IMPACT OF CONSERVATION RESERVE PROGRAM ON SURFACE SOIL PROPERTIES IN TWO WESTERN OKLAHOMA AREAS

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CHAPTER I

INTRODUCTION

Soil erosion which removes topsoil can seriously affect agricultural production because soil quality and soil productivity are destroyed. The quality and productivity of a soil are influenced by the organic matter content. Organic matter influences the physical, biological and chemical properties of the soil (Allison, 1973; Bohn et al., 1985; Cook and Ellis, 1987; Davies et al., 1993; Knuti et al., 1984; Kononova et al., 1966; Magdoff, 1992; Stevenson, 1994; Troeh et al., 1991). When soil is eroded, topsoil which is rich in plant nutrients and organic matter is lost. Topsoil is essential because it is the medium for plant establishment and growth and has been classified as the main indicator of soil quality and productivity (Gollany et al., 1992; Larney et al., 1995; Malhi et al., 1994). The surface soil properties that are important for both soil and water conservation, and soil productivity are negatively affected by topsoil removal. Simulated topsoil removal by Gollany et al. (1992) resulted in reduction of soil organic carbon content, available water holding capacity, and aggregate stability, and increased calcium carbonate that subsequently increased soil pH. These changes, as well as reduction of nitrogen content and nitrogen mineralization (Malhi et al., 1995), resulted in reduced crop yields (Gollany et al., 1992; Malhi et al., 1994; Larney et al., 1995). Larney et al. (1995) reported wheat yield reduction by 2 to 8 percent when a centimeter of topsoil is lost.

Soil that is protected or covered with vegetation, particularly grasses, is not as affected by erosion as soil without vegetation (Laycock, 1991; Romig et al., 1995). Vegetation can be used to prevent erosion and restore soil productivity. Laycock (1991) indicated that erosion started in the Great Plains with the onset of farming in the area. The Homestead Act of 1862 allowed people to cultivate and claim a total of 64.8 hectares of land. A farmer said "farming works against nature" (Romig et. al., 1995) by removing vegetation that protects the soil from erosion. The establishment of vegetation on highly erodible soil following the implementation of the CRP has extensively reduced erosion (Bjerke, 1991; Blackburn et al., 1991; Osborn, 1993). Blackburn et al. (1991) estimated a reduction of soil erosion of 595 million metric tonnes per year of the land enrolled by 1989. Bjerke (1991) estimated $1.2 billion in soil productivity benefits due to soil erosion reduction from the CRP land. Osborn (1993) estimated a reduction of 635 million metric tonnes per year of soil erosion on the land placed in the CRP.

The CRP encourages farmers to establish a vegetative cover for a period of ten to fifteen years (10 years grass and 15 years trees) (Bauer and Black, 1994; Bjerke, 1991; Kellogg et al., 1994; Osborn, 1993; Ribaudo et al., 1990). The land will not only be protected from erosion, but soil productivity will be restored by increasing soil organic matter, improving soil structure and creating stable soil aggregates. Grasses have natural soil building qualities (Knuti et al., 1984; Troeh et al; 1991) because of their fibrous root systems and addition of lignin to the soil. Lignin is an important component in the formation of soil humus.

The time required to rebuild soil properties is much longer than the time needed for soil degradation by continuous cultivation. Analysis of the CRP land should measure the gain in soil organic matter, the increase in water stable aggregates and the improvement of soil structure, increase in total nitrogen, as well as reduced soil erosion and pH. The improvement in surface soil properties (0 to 10 cm) on CRP land in western Oklahoma has not been determined. This study sought to determine the effects of CRP program on soil organic C content, water stable aggregates, structure, soil pH, total nitrogen, and thickness of the A horizon by comparing surface soil properties of CRP land with those of continuous cultivated land (CC).

CHAPTER II

LITERATURE REVIEW

Impact of Continuous Cultivation on Soil Organic Matter

"Grassland farming (native range, improved pasture and meadows) conserves and increases the organic matter content of a soil" (Knuti et al., page 29-30 1984). Cultivation decreases soil organic matter content (Ihori et al; 1995; Knuti et al., 1984; Kononova et al., 1966; Sims and Nielsen, 1986; Webb et al., 1980). Agricultural practices, particularly conventional cultivation, are responsible for the loss of organic matter from soils (Cambardella and Elliot, 1994; Harper, 1959; Stevenson, 1994; Webb et al., 1980). A loss of organic matter from the soil occurs by soil erosion and oxidation of organic matter when the soil is cultivated. Davies et al. (1993) found that soil organic matter content within a range of 19.6 g/kg to 48.0 g/kg for different soils beneath permanent grass dropped to a range of 16.3 g/kg to 43 g/kg three years after cultivation (following a 9-year cover of grass). Webb et al. (1980) reported a loss of soil organic matter from 35 g/kg in 1893 to 18 g/kg in 1926 because of cultivation. Soil organic matter losses during cultivation can be reduced if crop residues were retained on the soil (Davies et al., 1993).

The amount of organic matter in the soil is influenced by crop management systems. Cambardella and Elliot (1994) compared the distribution of organic carbon on three management systems: bare fallow, stubble mulch tillage and no-till (NT). Cambardella and Elliot (1994) found more soil organic carbon on no-till followed by stubble mulch, compared to bare fallow. Bare fallow had the least soil organic carbon in the surface 20 cm. Ismail et al. (1994) found more soil organic carbon on no-till compared to conventional tillage (CT) after 20 years. The land that Ismail et al. (1994) studied had been in pasture for 50 years prior to testing. Ismail et al. (1994) concluded that tillage encouraged the rate of soil organic matter decomposition. Ihori et al. (1995) reported a 26 percent mean loss of total soil carbon due to cultivation since the 1800's while no losses were indicated on uncultivated land. A tilled soil encourages microbial oxidation of residues compared to no-till (Magdoff, 1992; Reicosky et al., 1995). The soil organic carbon content of the surface soil profile was greater under no-till compared to other tillage systems, particularly conventional tillage, which increases the rate of soil organic matter decomposition (Alvarez et al., 1995; Bauer and Black, 1994; Cambardella and Elliot, 1994; Golabi et al., 1995; Griffith and Reetz, 1994; Ihori et al., 1995; Ismail et al., 1994; Reicosky et al., 1994; Zobeck et al., 1995).

Many tillage systems have different effects on soil organic matter. Alvarez et al. (1995) reported a 42-50 percent increase in soil organic carbon content in no-till farming in the 0-5cm depth than in chisel and moldboard tillage systems after a 12-year study. The greater soil organic carbon content on no-till treatment compared to other tillage methods which disturb the soil has been confirmed by several researchers as indicated by Reicosky et al. (1994). All studies done on no-till farming indicated increases in soil organic matter content compared to any tillage system that involved moldboard plowing (Duseja, 1991; Harper, 1959; Johnston, 1991; Webb et al., 1980).

Continuous no-till crop systems and any conservation crop systems that leave residues on the soil surface protect the soil from erosion, reduce evaporation (Tanchandrphongs, 1967) as well as preserve soil organic matter (Magdoff, 1992). Soil organic matter supplies a continuous input of plant nutrients, particularly nitrogen, phosphorus and sulfur (Bauer and Black 1994; Blevins and Frye 1993). Soil organic matter contains the primary natural source of nitrogen, 65 percent of the total soil phosphorus, and a significant amount of sulfur and other plant nutrients (Bauer and Black, 1994; Johnston, 1991; Stevenson, 1994;). Crop residues protect the soil from erosion as well as provide a source of soil organic matter. Soil organic matter improves soil quality for plant growth. Moldboard and other conventional tillage crop systems (when the crops are still young) leave the soil susceptible to erosion and promote biological oxidation of soil organic matter. Conventional tillage also promotes mineralization of organic nitrogen and subsequent possible leaching of nitrogen (Ismail et al., 1994; Magdoff, 1992; Reicosky et al., 1995; Tachandrphongs, 1967).

The key to successful erosion prevention is the maintenance of a good vegetative cover on the soil surface. Surface cover will minimize rainfall impact, slow runoff, increase infiltration and counteract wind speed as well as improve soil fertility and soil quality by conserving soil organic matter. Establishment of vegetation is the best and most cost effective erosion control practice (Reicosky et al., 1995; Troeh et al., 1991). Permanent soil cover protects the soil against erosion by providing uniform extensive soil cover and supplies soil organic matter. Potential crop yield increases of 20 percent or more for every one percent increase in soil organic matter were reported by Griffith and Reetz (1994). Laryea and Unger (1995) found a significant increase in sorghum grain yield on no-till with more soil organic matter than on sweep tillage or moldboard tillage with lower soil organic matter content.

Crop Management Systems and Surface Soil Properties

The deposition of organic matter by the plants on the soil surface and the decomposition of the plant roots within the soil improve both soil quality and soil productivity (Romig et al., 1995). Soil organic matter improves soil structure and enhances soil stability (Magdoff, 1992; Rose, 1991). Organic matter binds soil aggregates together creating stable soil aggregates and strong soil structure. A sandy soil which is low in soil organic matter has loose, unstable soil aggregates. But when enough organic matter is added to a sandy soil, aggregation improves and a relatively stable structure is produced (Allison, 1973; Cook and Ellis, 1987; Davies et al., 1993; Gabriels and Michiels, 1991; Kononova et al., 1966; Stevenson, 1994; Troeh et al., 1991). An improved and stable soil structure is an important factor for soil and water conservation. A soil with good aggregate stability and structure will be porous which improves infiltration rate and water holding capacity. Good soil structure promotes aeration which is essential for soil microorganism growth, exchange of gases, and nutrient availability (Romig et al., 1995). Perennial grass roots and dead and decomposed material provide organic matter which improves the soil structure and aggregation. Grasses have massive fibrous root systems that provide a continuous by-product for aggregate formation and stability (Blevins and Frye, 1993; Cook and Ellis, 1987; Gabriels and Michiels, 1991; Swift, 1991; Troeh et al., 1991; Waters and Oades, 1991). Cambardella and Elliot (1994) found that no-till and stubble mulch tillage had more soil organic carbon and nitrogen that created macroaggregates compared to conventional tillage. Cambardella and Elliot (1994) concluded that reduced tillage can create stable aggregates, improve soil structure and increase soil organic matter content.

Plowing encourages loss of soil organic matter through erosion and biological oxidation. The loss of organic matter, particularly through soil erosion, contributes to loss of soil fertility (Bauer and Black, 1994; Reicosky et al., 1995) and other soil properties such as aggregate porosity. Zwang (1994) found an increase in aggregate porosity and a decrease in aggregate strength when soil organic matter was increased. Zwang (1994) attributed increased aggregate porosity and decreased strength to the less humified soil organic matter. Zwang (1994) also reported more resistance to mechanical stress for virgin soil aggregates with more soil organic matter than the cultivated soils having less soil organic matter. Water stable aggregates and soil moisture retention were also found to increase when soil organic matter content increased (Unger, 1995).

Soil aggregate stability increases as organic matter increases (Auerswald, 1995; Fuller et al., 1995), but the stability decreases with increasing pH because "increasing pH decreases structural stability" (Auerswald, 1995). The decrease in structural stability with increasing pH was not completely understood (Auerswald, 1995). Stevenson (1994) reported that "increased ionization of acidic groups" of soil organic matter decreases structural stability.

Grassland and no-till farming areas have aggregated and porous soils with granular structure which is ideal for soil tilth (Karlen et al., 1990; Zobeck et al., 1995). Grassland and no-till lands usually have adequate amounts of soil organic matter. Cultivation of grassland areas results in reduction of soil organic matter, soil aggregation, pore space and nitrogen content in surface horizons (Fuller et al., 1995; Harper, 1959; Webb et al., 1980). Golabi et al. (1995) found more macropores in no-till compared to conventional tillage. Golabi et. al. (1995) concluded that infiltration would be faster under no-till compared to conventional tillage (crusted surface).

Soil aggregates of the grass sod are more stable than those of the cultivated land (Fuller et al., 1995; Zobeck et al., 1995). Cultivation reduces water-stable aggregate content (percentage) by breaking apart soil structure and creating a conducive environment for optimum microbial breakdown of organic matter. When land is cultivated, "the quality or organic binding agents such as carbohydrates" decline (Fuller et al., 1995). Rebuilding soil structure and stable aggregates after cultivation takes "much longer than their decline under cultivation" (Fuller et al., 1995). For example, Fuller et al. (1995) found minimum tillage of continuous wheat (8 years) not to have restored the stability of soil aggregates to levels found in the same soil under grass sod.

CHAPTER III

MATERIALS AND METHODS

Sample collection and preparation

The effect of CRP management on soils in two western Oklahoma areas was evaluated by determining and comparing soil organic C, aggregate stability and soil structure, total nitrogen, soil pH and thickness of A horizon of the CRP land and land which has been continuous cultivated (CC) during the CRP. The CRP land was planted with Old World Bluestem for the contract period (1986-1996) while the adjacent land was under continuous cultivation of wheat (1986-1996). All soil samples were taken from the Oklahoma State University's CRP research and extension sites at Duke in southwest Oklahoma (Jackson county) and at Forgan in northwest Oklahoma (Beaver county) during the summer of 1995. The Duke site was at R. B. Masters Farm on La Casa (Tillman) clay loam, 1 to 3 percent slope with a land capability unit of IIe-1-1 and a Hardland range site (Table 1, Bailey and Graft, 1961; Pigg, 1995). The Forgan site was at Albert Hodges Farm on Dalhart fine sandy loam, 1 to 3 percent slope with land capability unit IIIe-2 on a Sandy Plains range site (Table 1, Allgood et al., 1962; Pigg, 1995). The major land resource areas for the study sites were the Southern High Plains and the Central Rolling Red Plains for Forgan and Duke, respectively.

At Duke, a 1.8 ha (300x60m) plot of Old World Bluestem from the CRP land was sub-divided into four equal areas. From each area six transects were developed with eight sub-samples collected along each of the transects to represent a single sample. Six transects made 48 sub-samples with a total of 192 sub-samples for the whole area. Because each transect represents a single sample, a total of 24 samples were collected from the CRP land at a depth of 10 cm (4 inches) using a 2.5 cm diameter soil probe. The same procedure was used to collect an equal number of samples from the adjacent continuous wheat cultivated field separated from the CRP land by a two lane access road. The cultivated site was chisel plowed and a disk plow was used as needed. Anhydrous ammonia was applied at the rate of 67 kg ha^{-1} N annually and 112 kg ha^{-1} P of 18:46:0 (NPK) fertilizer every second or third year (J. H.Stiegler, personal communication, 1996).

A 2.0 cm diameter soil probe was used to estimate the thickness of the A horizon from a core soil sample, then visually differentiating the A from the B horizon by change in color. The thickness of A horizon was measured with a flexible plastic tape to the nearest 0.5 cm. The soil structure was described from a soil sample in the top 10 cm depth using a spade. Both soil structure and the thickness of A horizon were determined in the field (Soil Survey Investigation Staff, 1991) while the collected samples were taken to the laboratory and prepared for the determination of the soil organic carbon content, total nitrogen, water stable aggregates, and pH.

The same procedure as described above was used to collect soil samples at the Forgan site and analyze those samples for soil organic carbon, total nitrogen, water stable aggregates, and soil pH, soil structure description and the thickness of A horizon. Tillage involved "V" sweep plowing as needed for weed control and occasional disking. Approximately 45 kg ha^{-1} of anhydrous ammonia was applied to the cultivated site annually while 22.4 to 44.8 kg ha^{-1} P_2O_5 was applied every third year (J. H. Stiegler, personal communication, 1996).

The soil samples were air-dried in the laboratory at room temperature. A small sample from the bulk air-dried sample was collected from each and crushed with a mortar and pestle to pass the 2 mm sieve placed above a 1 mm sieve. The material that was retained on the 1 mm sieve was placed in containers and used for determination of aggregate stability. The soil which passed through the 1 mm sieve was used for pH determination. The remaining sample was ground with a soil grinder and used for organic carbon and total nitrogen analysis.

Water-Stable Aggregate

A 3.00 gram soil sample of the 2 to 1 mm diameter size was placed on a 0.5 mm sieve submerged in a plastic bowl filled with distilled water. The sieve with the sample was left overnight after which it was agitated 20 times in 40 seconds and taken from the water and placed on aluminum plate in an oven for 2 to 2.5 hours at 105 degrees Celsius. The sample (on the 0.5 mm sieve) was removed from the oven and, allowed to cool before weighing. After weighing, the sieve and sample were placed in a calgon solution in a plastic bowl to disperse the sample aggregates. After the aggregates were dispersed the sieve and sample were removed from the solution, washed to remove the calgon and placed in the oven for another 2 to 2.5 hrs at 105 degrees Celsius. The sieve and sample were removed, weighed when cooled and the sample discarded. The sieve and plate were then weighed. Aggregate stability was recorded as the percentage of the 2 to 0.5 mm aggregates retained after wet sieving. Aggregate stability was calculated as follows:

Aggregate (%)=(weight retained - sand weight/ sample weight-sand weight)*100

where weight retained = total weight retained on 0.5-mm aggregates

Sample weight = original weight of sample placed on the sieve

Sand weight = weight of 2-to 0.5-mm sand.

Organic Carbon

The soil organic carbon content of the samples from the research sites were analyzed as described by Yeomans and Bremner (1988). A small sample weighing 0.1 to 0.5 g ground to pass a 250 micron sieve was placed in a Pyrex 100 ml block digester tube with 5 ml of 1.00N potassium dichromate solution and 7.5 ml of concentrated sulfuric acid. The tube was placed in a 40-tube block digester and heated at 180 degrees Celsius for 30 minutes, removed, allowed to cool for 15 minutes and the contents were transferred to a 100 ml beaker and diluted to about 50 ml with distilled water. The diluted digest was allowed to cool to room temperature, then 0.3 ml of indicator solution was added and the digest titrated with Mohr's salt solution. Two boiled controls and two unboiled controls with 5 ml of 1.00N potassium dichromate and 7.5 ml of concentrated sulfuric acid were included in each series of analysis. The organic carbon content of the sample was calculated from the titration values for the sample, the boiled control and the unboiled, and expressed as a percentage of the sample weight.

Total Nitrogen

The total nitrogen content was determined by the Kjeldahl method. This method involved digestion, distillation and titration of the samples. Approximately 10 g of ground sample was placed in the labeled Kjeldahl flasks. Six Hengar selenized granules, one polyethylene bag of potassium sulfate (K_2SO_4), and 25 ml. of concentrated sulfuric acid (H_2SO_4) were added to each flask. The flasks were swirled to wet the samples and placed on the digestion unit. The flasks were rotated 180 degrees for adequate mixing after 30 minutes. The digestion time was approximately 90 minutes. At the end of the digestion, the burners were turned off and flasks allowed to cool for 20-30 minutes and later removed, loosely covered with stoppers and left to cool for 15 minutes. When the flasks had cooled, 300 ml of tap water, two pieces of zinc metal, 75 ml of sodium hydroxide (NaOH) were added to each, tightened with rubber stoppers and swirled to mix the contents before placing on the distillation rack. Receiving flasks containing 50 ml of boric acid with indicator were placed under the distillation units. The distillation was completed when the receiver flasks contained about 250 ml of distillate and indicator. The distillation unit and the tubes were allowed to drain before titrating each sample from the receiving flasks to a faint purple color with diluted H_2SO_4. Total nitrogen was calculated as:

%Nitrogen = (N * V *14.008 *100/1000)/sample weight

where N = Normality of the standard titration acid (0.12967).

V = Volume of acid used

14.008 = Milliequivalent weight of nitrogen. Division by 1000 convert mg to grams.

Soil pH

A soil sample weighing 10 grams was placed in a 20 ml of distilled water in a 50 ml beaker. The sample was stirred several times for 15 minutes and allowed to stand for another 15 minutes allowing the suspension to settle. A pH electrode connected to a pH meter was then placed in a clear supernatant and the pH was recorded.

Statistical Analysis

Statistical analysis of the data was done to compare the means of the surface soil properties (0-10cm) of the study areas at 0.05 probability level of significance using the t-tests of unpaired comparison assuming unequal variances.

CHAPTER IV

RESULTS AND DISCUSSION

Soil Organic Carbon

Comparison between tillage and sod

The organic C content of the Conservation Reserve Program (CRP) land planted with Old World Bluestem for 10 years was higher and significantly different compared to that of continuous cultivated land (CC) planted with hard red winter wheat at Duke and Forgan (Tables 3, 4 and 5). Continuous cultivated land had lower soil organic C content at both study sites (Figure 1) by 10 and 26 percent, respectively (Table 6). The organic C content on the CRP land ranges from 10.2 to 16.3 g/kg at Duke and 4.6 to 16.2 g/kg at Forgan. The continuous cultivated land has organic C content ranges of 8.5 to 15.7 g/kg and 3.1 to 11.7 g/kg at Duke and Forgan, respectively.

Continuous cultivation in this study had lower soil organic C content compared to the grass sod (Figure 1) because cultivation (tillage) creates a favorable environment for the decomposition of soil organic matter by aerating the soil, breaking up the organic residues and facilitating ideal temperature and oxidation conditions for optimum microbial activity. As the soil is tilled, the microbes decompose fresh organic residues and later decompose humus after depleting the fresh supply (Brady, 1990; Cambardella and Elliott, 1994;

Fuller et al., 1995; Gebhart et al., 1994; Haas et al., 1957; Haynes and Beare, 1996; Ismail et al., 1994; Johnston, 1991; Kooistra and Noordwijk, 1996; Laryea and Unger, 1995; Rowell, 1994; Stevenson, 1986; Tate, 1987; Tisdall, 1996; Webb et al., 1980; Zobeck et al., 1995).

Continuous cultivation of hard red winter wheat also reduces the biomass input to the soil by crop harvest and fallow period that would have otherwise been available under permanent grass sod (Gebhart et al., 1994; Griffith et al., 1986; Ross, 1989; Tate, 1987). The reduction of net plant biomass input from cultivated soils compared to grass sod would result in faster depletion of organic matter. Depletion of added organic fraction causes the microbes to turn to humus (preserved organic pools) causing significant reduction in the total organic carbon content of the soil (Reicosky et al., 1995; Rowell, 1994; Tate, 1987). The carbon biomass inputs from grassland soils were found to be 900 to 8000 g/kg higher compared to inputs from cultivated soils (Gebhart et al., 1994). Rowell (1994) reported 2240 kg/ha and 660 kg/ha of biomass input from grassland soils and arable soils, respectively, in England. The soil organic C from the cultivated land was lower compared to that of the grass sod.

Some researchers have also found higher amount of soil organic C content in the surface horizons of untilled soils compared to tilled soils which is consistent with the result of this study. In a comparison of soil organic C content of virgin soils and cropped soils in the Great Plains, Haas et al. (1957) reported an average of 19.4 g/kg and 11.0 g/kg of organic C content in virgin soils and cropped soils, respectively, after 36 years. A 50 percent decrease in soil organic matter from continuous cultivated soils compared to virgin soils was reported from Magruder Plots by Harper (1959) and Webb et al. (1980) over 65 and 85 years respectively. Gebhart et al. (1994) compared the soil organic C content from the cultivated land planted with different crops versus CRP land planted with grass versus native pasture at locations near Big Spring and Seminole, Texas, Colby and Atwood, Kansas and Valentine, Nebraska where they found higher soil organic C content by weight in native pasture followed by CRP land which in turn had higher organic C content than cultivated land which was similar to organic C result of this study.

Comparison between sites

Soil organic C content was higher at Duke compared to Forgan (Figure 1) because of higher precipitation and clay content at Duke compared to Forgan (Table 1, Brady, 1990; Gebhart et al., 1994; Ihori et al., 1995; Johnston, 1991). High rainfall is likely to result in adequate moisture for plant growth leading to high plant production compared to low rainfall areas. Higher clay content also provides cation exchange capacity that improves soil fertility which supports plant growth and the resultant organic C addition to the soil compared to low clay content. Generally a fine sandy loam holds less water than a clay loam and therefore the fine sandy loam would oxidize more organic matter than a clay loam (Brady, 1990; Gebhart et., 1994). Tillage, and the amount of surface residues (plant biomass) incorporated into the soil by the tillage equipment could have also contributed to the lower soil organic C content at Forgan compared to Duke in the CC land. At Duke the main tillage equipment was a chisel plow that generally leaves 50-75 percent crop residues on the soil surface while the main tillage equipment at Forgan was a V-sweep plow which generally leaves up to 85 percent crop residues on the soil surface (Table 2, Throckmorton, 1986; Troeh et al., 1991). The V-sweep plow incorporates 15 percent of the surface residues into the soil while the chisel plow incorporates up to 25 percent of the surface residues and that could be the reason why there was more organic C content in CC land at Duke compared to CC land at Forgan. However, the main difference in organic C content between the two sites could be because of soil and rainfall factors as explained earlier.

Water Stable Aggregates

Comparison between tillage and sod

The CRP soil had more and significantly different water stable aggregates compared to continuous cultivated soil at both study sites (Tables 3, 4, 5, and Fig. 2). The CRP soil at Duke had almost 6 times as much water stable aggregates than the CC soil. At Forgan, CRP soil had twice as much water stable aggregates than the CC soil. The CRP soil had 83 percent and 51 percent water stable aggregates at Duke and Forgan respectively (Table 6). The CRP land also had a moderate soil structure at both sites while continuous cultivated land had a weak soil structure (Tables 7 and 8).

The increased amount of water stable aggregates under land planted with grass compared to continuous cultivation of wheat identified from this study is consistent with other research (Reicosky et al., 1995; Zobeck et al., 1995). Soil organic matter is the main soil property that creates stable aggregates (Crosson and Stout, 1983). Any factor that causes soil organic matter (especially humus) to decline will result in reduced soil aggregate stability (Haynes and Beare, 1996; Reicosky et al., 1995; Thomas, 1986; Unger, 1995; Zobeck et al., 1995).

In a comparison of water stable aggregates between grass sod, 7 year and 70 year cultivated fields, Zobeck et al. (1995) found 4 times as many water stable aggregates in the grass sod than the 7 year and 70 year cultivated fields with the field that had been cultivated for 70 years having fewer amount of water stable aggregates. Grassland soil aggregates were more stable than those found in cultivated soils which is consistent with the results of this study.

The results of this study suggest that cultivation not only reduced organic matter but also decreased stable soil aggregates. Cultivation physically disrupts the soil aggregates and promotes the breakdown of soil organic matter resulting in less stable aggregates compared to permanent vegetation (Angers and Carter, 1996; Gregorich and Janzen, 1996; Griffith et al., 1986; Haynes and Beare, 1996; Kooistra and Noordwijk, 1996; Rowell, 1994; Tate, 1987; Thomas, 1986; Tisdall, 1996; Unger, 1995).

Under undisturbed grass cover, soil organic matter supplies a chain of binding agents in the form of fungal hyphae, polysaccharides and fine roots which cement soil aggregates into stable aggregates (Angers and Carter, 1996; Gabriel and Michiels, 1991; Haynes and Beare, 1996; Kononova et al., 1966; Stevenson, 1994; Swift, 1991; Tate, 1987; Waters and Oades, 1991). In this study moderate soil structure was found in the CRP soil planted with grass compared to weak soil structure in the CC soil. The fibrous root system from the grass performs an important function of binding aggregates into stable aggregates (Haynes and Beare, 1996; Lindstrom et al., 1994; Tate, 1987; Troeh et al., 1991).

Comparison between sites

Water stable aggregates can indicate soils resistance to dispersion, susceptibility to compaction, degree of aeration, soil drainage, infiltration rate and susceptibility to soil erosion (Griffith et al., 1986). The difference in water stable aggregates between CRP land and CC land was greater at Duke than it was at Forgan (Table 6 and Fig. 2) suggesting that cultivation would have more impact on aggregates of cohesive soils (clayey) than it would in loose soils (sandy). The reduction in water stable aggregates that occurred at Duke when clay loam was cultivated could have been due to inadequate organic matter content to maintain the stability of the aggregate structure. However, it has been estimated that clay loam requires 4.5 years under grass to develop improved and stable soil structure while sand loam require 7.8 years to do the same (Lindstrom et al., 1994). Soils with high clay content require higher addition of organic matter if they are to maintain structural stability (Haynes and Beare, 1996). Continuous cultivation has a greater impact on clay aggregates dispersion compared to sand aggregates (Fuller et al., 1995). This explains the greater amount of reduction of aggregate stability on the cultivated clay loam soil compared to fine sandy loam.

There is a larger amount of water stable aggregates in the CRP land at Duke compared to Forgan. Soils with more clay may respond more favorably than soils with less clay (more sand) in creating stable aggregates when soil organic matter accumulates. Water stable aggregates increase with increasing clay and organic matter content (Rasiah and Kay, 1994).

Total Nitrogen

The mean total nitrogen content of the CRP soil was the same as the continuous cultivated soil at Duke. Both CRP and CC plots at Duke had the same range in total nitrogen content (Table 3). At Forgan, mean total nitrogen content from the CRP land was slightly higher than that of the continuously cultivated land although the cultivated soil had higher total nitrogen range than the CRP soil (Table 4).

The total nitrogen content between CRP land and CC land was not significantly different at Duke but it was at Forgan (Table 5 and Fig. 3). The CRP program did not contribute significant nitrogen to the clay loam at Duke while it contributed 11 percent more total nitrogen to fine sandy loam at Forgan (Table 6) compared to CC. Nitrogen fertilization in the cultivated land masks the nitrogen decline from cultivation resulting in no difference in total nitrogen between CRP land and CC land at Duke.

Similar studies have also found inconsistent results on nitrogen content between no-till and continuous cultivation. No-till or grass sod has been reported to have higher nitrogen content than continuous cultivation by some researchers (Fox and Bandel, 1986; Haas et al., 1957; Ihori et al., 1995; Ismail et al., 1994; Tate, 1987) while others (Fox and Bandel, 1986; Laryea and Unger, 1995) have either found no difference or a decline of nitrogen content under no-till compared to continuous cultivation. Haas et al. (1957) reported 60 percent nitrogen losses from cultivated soils compared to prairie soils at Woodward, Oklahoma after 36 years. Similar results were reported by Fox and Bandel (1986), Tate (1987), Ismail et al. (1994), and Ihori et al. (1995). On the other hand, Fox and Bandel (1986) reported reduced nitrogen availability in untilled soils and also insignificant difference in organic nitrogen of the 5 to 10 years no-till versus plow-tillage of small grains in the United Kingdom. Laryea and Unger (1995) found higher nitrogen percentage from moldboard and sweep tillage systems than from no-tillage fields.

Although the difference in total nitrogen between CRP land and CC land at Duke was not significant, CRP land had slightly higher nitrogen content than the cultivated land (Table 3). The addition of nitrogen fertilizers (67 kg/ha N annually and 112 kg/ha of P every second or third year) that replaced mineralized nitrogen could account for lack of reduction of total nitrogen in the cultivated land at Duke. More nitrogen fertilizer was applied on the cultivated land at Duke than the cultivated land at Forgan (45 kg/ha N annually). Nitrogen fertilization at Duke might have been in excess of the plant uptake. The added nitrogen to the CC land resulted in no difference in total nitrogen between CRP soil and CC soil. Total nitrogen in the cultivated land might have been due to inorganic nitrogen fertilization and mineralized organic nitrogen. Glendining and Powlson (1991) reported greater increases in soil total nitrogen on nitrogen fertilized soils than unfertilized soils particularly when crop residues were incorporated, which was the case in this study. Application of ammoniacal fertilizers have the tendency of fixing ammonium (NH_4^+) (Stevenson, 1994) and that would increase total nitrogen in cultivated soils when NH_4^+ is mineralized.

If nitrogen fertilizers were not applied in the cultivated land and a longer time allowed before conducting this study, cultivated land would have contained significantly lower total nitrogen than the CRP land at both sites. Nitrogen fertilization in the cultivated land particularly at Duke masks losses of nitrogen due to cultivation. The significant difference in total nitrogen content between CRP land and CC land at Forgan was due to nitrogen fertilization not in excess of plant requirement within CC soils.

Carbon : Nitrogen Ratio

The C:N ratios of CRP plots at both study sites were slightly higher than those of the cultivated plots (Tables 3 and 4) but not significantly different (Table 5). The ratios were within the usual limits of most arable soils which ranges from 8 to 15 (Brady, 1990; Stevenson, 1994).

Although the C:N ratios were not significantly different between the plots at the study sites, the results were consistent with what Haas et al. (1957) reported in the Great Plains when they evaluated the C:N ratios of virgin soils and cropped soils in eleven locations. Haas et al. (1957) however did not test for significant difference between virgin soil and cropped soils. Factors that affect carbon and nitrogen losses from the soils would impact the C:N ratios in a similar way. Carbon:nitrogen ratios are important for microbial energy. Tate (1987) observed that high C:N ratios were insufficient in nitrogen particularly, during initial stages of decomposition process. In higher ratios, nitrogen becomes unavailable for plant growth because the small amount that is present is immobilized within microbial tissues (Munshower, 1994). Tillage systems had little effect in C:N ratios (Fox and Bandel, 1986). The CRP and continuous cultivation had similar effects on C:N ratios at both sites of this study. The C:N ratios of the fine sandy loam were higher than ratios of the clay loam because the sandy loam soil had lower nitrogen content due to less application of fertilizers.

Soil pH

Soil pH values of the CRP plots are lower than those of the continuous cultivated plots at both Duke and Forgan (Tables 3 and 4, and Fig. 4). Soil pH for the CRP plots between study sites is about the same. In the cultivated plots, soil pH of the Duke site was greater than that of the Forgan site.

The lower soil pH values from the grass sod (CRP) compared to the continuous cultivation (CC) is consistent with reported pH values by Ismail et al. (1994). Ismail et al. (1994) observed a difference associated with liming of cultivated soil and not in no-till. No lime was applied on soils used in this study, however.

The lower soil pH values in the CRP land compared to continuous cultivated soils of this study could be caused by the higher soil organic matter levels in the CRP land. The increase in organic acids (humic and fulvic) lowered the pH. The CRP land has lower pH values because high infiltration and reduced evaporation associated with no-till reduced the base saturation of the surface soil (Thomas, 1986). Thomas (1986) has reported two times as much loss of calcium under no-tillage systems compared to plow-tillage. High pH values in the cultivated plots could also be the result of mixing calcareous subsoil into surface horizons following erosion. Gollany et al., (1992) reported high pH values caused by an increase in free calcium carbonate on the surface where topsoil depth had been removed by erosion. In this study, the cultivated land has a thinner A horizon compared to CRP land (Tables 3 and 4) and indicates soil loss from cultivated soils might have resulted in free calcium carbonate accumulation to surface by mixing. Both soils at Duke and Forgan contained calcareous subsoil horizons.

A "healthy" soil should have pH range between 6.2 and 7.0 (Romig et. al., 1995). An implication of this study is that CRP has created healthy soil conditions because CRP soil has average pH values within the required limits. The continuous cultivation of both sites created slightly basic soil conditions which decreased soil quality.

Thickness of A horizon

The A horizon thickness was greater in the CRP land compared to the cultivated land at both study sites (Tables 3 and 4, and Fig. 5). Differences between CRP and continuous cultivation at both study sites were significant (Table 5) and CRP increased the thickness of A horizon by 13 percent at both study sites (Table 6) compared to CC.

The greater thickness of A horizon in the CRP land compared to CC land could be an indication of the soil protection by grass cover and the occurrence of erosion on the cultivated land, respectively, or soil surface variation before CRP. Assuming the bulk density of the soil was 1.3 g/cm^3, the net annual soil loss from cultivated soils calculated from A horizon thickness of this study were 31.2 Mg/ha and 18.2 Mg/ha at Duke and Forgan, respectively. This soil loss from cultivated soil of this study was similar to reported effects on vegetated and cultivated areas. A study by Blackburn et al., (1991) which covered the Great Plains region, reported reduction in runoff and soil erosion from the CRP land due to grass cover, and increase of soil structural stability as a result of not tilling the soil. Blackburn et al. (1991) reported 8.96 Mg/ha and 22.85 Mg/ha of soil loss by water erosion from CRP land and cultivated land respectively, and another 2.24 from CRP land and 18.82 Mg/ha from cultivated land due to wind erosion at

Harper, Oklahoma. They also reported reduction in water and wind erosion estimates in all the other Great Plains states because of the perennial grass cover on the CRP land. Continuous cultivation continues to result in significant loss of valuable topsoil as indicated from this study by the mean difference in thickness of A horizon between CRP soils and CC soils (Table 6).

Conclusions

The result of this study could be considered as a true testimony of the importance of topsoil. The cultivated soils of this study have lost some topsoil and explains why there is a general reduction of soil organic C content, water stable aggregates, nitrogen content (insignificant at Duke) and an increase in soil pH. The CRP land has not lost as much topsoil which is indicated by greater A horizon thickness. The CRP land has greater soil organic carbon content, water stable aggregates, nitrogen content (at Forgan) and a reduced soil pH. This study did not estimate the yield reduction caused by topsoil removal but the possibility of yield reduction is considerable as long as the soil quality is negatively affected as indicated from the cultivated land of this study.

The CRP program has proven to be an effective management system in restoring the surface soil properties that were reduced by continuous cultivation, and in conserving the soil. Over the past ten years the CRP land resulted in increased soil organic carbon content by 10 percent and 26 percent on a clay loam at Duke and a sand loam at Forgan, respectively. A moderate soil structure resulted from both soils under grass with a restoration of 83 percent and 51 percent stable aggregates on a clay loam and a sandy loam, respectively.

Total nitrogen increased by 11 percent in a sandy loam under grass sod while the increase in a clay loam was insignificant. Soil pH was reduced to neutral levels by the grass sod which is ideal for soil health. The differences in thickness of the surface horizon under grass sod and continuous cultivated land suggest that soil was protected from erosion by the permanent grass while accelerated erosion continued to occur on cultivated land because of lack of continuous permanent plant cover at both sites.

It would therefore be necessary to continue CRP practices, particularly on the land that has been cultivated, in order to restore soil quality and prevent further soil erosion. A rotation of grass sod with crops is suggested as a sustainable crop management system to restore and maintain soil health.

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APPENDIXES

APPENDIX A

TABLES

Table 1: Soil and general characteristics of the study sites.

Site Location	Annual Rainfall	Soil Family	Soil Series	Soil texture	Land capability unit	Slope percent
	(mm)					
Duke	660	Fine, mixed, thermic Typic Paleustoll	La Casa (Tillman)	Clay loam	I Ie-1-1	1 to 3
Forgan	457	Fine-Loamy, mixed, mesic Aridic Haplustoll	Dalhart	Fine sandy loam	I I Ie-2	1 to 3

Table 2: Tillage equipment, tillage depth and typical residues left after tillage

Site	Equipment type	Tillage depth (cm)	Percent residue remaining
Duke	Chisel plow	20 to 25	50 to 75
	disk plow	10	
Forgan	V sweep plow	8 to 13	85
	disk plow	10	

Table 3: Means and ranges of surface soil properties (0-10 cm) of CRP and CC of Tillman clay loam soil after 10 years of CRP at Duke

Soil Properties	Units	Plot			
		CRP		CC	
		Mean	Range	Mean	Range
Organic carbon	g/kg	12.8	10.2-16.3	11.5	8.5-15.7
Water stable aggregates	g/kg	215.1	104.0-384.0	36.6	6.7-81.7
Total nitrogen	g/kg	1.1	1.0-1.1	1.1	1.0-1.1
Carbon:Nitrogen ratio		11	9.0-15.0	10	8.0-14-0
Soil pH		7.1	6.9-7.4	8.4	7.4-8.5
Thickness of A horizon	cm	18.7	14-21.5	16.3	8.9-27.9

NB: Water stable aggregates are aggregates (2 to 0.5-mm) retained after wet sieving.

Table 4. Means and ranges of surface soil properties (0-10 cm) of CRP and CC of Dalhart fine sandy loam soil after 10 years of CRP at Forgan

		Plot			
		CRP		CC	
Soil Properties	Unit	Mean	Range	Mean	Range
Organic carbon	g/kg	9.1	4.6-16.2	6.7	3.1-11.7
Water stable aggregates	g/kg	116.9	56.6-188.4	57.6	31.7-94.7
Total nitrogen	g/kg	0.54	0.4-0.7	0.48	0.4-0.8
Carbon:Nitrogen ratio		17	9.0-36	14	8.0-23
Soil pH		7.2	6.6-8.5	7.8	6.6-8.8
Thickness of A hotizon	cm	11.1	7.5-17.0	9.7	6.5-13

Table 5: Comparison of two sample means assuming unequal variances of surface soil properties (0-10 cm) between CRP and CC at Duke and Forgan

	SITE	
Soil property	Duke	Forgan
Organic carbon	* (38)	* (40)
Water stable aggregates	* (27)	* (32)
Total nitrogen	ns (46)	* (45)
Carbon:Nitrogen ratio	ns (41)	ns (36)
Soil pH	* (46)	* (41)
Thickness of A horizon	* (33)	* (46)

Note: * = significantly different at 0.05 probability level.

ns = not significantly different at 0.05 probability level.

The numbers in brackets are the degrees of freedom

Table 6: Mean differences and percent increase (+) or decrease (-) of surface soil properties (0-10 cm) after 10 years of CRP following CC of wheat at Duke and Forgan

	Duke		Forgan	
Soil property	Mean difference between CRP and CC	Percent Change with CRP	Mean difference between CRP and C	Percent Change with CRP
Organic C (g/kg)	1.3	10	2.4	26
Water stable aggregates (g/kg)	178.5	83	59.3	51
Total nitrogen (g/kg)	ns	ns	0.06	11
C:N ratio	ns	ns	ns	ns
Soil pH	-1.3	-18	-0.6	-8
Thickness of A horizon (cm)	2.4	13	1.4	13

ns = the actual numbers were not significantly different at 0.05 level; so the mean difference was assumed to be zero.

Percent change with CRP = presented as percentage of the difference between CRP and CC over CRP assuming that CRP represent undisturbed soil.

Table 7: Soil structure description in the 0-10 cm depth of CRP and CC of Tillman clay loam at Duke

	CRP			C C		
Sample	Grade	Size	Shape	Grade	Size	Shape
1	2	m	sbk	1	m	sbk
2	2	f	sbk	1	c	sbk
3	2	f	sbk	1	c	sbk
4	2	f	sbk	1	m	sbk
5	3	f	sbk	1	m	sbk
6	2	f	sbk	1	m	sbk
7	2	m	sbk	1	c	sbk
8	2	f	sbk	1	c	sbk
9	2	m	sbk	1	m	sbk
10	2	m	sbk	1	m	sbk
11	2	m	sbk	1	m	sbk
12	3	f	sbk	1	m	sbk
13	2	m	sbk	1	m	sbk
14	2	f	sbk	1	m	sbk
15	3	m	sbk	1	m	sbk
16	2	m	sbk	1	m	sbk
17	2	f	sbk	1	m	sbk
18	2	m	sbk	1	m	sbk
19	2	m	sbk	1	m	sbk
20	2	m	sbk	1	m	sbk
21	2	f	sbk	1	m	sbk
22	2	c	sbk	1	m	sbk
23	2	m	sbk	1	m	sbk
24	2	m	sbk	1	m	sbk

Grade: 1 = weak soil structure, easily detroyed
2 = moderate soil structure, able to withstand stress
3 = strong soil structure that can withstand maximum stress
Size: f = fine soil peds
m = medium soil peds
c = coarse soil peds
Shape: sbk = sub angular blocky

Ref: Soil Survey Manual.

Table 8: Soil structure description in the 0-10 cm depth of CRP and CC of Dalhart fine sandy loam at Forgan

	CRP			C C		
Sample	Grade	Size	Shape	Grade	Size	Shape
1	2	f	gr	1	m	pl
2	2	f	gr	1	m	sbk
3	2	f	gr	1	f	gr
4	2	f	gr	1	m	sbk
5	2	f	gr	1	m	sbk
6	2	f	gr	1	m	sbk
7	2	f	gr	1	m	sbk
8	2	f	gr	1	f	gr
9	2	f	gr	1	f	gr
10	2	f	gr	1	m	sbk
11	2	f	gr	1	f	gr
12	2	f	gr	1	c	pl
13	2	f	gr	1	m	sbk
14	2	f	gr	1	f	gr
15	2	f	gr	1	m	pl
16	2	f	gr	1	f	gr
17	2	f	gr	1	m	sbk
18	2	f	gr	1	f	gr
19	2	f	gr	1	m	pl
20	2	f	gr	1	f	gr
21	2	f	gr	1	m	pl
22	2	f	gr	1	c	pl
23	2	f	gr	1	m	sbk
24	2	f	gr	1	m	sbk

Grade: 1 = weak soil structure
2 = moderate soil structure
3 = strong soil structure
Size: f = fine peds
m = medium peds
c = coars peds
Shape: pl = platy
gr = granular
sbk = sub angular blocky
Ref: Soil Survey Munual

APPENDIX B

FIGURES

Figure 1: Soil organic carbon content in the 0 to 10-cm depth between sites and plots after 10 years of CRP. Error bars are the standard error of the mean at 0.05 level

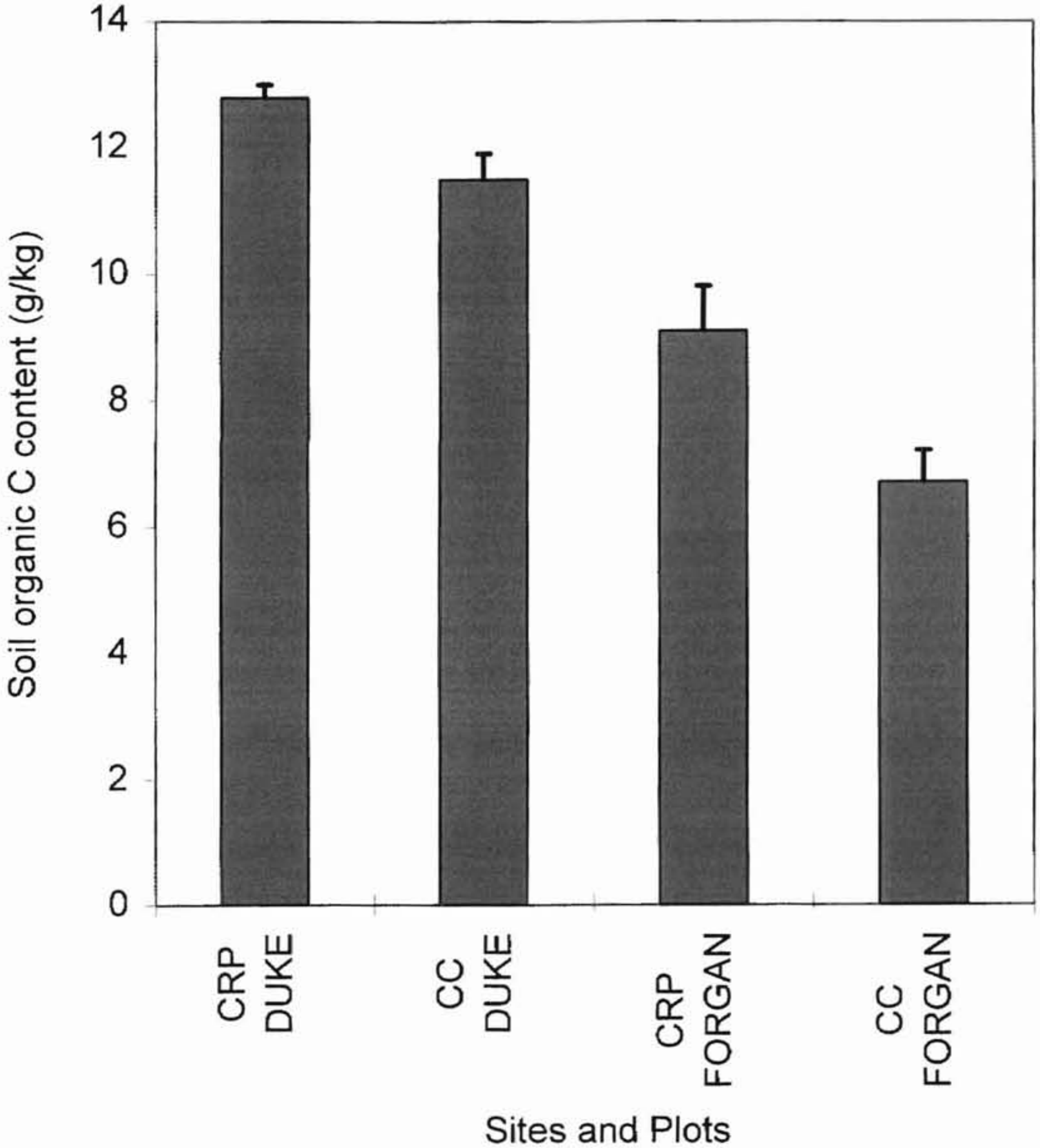


Figure 2: Water stable aggregates in the 0 to 10-cm depth between sites and plots after 10 years of CRP. Error bars are the standard error of the mean at 0.05 level

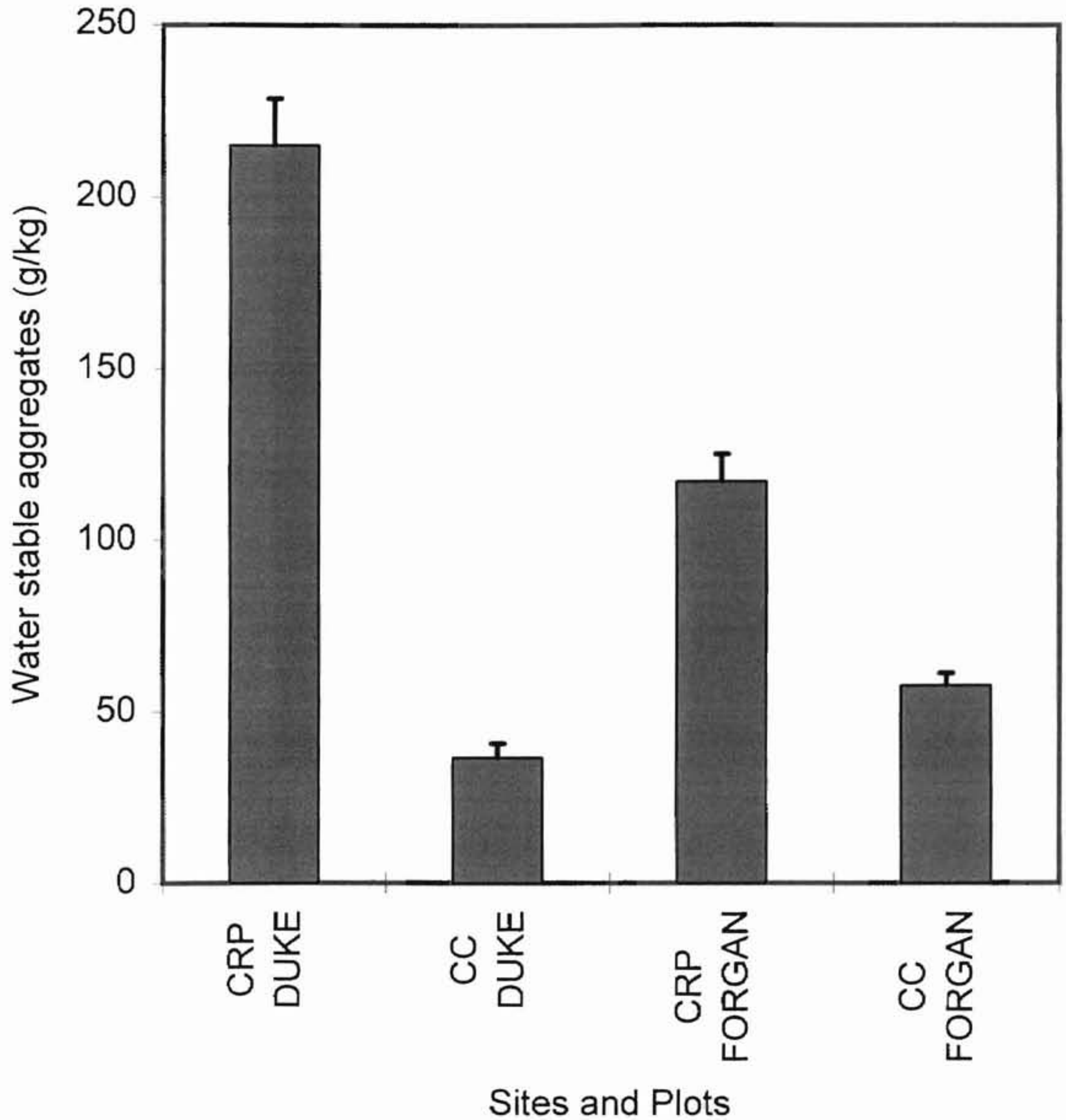


Figure 3: Total nitrogen content in the 0 to 10-cm depth between sites and plots after 10 years of CRP. Error bars are the standard error of the mean at 0.05 level

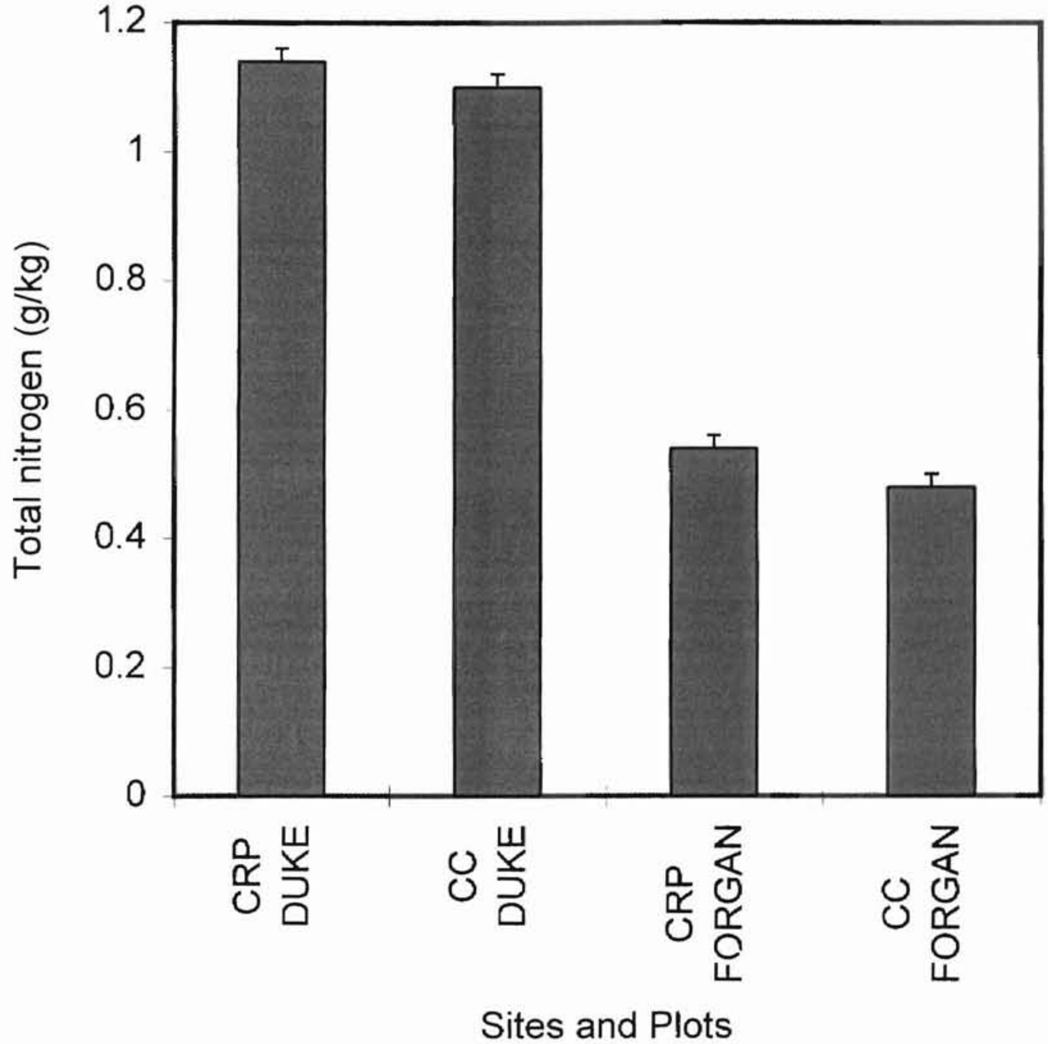


Figure 4: Soil pH in the 0 to 10-cm between sites and plots after 10 years of CRP. Error bars are the standard error of the mean at 0.05 level

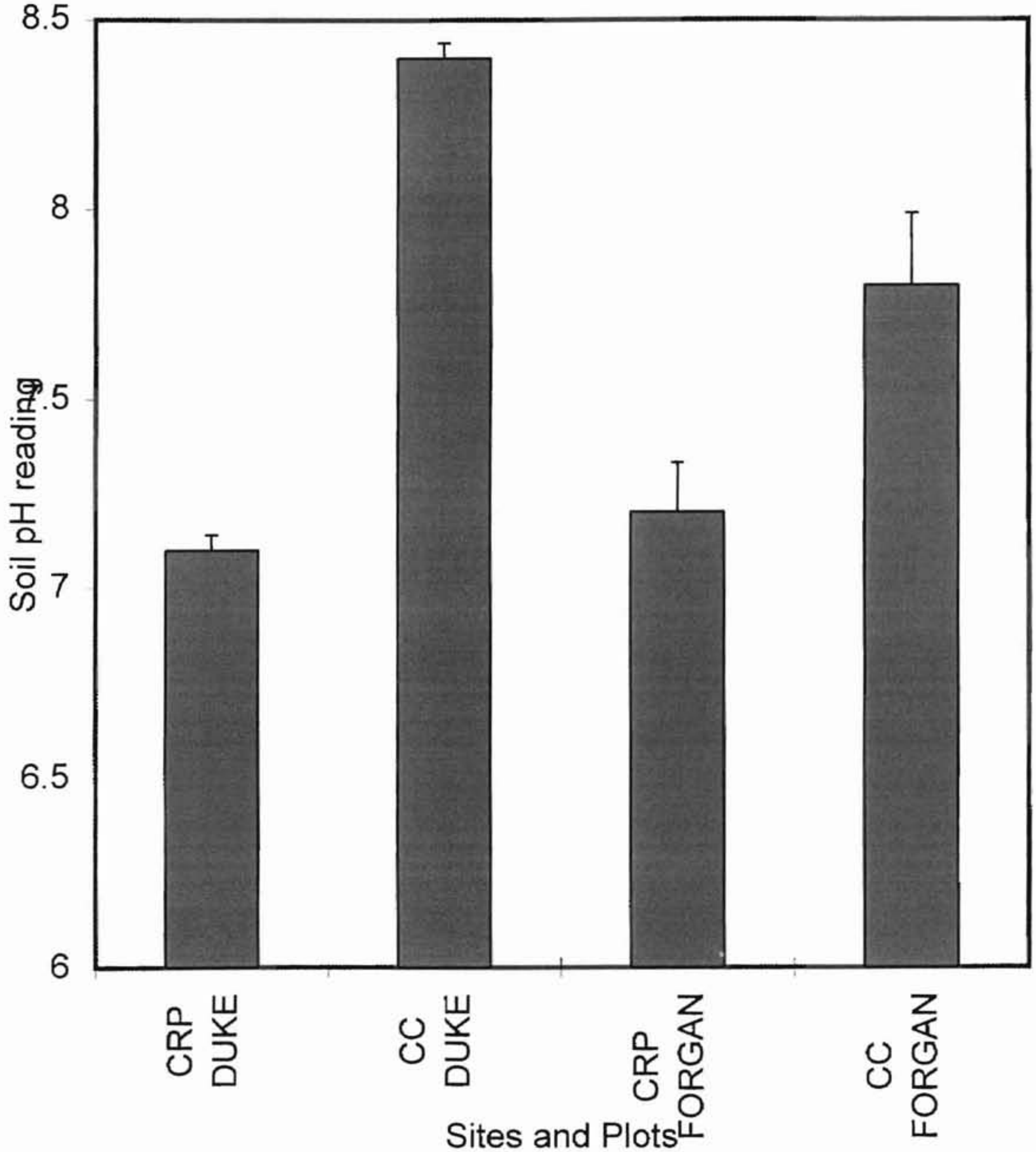
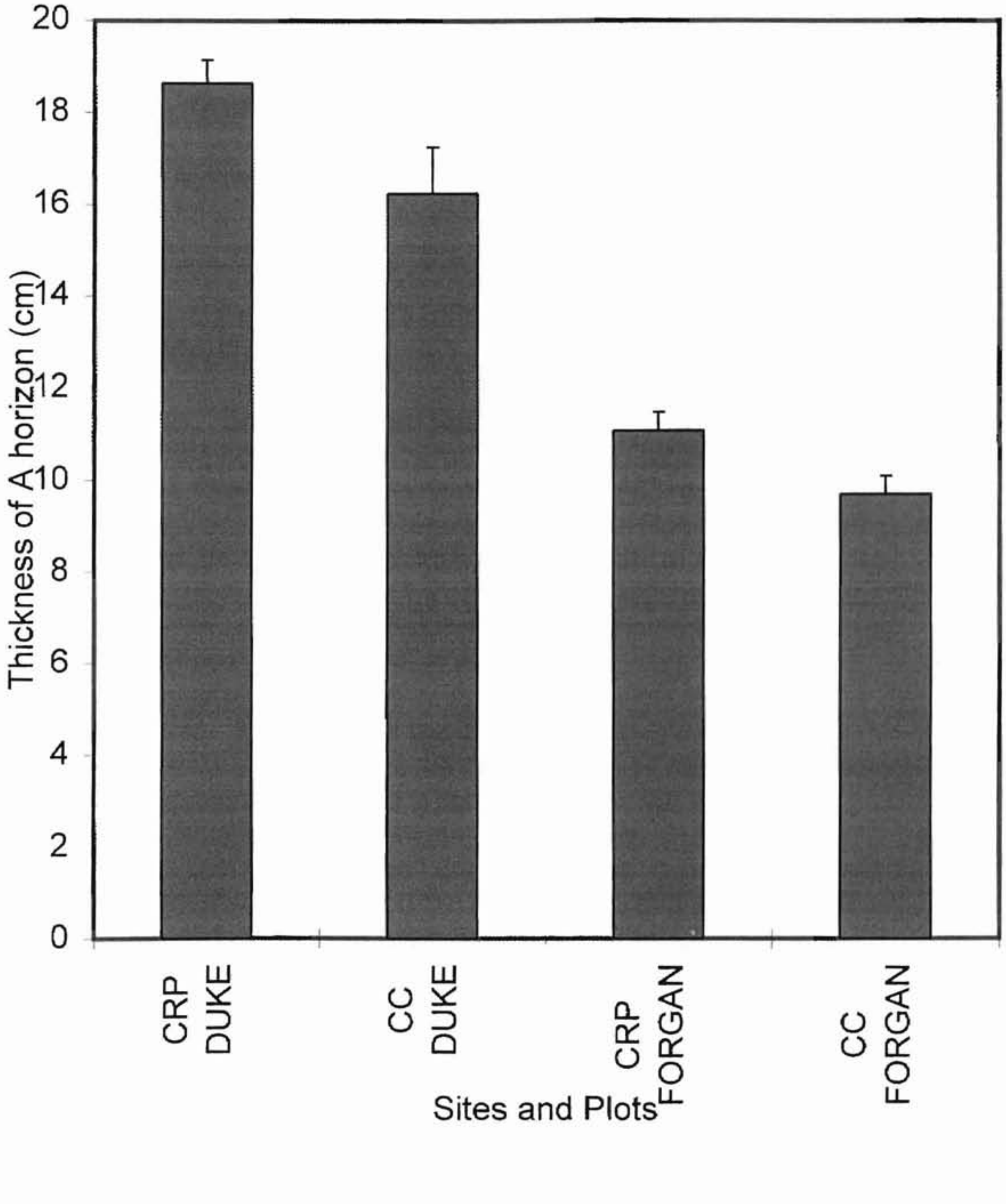


Figure 5: Thickness of A horizon between sites and plots after 10 years of CRP. Error bars are the standard error of the mean at 0.05 level



VITA

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