesic Typic Haplustoll) series at the COOPERATIVE USDA-ARS; SDSCD farm near Madison, South Dakota (NW 1/4, Sec. 35. T107N, R35W).

Two sets of plots were established in 1984. On one set, we identified three erosional classes (slightly eroded, moderately eroded and severely eroded) using depth to carbonate layer and comparisons to an adjacent uncultivated area as indicators of past erosion (Table 4). All were located on backslope positions within the same landscape (Fig. 3). A randomized complete block design was used as an experimental design with three replications for each erosional class.

On the second sets of plots, different amounts of topsoil were removed. Topsoil was removed in increments of 0, 30, and 45 cm in 1965, from nearly level summit positions of the same landscape (Fig. 3). Three replications for each treatment were established, each plot was 15 meters wide by 30 meters long.

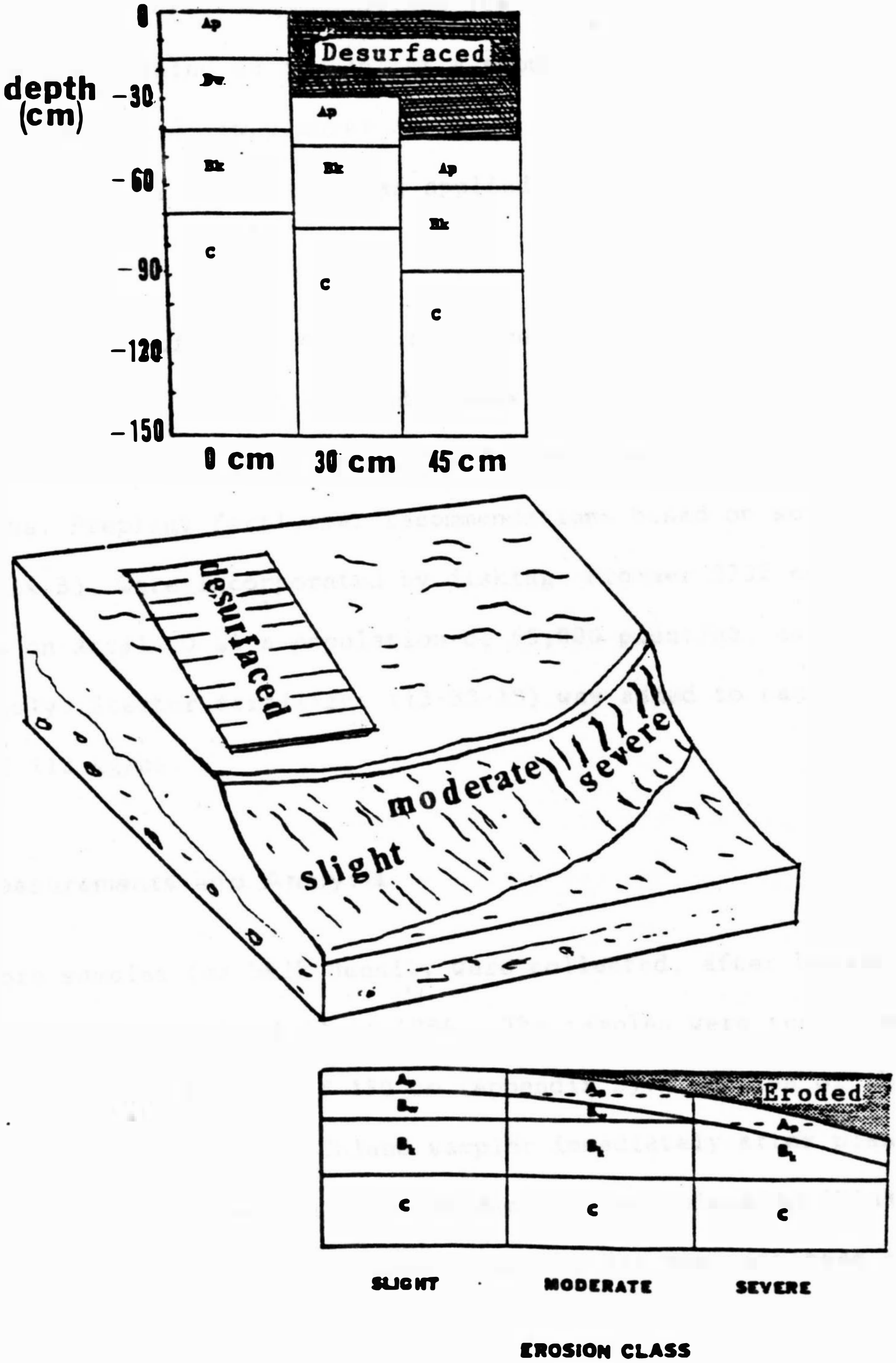
## Plot Management

Both sites were moldboard plowed in the fall of 1983. Preplant herbicides, Sutan (31.5 L/ha), Bladex (27.1 L/ha), and Ramrod (28 L/ha) were incorporated by disking in the spring of 1984.

Table 4. Site information and descriptions.

| 1. Treatments: | **Slight** | **Moderate** | **Severe** |
|---|---|---|---|
| 2. Depth of $CaCO_3$ | > 45 cm | > 30-45 cm | surface |
| 3. Size of plots(m) | 24 × 24 | 36 × 14 | 24 × 20 |
| 4. % slope | 0 - 2 | 7 | 9 |
| 5. Slope length(m) | 33 | 33 | 33 |
| 6. Aspect | SE | SE | SE |
| 7. Capability unit | IIs-1 | IIIe-5 | IIIe-5 |
| 8. T factor | 5 T/A/Yr | | |
| 9. Latitude | 44 02` | | |

Fig. 3 Schematic diagram of landscape position and morphological changes due to erosion and desurfacing.



Dyfonate insecticide was applied at a rate of 8.4 kg/ha. Ammonium nitrate fertilizer application rates were based on South Dakota State University soil test recommendations (Gerwing, et al., 1982). Pioneer 3732 corn was planted on May 16, at a population of 65,000 plant/ha, with a commercial 4-row planter on 76-cm row spacing. Additional starter fertilizer (13-33-13) was applied at planting at a rate of 140 kg/ha.

In the fall of 1984, both sites were moldboard plowed. Preplant herbicides, Lasso (33.9 L/ha) and Bladex (27 L/ha) were incorporated by disking on April 30. The insecticide Dyfonate was applied at a rate of 8.4 kg/ha. Preplant fertilizer recommendations based on soil test levels (Appendix B), were incorporated by disking. Pioneer 3732 corn was planted on April 30 at a population of 65,000 plant/ha, as mentioned previously. Starter fertilizer (13-33-13) was added to each plot at a rate of 112 kg/ha.

### Soil Measurements and Analysis

Core samples for bulk density were collected, after harvest, by a hydraulic probe in the fall of 1984. The samples were sectioned at 15 cm increments to a depth of 150 cm (Appendix D). Samples of the Ap horizon were taken with a Uhland sampler immediately after planting during each growing season for bulk density determination (Blake, 1965), and hydraulic conductivity determination by the constant head method (Klute, 1965).

Soil water at 0.03 MPa and 1.5 MPa were determined, in a pressure memberane apparatus, on undisturbed samples of the Ap horizon (Richards, 1965). The above measurements were also determined for disturbed samples of each subsurface horizon. Plant available water holding capacity was calculated as the difference between water contents at 0.03 MPa and 1.5 MPa. Soil moisture readings were recorded with a neutron probe throughout the growing season at two week intervals except during rainfall events.

Infiltration rates for all the treatments were determined during the growing season in 1985, and after canopy cover by a modified double cylinder infiltration technique (Bertrand, 1965). Two sets of metal cylinders were employed for each run. The inside and outside cylinders were 30 cm and 60 cm in diameter, respectively. The outside cylinders were used to avoid lateral movement of water through the soil under the cylinder. Both cylinders were driven into the soil to a depth of 15 cm from all sides. Three duplicate runs were carried out at the same time for each treatment. Ponded water was maintained in both cylinders at a level of 5 cm during the runs, while we measured water intake in the inside cylinder. A constant water head was maintained in the cylinders using automatic floats. The amount of water intake was recorded on hydrographs for a three hour period.

Aggregate stabilities were determined in the laboratory by a modification of a method described by Kemper (1965, 1984). Aggregate stabilities for the Ap horizons were determined on prehumidified samples, immediately after sample collection. The results were then adjusted to a constant water content (20% w/w) with a prediction equation previously developed to overcome seasonal and treatments variability in aggregate stabilities due to changes in water content.

Separate soil samples were collected each fall, from each treatment for soil testing and fertilizer recommendations, at the 0-15 and 15-60 cm depth (Appendix B). Readily oxidizeable organic matter was determined by a modified Walkley-Black method (Allison, 1965). Soil pH values were obtained in a 1:1 soil water suspension with a pH meter (Hach Model A1700), (Richards, 1954). Phosphorus was determined by the Olsen and the Bray methods, on both calcareous and noncalcareous samples. The Olsen (Olsen et al., 1954) test results were used in the fertilizer recommendation when the Olsen test was higher than the Bray results (Bray and Kurtz, 1945). Potassium levels were determined by extraction with ammonium acetate (Pratt, 1965). Nitrates were determined for both the 0-15 and 15-60 cm depth (Gelderman et al., 1980). Zinc availability was determined for each treatment (Gelderman et al., 1980).

A pedon was described for each treatment. Pedons were sampled by horizons. Organic matter and pH for each horizon were analyzed by methods described previously; calcium carbonate equivalents were determined using the titrimetric method (Bundy and Bremer, 1972); particle-size analysis was determined by the pipette method (Soil Survey Staff, 1972).

## Plant Measurements and Analysis

Residue cover was measured using the meterstick method (Hartwig and Loflen, 1978). Crop growth measurements (50% emergence, plant population at 4 leaf stage, 50% silking, plant height, 50% maturity) were collected each season for all the treatments. Leaf area was measured with a portable area meter (Li. Cor. Li-3000). Plant tissue analysis were determined for 25 leaves on each replicate of each treatment (Gelderman et al., 1978).

In 1984, yield was measured on two parallel rows that were selected randomly on each replication of each treatment. Each row was 6.1 meter long. In 1985, yield was measured on two parallel rows that were selected randomly on each replication. Rows were 7.6 meter and 5.1 meters long on the desurfaced plots and the erosional plots, respectively. Yields were reported on a 15.5% moisture basis.

Additional data included in the appendices were collected to be used in the Nitrogen-Tillage-Residue-Management (NTRM) model. This computer simulation model will provide a comprehensive model of the soil environment and its effect on crop growth. Also, it provides means of quickly and economically assessing soil erosion/ productivity relationships as influenced by existing and proposed management techniques.

## Statistical Methods

The Statistical Analysis System (SAS) was used for all statistical analysis generated in this study. Statistics for each parameter studied were generated by analysis of variance (ANOVA) procedures, using the proc ANOVA in SAS (Goodnight and Spector, 1985). The Waller-Duncan, K-ratio, t-test mean comparison test were used to determine significant difference between treatments for each parameter. The least significant difference (FLSD) was calculated and used to compare the simple treatment means for some parameters if the interaction term among the factors being investigated were significant.

# RESULTS AND DISCUSSION

## Soils of the Study Area

The study site is located on a soil mapped as a Beadle series, formed in loamy glacial till on upland. However, due to the absence of an argillic horizon and lower calcium carbonate near the surface (Tables 5a and 5b), this soil should be considered as a Beadle taxadjunct.

These soils are susceptible to the erosional processes primarily due to their position on the landscape, surface soil texture and land-use. This soil has become more susceptible to erosional damage due to cultivation. As sheet erosion advances more and more of the original A horizon is removed, and tillage operations mix undesirable subsoil material with the surface material imparting these characteristics to the A horizon.

## Pedon characteristics

Pedon descriptions and horizon characterization are found in (Appendix A). Selected horizon characteristics are summarized in Tables 5a and 5b. Horizon characterizations indicate that erosion has removed the original Ap horizon on the moderately eroded class. The Ap horizon on the moderately eroded soil corresponds to the Bw horizon of the original pedon. The higher clay content of the Ap horizon on the moderately eroded pedon may be a result of the erosional process and subsequent exposure of the Bw horizon (Frye et al., 1982; White et al.,

**Table 5a. Selected soil properties of the erosional classes and desurfaced levels.**

| Treatment | Horizon | Depth cm | Color moist | OM % | $CaCO_3$ % | Ratio CEC/clay |
|---|---|---|---|---|---|---|
| **Slight** | **Ap** | 0-17 | 10YR 2/1 | 3.70 | 0.50 | 0.83 |
| | **Bw** | 17-40 | 10YR 3/2 | 2.70 | 0.80 | 0.67 |
| | **Bk1** | 40-66 | 2.5Y 4/2 | 1.50 | 11.90 | 0.62 |
| | **Bk2** | 66-85 | 2.5Y 5/2 | 0.90 | 22.00 | 0.60 |
| | **C1** | 85-104 | 2.5Y 5/4 | 0.60 | 15.50 | 0.44 |
| | **C2** | 104-150 | 2.5Y 5/4 | 0.47 | 15.60 | 0.44 |
| **Moderate** | **Ap** | 0-25 | 10YR 2/1 | 3.50 | 1.73 | 0.77 |
| | **Bk1** | 25-44 | 10YR 4/2 | 1.50 | 18.70 | 0.58 |
| | **Bk2** | 44-75 | 2.5Y 5/4 | 1.06 | 21.10 | 0.59 |
| | **C** | 75-150 | 2.5Y 5/4 | 0.50 | 17.40 | 0.54 |
| **Severe** | **Ap** | 0-24 | 10YR 2/1 | 3.00 | 7.30 | 0.76 |
| | **Bk** | 24-59 | 10YR 5/3 | 0.86 | 22.20 | 0.56 |
| | **C1** | 59-77 | 2.5Y 4/4 | 0.57 | 21.10 | 0.53 |
| | **C2** | 77-150 | 2.5Y 5/4 | 0.48 | 15.80 | 0.54 |
| **0-cm removal** | **Ap** | 0-15 | 10YR 2/1 | 3.80 | 0.50 | 0.95 |
| | **Bw** | 15-41 | 10YR 3/2 | 2.60 | 3.13 | 0.62 |
| | **Bk1** | 41-67 | 2.5Y 4/4 | 1.87 | 22.80 | 0.63 |
| | **Bk2** | 67-84 | 2.5Y 5/4 | 0.81 | 24.90 | 0.61 |
| | **C1** | 84-100 | 2.5Y 5/4 | 0.77 | 23.40 | 0.60 |
| | **C2** | 100-150 | 2.5Y 5/4 | 0.57 | 18.50 | 0.56 |
| **30-cm removal** | **Ap** | 0-20 | 10YR 3/2 | 2.40 | 13.40 | 0.65 |
| | **Bk** | 20-57 | 10YR 5/3 | 1.47 | 23.90 | 0.55 |
| | **C1** | 57-104 | 2.5Y 4/4 | 0.70 | 20.10 | 0.58 |
| | **C2** | 104-150 | 2.5Y 4/4 | 0.25 | 18.00 | 0.72 |
| **45-cm removal** | **Ap** | 0-17 | 10YR 3/3 | 1.80 | 20.40 | 0.65 |
| | **BK** | 17-46 | 10YR 4/3 | 0.80 | 19.60 | 0.58 |
| | **C1** | 46-67 | 2.5Y 4/4 | 0.70 | 18.40 | 0.59 |
| | **C2** | 67-150 | 2.5Y 5/6 | 0.27 | 14.40 | 0.59 |

Table 5b. Selected soil properties of the erosional classes and desurfaced levels.

| | | Depth | Clay | Silt | Sand | |
|---|---|---|---|---|---|---|
| Treatment | Horizon | cm | ------- | % | ------- | Texture |
| **Slight** | **Ap** | 0-17 | 35.8 | 39.3 | 24.9 | CL |
| | **Bw** | 17-40 | 37.7 | 37.8 | 24.5 | CL |
| | **Bk1** | 40-66 | 35.0 | 37.5 | 27.5 | CL |
| | **Bk2** | 66-85 | 37.3 | 34.9 | 27.8 | CL |
| | **C1** | 85-104 | 34.9 | 34.4 | 30.7 | CL |
| | **C2** | 104-150 | 30.1 | 28.3 | 41.6 | CL |
| **Moderate** | **Ap** | 0-25 | 40.5 | 35.9 | 23.6 | C |
| | **Bk1** | 25-44 | 41.7 | 31.9 | 26.4 | C |
| | **Bk2** | 44-75 | 39.8 | 29.2 | 31.0 | CL |
| | **C** | 75-150 | 39.9 | 27.5 | 32.6 | CL |
| **Severe** | **Ap** | 0-24 | 31.0 | 41.3 | 27.7 | CL |
| | **Bk** | 24-59 | 34.9 | 34.7 | 30.4 | CL |
| | $C_1$ | 59-77 | 38.3 | 33.0 | 28.7 | CL |
| | $C_2$ | 77-150 | 34.7 | 45.1 | 20.2 | CL |
| **0-cm removal** | **Ap** | 0-15 | 30.3 | 53.3 | 16.4 | SiCL |
| | **Bw** | 15-41 | 39.9 | 52.8 | 7.3 | SiCL |
| | **Bk1** | 41-67 | 36.8 | 54.7 | 8.5 | SiCL |
| | **Bk2** | 67-84 | 34.5 | 57.9 | 7.6 | SiCL |
| | **C1** | 84-100 | 32.1 | 56.0 | 11.9 | SiCL |
| | **C2** | 100-150 | 32.1 | 48.2 | 19.7 | SiCL |
| **30-cm removal** | **Ap** | 0-20 | 38.6 | 56.6 | 4.8 | SiCL |
| | **Bk** | 20-57 | 31.4 | 56.5 | 12.1 | SiCL |
| | **C1** | 57-104 | 26.7 | 54.5 | 18.8 | SiL |
| | **C2** | 104-150 | 15.8 | 19.1 | 65.1 | SL |
| **45-cm removal** | **Ap** | 0-17 | 31.6 | 62.1 | 6.3 | SiCL |
| | **BK** | 17-46 | 30.7 | 51.1 | 18.2 | SiCL |
| | **C1** | 46-67 | 26.6 | 53.0 | 20.4 | SiL |
| | **C2** | 67-150 | 19.3 | 49.8 | 30.9 | SiL |

1985; Schertz et al., 1985). The Bw horizon is frequently of finer texture than the Ap horizon. This is as a result of pedogenic processes (illuviation and lessivage) and a consequent increase in clay content. The pedon description for the moderately eroded class indicates that this pedon has a higher clay content than the other pedons. The lower clay content on the severely eroded pedon may be due to the removal of the original Bw horizon in some area and the exposure of the original Bk horizon (Fig. 3). Tillage operations have mixed Bw and Bk horizons on severely eroded pedon, as indicated by horizon properties (Tables 5a and 5b).

Both sites are from the same soil series. However, there were differences between the two sites. This is probably due to field variation (Costigan and Mcburney, 1983; Costigan et al., 1983). The higher silt content of the desurfaced pedons is due to presence of fine sand and silt pockets especially in the C horizon on this site (Tables 5a and 5b).

The higher clay content of the Ap horizon on the 30-cm desurfaced pedon is due to exposure of the Bw horizon of the original pedon (Fig. 3). These pedon characterizations indicate that no change in texture has occurred due to topsoil removal.

The higher calcium carbonate content of the Ap horizon on the eroded classes corresponds to the calcium carbonate content of the Bw and Bk horizons of the original profile (Table 5a). Also, higher calcium carbonate content of the Ap horizon on the 30-cm and 45-cm desurfaced plots corresponds to the calcium carbonate content of the Bw and Bk horizons of the control plots, respectively.

The organic matter content of the Ap horizon on the eroded sites decreased as the erosion increased (Table 5a). This is another indication that soil has exposed the subsurface horizons. However, cultivation has mixed these subsurface horizons with the Ap horizon of the original pedon, and consequently organic matter has increased in comparison to the original subsurface horizons. The increase in organic matter of the eroded pedons is evidence of pedogenic processes (enrichment, decomposition, and humification) on the exposed horizons. The shift of the organic matter content of the other horizons of the eroded pedons relative to the original pedon is an indication of a loss of the original topsoil.

The organic matter content of the Ap horizon on the desurfaced plots decreases as topsoil thickness decreases. However, the decrease in organic matter is more pronounced on the desurfaced than the naturally eroded plots. This may be due to mechanical removal of the Ap horizon on the desurfaced plot and less mixing with subsurface horizons. While, the relatively slow erosional processes allow more mixing with the surface horizons on the eroded plots, as a result of cultivation (Frye et al., 1982; Carter et al., 1985).

The color of the Ap horizons for all the erosional classes is black (10YR 2/1) (Table 5a). The darker color of the Ap horizon on the eroded pedons in comparison with the corresponding horizons of the original

## Impact of Erosion and Desurfacing on Soil Physical Properties

Some physical properties of this soil have been altered by the topsoil removal, however the degree of changes were different between the eroded and desurfaced plots for some soil physical properties.

### Bulk Density.

Bulk density values were not significantly different among the three erosion classes for this soil (Table 6). This observation is in agreement with data from Sadler (1984) and Miller (1985). However bulk density values increased significantly ($p< 0.05$) as the thickness of desurfacing increased. Increased bulk density on desurfaced plots have been reported in other studies (Indorante et al., 1981; Bramble-Brodahl et al., 1985). Bulk density measurements on these desurfaced plots indicate no change from the original Bw and Bk horizons (Table 7). Higher bulk density on the desurfaced plots may be due to lower organic matter content (Frye et al., 1982; Peterson, 1964). These data indicate that erosion plots contain more voids than the desurfaced plots for this soil, and suggests that air and water movements through the soil profile may be less restricted than the desurfaced plots (Lindstrom et al., 1986).

### Available Water Holding Capacity.

Based on the water desorption curve for undisturbed soil samples of the Ap horizon, available water holding capacity has significantly decreased with the amount of topsoil removal increased on the erosion

Table 6. Effect of erosion and desurfacing on the surface bulk density.

| Erosion class<br>Desurfacing level | Slight<br>0-cm | Moderate<br>30-cm | Severe<br>45-cm | N | p(F)* |
|---|---|---|---|---|---|
| | Bulk Density (Mg m$^{-3}$) | | | | |
| Eroded site | 1.19a | 1.19a | 1.22a | 12 | 0.77 |
| Desurfaced site | 1.17a | 1.31b | 1.37b | 12 | <0.01 |

Means with same letter within the same row are not significant at the (0.05) level.

* p(F) the probability of a greater value of (F) from ANOVA.

Table 7. Selected soil properties of the erosional classes and desurfaced levels.

| Treatment | Horizon | Depth cm | Bulk density Mg m$^{-3}$ | Available water % w/w |
|---|---|---|---|---|
| Slight | Ap | 0-17 | 1.19 | 19.3 |
| | Bw | 17-40 | 1.26 | 18.5 |
| | Bk1 | 40-66 | 1.37 | 17.9 |
| | Bk2 | 66-85 | 1.52 | 15.2 |
| | C1 | 85-104 | 1.57 | 12.7 |
| | C2 | 104-150 | 1.56 | 12.5 |
| Moderate | Ap | 0-25 | 1.19 | 17.9 |
| | Bk1 | 25-44 | 1.42 | 17.1 |
| | Bk2 | 44-75 | 1.54 | 14.8 |
| | C | 75-150 | 1.60 | 13.1 |
| Severe | Ap | 0-24 | 1.22 | 14.8 |
| | Bk | 24-59 | 1.33 | 13.7 |
| | C1 | 59-77 | 1.53 | 12.6 |
| | C2 | 77-150 | 1.58 | 10.3 |
| 0-cm removal | Ap | 0-15 | 1.17 | 18.7 |
| | Bw | 15-41 | 1.26 | 17.2 |
| | Bk1 | 41-67 | 1.35 | 15.4 |
| | Bk2 | 67-84 | 1.39 | 13.7 |
| | C1 | 84-100 | 1.42 | 12.0 |
| | C2 | 100-150 | 1.51 | 11.2 |
| 30-cm removal | Ap | 0-20 | 1.34 | 16.6 |
| | Bk | 20-57 | 1.46 | 15.0 |
| | C1 | 57-104 | 1.47 | 8.4 |
| | C2 | 104-150 | 1.51 | 7.3 |
| 45-cm removal | Ap | 0-17 | 1.42 | 13.2 |
| | BK | 17-46 | 1.50 | 12.8 |
| | C1 | 46-67 | 1.47 | 10.8 |
| | C2 | 67-150 | 1.50 | 9.8 |

classes (Table 8). The same trend was observed for the desurfaced treatment, however the reduction in the available water holding capacity on these plots were very significant. The significant ($p< 0.05$) decrease in plant available water holding capacity on the moderately eroded class may be due to higher clay content as a result of Bw horizon exposure to the surface (Frye et al., 1982; Reuss and Campbell, 1961). The reduction in water holding capacity on the severely eroded plots may be related to the decrease in organic matter content. The decrease in plant available water holding capacity on the 30-cm and 45-cm desurfaced plots may be due to the additive effect of high clay, the lower organic matter content, the deterioration of surface soil structure and the reduction of total porosity.

### Hydraulic Conductivity.

Saturated hydraulic conductivity for the Ap horizon were determined on undisturbed samples. Hydraulic conductivity was not significantly (p 0.05) different among erosion classes (Table 9). This in agreement with Sadler (1984) and Miller (1985) data. Also, saturated hydraulic conductivity was not affected by the desurfacing (Table 9).

Permeabilities were slow, slow and moderately slow for slight, moderate and severe erosion classes, respectively. Premeabilities were slow, slow and moderately slow for the 0-cm, 30-cm, and 45-cm desurfaced plots.

### Infiltration.

Infiltration rates were high on all treatments except on the moderately eroded class (Fig. 4). The decrease in infiltration rate on the moderately eroded class may be due to a finer surface texture (Table 5b). The higher clay content of the surface may have changed water intake characteristics of this treatment (Eck and Ford, 1962). Frequent observations of rill erosion on these plots suggests that these plots had higher runoff. Moreover, a finer texture may have increased runoff (Allis and Kuhlman, 1962). High standard deviation between the runs is due to rainfall events, and consequent changes of water content after rainfall. From the curves we can conclude that infiltration rates on all treatments approached (12-16 cm/hr) after 4 hour, except the moderately eroded class, which approached 7-10 cm/hr after four hours.

### Soil Water.

Neutron probe readings throughout the growing season are reported in Appendix (D). Volumetric water content at the time of plant emergence indicates that water content in the top 45-cm of the profile was highest on the slightly eroded class and lowest on the moderately eroded class (Fig. 5a). This decrease in the water content of the moderately eroded class may be due to higher runoff and less infiltration as a result of higher clay content. Water content in the rooting zone, at the silking period, was highest on the slightly eroded class and lowest on the severely eroded class (Fig. 5a). Higher volumeteric water content on the desurfaced site indicates a higher water content in the profile

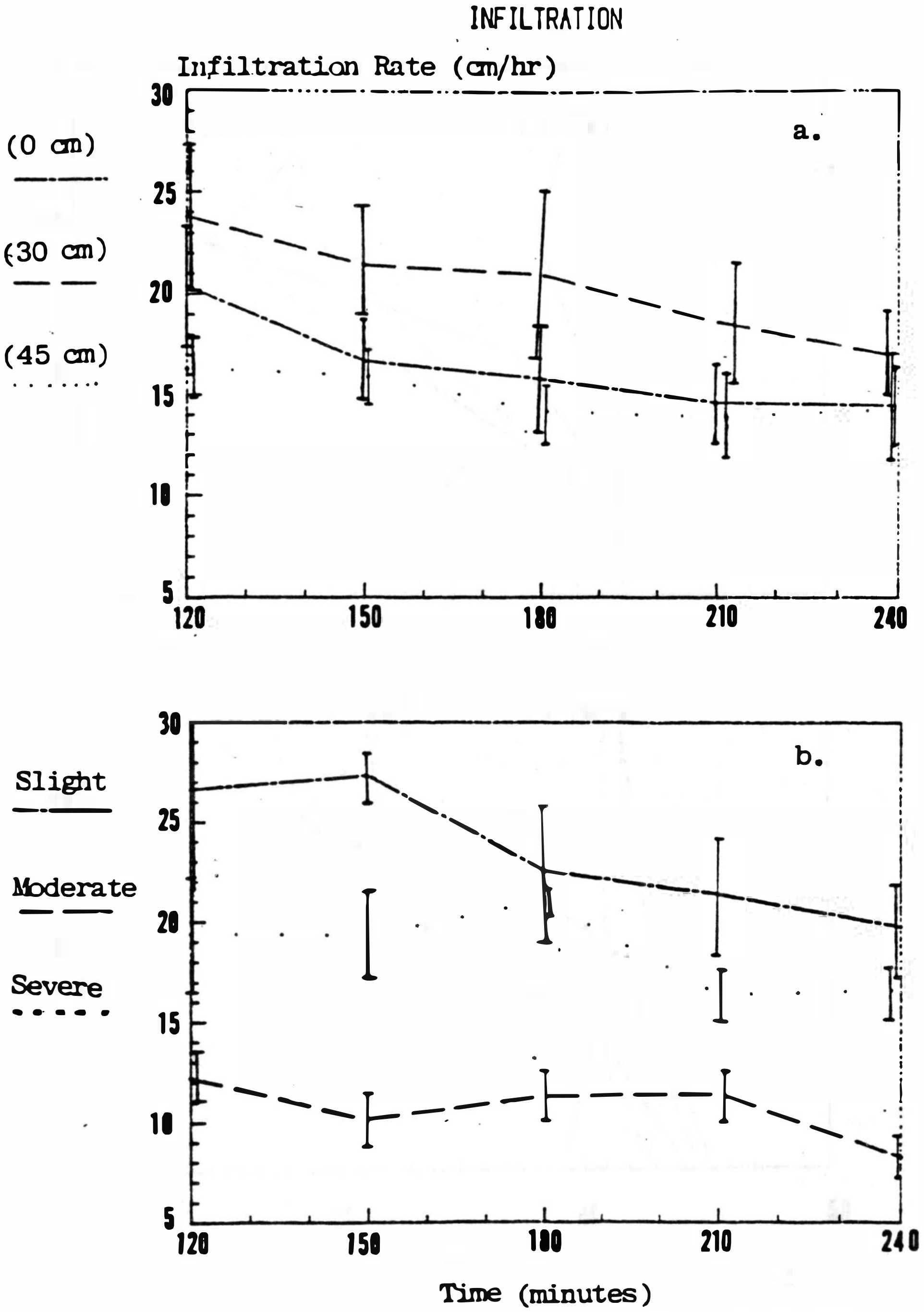


**Fig. 4 Effect of erosion and desurfacing on infiltration** rate (Bars represent standard deviation of the means).

a. Infiltration rate (cm/hr) for the desurfacing site.

b. Infiltration rate (cm/hr) for the erosion site.

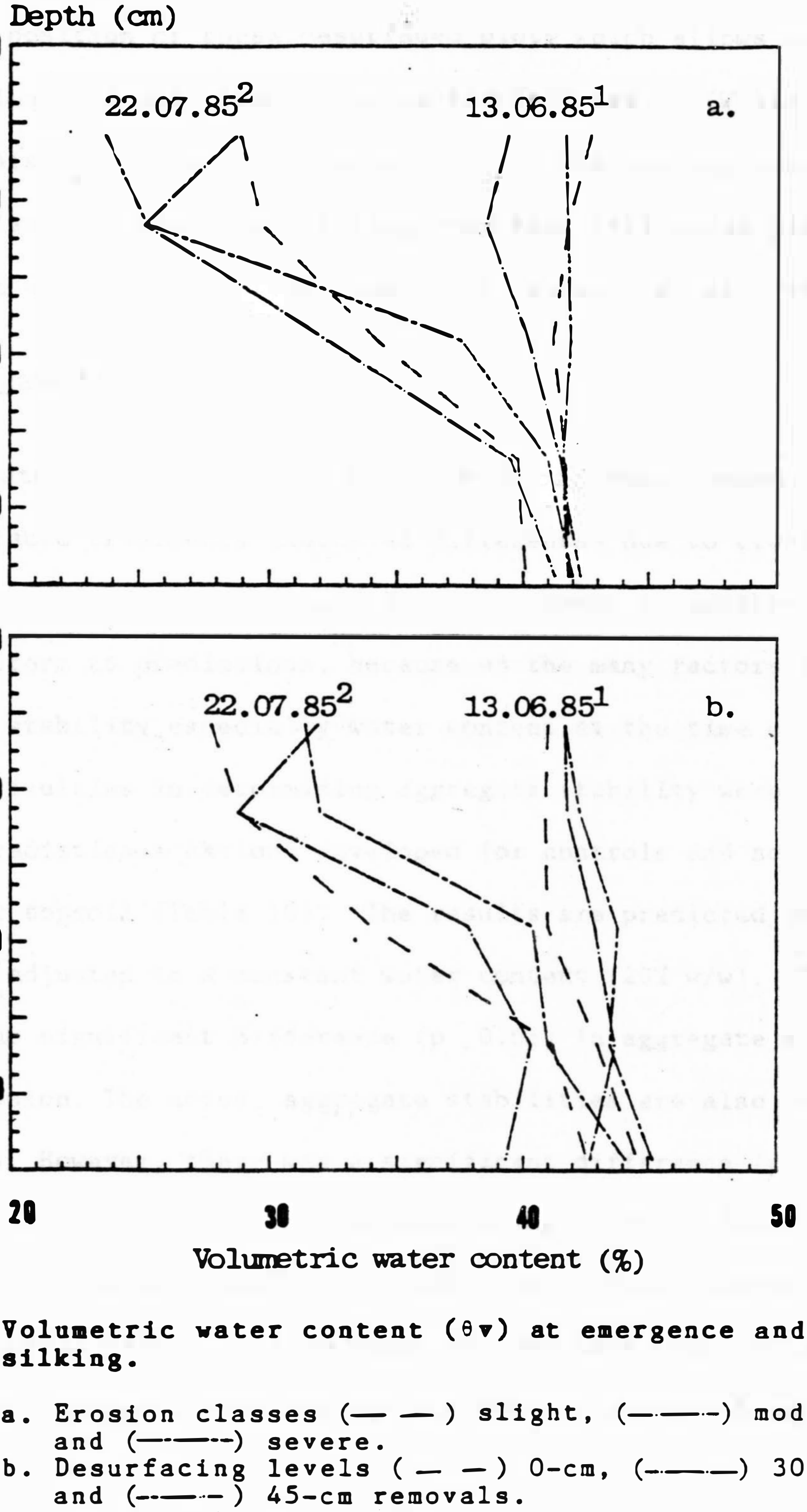


Fig. 5 Volumetric water content (θv) at emergence and silking.

a. Erosion classes (— —) slight, (—·—·-) moderate and (—··—··-) severe.
b. Desurfacing levels ( — —) 0-cm, (—·——) 30-cm, and (-·-—·-) 45-cm removals.
1. (13.06.85) emergence time.
2. (22.07.85) silking time.

(Fig. 5b). This higher volumetric water content may be due to the landscape position of these desurfaced plots which allows more time for infiltration, and less runoff during rainfall events (White et al., 1985). This difference of water content in the rooting zone, at the time of plant emergence and silking, may have influenced plant establishment and growth (Tan Piow, 1985; Schertz et al., 1985).

### Aggregate Stability.

Aggregate stability in the Ap horizons of eroded, moderately eroded and desurfaced treatments indicated differences due to treatment. However these difference changed from one season to another and did not always conform to predictions, because of the many factors that effect aggregate stability especially water content at the time of sampling. These difficulties in determining aggregate stability were overcome through prediction equations developed for controls and soils that have lost their topsoil (Table 10). The results are predicted results that have been adjusted to a constant water content (20% w/w). The results indicate no significant difference ($p \simeq 0.05$) in aggregate stabilities due to erosion. The actual aggregate stabilities are also reported in table (11). However, there was a significant difference ($p< 0.05$) in the aggregate stabilities due to the desurfacing. Perhaps quality and quantity of the organic matter, in addition to higher water content in the upper 45-cm of the profile (Fig. 5b) may have contributed to the significant decline of the aggregate stability on the 45-cm desurfaced plot.

**Table 10. Effect of erosion and desurfacing on the surface aggregate stability (Gravimetric moisture content = 0.20).**

| Erosion class<br>Desurfacing level | Slight<br>0-cm | Moderate<br>30-cm | Severe<br>45-cm | p(F)* |
|---|---|---|---|---|
| | | **Aggregate Stability (%)** | | |
| Eroded site | 99.7a | 98.3a | 86.8a | 0.67 |
| Desurfaced site | 99.5a | 93.5b | 61.1c | <0.01 |

Means with same letter within the same row are not significant at the (0.05) level.

* p(F) the probability of a greater value of (F) from ANOVA.

**Prediction equation for control plots:**

$$A.S.=161.02+0.75(Clay-33.37)-0.04(Clay-33.37)^2+1.68(OM-.9099)-26.00(OM-.9099)^2+13.82(OM-.9099)^3-3.20H_2O-0.69CaCO_3$$
$$(R^2=67\%)$$

**Prediction equation for eroded and desurfaced plots:**

$$A.S.=181.16+0.71(Clay-33.37)-0.04(Clay-33.37)^2+1.66(OM-.9099)-26.14(OM-.9099)^2+13.89(OM-.9099)^3-3.22H_2O-0.69CaCO_3$$
$$(R^2=67\%)$$

**Table 11. Effect of erosion and desurfacing on the surface aggregate stability (%) at actual field moisture.**

| | Slight<br>0-cm | $\theta_m$ | Moderate<br>30-cm | $\theta_m$ | Severe<br>45-cm | $\theta_m$ |
|---|---|---|---|---|---|---|
| Eroded site | 93.5 | 25 | 85.5 | 24 | 89.5 | 19 |
| Desurfaced site | 96.9 | 21 | 93.5 | 20 | 77.1 | 15 |

## Impact of erosion and desurfacing on soil chemical properties

### Organic Matter Content.

Changes in soil organic matter content of the Ap horizon, for the two growing season, for both sites are shown in (Table 12). Generally, the organic matter content decreased with increased topsoil removal (Frye et al., 1982; Schertz et al., 1985; Hayes et al., 1948). Erosion has decreased organic matter content significantly ($p < 0.05$), however the decrease of organic matter content on the desurfaced plots was more pronounced. The organic matter reductions of 0.4% and 0.8% for the Ap horizon were obtained on the moderately eroded and severely eroded classes, respectively. While the reduction in organic matter content on the 30-cm and 45-cm desurfaced plots were 1.4% and 2%, respectively.

This significant decrease in the organic matter may have contributed to the higher bulk density on the desurfaced sites (Peterson, 1964). The lower organic matter content with topsoil removal influenced the available water holding capacity, CEC, and soil structure. Furthermore, the decrease in the organic matter content can affect crop production through nutrient supply, and available water (Lindstrom et al., 1986).

### Calcium Carbonate Content.

Calcium carbonate contents of the severely eroded plots, and the 30 and 45 cm desurfaced plots is significantly higher ($p < 0.05$) than the slightly eroded, the moderately eroded and the 0-cm desurfaced plots (Table 13). Higher calcium carbonate content on the severely eroded

**Table 12. Effect of erosion and desurfacing on the surface organic matter content.**

| Erosion class<br>Desurfacing level | Slight<br>0-cm | Moderate<br>30-cm | Severe<br>45-cm | N | p(F)* |
|---|---|---|---|---|---|
| | | Organic Matter Content (%) | | | |
| | | (1984) | | | |
| Eroded Site | 3.6a | 3.2ab | 2.8b | 3 | 0.04 |
| Desurfaced site | 3.3a | 2.4b | 1.6c | 3 | 0.03 |
| | | (1985) | | | |
| Eroded site | 3.7a | 3.5ab | 3.0b | 9 | 0.04 |
| Desurfaced site | 3.8a | 2.4b | 1.8c | 9 | 0.03 |

Means with same letter within the same row are not significant at the (0.05) level.

* p(F) the probability of a greater value of (F) from ANOVA.

Table 13. Effect of erosion and desurfacing on selected soil chemical properties.

| Variable | Erosion class<br>Desurfacing level | Slight<br>0-cm | Moder.<br>30-cm | Severe<br>45-cm | N | p(F)* |
|---|---|---|---|---|---|---|
| $CaCO_3$ (%) | Eroded site | 0.5a | 1.7a | 7.3b | 9 | 0.01 |
| | Desurfaced site | 0.5a | 13.5b | 20.4c | 9 | <0.01 |
| pH (1:1) | Eroded site | 6.2a | 7.1b | 7.5c | 9 | <0.01 |
| | Desurfaced site | 7.0a | 7.6b | 7.6b | 9 | <0.01 |
| Salt mmhos/cm | Eroded site | 0.8a | 1.0a | 0.9a | 3 | 0.90 |
| | Desurfaced | 0.8a | 0.9a | 0.8a | 3 | 0.78 |

Means with same letter within the same row are not significant at the (0.05) level.

* p(F) the probability of a greater value of (F) from ANOVA.

class, the 30 and 45 cm desurfaced plots is due to exposure of the underlying Bk horizons.

### pH.

The pH also followed the same trend as calcium carbonate content (Table 13). The increase in pH values are highly significant ($p< 0.05$) as we move across theerosional classes. Also, there is a significant ($p< 0.05$) increase in the pH with topsoil removal on the desurfaced plots, however the extra 15-cm removal did not further increase pH value on the 45-cm desurfaced plot. The higher pH values of the Ap horizon, on the plots where the topsoils have been eroded or removed, is due to an increase in free calcium carbonate on the surface. There was not any significant difference ($p \simeq 0.05$) in salt content due to erosion nor desurfacing, in the Ap horizon of either sites.

### Soil Nutrient Status.

The major source of soil nitrogen is organic matter. Organic matter decomposition (mineralization) results in the release of nitrogen, which is considered as the most important source of soluble nitrogen in unfertilized soil.

In 1984, nitrogen fertilizer recommendations for a proposed 9 t/ha corn yield were 65 kg/ha, 77 kg/ha and 120 kg/ha for the 0-cm, 30-cm, and 45-cm desurfaced plots, respectively. Perhaps the lower nitrogen level of the desurfaced site (Table 14) is due to less mineralization of nitrogen (Lindstrom et al., 1986).

Table 14. Effect of erosion and desurfacing on the surface (0-15 cm) and subsurface (15-60 cm) $NO_3$-N content.

|  | Erosion class | Slight | Moderate | Severe |  |
|---|---|---|---|---|---|
| Method | Desurfacing level | 0-cm | 30-cm | 45-cm | N |
|  |  | $NO_3$-N (ppm) |  |  |  |
|  |  | (1984) |  |  |  |
| 0-15 | Eroded site | 23a | 22a | 19a | 3 |
| 15-60 |  | 25a | 21a | 31a | 3 |
| 0-15 | Desurfaced site | 13a | 11a | 4a | 3 |
| 15-60 |  | 19a | 17a | 13a | 3 |
|  |  | (1985) |  |  |  |
| 0-15 | Eroded site | 33a | 51a | 39a | 3 |
| 15-60 |  | 16a | 34b | 21ab | 3 |
| 0-15 | Desurfaced site | 22a | 21a | 21a | 3 |
| 15-60 |  | 15a | 16a | 8a | 3 |

Means with same letter within the same row are not significant at the (0.05) level.

In 1985, nitrogen fertilizer recommendation for a proposed 9 t/ha corn yield were 68 kg/ha, 85 kg/ha and 111 kg/ha for 0-cm, 30-cm and 45-cm desurfaced plots respectively. The nitrate soil test for the surface (0-15 cm) was not significantly different as topsoil thickness decreases, for either sites (Table 14). However, there was a significant increase in the subsurface nitrate (15-60 cm) on the eroded plots. This increase in the nitrate level may be due to less nitrogen uptake by the plant on the eroded plots.

Mineralization of organic matter by microorganisms results in the release of appreciable amounts of phosphorus. Soils with lower organic matter content such as the eroded and the desurfaced plots have less phosphorus content (Table 15). The decrease in available phosphorus with increase topsoil removal indicate a higher phosphorus fixing capacity of this soil. The higher phosphorus fixing capacity may be due to higher calcium carbonate and higher clay content, due to subsoil exposure (Stone et al., 1985). The increase in available phosphorus on the desurfaced plots, during 1985, is likely the result of residual effects of fertilizer application during the previous year.

The Bray test results were used in fertilizer recommendation where the Olsen test were lower. Phosphorus ($P_2O_5$) recommendation for the proposed 9 t/ha corn were 30 kg/ha for both the 30 and 45 cm desurfaced plots.

Potassium levels for both the eroded site and the desurfaced site were very high (Table 16). The high level of potassium in this soil is a

**Table 15. Effect of erosion and desurfacing on the surface phosphorus content.**

| Method | Erosion class<br>Desurfacing level | Slight<br>0-cm | Moderate<br>30-cm | Severe<br>45-cm | N |
|---|---|---|---|---|---|
| | | **Phosphorus (ppm)** | | | |
| | | (1984) | | | |
| Bray | Eroded site | 31a | 31a | -- | 3 |
| Olsen | | -- | -- | 22 | 3 |
| Bray | Desurfaced site | 28a | 1b | 2b | 3 |
| Olsen | | 19a | 6b | 7b | 3 |
| | | (1985) | | | |
| Bray | Eroded site | 27a | 24ab | 11b | 3 |
| Olsen | | 18a | 18a | 10b | 3 |
| Bray | Desurfaced site | 15a | 14a | 7a | 3 |
| Olsen | | 17a | 17a | 15a | 3 |

Means with same letter within the same row are not significant at the (0.05) level.

**Table 16. Effect of erosion and desurfacing on the surface potassium and zinc content.**

| Variable | Erosion class<br>Desurfacing level | Slight<br>0-cm | Moderate<br>30-cm | Severe<br>45-cm | N |
|---|---|---|---|---|---|
| | | (1984) | | | |
| Potassium | Eroded site | 222a | 190ab | 160b | 3 |
| (ppm) | Desurfaced site | 250a | 196b | 199b | 3 |
| Zinc | Eroded site | --- | --- | --- | |
| (ppm) | Desurfaced site | 1.3a | 0.8a | 1.4 | 3 |
| | | (1985) | | | |
| Potassium | Eroded site | 213a | 185b | 176b | 3 |
| (ppm) | Desurfaced site | 225a | 215a | 190b | 3 |
| Zinc | Eroded site | 1.1a | 0.8a | 0.7a | 3 |
| (ppm) | Desurfaced site | 1.1a | 1.0a | 1.5a | 3 |

Means with same letter within the same row are not significant at the (0.05) level.

result of the abundance of the micaceous clay minerals and feldspars which are rich in this glacial till derive parent material. Weathering of these minerals have released large amounts of potassium.

There was not a significant difference ($p > 0.05$) in zinc content between the erosional classes, or the desurfaced plots (Table 16). Zinc test values were near the upper limit of the marginal response on all plots, and zinc content of the leaf tissues for all treatments were at the sufficiency level (Appendix C) (Gerwing et al., 1982).

## Impact of Erosion and Desurfacing on Plant Parameters

Crop growth parameters were affected by topsoil thickness (Table 17). Generally, topsoil removal delayed plant emergence. Plant population were also reduced on the plots with less topsoil thickness, as was reported by Pierce et al. (1983). However, plant population was adequate on all the plots. A delay in development was also observed during the reproductive stage (Table 17). There was a delay in the date of 50% silking as topsoil thickness decreased.

Plant height was affected by topsoil thickness (Table 18). Plant height was reduced significantly on the severely eroded and the desurfaced plots in 1985. The reduction in plant height due to topsoil removal has been reported (Carter et al., 1985; Pettry et al., 1985).

Another plant growth parameter was leaf area measurement (Table 19). The reduction in leaf area was 12%, and 34% for moderately and severely

**Table 17. Effect of erosion and desurfacing on plant growth parameters.**

| Variable | Erosion class Desurfacing level | Slight 0-cm | Moderate 30-cm | Severe 45-cm | Units |
|---|---|---|---|---|---|
| | | (1984) | | | |
| Emergence (50%) | Eroded site | 27.05 | 26.05 | 28.05 | Date |
| | Desurfaced site | 27.05 | 30.05 | 30.05 | D.M. |
| Silking (50%) | Eroded site | 28.07 | 31.07 | 30.07 | Date |
| | Desurfaced site | 29.07 | 2.08 | 4.08 | D.M. |
| Plant pop*$10^3$ | Eroded site | 62.50 | 62.80 | 59.20 | plants |
| | Desurfaced site | 64.30 | 59.90 | 57.70 | per ha |
| | | (1985) | | | |
| Emergence (50%) | Eroded site | 09.05 | 11.05 | 12.05 | Date |
| | Desurfaced site | 10.05 | 10.05 | 11.05 | D.M. |
| Silking (50%) | Eroded site | 21.07 | 21.07 | 23.07 | Date |
| | Desurfaced site | 23.07 | 24.07 | 25.07 | D.M. |
| Plant pop*$10^3$ | Eroded site | 64.90 | 65.40 | 60.66 | plants |
| | Desurfaced site | 64.90 | 64.90 | 58.40 | per ha |

Table 18. Effect of erosion and desurfacing on plant height.

| Erosion class<br>Desurfacing level | Slight<br>0-cm | Moderate<br>30-cm | Severe<br>45-cm | N | p(F)* | Date<br>D.M. |
|---|---|---|---|---|---|---|
| | | **Plant Height (m)** | | | | |
| | | **(1984)** | | | | |
| Eroded site | 0.6a | 0.5a | 0.5a | 3 | 0.12 | 26.06 |
| Desurfaced site | 0.6a | 0.5b | 0.4b | 3 | 0.02 | 26.06 |
| | | **(1985)** | | | | |
| Eroded site | 1.6a | 1.7a | 1.4b | 9 | <0.01 | 23.07 |
| Desurfaced site | 1.8a | 1.6b | 1.5b | 9 | <0.01 | 23.07 |

Means with same letter within the same row are not significant at the (0.05) level.

* p(F) the probability of a greater value of (F) from ANOVA.

Table 19. Effect of erosion and desurfacing on leaf area.

| Erosion class<br>Desurfacing level | Slight<br>0-cm | Moderate<br>30-cm | Severe<br>45-cm | N | p(F)* | Date<br>D.M. |
|---|---|---|---|---|---|---|
| | | **Leaf Area (cm$^2$/plant)** | | | | |
| | | **(1984)** | | | | |
| Eroded site | 860a | 500b | 460b | 3 | 0.01 | 26.06 |
| Desurfaced site | 800a | 460b | 340b | 3 | 0.02 | 26.06 |
| | | **(1985)** | | | | |
| Eroded site | 3540a | 3110a | 2340b | 9 | <0.01 | 23.07 |
| Desurfaced site | 2600a | 2230b | 1790b | 9 | 0.01 | 23.07 |

Means with same letter within the same row are not significant at the (0.05) level.

* p(F) the probability of a greater value of (F) from ANOVA.

eroded plots, respectively. The reduction of leaf area, on the desurfaced plots, followed the same trend. Generally, all plots on the desurfaced treatments had lower values for both growing seasons. This delay in plant development may have affected yield.

Tissue analysis of the ear leaf (leaf opposite and below ear) were determined for 10 macro and micronutrients at silking (Appendix C). Tissue analysis indicates significantly lower potassium content of the ear leaf, on the severely eroded soil. The Diagnosis and Recommendation Integrated System (DRIS) indices was calculated for all the nutrients (Appendix C). The nutrient balance index (NBI) was 72, 96, and 170 on the slightly, moderately and severely eroded classes, respectively. This indicates that the slightly eroded soil is well balanced in nutrients, and the severely eroded class is the least balanced.

Corn yields were determined for each growing season (Table 20). In 1984, there was a significant yield reduction as topsoil thickness decreased on both sites. Although the slightly eroded class and the moderately eroded class had about the same plant population, however a yield reduction of 6% was obtained on the moderately eroded class. The yield reduction was 20% on the severely eroded class. While the yield reduction were 18% and 25% on the 30-cm and 45-cm removal respectively.

Yield on the slightly eroded class was not significantly different from the severely eroded class during 1985. However, there was a significant difference in yield on the desurfaced plots. The difference in the yield on the desurfaced plots was greatest in the year with

**Table 20. Effect of erosion and desurfacing on corn yield.**

| Erosion class<br>Desurfacing level | Slight<br>0-cm | Moderate<br>30-cm | Severe<br>45-cm | N | p(F)* |
|---|---|---|---|---|---|
| | **Corn Yield (Mg $ha^{-1}$)** | | | | |
| | | **(1984)** | | | |
| Eroded site | 8.6a | 8.1ab | 6.9b | 3 | 0.05 |
| Desurfaced site | 8.7a | 7.1ab | 6.5b | 3 | 0.05 |
| | | **(1985)** | | | |
| Eroded site | 8.3a | 7.9a | 7.8a | 9 | 0.29 |
| Desurfaced site | 9.7a | 9.1ab | 8.4b | 9 | 0.03 |

Means with same letter within the same row are not significant at the (0.05) level.

* p(F) the probability of a greater value of (F) from ANOVA.

**Mg/ha = 0.6272 * Bu/Ac.**

highest yields (Heilman and Thomas, 1961; Olson, 1977). The significant yield reduction on the eroded site, during the 1984 growing season, may be due to unfavorable climatic condition. While with more favorable climatic condition during the 1985 growing season, the effect of topsoil thickness on the grain yield was reduced, on the eroded site.

Higher moisture content in the rooting zone on the desurfaced site, due to the landscape position (LeMaster et al., 1985) and consequent high plant population may have increased the yield on these plots.

# SUMMARY

In summary, the effect of erosion and desurfacing on soil physical properties, soil chemical properties and plant growth parameters were studied over a two year period on a Beadle Taxadjunct (Fine, montmorillonitic, mesic, Typic Haplustoll). Soil erosion and desurfacing altered some soil physical and chemical properties of this soil while others were unaffected. The desurfacing had a marked effect on the bulk densities of the Ap horizon, while the erosion had no significant effect on the bulk denisties of the Ap horizon. There was not a significant difference in the aggregate stabilities between erosional classes, however there was a significant decline in the aggregate stabilities as the result of desurfacing. Available water holding capacity of the Ap horizon was significantly reduced as topsoil thickness decreased, however the reduction was more pronounced on the desurfaced plots. Surface hydraulic conductivities were not affected by topsoil thickness. Infiltration rate were slower only on the moderately eroded plots. Neutron probe data indicated that erosion has decreased volumetric water content in the upper 45 cm of the profiles, while desurfacing had increased volumetric water content in the root zone.

Soil erosion and desurfacing not only affected soil physical properties, but also affected some soil chemical properties of this soil. Soil erosion and desurfacing significantly decreased organic matter content, however the decrease of the organic matter were more drastic on the desurfaced plots. Significantly higher calcium carbonate content and pH values in the Ap horizon were obtained due to the topsoil lost. Salt contents were not affected by topsoil thickness on either site.

Nutrient status indicates no significant difference in the nitrate levels on the surface. Erosion and desurfacing influenced phosphorus and potassium levels. The phosphorus and potassium levels decreased as the topsoil thickness decreased. The zinc levels were not significantly influenced by erosion or desurfacing, for both growing seasons.

In general, plant emergence and silking were delayed on the plots with less topsoil thickness. Topsoil thickness significantly affected plant development. Both plant height and leaf area were reduced as topsoil depth decreased. Nutrient Balance index (NBI) indicates a well balanced nutrient on the control plots, and poor nutrient balance on the eroded and desurfaced plots. Significantly lower potassium level of the ear leaf were also obtained on the severely eroded plots. Consequently the yields were reduced as topsoil thickness decreased. The significance of the yield reduction was climatically dependant in the eroded site. However, grain yield reduction on the desurfaced plots was significantly reduced for both seasons. Moreover, the reduction in the corn yield was more pronounced in the year with the highest corn yield, on the desurfaced plots.

# V. CONCLUSIONS

Much of the information concerning possible erosion/productivity relationships has come from desurfacing. However, our data indicates that the naturally occuring erosion process are more like those in the actual field situation and less severe than desurfacing.

Topsoil removal by desurfacing is analogous to topsoil loss by accelerated erosion in some aspects:

(1) Both erosion and desurfacing have increased calcium carbonate content in the Ap horizon due to exposure of calcareous subsoil horizons. Consequently pH values have increased.

(2) Neither erosion nor desurfacing have changed saturated hydraulic conductivity or salt content in the Ap horizon.

(3) DRIS index indicated that plants on the eroded and desurfaced plots are poorly balanced in nutrients, although some of the nutrient levels in the soil are more than sufficient. Perhaps the high calcium carbonate content or poor physical soil structure may have limited plant nutrient uptake and root development. Additional research is needed to justify this speculation.

The abrupt loss of topsoil due to the desurfacing affected some soil properties more than the gradual topsoil loss due to accelerated erosion.

(1) Although both erosion and desurfacing decreased organic matter content. The decrease of organic matter content was more pronounced on the desurfaced plots than on the eroded plots. The gradual topsoil loss due to the erosion allows more subsurface mixing and consequently higher organic matter. The reduction in organic matter can affect CEC, bulk density, water retention and aggregate stability.

(2) There was not a significant difference in bulk densities among the erosional classes. This can be attributed to higher organic matter content and more mixing of the topsoil with the dense subsoil due to cultivation. However the significantly higher bulk densities of the desurfaced plots indicates that bulk densities have not changed much from the original Bw and Bk horizon. Higher bulk density can restrict root development.

(3) Available water holding capacity of the undisturbed Ap horizon were also significantly reduced due to the desurfacing, while the decrease in available water holding capacity due to the erosion was less pronounced. The decrease in the available water holding capacity on the desurfaced plots was attributed to a reduction of organic matter, higher bulk density and less porosity.

(4) Lower nitrate and phosphorus levels on the desurfaced plots compared to the naturally eroded soil may be due to less mineralization or higher calcium carbonate content in the Ap horizon. Further research will be required to determine nutrient availability on the desurfaced plots.

(5) Aggregate stabilities were also significantly reduced on the desurfaced plots, while there was not a significant change in aggregate stabilities due to the erosion. Lower aggregate stabilities of the desurfaced plots may be attributed to arrangement and condition of the organic matter. Further research is necessary to validate this speculation. The decrease in the aggregate stabilities can influence plant growth through its relationship to maintenance of porosity necessary for air, water and root movement.

Inconsistances in aggregate stability measurements with time arose from the failure to recognize the importance of the field water content as a factor affecting aggregate stability even with a prehumidifying treatment. To be comparable, samples should be treated in the same manner, and measurements should be made on samples of standardized moisture content when possible or a standard relation should be developed.

The prediction equations indicate that initial water content, organic matter, clay content, and calcium carbonate content are the variables that control aggregate stability in this soil. Furthermore, the data indicated that organic matter and field water content at the time of sample collection are the most important variables controlling aggregate stability in this soil. The results also indicated that total organic matter content alone is insufficient to explain the variation in aggregate stability. Arrangement and condition of the organic matter may be more important than the total quantity of organic matter.

The less desirable soil chemical and physical properties determined on the eroded and the desurfaced plots, compared to the control plots, affected plant growth and development. Delayed emergence and silking were observed on the eroded and the desurfaced plots. Delayed plant growth in conjunction with reduced plant development impaired corn yield on the eroded and the desurfaced plots. However, plant development and yield reduction was more pronounced on the desurfaced plots, even when the fertility was not limiting and moisture was reasonably adequate.

It is not enough to estimate how many kilograms of fertilizer it will take to replace the lost topsoil, but it is necessary to know how this topsoil loss affects productivity, in order to select management strategies that maximize long-term crop production without under utilizing soil resources.

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# APPENDICES

# Appendix A

# Pedon Morphology and Characterization

## Slightly Eroded Beadle

Ap 0-17 cm; very dark grayish brown (10YR 3/2) clay loam, black (10YR 2/1) moist; moderate, fine and very fine granular structure; hard when dry, friable when moist; abrupt, smooth boundary.

Bw 17-40 cm; dark grayish brown (10YR 4/2) clay loam, very dark grayish brown (10YR 3/2) moist; weak, medium prismatic structure parting to moderate, medium and fine subangular blocky structure; hard when dry, friable when moist; abrupt, wavy boundary.

Bk1 40-66 cm; grayish brown (2.5Y 5/2) clay loam, dark grayish brown (2.5Y 4/2) moist, weak medium prismatic structure parting to moderate, fine and medium subangular blocky structure; hard when dry, friable when moist; common, fine and medium soft lime accumulations; violent effervescence, clear, wavy boundary.

Bk2 66-85 cm; grayish brown (2.5Y 5/2) clay loam, light olive brown (2.5Y 5/4) moist; weak, coarse prismatic structure parting to moderate, medium subangular blocky structure; hard when dry, firm when moist; few fine distinct gray (2.5Y 5/0) and common coarse prominent brown (7.5YR 4/4, and 5YR 5/1) mottles; distinct fine iron concretions, weak platy structure; hard when dry, firm when moist; common, medium soft lime accumulations; violent effervescence; clear, wavy boundary.

C1 85-104 cm; light brownish gray (2.5Y 6/2) clay loam, light olive brown (2.5Y 5/4) moist; few, fine distinct gray (2.5Y 5/0) mottles; massive structure; hard when dry, firm when moist; few, fine soft lime accumulations; violent effervescence; clear, wavy boundary.

C2 104-150 cm; light brownish gray (2.5Y 6/2) clay loam, light olive brown (2.5Y 5/4) moist; few, fine distinct gray (2.5Y 5/0) and common coarse prominent brown (7.5YR 4/4, and 5YR 5/1) mottles; distinct fine iron concretions; weak platy structure; hard when dry, firm when moist; few, fine soft lime accumulations; violent effervescence.

## Moderately Eroded Beadle

Ap 0-25 cm; very dark grayish brown (10YR 3/2) clayey, black (10YR 2/1) moist, mixed with dark brown (10YR 4/3) moist; moderate, fine and very fine granular structure; hard when dry, friable when moist; abrupt, smooth boundary.

Bk1 25-44 cm; grayish brown (10YR 5/2) clayey, dark grayish brown (10YR 4/2) moist; moderate, medium prismatic structure parting to moderate, fine and medium subangular blocky structure; hard when dry, firm when moist; very dark grayish brown (10YR 3/2) coating on ped faces, common, medium soft lime accumulation; violent effervescence; abrupt, smooth boundary.

Bk2 44-75 cm; grayish brown (2.5Y 6/2) clay loam, light olive brown (2.5Y 5/4) moist; moderate, medium subangular blocky structure; hard when dry, firm when moist; common, medium soft lime accumulations; violent effervescence; clear, wavy boundary.

C1 75-150 cm; grayish brown (2.5Y 6/2) clay loam, light olive brown (2.5Y 5/4) moist; common, medium distinct gray (2.5Y 5/0) mottles; massive structure; hard when dry; firm when moist; common, soft lime accumulations; violent effervescence.

## Severely Eroded Beadle

Ap 0-24 cm; very dark grayish brown (10YR 3/2) clay loam, black (10YR 2/1) moist; mixed with brown (10YR 5/3); moderate, fine subangular blocky and fine granular structure; hard when dry, firm when moist; strong effervescence; abrupt, smooth boundary.

Bk 24-59 cm; pale brown (10YR 6/3) clay loam, brown (10YR 5/3) moist; moderate, coarse prismatic structure; hard when dry, firm when moist; common, medium soft accumualtions of calcium carbonate; few, fine iron concretions; violent effervescence; gradual, wavy boundary.

C1 59-77 cm; light brownish gray (2.5Y 6/2) clay loam, olive brown (2.5Y 4/4) moist; common, fine prominent yellowish red (5YR 4/6) and common, distinct gray (2.5Y 5/0) mottles; massive structure; hard when dry, firm when moist; 2% coarse fragments; common, fine soft lime accumulations; violent effervescence; gradual, wavy boundary.

C2 77-150 cm; light brownish gray (2.5Y 6/2) clay loam, olive brown (2.5Y 4/4) moist; few, fine prominent yellowish red (5YR 4/6) and common, medium distinct strong brown (7.5YR 5/6) and common, medium distinct gray (2.5Y 5/0) mottles; massive structure; hard when dry, firm when moist; 2% coarse fragments; few, fine soft lime accumulations; violent effervescence.

| | | | | Particle Size (% of Total) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Total | | | Silt Fraction | | | Sand Fraction | | | | |
| | | | | Clay | Silt | Sand | F | M | C | VF | F | M | C | VC |
| | | Depth | | <.002 | .002 -.05 | .05 -2 | .002- .005 | .005 -.02 | .02- .05 | .05- .10 | .10- .25 | .25- .50 | .50 - 1 | 1- 2 |
| Treatment | Horizon | cm | Text | µm | | | | | | | | | | |
| Slight | Ap | 0-17 | CL | 35.8 | 39.3 | 24.9 | 5.6 | 6.6 | 27.1 | 5.4 | 8.7 | 6.8 | 3.2 | 0.8 |
| | Bw | 17-40 | CL | 37.8 | 37.7 | 24.5 | 8.0 | 13.1 | 16.7 | 4.0 | 9.0 | 8.7 | 2.7 | 0.1 |
| | Bk1 | 40-66 | CL | 35.0 | 37.5 | 27.5 | 8.2 | 12.8 | 16.5 | 4.3 | 8.9 | 9.1 | 5.1 | 0.1 |
| | Bk2 | 66-85 | CL | 37.3 | 34.9 | 27.8 | 8.6 | 15.7 | 10.6 | 4.9 | 9.9 | 7.9 | 4.9 | 0.2 |
| | C1 | 85-104 | CL | 34.9 | 34.4 | 30.7 | 4.6 | 15.0 | 15.3 | 5.0 | 9.9 | 9.4 | 6.2 | 0.2 |
| | C2 | 104-130 | CL | 30.1 | 28.3 | 41.6 | 3.7 | 10.1 | 14.5 | 6.8 | 11.0 | 16.6 | 7.0 | 0.2 |
| Moderate | Ap | 0-25 | C | 40.5 | 35.9 | 23.6 | 9.3 | 10.5 | 16.1 | 4.3 | 9.6 | 5.3 | 3.3 | 1.1 |
| | Bk | 25-44 | C | 41.7 | 31.9 | 26.4 | 6.5 | 13.4 | 12.0 | 5.5 | 10.4 | 7.2 | 2.8 | 0.5 |
| | C1 | 44-75 | CL | 39.8 | 29.2 | 31.0 | 8.9 | 12.8 | 8.2 | 7.1 | 11.6 | 7.9 | 3.7 | 0.7 |
| | C2 | 75-150 | CL | 39.9 | 27.5 | 32.6 | 8.5 | 14.5 | 4.5 | 7.1 | 11.7 | 9.5 | 3.6 | 0.7 |
| Severe | Ap | 0-24 | CL | 31.0 | 41.3 | 27.7 | 6.5 | 13.5 | 21.3 | 4.1 | 10.9 | 7.9 | 4.1 | 0.6 |
| | Bk | 24-59 | CL | 34.9 | 34.7 | 30.4 | 6.8 | 11.2 | 16.7 | 6.2 | 10.6 | 9.1 | 3.7 | 0.8 |
| | C1 | 59-77 | CL | 38.3 | 33.0 | 28.7 | 8.1 | 9.4 | 15.5 | 6.4 | 10.2 | 7.8 | 3.7 | 0.6 |
| | C2 | 77-127 | CL | 34.7 | 45.1 | 20.2 | 12.1 | 15.2 | 17.8 | 5.5 | 7.4 | 4.7 | 2.2 | 0.4 |

| Treatment | Horizon | Extractable Bases<br>$Ca^{++}$ | <br>$Mg^{++}$ | cmol (+) $Kg^{-1}$<br>$Na^{+}$ | <br>$K^{+}$ | CEC<br>$NH_4OAC$ | OM<br>% | pH<br>(1:1) | $CaCO_3$<br>% | Ratio<br>CEC/Clay | Water Content %<br>.03 MPa | <br>1.5 MPa | Ratio<br>1.5 MPa<br>to Clay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Slight | Ap | 21.6 | 6.7 | 0.4 | 1.2 | 29.9 | 3.70 | 6.2 | 0.50 | 0.83 | 36.9 | 17.6 | 0.49 |
| | Bw | 16.2 | 7.8 | 0.4 | 1.1 | 25.5 | 2.70 | 7.1 | 0.80 | 0.67 | 35.2 | 16.7 | 0.44 |
| | Bk1 | -- | -- | 0.3 | 1.0 | 21.8 | 1.50 | 7.8 | 11.90 | 0.62 | 33.9 | 16.0 | 0.46 |
| | Bk2 | -- | -- | 0.3 | 0.6 | 22.4 | 0.90 | 8.0 | 22.00 | 0.60 | 30.7 | 15.5 | 0.42 |
| | C1 | -- | -- | 0.5 | 0.6 | 15.4 | 0.60 | 8.0 | 15.50 | 0.44 | 26.3 | 13.6 | 0.38 |
| | C2 | -- | -- | 0.5 | 0.5 | 13.3 | 0.47 | 8.0 | 15.60 | 0.44 | 23.9 | 11.4 | 0.38 |
| Moderate | Ap | 23.4 | 6.5 | 0.3 | 1.4 | 31.6 | 3.50 | 7.1 | 1.73 | 0.77 | 37.0 | 19.1 | 0.47 |
| | Bk1 | 13.7 | 9.2 | 0.3 | 1.0 | 24.2 | 1.50 | 7.6 | 18.70 | 0.58 | 32.7 | 15.6 | 0.37 |
| | Bk2 | -- | -- | 0.5 | 0.8 | 23.5 | 1.06 | 7.9 | 21.10 | 0.59 | 28.4 | 13.6 | 0.34 |
| | C | -- | -- | 0.5 | 0.8 | 21.7 | 0.50 | 7.8 | 17.40 | 0.54 | 24.8 | 11.7 | 0.29 |
| Severe | Ap | -- | -- | 0.3 | 1.5 | 22.7 | 3.00 | 7.5 | 7.30 | 0.76 | 28.0 | 13.2 | 0.45 |
| | Bk | -- | -- | 0.5 | 1.2 | 19.7 | 0.86 | 7.9 | 22.20 | 0.56 | 26.6 | 12.9 | 0.37 |
| | C1 | -- | -- | 0.6 | 0.8 | 20.4 | 0.57 | 8.1 | 21.10 | 0.53 | 23.8 | 11.2 | 0.29 |
| | C2 | -- | -- | 0.8 | 0.8 | 18.7 | 0.48 | 8.1 | 15.80 | 0.54 | 21.0 | 10.7 | 0.30 |

## 0-cm Removal

Ap 0-15 cm; very dark grayish brown (10YR 3/2) silty clay loam, black (10YR 2/1) moist; moderate, fine and very fine granular structure; hard when dry, friable when moist; abrupt, smooth boundary.

Bw 15-41 cm; dark grayish brown (10YR 4/2) silty clay loam, very dark grayish brown (10YR 3/2) moist, mixed with black (10YR 2/1) moist; weak, medium prismatic structure parting to moderate, medium and fine subangular blocky structure; hard when dry, friable when moist; abrupt, wavy boundary.

Bk1 41-67 cm; grayish brown (2.5Y 5/2) silty clay loam, olive brown (2.5Y 4/4) moist; weak, coarse prismatic structure parting to moderate medium subangular blocky structure; hard when dry, friable when moist; violent effervescence; common, fine and medium soft lime accumulations; clear, wavy boundary.

Bk2 67-84 cm; light yellowish brown (2.5Y 6/4) silty clay loam, olive brown (2.5Y 5/4) moist; weak, coarse prismatic structure parting to moderate, medium subangular blocky structure; hard when dry, firm when moist; common, fine and medium soft lime accumulations; violent effervescence; clear, wavy boundary.

C1 84-100 cm; light brownish gray (2.5YR 6/2) silty clay loam, olive brown (2.5Y 5/4) moist, mixed with grayish brown (2.5Y 5/2) mottles; massive structure; hard when dry, firm when moist; few, fine soft lime accumulations; violent effervescence, clear, wavy boundary.

C2 100-150 cm; light brownish gray (2.5YR 6/2) silty clay loam, light olive brown (2.5Y 5/4) moist; few fine distinct gray (2.5Y 5/0) and common, coarse prominent brown (5YR 4/4) and yellowish red (5YR 4/6) mottles; distinct iron concretions; weak fine platy structure; hard when dry, firm when moist; violent effervescence.

## 30-cm Removal

Ap 0-20 cm; grayish brown (10YR 5/2) silt clay loam, very dark grayish brown (10YR 3/2) moist, moderate, medium granular structure parting to moderate, medium subangular blocky structure; hard when dry, friable when moist; strong effervescence; abrupt, smooth boundary.

Bk1 20-57 cm; pale brown (10YR 6/2) silty clay loam, grayish brown (10YR 5/3) moist, mixed with very dark brown (10YR 4/2) moist; moderate, medium prismatic parting to moderate medium subangular blocky structure; hard when dry, firm when moist; common, medium soft lime accumulations; violent effervescence; clear, wavy boundary.

C1 57-104 cm; light brownish gray (2.5Y 6/2) silt loam, light brownish gray (2.5Y 6/2) moist, mixed with dark yellowish brown (10YR 4/4) moist; massive structure; hard when dry, firm when moist; common, coarse prominent brown (7.5YR 4/4) and few, fine distinct gray (2.5Y 5/0) mottles; common, fine soft lime accumulations; 2% coarse fragments; violent effervescence; gradual, wavy boundary.

C2 104-150 cm; olive brown (2.5Y 4/4) sandy loam, olive brown (2.5Y 4/4) moist, mixed with yellowish brown (10YR 5/6), many, fine distinct gray (2.5Y 6/0) and strong brown (7.5 YR 5/6) mottles; massive structure; 2% coarse fragments; few, fine soft lime accumulations; violent effervescence.

## 45-cm Removal

Ap 0-17 cm; pale brown (10YR 6/3) silty clay loam, dark brown (10YR 3/3) moist; moderate, medium granular and moderate, fine subangular blocky structure; hard when dry, friable when moist; few, fine soft lime accumulations; violent effervescence; abrupt, wavy boundary.

Bk 17-46 cm; light yellowish brown (10YR 6/4) silty clay loam, dark brown (10YR 4/3) moist, mixed with olive brown (2.5Y 4/4) moist; few, fine distinct gray (2.5Y 5/0) mottles; weak, medium prismatic structure parting to moderate, medium subangular blocky structure; hard when dry, friable when moist; common, medium soft lime accumulations; violent effervescence; clear, smooth boundary.

C1 46-67 cm; grayish brown (2.5Y 5/2) silt loam, olive brown (2.5Y 4/4) moist, mixed with grayish brown (2.5Y 5/2) moist; moderate, thin platy structure; friable when moist; common, coarse prominent strong brown (7.5YR 4/4) and few, fine distinct gray (2.5Y 6/0) mottles; common, fine slightly elongated lime accumulation; violent effervescence; gradual, wavy boundary.

C2 67-150 cm; pale yellow (2.5Y 7/4) silt loam, light olive brown (2.5Y 5/6) moist, mixed with grayish brown (2.5Y 5/2) moist; massive structure; common, fine soft lime accumulations; strong effervescence.

| | | | | Particle Size (% of Total) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Total | | | Silt Fraction | | | Sand Fraction | | | | |
| | | | | Clay <.002 | Silt .002 -.05 | Sand .05 -2 | F .002- .005 | M .005 -.02 | C .02- .05 | VF .05- .10 | F .10- .25 | M .25- .50 | C .50 - 1 | VC 1- 2 |
| Treatment | Horizon | Depth cm | Text | µm | | | | | | | | | | |
| 0-cm removal | Ap | 0-15 | SiCL | 30.3 | 53.3 | 16.4 | 7.5 | 17.9 | 27.9 | 4.8 | 5.8 | 4.2 | 1.2 | 0.4 |
| | Bw | 15-41 | SiCL | 39.9 | 52.8 | 7.3 | 11.3 | 12.9 | 29.0 | 2.6 | 2.0 | 1.9 | 0.5 | 0.3 |
| | Bk1 | 41-67 | SiCL | 36.8 | 54.7 | 8.5 | 10.2 | 15.5 | 29.0 | 2.8 | 4.1 | 1.1 | 0.4 | 0.2 |
| | Bk2 | 67-84 | SiCL | 34.5 | 57.9 | 7.6 | 11.8 | 20.6 | 25.5 | 3.5 | 2.5 | 1.1 | 0.3 | 0.2 |
| | C1 | 84-100 | SiCL | 32.1 | 56.0 | 11.9 | 12.1 | 19.1 | 24.8 | 6.6 | 4.3 | 0.6 | 0.2 | 0.2 |
| | C2 | 100-135 | SiCL | 32.1 | 48.2 | 19.7 | 9.8 | 13.3 | 25.1 | 9.3 | 7.5 | 1.5 | 1.2 | 0.2 |
| 30-cm removal | Ap | 0-20 | SiCL | 38.6 | 56.6 | 4.8 | 5.0 | 21.9 | 29.7 | 2.3 | 0.7 | 1.4 | 0.3 | 0.1 |
| | Bk | 20-57 | SiCL | 31.4 | 56.5 | 12.1 | 8.8 | 23.2 | 24.5 | 4.5 | 3.5 | 1.6 | 2.2 | 0.3 |
| | C1 | 57-104 | SiL | 26.7 | 54.5 | 18.8 | 8.9 | 18.9 | 26.7 | 6.6 | 5.6 | 4.2 | 2.2 | 0.2 |
| | C2 | 104-150 | SL | 15.8 | 19.1 | 65.1 | 0.9 | 5.7 | 12.5 | 19.8 | 39.6 | 5.2 | 0.4 | 0.1 |
| 45-cm removal | Ap | 0-17 | SiCL | 31.6 | 62.1 | 6.3 | 6.8 | 16.2 | 38.4 | 3.0 | 2.5 | 0.4 | 0.2 | 0.2 |
| | Bk | 17-46 | SiCL | 30.7 | 51.1 | 18.2 | 4.8 | 18.2 | 28.1 | 7.8 | 8.1 | 1.7 | 0.5 | 0.1 |
| | C1 | 46-67 | SiL | 26.6 | 53.0 | 20.4 | 8.4 | 14.3 | 30.3 | 11.6 | 6.9 | 1.3 | 0.3 | 0.2 |
| | C2 | 67-150 | SiL | 19.3 | 49.8 | 30.9 | 6.2 | 10.7 | 32.9 | 14.8 | 13.7 | 1.5 | 0.7 | 0.2 |

| Treatment | Horizon | Extractable Bases $Ca^{++}$ | $Mg^{++}$ | $Na^{+}$ | $K^{+}$ | CEC $NH_4OAC$ | OM | pH | $CaCO_3$ | Ratio | Water Content .03 MPa | 1.5 MPa | Ratio 1.5 MPa |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | cmol (+) $Kg^{-1}$ |  |  |  |  | % | (1:1) | % | CEC/Clay | % |  | to Clay |
| 0-cm removal | Ap | 20.5 | 6.6 | 0.4 | 1.2 | 28.7 | 3.80 | 7.0 | 0.50 | 0.95 | 33.9 | 15.2 | 0.50 |
|  | Bw | 16.6 | 6.8 | 0.4 | 1.0 | 24.8 | 2.60 | 7.4 | 3.13 | 0.62 | 32.1 | 14.9 | 0.37 |
|  | Bk1 | -- | -- | 0.3 | 0.6 | 23.0 | 1.87 | 7.7 | 22.80 | 0.63 | 28.5 | 13.1 | 0.36 |
|  | Bk2 | -- | -- | 0.3 | 0.6 | 21.1 | 0.81 | 7.7 | 24.90 | 0.61 | 26.1 | 12.4 | 0.36 |
|  | C1 | -- | -- | 0.5 | 0.5 | 19.4 | 0.77 | 7.9 | 23.40 | 0.60 | 23.3 | 11.3 | 0.35 |
|  | C2 | -- | -- | 0.7 | 0.5 | 17.7 | 0.57 | 7.9 | 18.50 | 0.56 | 21.0 | 9.8 | 0.30 |
| 30-cm removal | Ap | -- | -- | 0.3 | 1.5 | 25.1 | 2.40 | 7.6 | 13.40 | 0.65 | 31.4 | 14.8 | 0.38 |
|  | Bk | -- | -- | 0.3 | 1.2 | 17.2 | 1.47 | 7.7 | 23.90 | 0.55 | 28.5 | 13.5 | 0.43 |
|  | C1 | -- | -- | 0.5 | 0.9 | 15.7 | 0.70 | 8.1 | 20.10 | 0.58 | 20.6 | 12.2 | 0.46 |
|  | C2 | -- | -- | 0.5 | 0.9 | 11.5 | 0.25 | 8.0 | 18.00 | 0.72 | 15.4 | 8.1 | 0.51 |
| 45-cm removal | Ap | -- | -- | 0.3 | 1.5 | 20.5 | 1.80 | 7.6 | 20.40 | 0.65 | 25.8 | 12.6 | 0.40 |
|  | Bk | -- | -- | 0.5 | 1.1 | 17.8 | 0.80 | 7.8 | 19.60 | 0.58 | 24.2 | 11.4 | 0.37 |
|  | C1 | -- | -- | 0.6 | 0.8 | 15.6 | 0.70 | 7.8 | 18.40 | 0.59 | 20.5 | 9.7 | 0.36 |
|  | C2 | -- | -- | 0.6 | 0.8 | 11.4 | 0.27 | 7.9 | 14.40 | 0.59 | 18.3 | 8.5 | 0.40 |

# Appendix B

## Soil Test Data for Conventional and Ridge Till

### Soil Test for Conventional Tillage

| Variable | Erosion class | Slight | Moderate | Severe | p(F) | Units |
|---|---|---|---|---|---|---|
| | Desurfacing L. | 0-cm | 30-cm | 45-cm | | |
| NO3-N (0-15 cm) | Eroded site | 33.0a | 51.0a | 39.0a | 0.13 | ppm |
| | Desurfaced | 22.0a | 21.0a | 21.0a | 0.61 | |
| NO3-N (15-60 cm) | Eroded site | 16.0a | 34.0a | 39.0a | 0.07 | ppm |
| | Desurfaced | 15.0a | 16.0a | 0.8a | 0.27 | |
| OM | Eroded site | 3.06 | 3.06 | 3.06 | 1.00 | % |
| | Desurfaced | 2.90 | 2.10 | 1.87 | 0.50 | |
| P (Bray) | Eroded site | 27.0a | 24.0ab | 10.7b | 0.06 | ppm |
| | Desurfaced | 15.3 | 14.0 | 6.7 | 0.55 | |
| P (Olsen) | Eroded site | 18.3a | 18.3a | 10.0b | <0.01** | ppm |
| | Desurfaced | 17.0a | 17.0a | 15.3a | 0.80 | |
| k | Eroded site | 213a | 185b | 176b | <0.01** | ppm |
| | Desurfaced | 225a | 215a | 190a | 0.57 | |
| Zn | Eroded site | 1.1a | 0.8a | 0.7a | 0.2 | ppm |
| | Desurfaced | 1.1a | 1.0a | 1.5a | 0.05 | |
| Salt | Eroded Site | 0.8 | 1.0 | 0.9 | | mmhos/cm |
| | Desurfaced | 0.8 | 0.9 | 0.8 | | |
| pH | Eroded site | 7.0a | 7.3ab | 7.9b | 0.05* | |
| | Desurfaced | 8.0 | 8.1 | 8.0 | 0.50 | |

Means with same letter are not significant at the 0.05 level.

## Soil Test for Ridge Tillage

| Variable | Erosion class | Slight | Moderate | Severe | p(F) | Units |
|---|---|---|---|---|---|---|
| | Desurfacing L. | 0-cm | 30-cm | 45-cm | | |
| NO3-N (0-15 cm) | Eroded site | 39.6a | 76.3a | 55.7a | 0.36 | ppm |
| | Desurfaced | 37.0a | 29.3a | 20.3a | 0.21 | |
| NO3-N (15-60 cm) | Eroded site | 80.0a | 90.7a | 67.0a | 0.60 | ppm |
| | Desurfaced | 50.3a | 26.0a | 29.0a | 0.15 | |
| OM | Eroded site | 2.93 | 2.80 | 2.73 | 0.45 | % |
| | Desurfaced | 2.70 | 1.80 | 1.40 | 0.50 | |
| P (Bray) | Eroded site | 41.7a | 33.7ab | 4.3b | <0.01** | ppm |
| | Desurfaced | 22.3 | 1.0 | 10.3 | 0.55 | |
| P (Olsen) | Eroded site | 31.3a | 26.7a | 10.3b | 0.11 | ppm |
| | Desurfaced | 20.7a | 10.3a | 12.7a | 0.34 | |
| k | Eroded site | 231a | 195b | 190b | <0.04* | ppm |
| | Desurfaced | 210a | 156a | 133a | 0.33 | |
| Zn | Eroded site | 1.0a | 0.9a | 0.6b | 0.02* | ppm |
| | Desurfaced | 1.7a | 0.7b | 1.1b | 0.01** | |
| Salt | Eroded Site | 0.8 | 1.0 | 0.9 | | mmhos/cm |
| | Desurfaced | 1.7 | 0.7 | 1.1 | | |
| pH | Eroded site | 7.3a | 7.1ab | 7.9b | 0.07 | |
| | Desurfaced | 7.8 | 8.1 | 8.1 | 0.10 | |

Means with same letter are not significant at the 0.05 level.

# Appendix C

## Plant Tissue Analysis and DRIS Index

## Tissue analysis
## 02.08.1985

| Variable | Erosion class | Slight | Moderate | Severe | p(F) | Units |
|---|---|---|---|---|---|---|
| | Desurfacing L. | 0-cm | 30-cm | 45-cm | | |
| N | Eroded site | 2.72 | 2.48 | 2.67 | 0.16 | % |
| | Desurfaced | 2.86a | 2.82ab | 2.78b | 0.04 | % |
| P | Eroded site | 0.26 | 0.25 | 0.24 | 0.12 | % |
| | Desurfaced | 0.24 | 0.24 | 0.22 | 0.08 | % |
| K | Eroded site | 1.97a | 1.92a | 1.51b | 0.03* | % |
| | Desurfaced | 1.38 | 1.23 | 1.27 | 0.62 | % |
| S | Eroded site | 0.15 | 0.13 | 0.06 | 0.05* | % |
| | Desurfaced | 0.16 | 0.11 | 0.14 | 0.74 | % |
| Ca | Eroded site | 0.64 | 0.78 | 0.70 | 0.53 | % |
| | Desurfaced | 0.70 | 0.75 | 0.64 | 0.70 | % |
| Mg | Eroded site | 0.31 | 0.36 | 0.35 | 0.26 | % |
| | Desurfaced | 0.46 | 0.43 | 0.45 | 0.66 | % |
| Zn | Eroded site | 21.67 | 22.33 | 22.33 | 0.96 | ppm |
| | Desurfaced | 25.33 | 23.66 | 30.00 | 0.28 | ppm |
| Fe | Eroded site | 153.33 | 93.33 | 93.33 | 0.07 | ppm |
| | Desurfaced | 93.33 | 93.33 | 93.33 | 0.98 | ppm |
| Mn | Eroded site | 110.66 | 104.33 | 111.33 | 0.84 | ppm |
| | Desurfaced | 99.33 | 94.00 | 81.00 | 0.07 | ppm |
| Cu | Eroded site | 12.00 | 6.33 | 7.66 | 0.23 | ppm |
| | Desurfaced | 10.67 | 9.00 | 12.00 | 0.76 | ppm |

Means with same letter are not significant at the 0.05 level.

DRIS Indices for conventional tillage
(1985)

| Treatment | N index | P index | K index | S index | Ca index | Fe index | Mg index | Mn index | Zn index | Cu index | Nutrient Balance Index |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Slightly eroded | -3.41 | -1.40 | 2.10 | -22.1 | 2.11 | 5.01 | 1.17 | 21.18 | -8.82 | 4.20 | 71.53 |
| Moderately eroded | -2.84 | 1.02 | 4.83 | -25.5 | 11.19 | -7.00 | 7.59 | 23.34 | -5.55 | -7.10 | 95.98 |
| Severely eroded | 10.36 | 6.00 | 4.56 | -82.3 | 13.11 | -2.83 | 12.09 | 34.44 | 1.40 | 0.11 | 170.17 |
| 0-cm removal | 0.10 | -2.12 | -7.51 | -17.2 | 5.04 | -8.99 | 12.76 | 18.33 | -3.62 | 3.17 | 78.80 |
| 30-cm removal | 3.88 | 0.85 | -8.22 | -33.6 | 10.29 | -6.51 | 13.66 | 20.86 | -2.45 | 1.27 | 101.63 |
| 45-cm removal | 1.10 | -3.46 | -8.62 | -21.7 | 3.52 | -7.74 | 13.14 | 13.30 | 3.63 | 6.80 | 82.97 |

# Appendix D

# NTRM Information

## Neutron probe reading for conventional tillage
## Soil moisture content (θv)

| Date | Depth | ---- Erosion Site ---- | | | --- Desurfaced --- | | |
|---|---|---|---|---|---|---|---|
| | cm | Slight | Moderate | Severe | 0-cm | 30-cm | 45-cm |
| 31.05 | 25 | 40.77 | 40.26 | 38.13 | 40.29 | 41.03 | 38.70 |
| | 45 | 39.54 | 40.64 | 41.27 | 40.11 | 40.25 | 41.84 |
| | 75 | 41.00 | 41.85 | 40.93 | 40.42 | 42.20 | 44.17 |
| | 105 | 41.32 | 41.92 | 40.98 | 42.36 | 42.88 | 42.58 |
| | 140 | 41.55 | 42.20 | 41.72 | 44.41 | 42.14 | 42.92 |
| 13.06 | 25 | 40.76 | 39.39 | 37.64 | 40.01 | 41.76 | 41.71 |
| | 45 | 36.61 | 38.45 | 40.52 | 40.85 | 41.82 | 42.34 |
| | 75 | 40.52 | 40.20 | 41.85 | 41.03 | 42.94 | 43.76 |
| | 105 | 41.93 | 41.46 | 41.61 | 43.00 | 47.70 | 43.50 |
| | 140 | 42.97 | 42.28 | 41.83 | 44.58 | 42.65 | 45.20 |
| 25.06 | 25 | 38.48 | 35.54 | 34.60 | 37.94 | 40.11 | 38.84 |
| | 45 | 38.51 | 37.01 | 39.07 | 39.98 | 41.07 | 41.76 |
| | 75 | 40.19 | 37.97 | 41.48 | 40.57 | 42.26 | 43.16 |
| | 105 | 41.45 | 40.85 | 41.66 | 42.50 | 42.88 | 42.33 |
| | 140 | 42.16 | 42.07 | 42.05 | 44.37 | 42.03 | 45.12 |
| 09.07 | 25 | 31.65 | 27.25 | 27.22 | 30.51 | 48.76 | 34.35 |
| | 45 | 35.18 | 30.24 | 35.34 | 34.80 | 38.27 | 39.40 |
| | 75 | 36.92 | 35.97 | 41.02 | 39.84 | 39.98 | 42.34 |
| | 105 | 40.53 | 40.33 | 41.22 | 42.26 | 41.01 | 39.87 |
| | 140 | 41.99 | 41.64 | 42.05 | 43.65 | 40.29 | 44.69 |
| 23.07 | 25 | 28.62 | 28.68 | 23.66 | 27.77 | 31.09 | 31.40 |
| | 45 | 26.32 | 29.17 | 25.31 | 28.88 | 28.83 | 31.97 |
| | 75 | 33.68 | 32.23 | 37.47 | 33.95 | 37.82 | 40.41 |
| | 105 | 39.97 | 39.46 | 41.00 | 41.16 | 40.27 | 39.87 |
| | 140 | 41.13 | 41.26 | 42.02 | 42.63 | 39.39 | 44.10 |
| 06.08 | 25 | 23.64 | 23.54 | 21.06 | 27.57 | 29.98 | 31.38 |
| | 45 | 23.59 | 23.16 | 24.34 | 27.43 | 26.90 | 29.55 |
| | 75 | 28.19 | 29.17 | 33.25 | 36.83 | 32.65 | 36.58 |
| | 105 | 39.12 | 38.48 | 40.07 | 39.57 | 39.22 | 39.29 |
| | 140 | 40.94 | 40.21 | 41.54 | 40.48 | 39.09 | 43.59 |
| 22.08 | 25 | 30.37 | 32.02 | 27.44 | 34.91 | 35.64 | 31.27 |
| | 45 | 24.38 | 29.30 | 25.43 | 30.20 | 30.40 | 29.55 |
| | 75 | 25.22 | 32.50 | 31.92 | 30.75 | 31.72 | 36.58 |
| | 105 | 38.76 | 38.78 | 39.69 | 39.57 | 37.99 | 39.29 |
| | 140 | 40.78 | 41.19 | 41.40 | 40.48 | 38.98 | 43.38 |
| 10.09 | 25 | 34.84 | 37.53 | 31.45 | 38.19 | 39.02 | 36.38 |
| | 45 | 27.51 | 30.04 | 26.04 | 32.01 | 32.73 | 33.45 |
| | 75 | 29.77 | 31.25 | 31.63 | 32.84 | 31.72 | 35.82 |
| | 105 | 38.73 | 38.16 | 39.68 | 39.96 | 37.99 | 39.34 |
| | 140 | 40.49 | 40.02 | 41.24 | 38.97 | 38.98 | 43.08 |

**Neutron probe reading for ridge tillage**
**Soil moisture content ($\theta v$)**

| Date | Depth | Desurfaced | | |
|---|---|---|---|---|
| | cm | 0-cm | 30-cm | 45-cm |
| 31.05 | 25 | 37.91 | 40.61 | 41.02 |
| | 45 | 39.10 | 41.96 | 41.96 |
| | 75 | 40.36 | 42.78 | 42.10 |
| | 105 | 42.34 | 41.65 | 42.71 |
| | 140 | 43.37 | 41.65 | 42.71 |
| 13.06 | 25 | 38.05 | 41.50 | 41.94 |
| | 45 | 39.05 | 42.11 | 42.73 |
| | 75 | 40.88 | 43.11 | 43.84 |
| | 105 | 42.86 | 42.22 | 43.69 |
| | 140 | 44.07 | 42.36 | 44.37 |
| 25.06 | 25 | 36.55 | 40.61 | 40.99 |
| | 45 | 38.73 | 42.44 | 42.16 |
| | 75 | 40.45 | 42.98 | 43.32 |
| | 105 | 42.45 | 41.49 | 42.64 |
| | 140 | 43.43 | 41.57 | 44.15 |
| 09.07 | 25 | 30.17 | 36.01 | 36.34 |
| | 45 | 34.47 | 40.03 | 40.60 |
| | 75 | 39.54 | 42.22 | 42.25 |
| | 105 | 41.94 | 39.99 | 42.42 |
| | 140 | 42.57 | 40.18 | 43.66 |
| 23.07 | 25 | 27.14 | 35.69 | 32.20 |
| | 45 | 35.48 | 40.39 | 33.91 |
| | 75 | 35.48 | 40.39 | 40.00 |
| | 105 | 40.86 | 38.19 | 39.31 |
| | 140 | 41.15 | 39.77 | 43.14 |
| 06.08 | 25 | 27.59 | 30.51 | 30.90 |
| | 45 | 27.13 | 28.70 | 31.43 |
| | 75 | 31.87 | 36.89 | 36.38 |
| | 105 | 38.96 | 36.83 | 38.25 |
| | 140 | 40.65 | 38.52 | 42.90 |
| 22.08 | 25 | 33.97 | 35.51 | 35.57 |
| | 45 | 30.20 | 30.91 | 32.22 |
| | 75 | 32.33 | 35.21 | 35.99 |
| | 105 | 38.12 | 36.35 | 37.58 |
| | 140 | 39.10 | 38.19 | 43.13 |
| 10.09 | 25 | 38.87 | 38.94 | 37.67 |
| | 45 | 31.72 | 34.09 | 32.59 |
| | 75 | 32.31 | 35.02 | 35.34 |
| | 105 | 37.91 | 36.26 | 39.28 |
| | 140 | 39.29 | 42.63 | 41.94 |

**Bulk Density (Mg $m^{-3}$)**

| Depth | ---- erosion classes --- | | | -- Desurfacing --- | | | |
|---|---|---|---|---|---|---|---|
| (cm) | Slight | Moderate | Severe | 0-cm | 30-cm | 45-cm | N |
| 15 | 1.16 | 1.19 | 1.22 | 1.06 | 1.34 | 1.37 | 6 |
| 30 | 1.26 | 1.32 | 1.36 | 1.26 | 1.48 | 1.52 | 6 |
| 45 | 1.37 | 1.35 | 1.48 | 1.32 | 1.43 | 1.48 | 6 |
| 60 | 1.49 | 1.48 | 1.53 | 1.32 | 1.46 | 1.48 | 6 |
| 75 | 1.55 | 1.53 | 1.69 | 1.39 | 1.51 | 1.50 | 6 |
| 90 | 1.59 | 1.55 | 1.63 | 1.42 | 1.45 | 1.55 | 6 |
| 105 | 1.57 | 1.52 | 1.59 | 1.53 | 1.45 | 1.53 | 6 |
| 120 | 1.56 | 1.51 | 1.57 | 1.45 | 1.47 | 1.46 | 6 |
| 135 | 1.53 | 1.65 | 1.64 | 1.54 | 1.49 | 1.58 | 6 |
| 150 | 1.70 | 1.61 | 1.61 | 1.48 | 1.61 | 1.51 | 6 |

**Plant growth parameters for Ridge tillage (1985)**

| Variable | Erosion class | Slight | Moderate | Severe | Units |
|---|---|---|---|---|---|
| | Desurfacing level | 0-cm | 30-cm | 45-cm | |
| Emergence 50% | Eroded site | 10.05 | 11.05 | 11.05 | date |
| | Desurfaced | 11.05 | 13.05 | 13.05 | |
| Silking 50% | Eroded site | 22.07 | 22.07 | 23.07 | date |
| | Desurfaced | 24.07 | 26.07 | 26.07 | |
| Plant height | Eroded site | 1.65 | 1.55 | 1.56 | (m) |
| | Desurfaced | 1.61 | 1.56 | 1.54 | |
| Leaf area | Eroded site | 3278 | 2875 | 2276 | $cm^2$ /plant |
| | Desurfaced | 2633 | 1885 | 1581 | |

**Plant growth parameters for Egan (1985)**

| Variable | Slight | Moderate | Severe | Units |
|---|---|---|---|---|
| Emergence 50% | 09.05 | 11.05 | 12.05 | date |
| Plant height | 1.79 | 1.73 | 1.38 | (m) |
| Leaf area | 2835 | 2237 | 1965 | $cm^2$ /plant |

# Appendix E

# Statistical Analysis

```
                                         AGGREGATE STABILITY PRETREATMENT EFFECT
                                            ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: STAB
SOURCE                     DF          SUM OF SQUARES          MEAN SQUARE        F VALUE          PR > F        R-SQUARE             C.V.
MODEL                      45          26954.18750000         598.98194444           9.76          0.0972        0.995465          10.5916
ERROR                       2            122.79166667          61.39583333                      ROOT MSE                         STAB MEAN
CORRECTED TOTAL            47          27076.97916667                                         7.83554933                       73.97916667

SOURCE                     DF              ANOVA SS     F VALUE      PR > F

SAMPLE                      1         1333.52083333       21.72      0.0431
TREAT                       1           20.02083333        0.33      0.6256
SAMPLE*TREAT                1          295.02083333        4.81      0.1597
METHOD                      1        16096.68750000      262.18      0.0038
SAMPLE*METHOD               1         1530.02083333       24.92      0.0379
TREAT*METHOD                1           17.52083333        0.29      0.6466
SAMPLE*TREAT*METHOD         1           35.02083333        0.57      0.5289
RUN                         1          165.02083333        2.69      0.2428
SAMPLE*RUN                  1            2.52083333        0.04      0.8582
TREAT*RUN                   1          180.18750000        2.93      0.2288
SAMPLE*TREAT*RUN            1          123.52083333        2.01      0.2918
METHOD*RUN                  1           11.02083333        0.18      0.7130
SAMPLE*METHOD*RUN           1           13.02083333        0.21      0.6904
TREAT*METHOD*RUN            1          256.68750000        4.18      0.1776
SAMP*TREA*METH*RUN          1          500.52083333        8.15      0.1039
REP                         2          203.79166667        1.66      0.3760
SAMPLE*REP                  2         1104.54166667        9.00      0.1000
REP*TREAT                   2          205.04166667        1.67      0.3746
REP*METHOD                  2           38.37500000        0.31      0.7619
REP*RUN                     2          177.54166667        1.45      0.4089
SAMPLE*REP*TREAT            2          273.79166667        2.23      0.3096
SAMPLE*REP*METHOD           2          576.79166667        4.70      0.1755
SAMPLE*REP*RUN              2          880.29166667        7.17      0.1224
REP*TREAT*METHOD            2          323.29166667        2.63      0.2753
REP*TREAT*RUN               2           28.62500000        0.23      0.8110
REP*METHOD*RUN              2          188.29166667        1.53      0.3947
SAMP*REP*TREA*METH          2          509.04166667        4.15      0.1943
SAMPL*REP*TREAT*RUN         2          485.04166667        3.95      0.2020
SAMPL*REP*METHO*RUN         2         1170.04166667        9.53      0.0950
REP*TREAT*METHO*RUN         2          209.37500000        1.71      0.3697
```

```
                                    AGGREAGATE STABILITY PRETREATMENT EFFECTS
                                                SAMPLE=AIR DRY
                                         ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: AGSTAB
SOURCE                    DF        SUM OF SQUARES         MEAN SQUARE       F VALUE          PR > F        R-SQUARE             C.V.
MODEL                     41        1046.72788992         25.52994853          1.56          0.3044        0.914048           4.2914
ERROR                      6          98.42787675         16.40464613                      ROOT MSE                       AGSTAB MEAN
CORRECTED TOTAL           47        1145.15576667                                         4.05026495                      94.38083333

SOURCE                    DF             ANOVA SS      F VALUE      PR > F

SOIL                       2         141.25175556         4.31      0.0693
TREAT                      2           2.70538056         0.08      0.9219
SOIL*TREAT                 3         152.81553056         3.11      0.1104
TIME                       1          30.23354023         1.84      0.2234
SOIL*TIME                  2           0.00000000         0.00      1.0000
TREAT*TIME                 2          24.10443032         0.73      0.5183
SOIL*TREAT*TIME            3          28.34785539         0.58      0.6516
REP                        2          10.03486667         0.31      0.7473
SOIL*REP                   4          61.00876111         0.93      0.5054
REP*TREAT                  4          61.72144444         0.94      0.5006
REP*TIME                   2         298.21164191         9.09      0.0153
SOIL*REP*TREAT             6          96.32312778         0.98      0.5101
SOIL*REP*TIME              4          34.88184380         0.53      0.7185
REP*TREAT*TIME             4         106.70883753         1.63      0.2829

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SOIL*REP AS AN ERROR TERM
SOURCE                    DF             ANOVA SS      F VALUE      PR > F
SOIL                       2         141.25175556         4.63      0.0910

TESTS OF HYPOTHESES USING THE ANOVA MS FOR REP*TREAT AS AN ERROR TERM
SOURCE                    DF             ANOVA SS      F VALUE      PR > F
TREAT                      2           2.70538056         0.09      0.9178

TESTS OF HYPOTHESES USING THE ANOVA MS FOR REP*TIME AS AN ERROR TERM
SOURCE                    DF             ANOVA SS      F VALUE      PR > F
TIME                       1          30.23354023         0.20      0.6966
```

```
                                     AGGREAGATE STABILITY PRETREATMENT EFFECTS
                                                 SAMPLE=FRESH
                                         ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: AGSTAB
SOURCE                  DF          SUM OF SQUARES         MEAN SQUARE       F VALUE          PR > F         R-SQUARE           C.V.

MODEL                   41           7876.45154583        192.10857429          7.57          0.0086         0.981033         6.3856

ERROR                    6            152.27757917         25.37959653                      ROOT MSE                     AGSTAB MEAN

CORRECTED TOTAL         47           8028.72912500                                        5.03781664                     78.89375000

SOURCE                  DF                 ANOVA SS      F VALUE     PR > F

SOIL                     2            3792.24569444        74.71     0.0001
TREAT                    2             784.32740278        15.45     0.0043
SOIL*TREAT               3             377.59316111         4.96     0.0460
TIME                     1              61.06540833         2.41     0.1718
SOIL*TIME                2             147.95007222         2.91     0.1305
TREAT*TIME               2             201.13896944         3.96     0.0800
SOIL*TREAT*TIME          3              92.58841667         1.22     0.3820
REP                      2             551.74718750        10.87     0.0101
SOIL*REP                 4             994.79335139         9.80     0.0084
REP*TREAT                4             126.65250139         1.25     0.3844
REP*TIME                 2              20.20302917         0.40     0.6882
SOIL*REP*TREAT           6             284.06472639         1.87     0.2336
SOIL*REP*TIME            4             341.64383194         3.37     0.0901
REP*TREAT*TIME           4             100.43779306         0.99     0.4796

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SOIL*REP AS AN ERROR TERM
SOURCE                  DF                 ANOVA SS      F VALUE     PR > F

SOIL                     2            3792.24569444         7.62     0.0432

TESTS OF HYPOTHESES USING THE ANOVA MS FOR REP*TREAT AS AN ERROR TERM
SOURCE                  DF                 ANOVA SS      F VALUE     PR > F

TREAT                    2             784.32740278        12.39     0.0193

TESTS OF HYPOTHESES USING THE ANOVA MS FOR REP*TIME AS AN ERROR TERM
SOURCE                  DF                 ANOVA SS      F VALUE     PR > F

TIME                     1              61.06540833         6.05     0.1332
```

# Aggregate Stability Pretreatment Effects

```
                                                        SAS
                                                  SAMPLE=AIR DRY
                                          ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: AGSTAB

SOURCE                   DF        SUM OF SQUARES         MEAN SQUARE        F VALUE          PR > F        R-SQUARE          C.V.

MODEL                    17          489.30871111         28.78286536              .               .        1.000000        0.0000

ERROR                     0            0.00000000          0.00000000                       ROOT MSE                   AGSTAB MEAN

CORRECTED TOTAL          17          489.30871111                                         0.00000000                   96.50222222

SOURCE                   DF             ANOVA SS    F VALUE    PR > F

TREAT                     2          15.13647778          .         .
TIME                      1          19.09620000          .         .
TREAT*TIME                2          17.34943333          .         .
REP                       2          63.48294444          .         .
REP*TREAT                 4          85.00438889          .         .
REP*TIME                  2         152.23693333          .         .
REP*TREAT*TIME            4         137.00243333          .         .


TESTS OF HYPOTHESES USING THE ANOVA MS FOR REP*TREAT AS AN ERROR TERM

SOURCE                   DF             ANOVA SS    F VALUE    PR > F

TREAT                     2          15.13647778       0.36    0.7205


TESTS OF HYPOTHESES USING THE ANOVA MS FOR REP*TIME AS AN ERROR TERM

SOURCE                   DF             ANOVA SS    F VALUE    PR > F

TIME                      1          19.09620000       0.25    0.6661


TESTS OF HYPOTHESES USING THE ANOVA MS FOR REP*TREAT*TIME AS AN ERROR TERM

SOURCE                   DF             ANOVA SS    F VALUE    PR > F

TREAT*TIME                2          17.34943333       0.25    0.7878
```

# Aggregate Stability Pretreatment Effect

```
                                                        SAS
                                                   SAMPLE=FRESH
                                           ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: AGSTAB
SOURCE                      DF        SUM OF SQUARES           MEAN SQUARE         F VALUE             PR > F          R-SQUARE                C.V.

MODEL                       17         1045.52384444           61.50140261               .                  .          1.000000              0.0000

ERROR                        0            0.00000000            0.00000000                           ROOT MSE                           AGSTAB MEAN

CORRECTED TOTAL             17         1045.52384444                                               0.00000000                           86.55555556


SOURCE                      DF             ANOVA SS      F VALUE       PR > F

TREAT                        2         176.69674444            .            .
TIME                         1          64.98000000            .            .
TREAT*TIME                   2          54.58323333            .            .
REP                          2         522.45067778            .            .
REP*TREAT                    4         151.60722222            .            .
REP*TIME                     2          11.96523333            .            .
REP*TREAT*TIME               4          63.24073333            .            .


TESTS OF HYPOTHESES USING THE ANOVA MS FOR REP*TREAT AS AN ERROR TERM

SOURCE                      DF             ANOVA SS      F VALUE       PR > F

TREAT                        2         176.69674444         2.33       0.2132


TESTS OF HYPOTHESES USING THE ANOVA MS FOR REP*TIME AS AN ERROR TERM

SOURCE                      DF             ANOVA SS      F VALUE       PR > F

TIME                         1          64.98000000        10.86       0.0810


TESTS OF HYPOTHESES USING THE ANOVA MS FOR REP*TREAT*TIME AS AN ERROR TERM

SOURCE                      DF             ANOVA SS      F VALUE       PR > F

TREAT*TIME                   2          54.58323333         1.73       0.2881
```

```
                                            AGGREAGATE STABILITY PRETREATMENT EFFECTS
                                                         SAMPLE=AIR DRY
                                                  ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: AGSTAB
SOURCE                  DF        SUM OF SQUARES          MEAN SQUARE        F VALUE           PR > F        R-SQUARE          C.V.
MODEL                   41         1046.72788992          25.52994853           1.56           0.3044        0.914048        4.2914
ERROR                    6           98.42787675          16.40464613                        ROOT MSE                   AGSTAB MEAN
CORRECTED TOTAL         47         1145.15576667                                           4.05026495                   94.38083333

SOURCE                  DF              ANOVA SS     F VALUE      PR > F

SOIL                     2          141.25175556        4.31      0.0693
TREAT                    2            2.70538056        0.08      0.9219
SOIL*TREAT               3          152.81553056        3.11      0.1104
TIME                     1           30.23354023        1.84      0.2234
SOIL*TIME                2            0.00000000        0.00      1.0000
TREAT*TIME               2           24.10443032        0.73      0.5183
SOIL*TREAT*TIME          3           28.34785539        0.58      0.6516
REP                      2           10.03496667        0.31      0.7473
SOIL*REP                 4           61.00876111        0.93      0.5054
REP*TREAT                4           61.72144444        0.94      0.5006
REP*TIME                 2          298.21164191        9.09      0.0153
SOIL*REP*TREAT           6           96.32312778        0.98      0.5101
SOIL*REP*TIME            4           34.89184380        0.53      0.7185
REP*TREAT*TIME           4          106.70883753        1.63      0.2829

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SOIL*REP AS AN ERROR TERM
SOURCE                  DF              ANOVA SS     F VALUE      PR > F
SOIL                     2          141.25175556        4.63      0.0910

TESTS OF HYPOTHESES USING THE ANOVA MS FOR REP*TREAT AS AN ERROR TERM
SOURCE                  DF              ANOVA SS     F VALUE      PR > F
TREAT                    2            2.70538056        0.09      0.9178

TESTS OF HYPOTHESES USING THE ANOVA MS FOR REP*TIME AS AN ERROR TERM
SOURCE                  DF              ANOVA SS     F VALUE      PR > F
TIME                     1           30.23354023        0.20      0.6966
```

```
                              1985 TISSUE ANALYSIS FOR CONVENTIONAL TILLAGE TREATMENT
                                                   SOIL=ERODED
                                          ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: N
SOURCE                  DF         SUM OF SQUARES          MEAN SQUARE        F VALUE         PR > F        R-SQUARE          C.V.
MODEL                    4             0.16044444           0.04011111           2.41         0.2076        0.706735        4.9158
ERROR                    4             0.06657778           0.01664444                      ROOT MSE                      N MEAN
CORRECTED TOTAL          8             0.22702222                                         0.12901335                  2.62444444

SOURCE                  DF               ANOVA SS    F VALUE      PR > F
TREAT                    2             0.09815556       2.95      0.1633
REP                      2             0.06228889       1.87      0.2669


                                                  SOIL=DESURFACED
                                          ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: N
SOURCE                  DF         SUM OF SQUARES          MEAN SQUARE        F VALUE         PR > F        R-SQUARE          C.V.
MODEL                    4             0.09084444           0.02271111           1.77         0.2968        0.639050        4.0131
ERROR                    4             0.05131111           0.01282778                      ROOT MSE                      N MEAN
CORRECTED TOTAL          8             0.14215556                                         0.11325978                  2.82222222

SOURCE                  DF               ANOVA SS    F VALUE      PR > F
TREAT                    2             0.00808889       0.32      0.7462
REP                      2             0.08275556       3.23      0.1465
```

```
                         1985 TISSUE ANALYSIS FOR CONVENTIONAL TILLAGE TREATMENT
                                             SOIL=ERODED
                                   ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: P

SOURCE                 DF        SUM OF SQUARES        MEAN SQUARE       F VALUE        PR > F       R-SQUARE          C.V.

MODEL                   4            0.00113333         0.00028333          2.43        0.2056       0.708333        4.3205

ERROR                   4            0.00046667         0.00011667                    ROOT MSE                       P MEAN

CORRECTED TOTAL         8            0.00160000                                     0.01080123                   0.25000000

SOURCE                 DF              ANOVA SS    F VALUE    PR > F

TREAT                   2            0.00086667       3.71    0.1225
REP                     2            0.00026667       1.14    0.4050


                                           SOIL=DESURFACED
                                   ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: P

SOURCE                 DF        SUM OF SQUARES        MEAN SQUARE       F VALUE        PR > F       R-SQUARE          C.V.

MODEL                   4            0.00077778         0.00019444          3.18        0.1442       0.760870        3.3344

ERROR                   4            0.00024444         0.00006111                    ROOT MSE                       P MEAN

CORRECTED TOTAL         8            0.00102222                                     0.00781736                   0.23444444

SOURCE                 DF              ANOVA SS    F VALUE    PR > F

TREAT                   2            0.00062222       5.09    0.0796
REP                     2            0.00015556       1.27    0.3735
```

```
                         1985 TISSUE ANALYSIS FOR CONVENTIONAL TILLAGE TREATMENT
                                              SOIL=ERODED
                                     ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: K
SOURCE                 DF      SUM OF SQUARES      MEAN SQUARE     F VALUE       PR > F      R-SQUARE          C.V.
MODEL                   4          0.40666667       0.10166667        4.88       0.0769      0.829932        8.0188
ERROR                   4          0.08333333       0.02083333                 ROOT MSE                     K MEAN
CORRECTED TOTAL         8          0.49000000                                0.14433757                 1.80000000

SOURCE                 DF           ANOVA SS    F VALUE     PR > F
TREAT                   2         0.36500000       8.76     0.0345
REP                     2         0.04166667       1.00     0.4444


                                            SOIL=DESURFACED
                                     ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: K
SOURCE                 DF      SUM OF SQUARES      MEAN SQUARE     F VALUE       PR > F      R-SQUARE          C.V.
MODEL                   4          0.07944444       0.01986111        0.58       0.6966      0.365729       14.3376
ERROR                   4          0.13777778       0.03444444                 ROOT MSE                     K MEAN
CORRECTED TOTAL         8          0.21722222                                0.18559215                 1.29444444

SOURCE                 DF           ANOVA SS    F VALUE     PR > F
TREAT                   2         0.03722222       0.54     0.6198
REP                     2         0.04222222       0.61     0.5859
```

```
                                 1985 TISSUE ANALYSIS FOR CONVENTIONAL TILLAGE TREATMENT
                                                     SOIL=ERODED
                                           ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: S
SOURCE                 DF        SUM OF SQUARES          MEAN SQUARE         F VALUE          PR > F        R-SQUARE            C.V.
MODEL                   4            0.01477778           0.00369444            3.59          0.1215        0.782353         28.8531
ERROR                   4            0.00411111           0.00102778                        ROOT MSE                          S MEAN
CORRECTED TOTAL         8            0.01888889                                           0.03205897                      0.11111111

SOURCE                 DF             ANOVA SS      F VALUE       PR > F
TREAT                   2           0.01415556         6.89       0.0507
REP                     2           0.00062222         0.30       0.7544


                                                   SOIL=DESURFACED
                                           ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: S
SOURCE                 DF        SUM OF SQUARES          MEAN SQUARE         F VALUE          PR > F        R-SQUARE            C.V.
MODEL                   4            0.01257778           0.00314444            0.47          0.7589        0.319593         59.3852
ERROR                   4            0.02677778           0.00669444                        ROOT MSE                          S MEAN
CORRECTED TOTAL         8            0.03935556                                           0.08181958                      0.13777778

SOURCE                 DF             ANOVA SS      F VALUE       PR > F
TREAT                   2           0.00428889         0.32       0.7430
REP                     2           0.00828889         0.62       0.5831
```

# 1985 Hydraulic Conductivity After 4 hr

```
                                                      SOIL=ERODED
                                            ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: KW4

SOURCE                   DF         SUM OF SQUARES          MEAN SQUARE        F VALUE          PR > F         R-SQUARE             C.V.

MODEL                     4             1.30163644           0.32540911           1.28          0.4093         0.560778          92.3692

ERROR                     4             1.01948978           0.25487244                       ROOT MSE                          KW4 MEAN

CORRECTED TOTAL           8             2.32112622                                          0.50484893                        0.54655556

SOURCE                   DF               ANOVA SS      F VALUE      PR > F

REP                       2             0.53068822         1.04      0.4325
TREAT                     2             0.77094822         1.51      0.3242


                                                     SOIL=DESURFACED
                                            ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: KW4

SOURCE                   DF         SUM OF SQUARES          MEAN SQUARE        F VALUE          PR > F         R-SQUARE             C.V.

MODEL                     4             0.38491178           0.09622794           1.99          0.2612         0.665220          53.9517

ERROR                     4             0.19371111           0.04842778                       ROOT MSE                          KW4 MEAN

CORRECTED TOTAL           8             0.57862289                                          0.22006312                        0.40788889

SOURCE                   DF               ANOVA SS      F VALUE      PR > F

REP                       2             0.27596689         2.85      0.1701
TREAT                     2             0.10894489         1.12      0.4096
```

# Available Water Holding Capacity
# Eroded Soil

```
                                   ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: AWH
SOURCE                 DF      SUM OF SQUARES       MEAN SQUARE      F VALUE        PR > F       R-SQUARE         C.V.
MODEL                   4         20.03317778        5.00829444         4.02        0.1031       0.800976       6.7170
ERROR                   4          4.97777778        1.24444444                   ROOT MSE                   AWH MEAN
CORRECTED TOTAL         8         25.01095556                                   1.11554670                16.60777778

SOURCE                 DF            ANOVA SS    F VALUE     PR > F
REP                     2          1.18222222       0.48     0.6530
TREAT                   2         18.85095556       7.57     0.0436


                                          SOIL=DESURFACED
                                   ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: AWH
SOURCE                 DF      SUM OF SQUARES       MEAN SQUARE      F VALUE        PR > F       R-SQUARE         C.V.
MODEL                   4        150.43157778       37.60789444        21.15        0.0059       0.954862      10.1790
ERROR                   4          7.11111111        1.77777778                   ROOT MSE                   AWH MEAN
CORRECTED TOTAL         8        157.54268889                                   1.33333333                13.09888889

SOURCE                 DF            ANOVA SS    F VALUE     PR > F
REP                     2          1.55555556       0.44     0.6732
TREAT                   2        148.87602222      41.87     0.0021
```

# Bulk densities

```
                                                 SOIL=ERODED
                                        ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: BD
SOURCE                 DF        SUM OF SQUARES         MEAN SQUARE       F VALUE          PR > F       R-SQUARE          C.V.
MODEL                   4            0.02177778          0.00544444          1.35          0.3867       0.574780        5.5617
ERROR                   4            0.01611111          0.00402778                      ROOT MSE                      BD MEAN
CORRECTED TOTAL         8            0.03788889                                        0.06346478                   1.14111111

SOURCE                 DF              ANOVA SS     F VALUE     PR > F
REP                     2            0.01428889        1.77     0.2809
TREAT                   2            0.00748889        0.93     0.4660


                                                SOIL=DESURFACED
                                        ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: BD
SOURCE                 DF        SUM OF SQUARES         MEAN SQUARE       F VALUE          PR > F       R-SQUARE          C.V.
MODEL                   4            0.07017778          0.01754444          5.12          0.0714       0.836556        4.7642
ERROR                   4            0.01371111          0.00342778                      ROOT MSE                      BD MEAN
CORRECTED TOTAL         8            0.08388889                                        0.05854723                   1.22888889

SOURCE                 DF              ANOVA SS     F VALUE     PR > F
REP                     2            0.01068889        1.56     0.3158
TREAT                   2            0.05948889        8.68     0.0351
```

## Aggregate Stability

```
                                                          SOIL=ERODED
                                               ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: AS
SOURCE                    DF         SUM OF SQUARES          MEAN SQUARE       F VALUE          PR > F       R-SQUARE            C.V.
MODEL                      4           478.93515000         119.73378750          1.61          0.3630       0.681863         10.4644
ERROR                      3           223.45685000          74.48561667                      ROOT MSE                        AS MEAN
CORRECTED TOTAL            7           702.39200000                                         8.63050501                     82.47500000

SOURCE                    DF              ANOVA SS     F VALUE      PR > F
REP                        2          112.04513333        0.75      0.5436
TREAT                      2          366.89001667        2.46      0.2329


                                                        SOIL=DESURFACED
                                               ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: AS
SOURCE                    DF         SUM OF SQUARES          MEAN SQUARE       F VALUE          PR > F       R-SQUARE            C.V.
MODEL                      4           199.00064444          49.75016111         18.23          0.0078       0.947997          2.0817
ERROR                      4            10.91631111           2.72907778                      ROOT MSE                        AS MEAN
CORRECTED TOTAL            8           209.91695556                                         1.65199206                     79.35777778

SOURCE                    DF              ANOVA SS     F VALUE      PR > F
REP                        2            1.65735556        0.30      0.7538
TREAT                      2          197.34328889       36.16      0.0027
```