THESIS

EFFECTS OF IRRIGATED AND DRYLAND CULTIVATION ON SOIL CARBON, NITROGEN AND PHOSPHORUS IN NORTHEASTERN COLORADO

Submitted by

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We hereby recommend that the thesis prepared under our supervision by Penelope J. Sinton entitled effects of irrigated and dryland cultivation on soil carbon, nitrogen and phosphorus in northeastern Colorado be accepted as fulfilling in part requirements for the degree of master of science.

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ABSTRACT OF THESIS

EFFECTS OF IRRIGATED AND DRYLAND CULTIVATION ON CARBON AND NITROGEN IN NORTHEASTERN COLORADO

I investigated the effects of irrigated and fertilized corn agriculture on soil C, N and P in northeastern Colorado as they compare to dryland wheat-fallow fields and native rangelands in the semiarid shortgrass steppe of northeastern Colorado. Three replicates each of native rangeland, dryland wheat-fallow, and irrigated corn fields located in or adjacent to the Pawnee National Grasslands were selected for this study. I measured potentially mineralizable C and N from 0-15cm in the soil profile, particulate organic matter (POM) C and N in the upper 30cm, total and $NaHCO_3$-P to a depth of 105cm, and total soil C and N to a depth of 195cm in the soil profile.

Irrigated corn fields contained significantly lower mineralizable, POM, and total C and N than rangelands in the upper 5cm of soil. Corn fields also had significantly greater $NaHCO_3$-P content than rangelands or wheat-fallow fields to a 1-meter depth in the soil. Wheat-fallow fields had significantly less potentially mineralizable and POM C and N than rangelands or corn fields in the upper 5cm of soil. Cumulative losses of total C and N in wheat-fallow fields extended to depths of 75cm or more. There were no significant differences in total P among landuse types. Differences in C and N between

corn and wheat-fallow fields are likely due to differences in the quantity of plant residue inputs.

The distribution of C, N and $NaHCO_3$-P through the soil profile in corn fields also differed from rangelands. Soil C, N and $NaHCO_3$-P in the soil profile of rangelands decreased from the surface down, whereas in corn fields C, N and $NaHCO_3$-P increased from the surface to 30cm and then decreased. Distribution of C, N and P in corn fields may be due to leaching of C or N or decomposition changes in the soil profile. In wheat-fallow fields, C, N and $NaHCO_3$-P showed a more uniform distribution in the upper 30cm of soil than rangelands, likely due to tillage practices that mix the upper soil layers in wheat-fallow fields. These results indicate that irrigated and fertilized corn crops in this region of the semiarid shortgrass steppe depletes pools of C and N at the soil surface but does not cause a change in C or N below the 5cm layer of soil. The differences in amount and distribution of C and N observed in this study among dryland wheat-fallow and irrigated corn fields indicate that the type of crop grown in this region should be an important consideration for regional studies that evaluate C and N changes due to cultivation.

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CHAPTER I. INTRODUCTION

Historical cultivation management practices in the U.S. have reduced soil organic carbon (C), total nitrogen (N) and phosphorus (P) (Haas et al. 1957, Tiessen et al. 1982, Anderson and Coleman 1985, Aguilar et al. 1988, Burke et al. 1989). Losses of soil C, N and P from cultivation depend on many factors related to the type of landuse management, including crop type (Buyanovsky and Wagner 1997), tillage intensity (Balesdent et al. 1988), fertilizer inputs and fallow practices (Doran 1980). In the semiarid shortgrass steppe region of the U.S., dryland winter wheat with fallow rotations dominates cropland use (Colorado Agricultural Statistics 1999). Previous studies have shown that dryland wheat-fallow cultivation in this region can cause losses of C, N and P as much as 55% in the top 15cm of soil and 32% in the 15-30cm layer of soil (Bowman et al. 1990).

Cropland area in this region is also used for irrigated crops, including irrigated corn crops. Although irrigated corn represents a smaller proportion of the cultivated land area, this landuse management type produces twice as much grain (Colorado Agricultural Statistics 1999) and dominates the per area trace gas balance with the atmosphere (Mosier et al. 1991); N_2O flux per day in irrigated corn fields is 89% higher per square meter, and CH_4 uptake per day is 85% lower in irrigated corn fields per square meter than in wheat-fallow fields (Mosier et al. 1991, Burke, unpublished data). Furthermore, aboveground net primary production in irrigated, fertilized corn is 15 times that produced by dryland wheat-fallow fields (D.P. Smith, unpublished data). These differences between dryland wheat-fallow and irrigated corn systems suggest that irrigated corn agroecosystems could play a disproportionately large and important role in the biogeochemical processes in this region. Despite these differences among landuse types, studies in this region have not previously addressed the affects of irrigated corn crops on changes in soil C, N and P storage.

Not only is there a lack of empirical knowledge about how irrigated corn crops affect soil C, N and P in semiarid grassland regions, but a second gap in our understanding of the effects of cultivation on C, N and P is related to changes that occur below the plow layer. Lal et al. (1998) pointed out that one of the major knowledge gaps in soil science was a lack of data on changes in soil C with depth resulting from cultivation. Changes in C and N in the soil can extend below the plow layer as compaction, erosion and leaching continue to occur in cultivated soils (Aguilar et al. 1988). As upper soil layers are compacted and eroded away, subsurface soil may become incorporated into the surface layer, diluting C, N and P contents. Where there is adequate water influx through a soil, dissolved organic compounds (Ajwa et al. 1998) and N (Liang et al. 1991, Ajwa et al. 1998) can be transported downward in the profile, thus altering the vertical distribution of C and N.

The objective of this thesis is to compare differences in soil C, N and P among dryland wheat-fallow, irrigated corn, and native rangeland systems in the shortgrass steppe region in northeastern Colorado. The first study in this thesis (Chapter II) specifically deals with changes in total, mineralizable, and particulate organic matter C and N that occur in the upper 30cm of the soil profile where cultivation practices most directly affect soil C and N (Balesdent et al. 1988). It is this region of the soil profile that is also most relevant to land managers in terms of soil fertility and crop production (Bauer and Black 1994, Burke et al. 1995). I hypothesized that irrigated, fertilized croplands in the shortgrass steppe would not cause a loss of C, N, potentially mineralizable or POM fractions of C and N whereas dryland wheat-fallow fields would cause losses of these pools.

The second chapter of this thesis addresses changes in C, N and P that have occurred with depth, including the distribution and accumulation of C, N and P throughout a 1 or 2-meter soil profile. I hypothesized in this study that changes in soil C, N and P properties have occurred in both irrigated corn and dryland wheat-fallow fields below the plow layer because irrigation and fallow practices are known to leach N and organic matter downward in the soil profile. Furthermore, a loss of soil mass due to erosion has likely occurred, particularly in wheat-fallow systems, and may be reflected in the soil profile by losses of total P and differences in C and N contents between cultivated and uncultivated systems (Aguilar et al. 1988). Understanding the differences in total soil storage of organic C, total N and P under irrigated and nonirrigated agroecosystems in this region will be an important step in our understanding of how differences in landuse management can affect soil C, N and P in the shortgrass steppe.

As a caveat to these objectives, this study also recognizes that, just as landuse management practices affect soil properties, the initial soil conditions also govern initial landuse decisions. Therefore, the cause and effect pattern is a circular one where one factor affects the other and then vice versa. Generalizations about how landuse management types affect soil C, N and P should be treated with caution as these generalizations should take into account the initial soil conditions that caused the differences in landuse practices in the first place.

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CHAPTER II. CHANGES IN C AND N IN IRRIGATED AND DRYLAND AGROECOSYSTEMS OF NORTHEASTERN COLORADO

Introduction.

Dryland winter wheat with fallow rotations dominates cropland use in the shortgrass steppe region of the United States. In northeastern Colorado, about 40% of croplands support winter wheat production (Colorado Agricultural Statistics 1999). On the other hand, irrigated corn, although representing a smaller proportion of the cultivated land area, produces twice as much grain (Colorado Agricultural Statistics 1999) and a higher per area trace gas flux than winter wheat fields in this region (Mosier et al. in press) (Table 2.1).

Table 2.1 Total grain production and trace gases from irrigated corn crops and dryland winter wheat-fallow fields in Colorado.

Cropping Practice	**Production (1,000 bu)**	**CH_4 uptake ($C/m^2/d$)**	**N_2O flux ($N/m^2/d$)**
Corn for grain	151,134[1]	.03[2]	1.7[2]
Winter wheat	73,426[1]	.2[2]	.3[2]

1. Colorado Agricultural Statistics 1999
2. Mosier et al. in press

Thus irrigated corn agriculture may have a disproportionate influence relative to its land area on soil biogeochemical processes in this region. Agronomic studies in this region, however, have thus far concentrated primarily on dryland wheat-fallow systems (Woods and Schuman 1988, Burke et al. 1989, Burke et al. 1995, Bowman et al. 1990, Ihori et al. 1995, Wood et al. 1990, and others). The objective of this study is to investigate the effects of irrigated corn crops on total, intermediate and active turnover pools of soil organic C and total N in northeastern Colorado as they compare to dryland wheat-fallow fields and rangelands. This chapter focuses comparisons in the upper part of the soil profile (0-30cm) because this layer of the soil profile is most directly affected by cultivation practices (Balesdent et al. 1988) and it is this layer that is most relevant to land managers in terms of soil fertility and crop production (Bauer and Black 1994, Burke et al. 1995).

Cultivation reduces soil organic carbon and nitrogen by simultaneously increasing the rate of outputs while decreasing the rate of inputs (Tiessen et al. 1982, Anderson and Coleman 1985). The source of inputs to soil C and N is plant residues. Residue inputs are decreased in cultivated systems by crop removal (Doran 1980) and the replacement of perennial species with annual species, which have a lower root:shoot ratio (Burke et al. 1997). The type of crop grown, fertilizer supplements, and water availability also influence the quantity of residue production (Lauenroth et al. 2000). Water availability is especially important in northeastern Colorado where annual precipitation is low and NPP is primarily water-limited (Sala et al. 1988, Sala et al. 1992, Lauenroth et al. 2000). Aboveground net primary production in corn fields is an average of 15 times that of wheat-fallow fields and 18 times more than rangelands (D.P. Smith, unpublished data), and the residues in corn fields left after harvest are estimated to still be between 3 and 5 times that of wheat-fallow fields (Buyanovsky and Wagner 1997).

Outputs from soil C and N in semiarid agroecosystems include decomposition, erosion and leaching (Tiessen et al. 1982, Aguilar et al. 1988, Paustian et al. 1997). Plowing stimulates decomposition by incorporating plant residues into the soil, and by breaking up macro-sized aggregates that contain high amounts of labile C and N (Elliott 1986, Doran and Werner 1990). Degradation of soil aggregates also increases erosion (Doran and Werner 1990). Fallow periods can alter decomposition rates by changing decomposer communities (Doran 1980), soil physical properties (Doran 1980, Buyanovsky et al. 1997) and the quality and quantity of residue inputs (Haas et al. 1957, Lesoing and Doran 1997). Variations in soil water content can also affect decomposition through changes in mineralization rates (Stanford and Epstein 1974, Doran 1980).

Most of the changes in soil organic matter content in cultivated soils occur in the active and intermediate fractions of the soil (Schimel et al. 1985, Cambardella et al. 1992). Though these fractions comprise a small proportion of the total ecosystem organic C storage, they are important for soil fertility and organic matter dynamics (Cambardella et al. 1992, Burke et al. 1997). Comparing changes in the active (i.e., mineralizable) and intermediate (i.e., particulate organic matter or POM) fractions of soil organic matter between cultivated and uncultivated systems provides a useful way to understand the effects of management practices on soil organic matter dynamics (Balesdent et al. 1988, Cambardella and Elliott 1992). Mineralizable C and N have the fastest turnover time of 1-2 years, while fine POM has a turnover time of 30 years; coarse POM is intermediate between the two and has a turnover time of 7 years (Parton et al. 1987, Burke et al. 1997, Kelly et al. 1996). Changes in the different soil fractions due to cultivation are influenced by soil texture (Elliott 1986, Schimel 1986), litter inputs (Burke et al. 1997) and tillage practices (Tiessen and Stewart 1983, Balesdent et al. 1988, Cambardella and Elliott 1992).

Current knowledge of the effects of cultivation on soil C and N suggests that irrigation and fertilization may play an important role in determining patterns of accumulation and loss of C and N in the semiarid region of the Great Plains (Lueking and Schepers 1985, Mosier et al. 1986, Mosier et al. 1991). Understanding the differences in soil C and N under irrigated and nonirrigated agroecosystems will be an important component in regional modeling approaches that evaluate the impacts of management and climatic change on soil C and N. The specific objectives of this study are to determine whether there are differences in (1) organic carbon and total nitrogen contents of soils and (2) potentially mineralizable and particulate organic matter (POM) pools of C and N, among irrigated corn, dryland wheat-fallow, and uncultivated native rangeland systems in northeastern Colorado. My hypothesis is that that cultivation in irrigated, fertilized corn fields will not cause a loss of C, N, potentially mineralizable or POM fractions of C and N whereas the cultivation practices in dryland wheat-fallow fields will cause the losses of these pools.

Materials and Methods.

Study Area

I selected three fields each of dryland wheat-fallow, native rangeland, and irrigated corn management for study. Rangeland sites are located on the Pawnee National Grasslands (PNG) of northeastern Colorado (40°49'N, 107°47'W). Wheat and corn fields are located on private lands adjacent to the PNG. The soil in this region is derived from calcareous loamy alluvium. Soils in this region are classified as Aridic Argiustolls (Soil Survey Staff, 1982). The soil series varied widely among fields and landuse types in this study and are listed in Appendix A. Descriptions of these soil series and soil profiles are summarized in Appendix B. The rangeland sites have never been cultivated and are moderately grazed by cattle during summer. Adjacent wheat-fallow fields have been planted with winter wheat since the 1930's. A sweep plow is used in all of the wheat-fallow fields which extends an average depth of 15cm into the soil. The selected corn fields have been planted with continuous corn since at least 1993. Previous to 1993, these corn fields were ever used for irrigated corn or hay fields at least since 1963, and aerial photos dating back to 1938 show no indication that the fields were used for wheat-fallow. Corn fields are fertilized with ammonium nitrate (140 kg per hectare over the field season) and are grown for grain. Two of the fields are irrigated by a center pivot and the third is flood irrigated. The plow method used in the irrigated corn fields is with a moldboard plow, which extends into the soil approximately 25cm.

Mean annual temperature in this area is 8.6 ± 0.6°C and mean annual precipitation varies between 320 and 400mm (Lauenroth and Sala 1992). The vegetation of the native rangeland sites is dominated by the shortgrasses *Bouteloua gracilis* (Kunth) lag. ex Steud. and buffalograss *Buchloe dactyloides* (Nutt.) Englem.. A variety of forbs, subshrubs, succulents and annual grasses are also present.

Sampling protocol and laboratory analyses

In the summer of 1999, I took five randomly located 2-meter deep cores from each field (there are four fields because wheat and fallow portions of the wheat-fallow fields were sampled and analyzed separately) for a total of 60 cores. For the wheat and corn fields I cored between rows. An effort was also made to identify and sample soils from the summit of each field in order to minimize topographic differences among landuse management types. I divided each core into 15-cm depth increments for the first meter and 30-cm increments for the second meter. The 0-15 and 15-30-cm depth increments were used for this chapter of my thesis, and the lower depths were used for the second chapter. I then air dried and sieved the soil samples through a 2-mm diameter sieve. I sieved the soils and then weighed the entire sample to estimate the fine soil mass of each sample. I ground a subsample from each depth increment and analyzed these for total C and N using an automated dry combustion LECO CHN-1000 (Laboratory Equipment Corp., St. Joseph, MO).

I then measured the inorganic C fraction of each sample by adding 6N HCl (with 3% Fe_2Cl_3) to a 1g subsample of soil and measuring the voltage produced (Nelson and Sommers 1982). I obtained the organic C fraction by subtracting % inorganic C from % total C (Nelson and Sommers 1982).

I estimated particulate organic matter (POM) carbon and nitrogen by following a modified method from Cambardella and Elliott (1992). I dispersed five composite samples at depths of 0-5-cm, 5-15-cm and 15-30-cm from each field in 100 ml of 5 g/L sodium hexametaphosphate and shaken overnight (18h) on an orbital shaker. I then passed the dispersed soils samples through a sieve stack made up of a 500-μm and 53-μm sieves and rinsed them several times with water. Material retained on the 53-μm sieve is the fine POM and the coarse POM is the material that is retained on the 500-μm sieve. I collected these particle size fractions and dried them overnight at 105°C. I weighed the dried samples and then ground them on a ball mill grinder, and analyzed them for total C and N using an automated dry combustion method (described previously). I analyzed the inorganic C content from samples known to contain high levels of carbonates by using the voltmeter method (described previously), and then subtracting the inorganic C from the total C fraction to estimate the percent organic C.

To measure potentially mineralizable C and N, I followed methods used by Schimel (1986) to estimate potential net C and N mineralization. This involved taking soil samples to a depth of 15cm with a 5-cm diameter corer. In the field, I divided the collected samples into depth increments of 0-5-cm and 5-15-cm. I sieved the fresh soils and extracted inorganic N from a 25-g subsample with 2N KCl. Samples were stored in the refrigerator for the remainder of the time needed to prepare my incubations. I measured field capacity for each soil and analyzed samples for current water content using a gravimetric method (Cassel and Nielsen 1986). I then brought soil samples up to field capacity and placed them in a sealed 1-L jar with enough water to cover the bottom to prevent the soils from drying out (Schimel 1986). A vial containing 2 ml of 1N NaOH solution was added to the jar to catch respired CO_2. I incubated the soils for 30 days at 25°C, extracted soils for inorganic N using KCl, and titrated the base traps to assess CO_2 evolved (Snyder and Trofymow 1984). Extracted N was then filtered and measured using a Latchet autoanalyzer (EPA 1979). The amount of CO_2 evolved was then calculated by the difference between the amount of titrant in the blank and the sample. Mineralized C was calculated as the amount of CO_2 evolved per gram of soil during the incubation. N mineralized was calculated by the difference between final and initial N extracted by the KCl.

I measured soil textures using a modified method from Gee and Bauder (1986). I subsampled 30g of soil and added 5% sodium hexametaphosphate (HMP) solution to the soil, and shook the mixture for ~18 hours on an orbital shaker. I estimated the clay fraction with a hydrometer. I measured the sand fraction by pouring the sample's contents through a 53-μm sieve to catch the sand portion of the soil, and dried and weighed the contents left on the sieve. To estimate the silt fraction, I subtracted the percent sand from the percent clay.

Statistical design and methods

The design of my experiment was a completely randomized design. For all analyses, there were four treatments each replicated three times. The treatments were corn, rangeland, wheat and fallow. Wheat and fallow treatments are part of the same landuse type (dryland wheat-fallow), but the two portions were sampled and analyzed separately because we thought it likely that differences would occur in active and intermediate fractions of C and N between wheat and fallow portions. For statistical analyses of total organic C and N and the C/N ratio, I averaged wheat and fallow fields together. Texture varied substantially across replicates of my treatments, and therefore texture was used as a covariate in all analyses of total organic C and N. Texture did not help to explain the variability ($p > .75$) between landuse types for potentially mineralizable C and N or POM fractions, so texture was not used as a covariate in these analyses. I checked all data for normality and homogeneity of variance and I made necessary transformations where needed. POM and mineralizable C and N data showed a heterogeneity of variance and were therefore log transformed. To test for differences in mineralizable C and N and POM fractions by depth and differences in C and N content cumulatively to 30cm, I ran a general linear model one-way analyses of variance (ANOVA) procedures using SAS (SAS Institute 1999). To include texture in my analyses of cumulative total organic C and N, I calculated a weighted average (by mass at each depth) of percent sand for the entire solum.

Results and Discussion.

Soil textures varied within landuse types (Appendix C). An ANOVA test for significant differences between replicates of a single landuse showed that texture varied significantly in at least one replicate for all landuse types. There were no significant differences in texture between landuse types, however, likely due to the high variability in texture within a landuse type. The differences in texture among landuse management types make conclusions regarding the effects of landuse management practices on soil properties difficult, since initial soil characteristics were not homogenous in the first place. Therefore, differences in C and N among landuse management types can not be attributed entirely to differences in the type of landuse practice.

Total Nitrogen and Organic Carbon

Wheat-fallow fields contained significantly less organic C and total N in the upper 30cm of the soil profile than in rangelands and corn fields, while corn fields were not significantly different from rangelands in C or N (Figure 2.1). Wheat-fallow fields had an average of 39% less C than rangelands ($p = .02$) and 39% less C than corn fields (p = =.03). No significant differences in C occurred between corn fields and rangelands (p =

.89). Soil N inventory among landuse types mimicked that of C. Wheat-fallow fields contained 38% less N than rangelands (p = .02) and 32% less N than corn fields (p = .01).

The C/N ratio in both cultivated fields appeared to narrow relative to rangelands (Figure 2.2). However, a significantly lower C/N ratio only occurred in corn fields relative to rangelands (p = .007); there were no significant differences between wheat-fallow fields and rangelands (p = .23).

The significantly lower C and N contents in wheat-fallow fields relative to rangelands in the upper 30cm of soil is consistent with many other studies that have found significantly lower C and N inventories in this region of the soil profile (Haas et al. 1957, Tiessen et al. 1982, Schimel et al. 1985, Aguilar et al. 1988, Burke et al. 1989, Burke et al. 1995, Bowman et al. 1990, Wood et al. 1990 and many others). However, lower C/N ratios are also typically found in wheat-fallow fields compared to rangelands in this region (Ihori et al. 1995, Bowman et al. 1990, Burke et al. 1995) as a result of elevated rates of C and N mineralization under wheat-fallow cultivation (Davidson and Ackerman 1993). Differences in sampling depth between this study and previous studies may have contributed to this discrepency in results.

My results did not show significant differences in total soil organic C or N inventories between rangelands and corn fields, which supports my first hypothesis that irrigated corn agriculture does not cause a loss of soil organic C or total N. This result most closely agrees with the study done by Lueking and Schepers (1985) who found no losses of C or N in irrigated, fertilized corn fields relative to native prairie in the sandhills of Nebraska. However, the C/N ratio in their study increased under irrigated corn agriculture which is the opposite trend I observed in this study. The difference between their results an the results from this study may be due to differences in sampling depths. Lueking and Schepers (1985) sampled to a depth of 15cm whereas I compared differences to a cumulative depth of 30cm.

My results also show that dryland wheat-fallow agriculture contained significantly less organic C and total N than irrigated corn fields. This result supports my hypothesis that C and N inventories would be greater in irrigated corn than dryland wheat-fallow fields. The differences in soil C and N contents between these land use types are likely caused by the large differences in plant residue inputs and fertilizer N and water additions in corn fields.

Particulate Organic Matter Fractions

Wheat and fallow fields contained significantly less particulate organic matter (POM) than rangelands at all depths to 30cm while in corn fields, POM was significantly less than in rangelands only in the upper 5cm (Figure 2.3). Coarse POM-C and POM-N seemed to be more sensitive to differences in landuse than fine POM-C and POM-N, but a consistent pattern of lower POM quantities among cultivated landuse types only occurred in the 0-5cm layer of soil. Fallow fields contained significantly lower amounts of POM at depths 0-5cm and 5-15cm than corn fields or rangelands, and coarse POM-N and fine POM-C were also significantly lower in fallow fields than in rangelands or corn fields at the 15-30cm depth. Wheat fields had significantly less coarse and fine POM-C and POM-N in the 0-5cm layer of soil than rangelands but significantly more POM-C and POM-N than fallow fields at this depth. Fine POM-C continued to be significantly lower in wheat fields than in rangelands and corn fields at the 5-15cm and 15-30cm depths.

Finally, corn fields had significantly less coarse and fine POM-C and coarse POM-N than rangelands in the upper 5cm of soil. Below this depth, there were no significant differences from rangelands.

Losses of these "intermediate" fractions of C and N commonly occur as a result of cultivation since these fractions are rapidly and easily mineralized (Schimel et al. 1985, Cambardella and Elliott 1994). Active pools of C and N are also rapidly lost due to cultivation, but these pools are more quickly replenished, often at the expense of more intermediate pools (Schimel et al. 1985). The magnitude of loss of POM fractions in cultivated fields depends on a number of factors including tillage intensity (Tiessen and Stewart 1983, Balesdent et al. 1988, Cambardella and Elliott 1992) and plant residue inputs (Wood et al. 1990, Burke et al. 1997). Conventionally tilled dryland wheat-fallow fields such as those in my study have largely reduced litter inputs and are tilled continually throughout the growing season. This landuse type showed significant losses of coarse and fine POM-C and POM-N to depths of 30cm. Similar results have been shown from previous studies (Elliott 1986, Cambardella and Elliott 1992, Robles and Burke 1997). In addition, significant differences in coarse and fine fractions of POM occurred between fallow and wheat portions of the same field, demonstrating the sensitivity of POM to short-term changes in litter inputs. Compared to wheat-fallow fields, plant residue inputs in irrigated corn fields are much higher (Buyanovsky and Wagner 1997). This differences in plant residue inputs may have been why POM fractions in corn fields were significantly higher than in wheat or fallow fields. In addition, high decomposition rates and greater disturbance by tillage practices in the surface 5cm in corn fields could have caused POM to be significantly lower in corn fields than in rangelands, despite higher plant residue inputs. The lower POM at this depth, however, was apparently not large enough to reflect lower total organic C or N in the 0-30cm depth.

Potential Mineralization Rates

Potentially mineralizable C and N significantly differed between landuse types in the upper 5cm soil layer (Figure 2.4). Rangelands and corn fields had a significantly higher rate of potentially mineralizable C than wheat or fallow fields. Wheat fields also had a significantly higher rate of potentially mineralizable C than fallow fields. Fallow fields had significantly lower potentially mineralizable N than each of the other 3 landuse types. There were no significant differences in potentially mineralizable C or N at the 5-15cm depth in the soil among any of the landuse types.

My results support those of Schimel et al. (1985), Woods et al. (1990), Ihori et al. (1995) and others who have also found that tillage has caused a loss of potentially mineralizable C and N in dryland wheat-fallow crops. Potentially mineralizable C and N often decreases with tillage as a result of reductions in plant residue inputs and the destabilization of soil aggregates (Schimel et al. 1985, Wood et al. 1990, Burke et al. 1995, Ihori et al. 1995). In irrigated corn fields, however, there were no significant reductions in potentially mineralizable C or N relative to rangelands. One explanation as to why corn fields did not have lower potentially mineralizable C and N than rangelands is that the increase in plant residue inputs in corn systems was sufficient to maintain levels of mineralizable C and N. Wood et al. (1990) also found that potential C and N mineralization rates were controlled by the quantity of plant residue return to the soil.

There were also significant differences in potentially mineralizable C and N between wheat and fallow portions of the wheat-fallow fields which shows the sensitivity of this pool of organic matter to differences in plant residue inputs. In addition, fertilizer N applications could have contributed to the higher potential N mineralization activity in corn fields.

No significant differences in potentially mineralizable C or N occurred in the 5-15cm depth among the landuse types. However, differences in mineralizable C and N to 15cm have been reported in other studies (Ihori et al. 1995, Schimel et al. 1995). A possible reason why I did not see significant differences to this depth could be that during my field sampling, the soils were unusually wet following a recent series of rain showers in the area. Because my samples were extremely wet, it was impossible to thoroughly sieve out roots and plant debris from many of the samples at the lower depths and in addition, the field capacities of these soils were often exceeded. The combination of factors probably produced the high variability in C and N measurements among landuse types seen at the 5-15cm depth in this study, thus masking possible significant differences among landuse types.

The maintenance of potentially mineralizable C and N in corn fields seems at odds with my earlier results, which showed a reduction in POM-C and POM-N in corn fields at the same depth. Both fractions are rapidly lost as a result of cultivation and I expected that neither of these fractions would change with irrigated cultivation. One reason for this pattern, as hypothesized by Schimel et al. (1985) and modeled by Parton et al. (1983), of a reduction in POM fractions but not potentially mineralizable C and N could be that the active fraction, although most rapidly lost due to cultivation, is also rapidly replenished at the expense of intermediate fractions. The result may be a large loss in the intermediate fractions of soil organic matter but not necessarily a decrease of active fractions (Schimel et al. 1985).

Conclusions.

This study shows that dryland wheat-fallow agriculture in the semiarid region of the shortgrass steppe causes significant losses of soil organic C and total N in the upper 30cm layer of the soil profile but that irrigated, fertilized croplands in this region do not. Significant losses of soil C and N occurred in dryland wheat-fallow fields in the 30cm layer of soil but no losses in C or N occurred at this depth in corn fields. Active and intermediate pools of C and N were also lower in wheat-fallow fields than native rangelands, while corn fields, on the other hand, only showed lower intermediate pools of C and N than rangelands in the upper 5cm of the soil. No losses in the intermediate fraction of organic matter below 5cm or losses of active C or N occurred in corn fields. Furthermore, wheat-fallow fields also had significantly lower total organic C and N, and lower amounts of active and intermediate fractions of C and N than corn fields. These differences in total soil organic C and N and active and intermediate fractions of C and N among landuse types show that irrigation and fertilization play an important role in maintaining soil organic C and total N in cultivated cropland systems in the semiarid region of the shortgrass steppe. The differences in type of crop grown, and the plowing practices used, also likely contribute to soil C and N differences among croplands.

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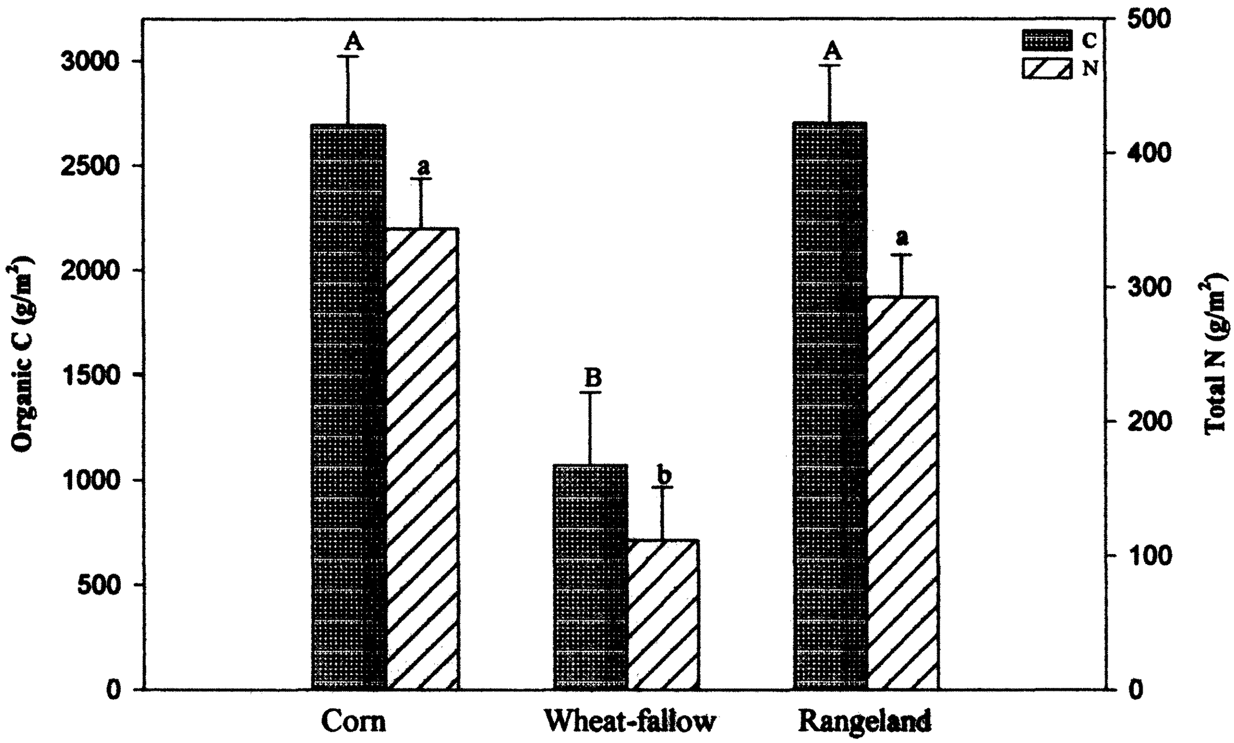

Figure 2.1 Soil organic carbon (C) and total nitrogen (N) contents to a depth of 30cm from three landuse management types (dryland wheat-fallow, irrigated corn and native rangeland) located in or adjacent to the Pawnee National Grasslands in Weld County, Colorado. An ANOVA test was used totest for significant differences among landuse management types. Significant differences in C and N ($p < .05$) among landuse management types are indicated by the different letters. The vertical line on each bar indicates one standard error.

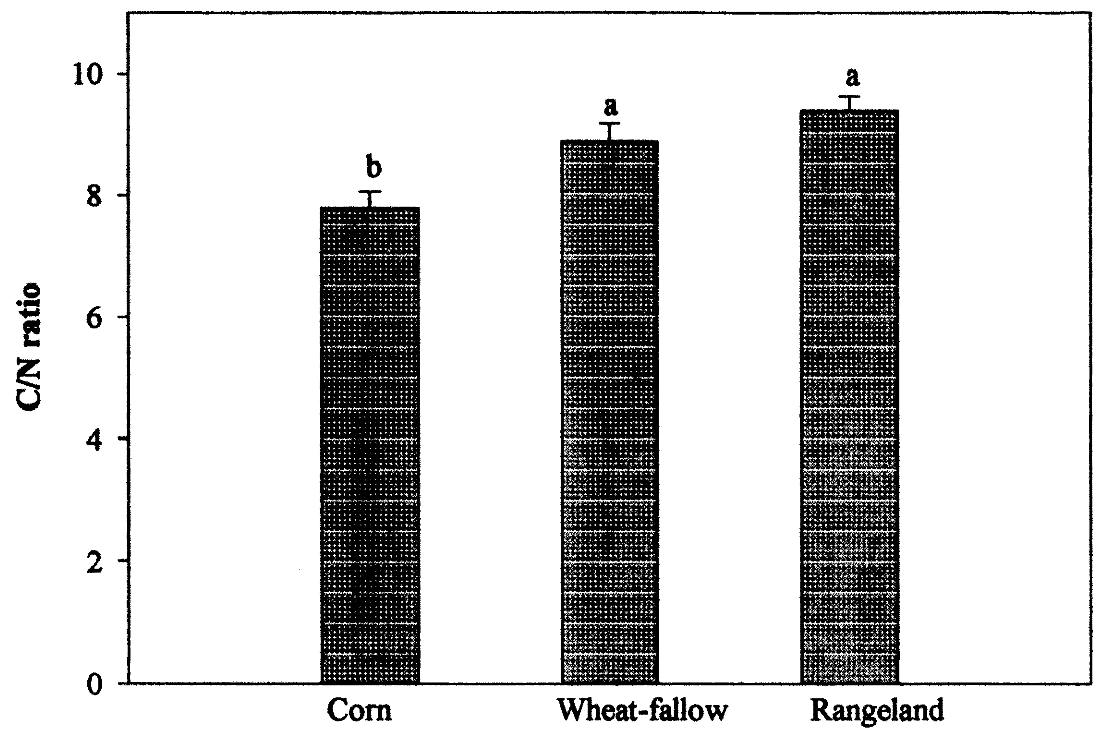

Figure 2.2 The C/N ratio at the 0-30cm depth increment from three landuse management types (dryland wheat-fallow, irrigated corn and native rangeland) located in or adjacent to the Pawnee National Grasslands in Weld County, Colorado. An ANOVA test was used totest for significant differences among landuse management types. Significant differences in the C/N ratio ($p < .05$) among landuse management types are indicated by the different letters. The vertical line on each bar represents one standard error.

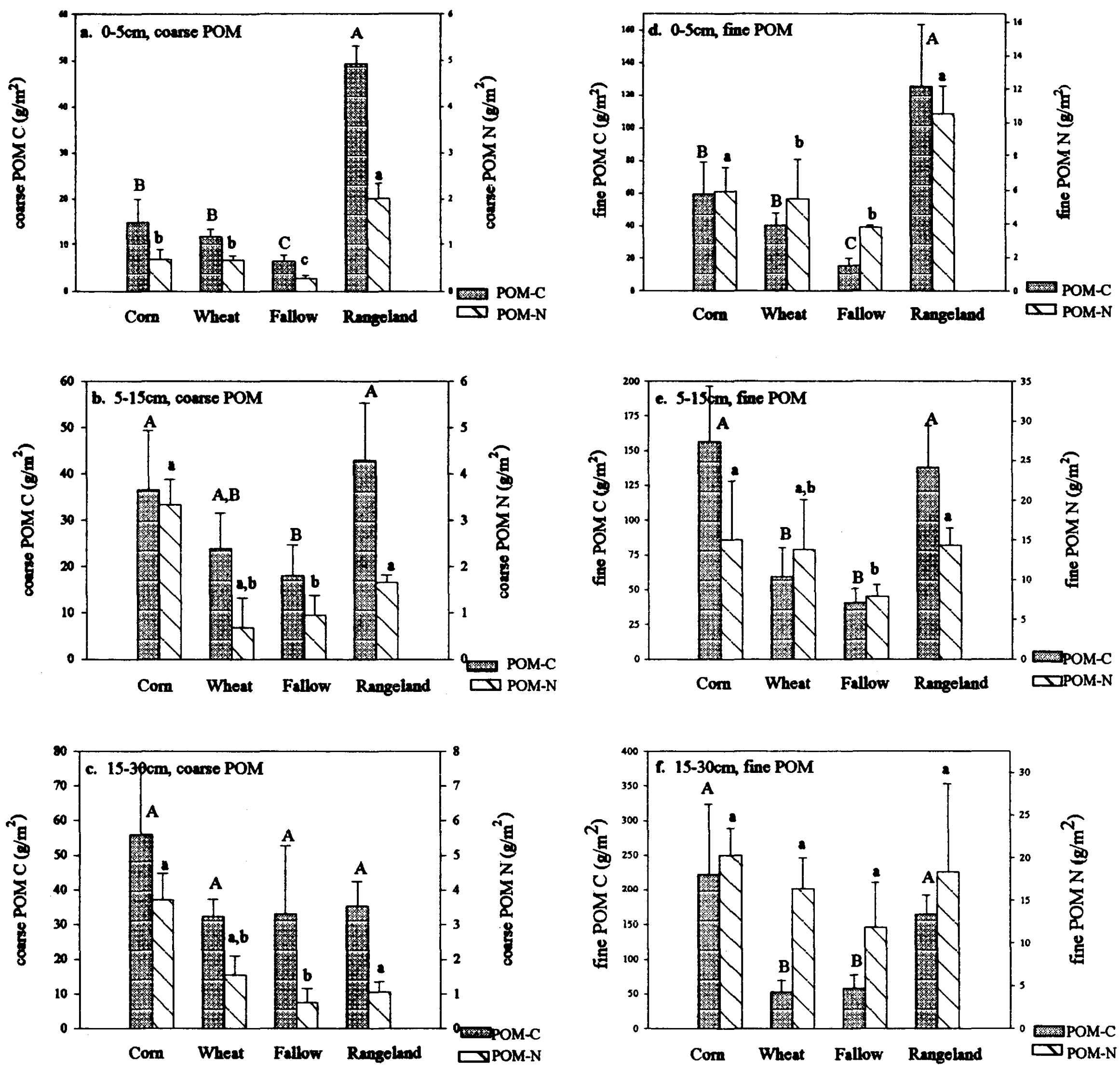

Figure 2.3 Carbon (C) and nitrogen (N) contents of coarse and fine particulate organic matter fractions (cPOM and fPOM) of three soil depths from four landuse management types (irrigated corn, dryland wheat, dryland fallow and native rangeland) in or adjacent to the Pawnee National Grasslands in Weld County, Colorado. (a) cPOM at 0-5cm in the soil; (b) cPOM at 5-15cm; (c) cPOM at 15-30cm; (d) fPOM at 0-5cm; (e) fPOM at 5-15cm; (f) fPOM at 15-30cm. An ANOVA test was used to test for significant differences for C and N contents of cPOM and fPOM among landuse management types for each depth. Significant differences ($p < .05$) among landuse management types are indicated by different letters. The vertical line on each bar indicates one standard error.

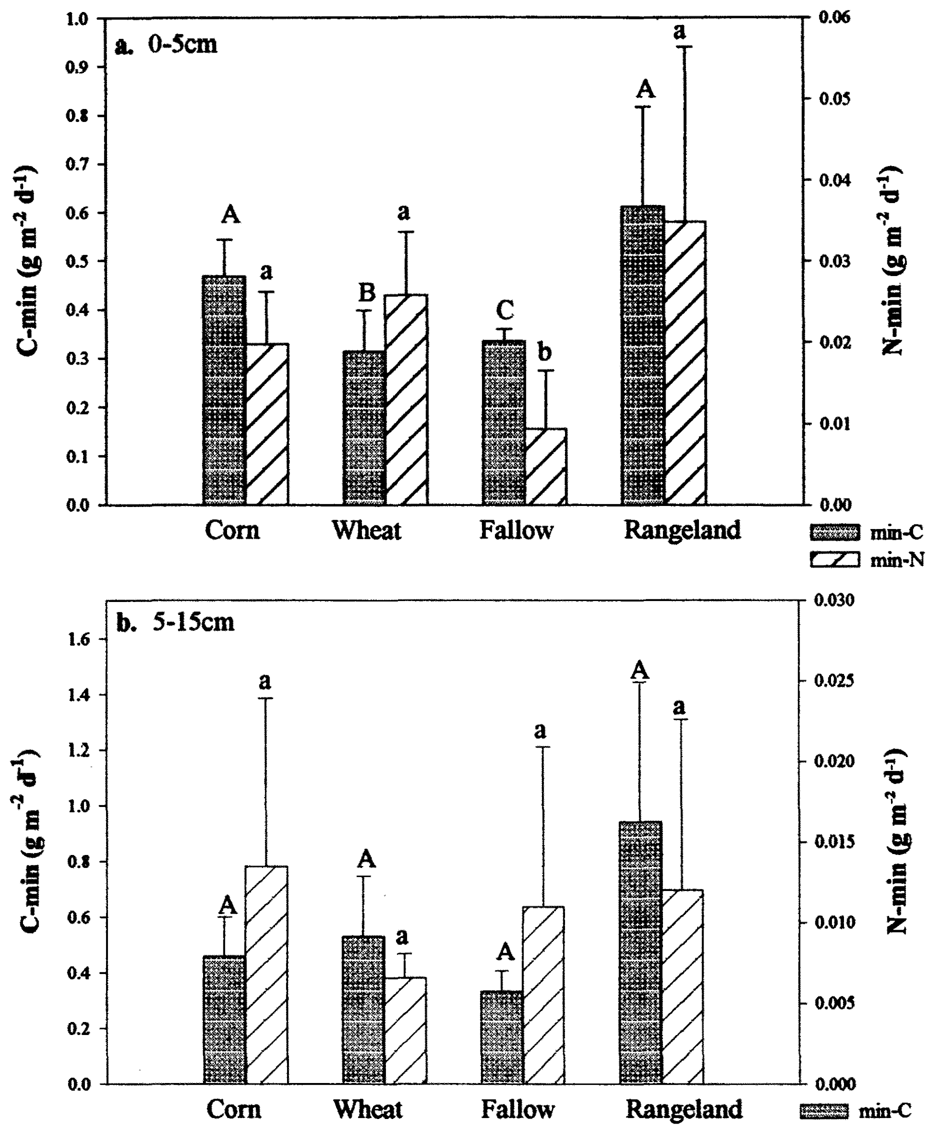

Figure 2.4 Potentially mineralizable carbon (C-min) and potentially mineralizable nitrogen (N-min) in the (a) 0-5cm layer of soil, and the (b) 5-15cm layer of soil from four landuse management types (irrigated corn, dryland wheat, dryland fallow and native rangeland) in or adjacent to the Pawnee National Grasslands in Weld County, Colorado. An ANOVA test was used to determine significant differences in potentially mineralizable C or N among landuse management types for each depth. Significant differences ($p < .05$) among landuse management types are indicated by different letters. The vertical line on each bar indicates one standard error.

CHAPTER III. DISTRIBUTION AND CHANGES OF C, N AND P WITH DEPTH IN IRRIGATED AND DRYLAND AGROECOSYSTEMS OF NORTHEASTERN COLORADO

Introduction.

To assess the full potential of soil organic carbon (SOC) and nitrogen (N) changes in the soil due to cultivation, an inventory of changes in SOC and N of the entire soil profile is needed (Yonker et al. 1988, Tiessen et al. 1982, Davidson and Ackerman 1993). This is because changes in C and N in the soil can extend below the plow layer as compaction, erosion and leaching occur in cultivated soils (Aguilar et al. 1988). As upper soil layers are compacted and eroded away, subsurface soil may become incorporated into the surface layer, further diluting organic C and N contents. Where there is adequate water influx through a soil, dissolved organic compounds (Ajwa et al. 1998) and N (Liang et al. 1991, Ajwa et al. 1998) can be transported downward in the profile, thus altering the vertical distribution of C and N. Evans et al. (1994) also found that fallow practices in wheat-fallow fields in the shortgrass steppe have caused N leaching to occur below the rooting zone of wheat plants. The total quantity of phosphorus (P) and available P fractions are also altered by cultivation practices (Aguilar et al. 1988). Total P can decrease following cultivation as a result of accelerated rates of erosion and crop removal (Barber 1979, Aguilar et al. 1988). The relative proportions of inorganic and organic P also change as P mineralization rates increase due to cultivation (Barber 1979, Aguilar et al. 1988).

The objective of this chapter is to investigate whether changes in C, N and P have occurred below the plow layer by comparing the vertical distribution and cumulative contents of C, N and P among landuse types. My hypothesis is that changes in the amount and distribution of soil C, N and P have occurred in both irrigated corn and dryland wheat-fallow fields below the plow layer because irrigation and fallow practices are known to leach N and organic matter downward in the soil profile. Changes in plant residue inputs and decomposition rates can also affect C and N below the plow layer (Aguilar et al. 1988). P distribution in the soil is strongly influenced by the type of parent material but may be altered from its uncultivated state by cropland practices that alter the biochemical processes in the soil profile (McGill and Cole 1981). Furthermore, a loss of soil mass due to erosion has likely occurred, particularly in wheat-fallow systems, and can be reflected in the soil profile by losses of total P and differences in C and N contents between cultivated and uncultivated systems (Aguilar et al. 1988).

As addressed in the previous chapter, large differences exist between irrigated and dryland agriculture in the shortgrass steppe with regard to the quantity and types of C and N inputs and manipulation of the soil. Although irrigated corn represents a geographically small proportion of managed land, its very different management regime and much greater productivity (CO Agricultural Statistics Service 1999, D.P. Smith, unpublished data) suggest that this farming system could play an important role in the biogeochemical processes in this region.

Materials and Methods.

Study Area

As described in the previous chapter, I selected three fields each of dryland wheat-fallow, native rangeland, and irrigated corn sites for study. Rangeland sites are located on the Pawnee National Grasslands (PNG) of northeastern Colorado (40°49'N, 107°47'W). Wheat and corn fields are located on private lands adjacent to the PNG. The soil in this region is derived from calcareous loamy alluvium. Soils in this region are classified as Aridic Argiustolls (Soil Survey Staff 1982). The soil series varied widely among fields and landuse types in this study (Appendix A). Descriptions of the soil series and soil profiles are summarized in Appendix B. The rangeland sites have never been cultivated and are moderately grazed by cattle during summer. Adjacent wheat-fallow fields have been planted with winter wheat since the 1930's. A sweep plow is used in all of the wheat-fallow fields which extends an average depth of 15cm into the soil. The selected corn fields have been planted with continuous corn since at least 1993. Previous to 1993, these corn fields were used for irrigated corn or hay fields at least since 1963, and aerial photos dating back to 1938 show no indication that the fields were used for wheat-fallow. Corn fields are fertilized with nitrate-ammonium (140 kg per hectare over the field season) and are grown for grain. Two of the fields are irrigated by a center pivot and the third is flood irrigated. The plow method used in the irrigated corn fields is with a moldboard plow, which extends into the soil approximately 25cm.

Mean annual temperature in this area ranges between 8.6 ± 0.6°C and mean annual precipitation varies between 320 and 400mm (Lauenroth and Sala 1992). The vegetation of the native rangeland sites is dominated by *Bouteloua gracilis* (Kunth) lag.

ex Steud. and *Buchloe dactyloides* (Nutt.) Englem.. A variety of forbs, subshrubs, succulents and annual grasses are also present.

Sampling protocol and laboratory analyses

In the summer of 1999, I took five randomly located 2-meter deep cores from three separate fields of three landuse types: wheat-fallow, corn and rangeland. Wheat and fallow portions of the wheat-fallow fields were sampled and analyzed separately for a total of 3 fallow and 3 wheat fields. For the wheat and corn fields I cored between rows. I divided each core sample into depth increments of 0-5cm, 5-15cm, 15-30cm, 30-45cm, 45-60cm, 60-75cm, 75-90cm, 90-105cm, 105-135cm, 135-165cm and 165-195cm. I then air dried and sieved the soil samples through a 2mm diameter sieve. I weighed the sieved soils to estimate the fine soil mass of each sample. I ground a subsample from each depth increment and analyzed these for total C and N using automated dry combustion on a LECO CHN-1000 (Laboratory Equipment Corp., St. Joseph, MO).

I measured the inorganic C fraction of each sample by adding 6N HCl (with 3% Fe_2Cl_3) to a 1g subsample of soil and measuring the voltage produced (Nelson and Sommers 1982). I obtained the organic C fraction by subtracting % inorganic C from % total C (Nelson and Sommers 1982).

I measured phosphorus contents and following modified methods of Olsen and Sommers (1982). I measured total phosphorus by digesting the soil with 60% perchloric acid ($HClO_4$) and analyzing it by inductively coupled plasma optical emission spectroscopy. Inorganic P was extracted with 0.5*M* $NaHCO_3$ and analyzed by a colorimetric assay.

I measured texture by using a modified method from Gee and Bauder (1986). I subsampled 30g of soil and added 5% sodium hexametaphosphate (HMP) solution to the soil, and shook the mixture for ~18 hours on an orbital shaker. I estimated the clay fraction with a hydrometer. I measured the sand fraction by pouring the sample's contents through a 53-μm sieve to catch the sand portion of the soil, and dried and weighed the contents left on the sieve. To estimate the silt fraction, I subtracted the percent sand from the percent clay.

Statistical Design and Analysis

The design of my experiment was a completely randomized design. For all C and N analyses, there were three replicates each of four treatments (corn, rangeland, wheat and fallow). Wheat and fallow treatments are part of the same landuse type (dryland wheat-fallow), but for C and N analyses these two portions of the same landuse management type were sampled and analyzed separately, and then averaged together in all subsequent statistical analyses. For all P analyses, there were three replicates each of three treatments. The treatments were corn, rangeland and wheat-fallow. Wheat and fallow portions of the wheat-fallow fields were sampled separately and composited before all P analyses in order to save analysis costs. Texture varied substantially across replicates of my treatments and therefore texture (percent sand) was used as a covariate in all analyses of C, N and P. I checked all data for normality and homogeneity of variance and I made necessary transformations where needed. Comparisons of cumulative C, N and P, and C, N and P by depth among landuse types were tested using general linear model one-way analyses of variance (ANOVA) procedures in SAS (SAS Institute 1999).

To include texture in my analyses of cumulative C, N and P, I calculated a weighted average (by mass at each depth) of the percent sand for the entire solum. To compare differences in the vertical distribution of C, N and P among landuse types, I statistically analyzed differences in C, N and P contents (g m^{-1} cm^{-1}) among depth increments in soil profiles of a single landuse type. This was done using a repeated measures mixed model analysis of variance procedure in SAS (SAS Institute 1999). Depth and texture variables were treated as fixed effects and depths within a replicate were randomized. All C and N analyses were made to a depth of 195cm. All P analyses were made to a depth of 105cm.

Results.

Differences in C, N and P by depth

Comparisons of soil C, N and P contents at each depth increment among landuse types revealed that differences in C, N and $NaHCO_3$-extractable P contents extended as deep in the soil profile as 195cm for C and N and 30cm for $NaHCO_3$-extractable P (Figure 3.1a-3.3a). There were no significant differences in total P content among landuse types at any depth (Figure 3.4a).

Soil organic C was significantly greater in rangelands than both corn ($p < .0001$) or wheat-fallow ($p = .0002$) fields at the 0-5cm of soil. Rangelands continued to have significantly greater organic C inventory than wheat-fallow fields at depths 5-15cm and 30-45cm. From 45 to 75cm and below 165cm rangelands also contained significantly greater organic C than corn fields. Wheat-fallow fields also had significantly more organic C than corn fields at the 165-195cm depth.

Differences in N among landuse types by depth mimicked that of organic C where rangelands contained significantly greater N than corn ($p = .002$) or wheat-fallow ($p = .001$) fields at the 0-5cm depth. Rangelands also contained significantly greater N than cornfields at the 165-195cm depth. Finally, wheat-fallow fields contained significantly more N at the 165-195cm depth than rangelands or corn fields.

$NaHCO_3$-extractable P content was significantly greater in corn fields than rangelands at the 5-15cm depth, while corn fields had significantly greater $NaHCO_3$-extractable P than wheat-fallow fields in the upper 30cm of soil. No significant differences in $NaHCO_3$-extractable P below 30cm occurred among landuse types.

Distribution of C, N and P in the soil profile

Distribution of C, N and P among landuse types differed primarily in the upper 30cm of the soil (Figures 3.1a-3.4a). In rangelands, organic C content per centimeter decreased from the surface down. The amount of C per centimeter in the upper 5cm of rangeland soil profiles was significantly greater than all depths below 5cm. In corn fields, however, C content increased from the surface down to 30cm, and then decreased. Although there were no significant differences in C content in corn fields from the surface to 30cm, C content at depths 5-15cm and 15-30cm was significantly higher than all depths below 45cm, whereas C content at the 0-5cm depth was not significantly different from contents further down in the soil profile. Organic C content in wheat-fallow fields showed a more or less uniform distribution from the surface down to 90cm. There were no significant differences in C content at any depth until 90cm in the soil profiles of wheat-fallow fields. Below 90cm, C contents decrease and are significantly lower than C contents above 90cm.

The distribution of N and $NaHCO_3$-extractable P mimicked that of C and N in all landuse types. In rangelands, N and $NaHCO_3$-extractable P decreased from the surface down and were significantly greater at the 0-5cm depth than all depths below 5cm. In corn fields, N and $NaHCO_3$-extractable P increased from the surface down. N and $NaHCO_3$-extractable P contents between 5 and 30cm were significantly greater than contents below this depth, while N and $NaHCO_3$-extractable P content at the surface 5cm depth was not significantly different than lower depths. Wheat-fallow fields showed a uniform distribution of N and $NaHCO_3$-extractable P to 90cm. Below 90cm, N content was significantly lower than N at above 90cm.

Total P distribution in rangelands increased from the surface down to 60cm and then decreases slightly until 90cm. Total P was significantly greater in rangelands at depths 45-60cm and 90-105cm than in the upper 15cm of soil. In corn fields total P inventories per centimeter increased from the surface down to 30cm, and then decreased. Total P was significantly lower at the 0-5cm depth of soil than at depths 5-45cm. Finally, total P content per centimeter in wheat-fallow fields appeared to increase slightly from the surface down to 60cm, but no significant differences in total P content among depths occurred.

Total Profile C, N and P inventory

Organic C, total N, total P and $NaHCO_3$-extractable P were analyzed on a total profile basis by estimating cumulative content from the surface down (Figure 3.1b-3.4b). Results from these analyses showed that the effects of cultivation on cumulative C and N contents can be seen below the plow layer in wheat-fallow fields, while in corn fields, cultivation affected only the cumulative $NaHCO_3$-extractable P inventory. Cumulative soil C or N did not significantly differ between corn fields and rangelands below 5cm. In wheat-fallow fields, cumulative C content was significantly lower ($p = .03$) than rangelands to a depth of 135cm, while cumulative N content was significantly lower ($p = .03$) in wheat-fallow fields than rangelands to a depth of 75cm. Cumulative total P content did not significantly differ among landuse types, but the cumulative $NaHCO_3$-extractable P content in corn fields was significantly greater than in rangelands or wheat-fallow fields to a depth of 105cm.

Discussion.

Relatively few agronomic studies have considered changes in C, N or P inventories below the plow layer in cultivated fields as they compare to native or uncultivated conditions. There are, however, some exceptions. Meints and Peterson (1977), for instance, compared changes in the distribution of organic C and several N fractions throughout soil profiles in as deep as 3 meters compared to uncultivated rangelands. They found that changes in organic C and organic N fractions occured throughout the soil profile in cultivated fields. A more recent study by Mikhailova et al. (2000) found significant losses of organic C below 1 meter in cultivated fields of a mixed grass prairie. Results from my study also show that rangelands had a significantly lower organic C content to a depth of 135cm and a significantly lower total N content to a depth of 75cm than rangelands.

Other studies have compared changes in C, N or P between cultivated and native grasslands or rangelands to a depth of 1 meter. Tiessen et al. (1982) and Aguilar et al. (1988), for instance, found that significant losses of C, N and P occurred down to 1 meter between dryland wheat-fallow fields and native grasslands. Collins et al. (1999) compared changes in C and N between corn fields and grasslands in the Corn Belt and found significant differences to a depth of 50cm. The results from this study also show significantly lower cumulative C and N inventories in dryland wheat-fallow fields relative to native rangeland at the 1 meter depth interval. However, there were no significant differences in C or N between corn fields and rangelands below 5cm, contrary to what Collins et al. (1999) observed.

The differences observed in C and N among landuse types both by depth and cumulatively across the profile can be explained by changes in the rates of inputs and outputs of C and N. In rangelands in this region, inventories of C and N are typically highest in the surface 5cm of soil because organic matter inputs, especially from plant roots, are highest at this depth (Burke et al. 1987, Gill et al. 1999, Dodd et al. 2000). The rangelands in my study had similar distributions of C and N with depth.

Cultivation practices can raise decomposition rates by increasing soil temperature and moisture conditions, and physically disturbing the soil which leads to increased exposure of labile forms of C and N. The observed pattern of increasing C and N inventory with depth in the surface 15 or 30cm in wheat-fallow and corn fields is likely in part caused by tillage practices which mix plant residues from the surface into the upper 5-10cm (in wheat-fallow fields) or 15-20cm (in corn fields) of soil. In addition, higher rates of decomposition at the surface of the soil than at depth, caused by a higher frequency of physical disturbance and higher soil temperatures at the surface than at

30cm could cause the observed differences in distribution of C and N in the upper soil layers. Leaching of dissolved organic carbon (DOC) and NO_3^- from the surface downward could also be responsible for the pattern of increasing C and N with depth. Evans et al. (1994) showed that fallow practices can cause leaching of NO_3^- in wheat-fallow fields in this region and other studies have demonstrated that NO_3^- (Liang et al. 1991) and DOC (Wang and Alva 1998) leaching can occur as a result of fertilizer N additions. However, leaching of these labile forms of C and N would result in higher potentially mineralizable rates of C and N with depth (Ajwa et al. 1994); results from the previous chapter of this thesis, however, do not show that potentially mineralizable C and N increase with depth in these cultivated fields.

The losses of C and N in wheat-fallow fields extended far below the plow layer. In addition to changes in decomposition, another cause for the decline in C and N contents wheat-fallow fields may likely be due to greatly reduced organic matter inputs from plant residues. Although aboveground NPP in wheat-fallow fields in this region is greater than in rangelands (D.P. Smith, unpublished data), belowground NPP is much lower in wheat-fallow fields than in rangelands (D.P. Smith, unpublished data), and the quantity of residues left after harvesting is small (Buyanovsky and Wagner 1997). It is also possible that soil erosion at the surface of the profile caused an apparent depletion of C and N in wheat-fallow fields below the plow layer. Cultivation often causes elevated rates of erosion and compaction of surface soil layers (Aguilar et al. 1988). Without a baseline for comparison deep in the soil profile to establish changes in profile thickness, the “effective” sampling depth of the eroded soil profile could possibly have been lower in the profile than in uncultivated systems (Davidson and Ackerman 1993, Aguilar et al.

1988). However, errors due to measuring fixed sampling depths are usually 6% or less and the error caused by sampling at fixed depths are likely highest in the upper 15 to 30cm of the soil profile (Davidson and Ackerman 1993). It is doubtful, furthermore, that changes in the thickness of the soil profile from erosion and compaction could have been reflected in C and N differences as far down in the soil profile as was seen in this study.

Contrary to reductions in plant residue inputs in wheat-fallow fields, inputs of organic matter from plant residues in irrigated corn fields are much greater than in rangelands in this region (Lauenroth, unpublished data). Despite the increase of organic matter inputs, C contents were still significantly lower than rangelands in the upper 5cm of soil. Reduced belowground NPP inputs in corn fields (D.P. Smith, unpublished data) and elevated decomposition rates or translocation of C due to leaching of soluble forms likely explains most of these differences between corn and rangelands. In addition to increased soil temperature and moisture and physical disturbance due to tillage, decomposition rates in corn fields could also be elevated by the addition of fertilizer N which can increase the rate of C mineralization if microbial populations are N limited.

The distribution and accumulation of total and $NaHCO_3$-extractable P are strongly regulated by the type of parent material (Barber 1979, Aguilar et al. 1988), although they can be further altered by weathering and biochemical mineralization (McGill and Cole 1981). In this study, soil textures varied substantially within and among landuse management types (Appendix B), indicating that parent material likely differed among corn, wheat-fallow and rangeland fields. Therefore, it is likely that differences in parent material, rather than landuse management practices, caused the differences in the amount and distribution of total and $NaHCO_3$-extractable P among landuse management types in this study.

Conclusions.

The results of this study show that cultivation has affected both irrigated corn and dryland wheat-fallow agroecosystems below the plow layer in the shortgrass steppe region of the Great Plains. However, the nature of these changes differs dramatically among cultivated landuse types. Cultivation has caused a redistribution of C and N in irrigated corn fields changes while in wheat-fallow fields, losses of C and N occurred deep into the soil profile. Differences in the quantity and distribution of total and $NaHCO_3$-extractable P among landuse management types in this study was likely due to the level of control of parent material differences rather than cultivation practices.

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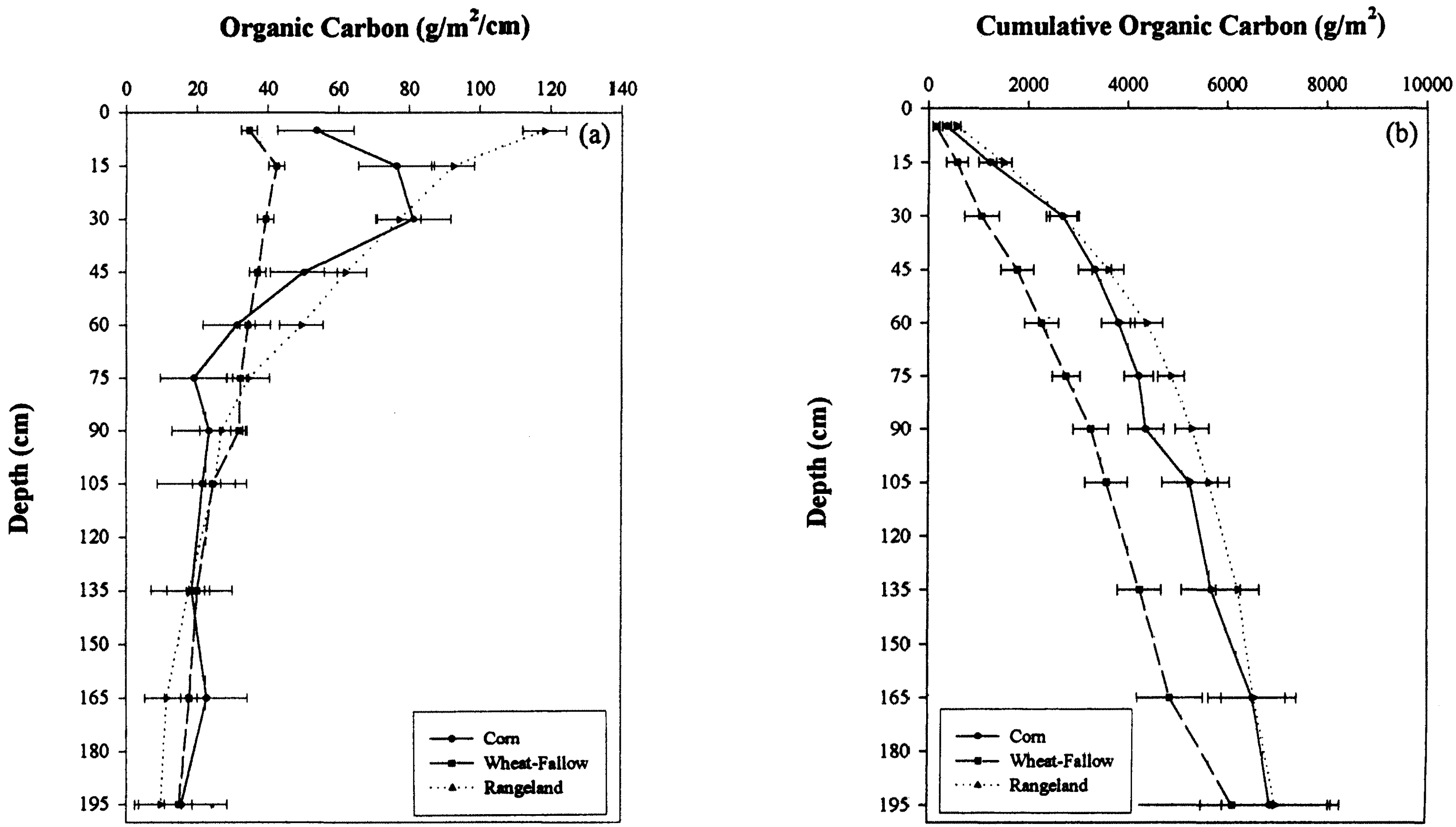

Figure 3.1 (a) Total organic carbon per centimeter and (b) cumulative organic carbon content to a depth of 195cm from three landuse management types (dryland wheat-fallow, irrigated corn, and native rangeland) in or adjacent to the Pawnee National Grasslands in Weld County, Colorado. The vertical bars at each data point represent one standard error.

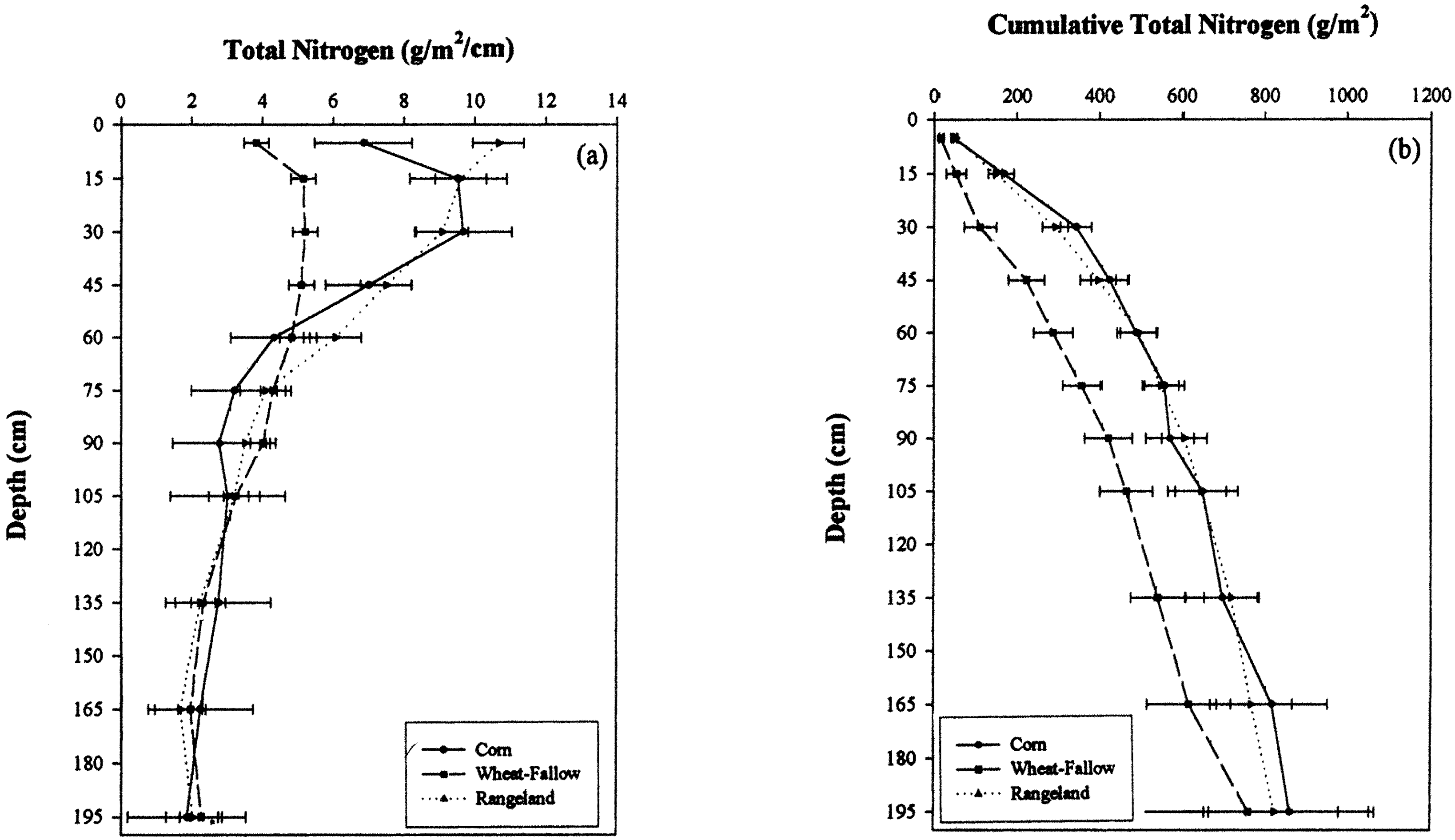

Figure 3.2 (a) Total nitrogen per centimeter and (b) cumulative total nitrogen content to a depth of 195cm from three landuse management types (dryland wheat-fallow, irrigated corn, and native rangeland) in or adjacent to the Pawnee National Grasslands in Weld County, Colorado. The vertical bars at each data point represent one standard error.

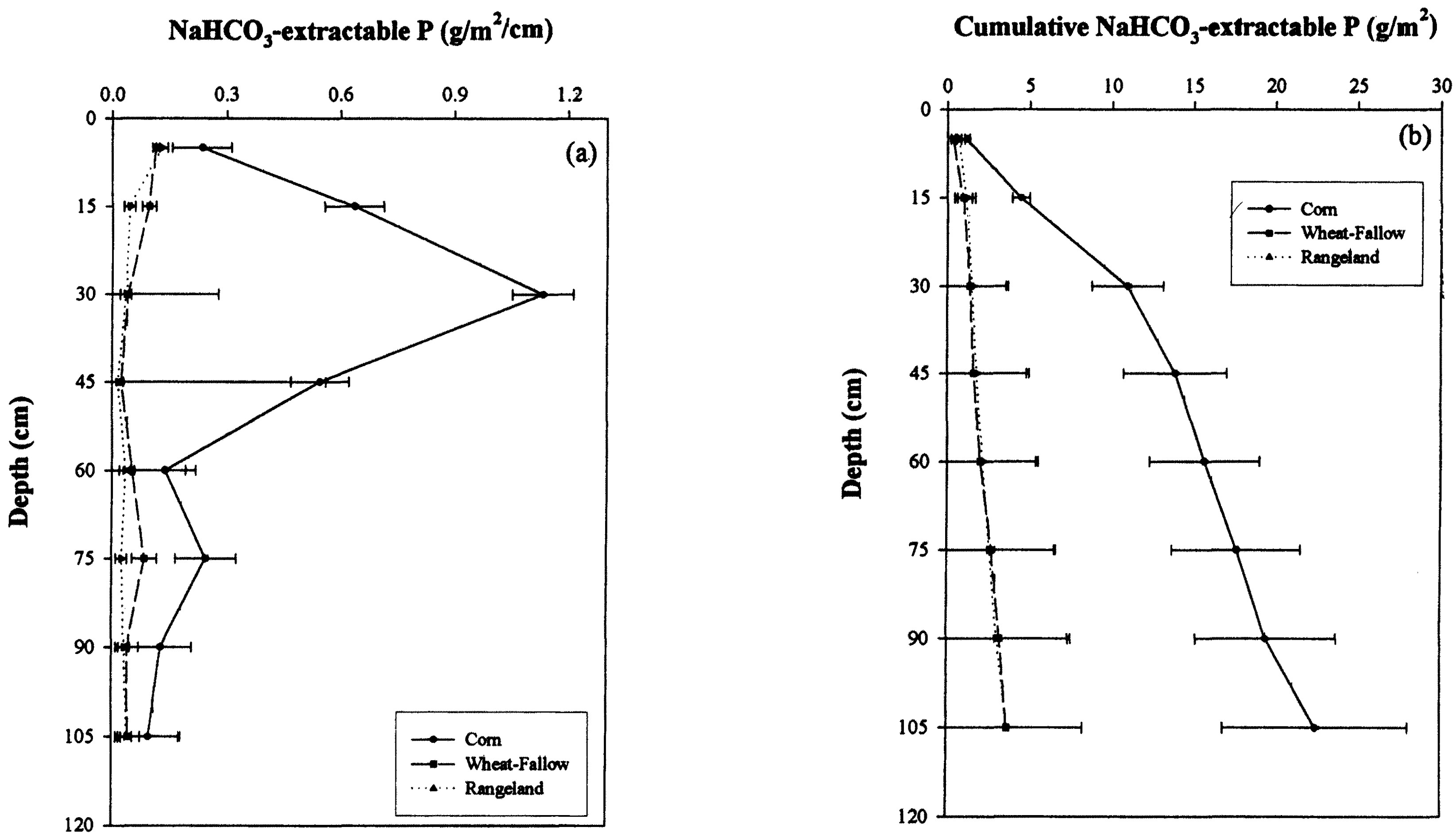

Figure 3.3 (a) NaHCO$_3$-phosphorus (P) per centimeter and (b) cumulative NaHCO$_3$-P content to a depth of 195cm from three landuse management types (dryland wheat-fallow, irrigated corn, and native rangeland) in or adjacent to the Pawnee National Grasslands in Weld County, Colorado. The vertical bars at each data point represent one standard error.

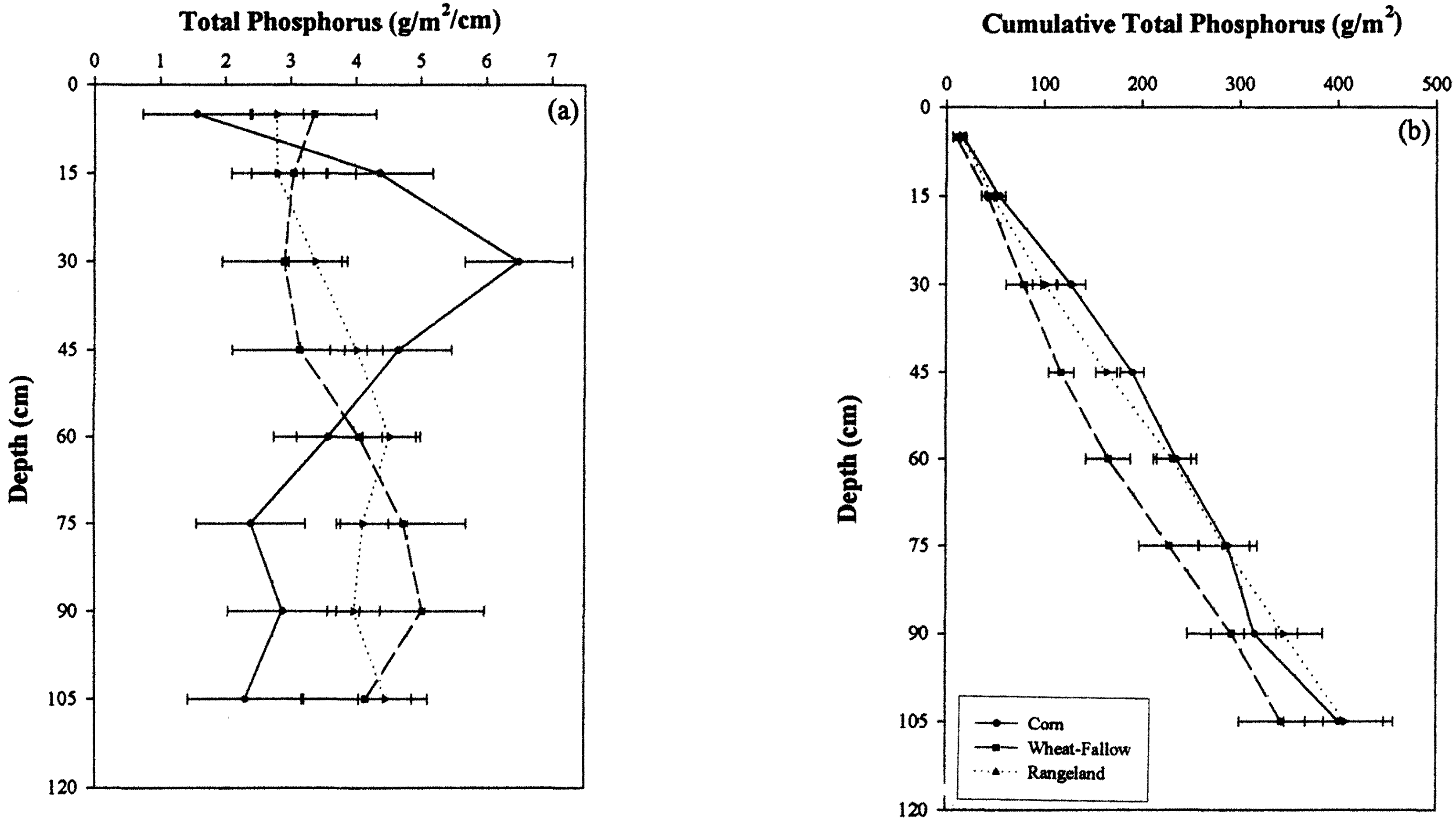

Figure 3.4 (a) Total phosphorus per centimeter and (b) cumulative total phosphorus content to a depth of 195cm from three landuse management types (dryland wheat-fallow, irrigated corn, and native rangeland) in or adjacent to the Pawnee National Grasslands in Weld County, Colorado. The vertical bars at each data point represent one standard error.

CHAPTER IV. CONCLUSIONS

The studies in this thesis demonstrate that changes in the amount and distribution of soil organic C and total soil N occur in both dryland wheat-fallow fields and irrigated corn fields in the semiarid region of the shortgrass steppe as a result of cultivation. However, the nature of these changes differs among landuse management types. The first study of this thesis (Chapter II) showed that dryland wheat-fallow cultivation caused a loss of active, intermediate and total soil organic C and total N in the upper 30cm layer of the soil profile. Losses of organic C and total N in cultivated fields were inferred from differences between cultivated fields and native, uncultivated rangelands. Irrigated corn fields, on the other hand, only showed losses of active and intermediate fractions of C and N in the upper 5cm of the soil; no losses of total organic C and total N occurred in the 0-30cm layer of soil in this landuse type. Furthermore, active and intermediate fractions and C and N in corn fields were significantly higher than in wheat-fallow fields. These differences among landuse types were attributed to both differences in plant residue inputs and changes in the rate of decomposition or elevated erosion rates in cultivated systems relative to rangelands. Increased plant residue inputs in corn fields relative to rangelands, however, apparently offset the rise in decomposition rates and mitigated further losses of C or N below 5cm. Dryland wheat-fallow cultivation on the other hand reduces plant residue inputs to the soil. The reduction in C and N inputs coupled with increased rates of C and N outputs in wheat-fallow fields caused greater losses of C and N than irrigated corn fields in both quantity and depth in the soil profile.

The results of the second study in this thesis (Chapter III) showed that cultivation affected both irrigated corn and dryland wheat-fallow agroecosystems below the plow layer in the shortgrass steppe region of the Great Plains. However, only dryland wheat-fallow fields showed losses of organic C and total N below 30cm while in corn fields, losses of organic C only occurred in the upper 5cm and no significant differences in total N content occurred between corn fields and rangelands. Again, differences in C and N losses among the cultivated landuse types may likely be due to differences in both plant residue inputs and decomposition rates with depth, as well as possible elevated erosion of surface soil layers. Cumulative $NaHCO_3$-extractable P was also significantly greater in the 1-meter soil profile in corn fields than rangelands or wheat-fallow fields, while cumulative total P was not significantly different among any landuse types. The patterns observed in total and $NaHCO_3$-extractable P, however, are likely due to differences in parent material within and among landuse management types, which strongly influence soil P contents.

The distribution of C and N also differed among landuse types. Soil organic C and total N decreased from the surface down in rangelands, while in corn fields, C and N increased from the surface to 30cm and then decreased. Finally, soil organic C and total N in wheat-fallow fields showed a more or less uniform in their distribution throughout the soil profile. The changes in distribution of C and N in corn fields relative to uncultivated rangelands could either be due to a redistribution of fertilizer N or organic C due to leaching or tillage practices, differences in decomposition rates throughout the soil profile, or both. Uniform distribution of C and N in wheat-fallow fields were likely due to a combination of tillage practices that mix the upper few centimeters of soil and reduced C and N inputs below the plow layer. A difference in the tillage depth between wheat-fallow and corn fields also may have contributed to differences in distribution observed between these landuse types. Differences in the distribution of $NaHCO_3$-extractable P among landuse management types were attributed to differences in the underlying parent material among landuse types.

Agronomic studies in this region have thus far concentrated only on losses of C, N and P in the upper soil layers in dryland wheat-fallow systems (Woods and Schuman 1988, Burke et al. 1989, Burke et al. 1995, Bowman et al. 1990, Ihori et al. 1995, Wood et al. 1990, and others). The results from the studies in this thesis indicate that changes in C and N under irrigated corn fields differ from dryland wheat-fallow fields and that changes in C and N continue to occur below the plow layer in wheat-fallow fields.

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Appendix A. Soil series classification of the fields and replicates sampled in this study. All fields are located in or adjacent to the Pawnee National Grasslands in Weld County, Colorado. Soil series classifications were obtained from the Soil Survey Staff of Weld County, Colorado (1982). Fields include irrigated corn, dryland wheat-fallow, and native, uncultivated rangelands. Three replicates of each field were sampled from for this study.

Field and Replicate	Soil Series
Corn 1	Haverson loam
Corn 2	Altvan fine sandy loam
Corn 3	Dacono clay loam
Wheat-fallow 1	Ascalon fine sandy loam
Wheat-fallow 2	Otero fine sandy loam
Wheat-fallow 3	Manzanola clay loam
Rangeland 1	Ascalon fine sandy loam
Rangeland 2	Manzanola clay loam
Rangeland 3	Ascalon fine sandy loam

Appendix B. Soil series descriptions of some soils found in Weld County, Colorado. Series descriptions are from the Soil Survey Staff of Weld County, Colorado (1982).

Altvan fine sandy loam, 0 to 6 percent slopes

Deep, well drained soil on smooth to moderately dissected plains. It formed in calcareous gravelly alluvium. Surface layer is dark grayish brown fine sandy loam 15 centimeters thick. Subsoil is sandy clay loam 45 centimeters thick. Substratum is calcareous sandy clay loam 13 centimeters thick over gravelly coarse sand that extends to a depth of 152 centimeters or more.

Ascalon fine sandy loam, 0 to 6 percent slopes

Deep, well drained soil on smooth to moderately dissected plains. It formed on calcareous gravelly alluvium. Surface layer is dark brown fine sandy loam 20 centimeters thick. Subsoil is sandy clay loam 36 centimeters thick. Substratum is calcareous sandy loam 152 centimeters or more. Moderate permeability and high available water capacity.

Dacono clay loam, 0 to 6 percent slopes

Deep, well drained soil on plains and adjacent stream terraces. It formed on calcareous loamy alluvium. Surface layer is dark grayish brown clay loam 10 centimeters thick. Subsoil is pale brown and light browish gray loam 31 centimeters thick. Underlying material to a depth of 152 centimeters is very fine sandy loam stratified with thin lenses of sand, loamy sand, and clay loam. The soil is calcareous throughout.

Haverson loam, 0 to 3 percent slopes

Deep, well drained soil on flood plains and adjacent stream terraces. It formed on stratified, calcareous, loamy alluvium. Surface layer is pale brown and light brownish gray loam 31 centimeters thick. Subsoil is very fine sandy loam stratified with thin lenses of sand, loamy sand, and clay loam 152 centimeters or more.

Appendix B (continued)

Manzanola clay loam, 0 to 3 percent slopes

Deep, well drained soil on plains in swales and on adjacent stream terraces. It formed on calcareous clayey alluvium. Slopes are plane or concave. Surface layer is grayish brown heavy clay loam 8 centimeters thick. Subsoil is calcareous clay 56 centimeters thick. Substratum is calcareous clay and clay loam 152 centimeters or more.

Otero sandy loam, 0 to 3 percent slopes

Deep, well drained soil on smooth to moderately dissected plains and alluvial fans. It formed on calcareous loamy alluvium. Surface layer is brown sandy loam 13 centimeters thick. Subsurface layer is sandy loam 152 centimeters or more. The soil is calcareous throughout.

Appendix C. Soil textures of three different landuse management types (irrigated corn, dryland wheat-fallow and native rangeland) located in or adjacent to the Pawnee National Grasslands in Weld County, Colorado. Each landuse management type has three replicates. Data are averaged across the 3 replicate plots.

Depth	%sand	%silt	%clay	Depth	%sand	%silt	%clay	Depth	%sand	%silt	%clay
Corn 1				Corn 2				Corn 3			
0-15cm	66.3	11.8	21.9	0-15cm	67.4	15.0	17.6	0-15cm	60.8	17.5	21.7
15-30cm	64.7	13.4	21.8	15-30cm	68.2	15.9	15.9	15-30cm	61.5	20.1	18.4
30-45cm	56.1	16.9	27.0	30-45cm	59.6	19.3	21.0	30-45cm	61.4	18.5	20.1
45-60cm	54.9	16.7	28.4	45-60cm	58.0	20.2	21.8	45-60cm	64.8	12.6	22.6
60-75cm	53.7	17.7	28.6	60-75cm	61.5	17.6	20.9	60-75cm	63.3	13.3	23.3
75-90cm	52.7	20.3	27.1	75-90cm	78.4	13.3	8.3	75-90cm	74.2	9.1	16.7
90-105cm	64.4	17.0	18.6					90-105cm	76.7	8.3	15.0
105-135cm	52.7	18.6	28.7					105-135cm	71.8	12.4	15.7
135-165cm	54.8	16.7	28.5					135-165cm	77.5	8.3	14.2
165-195cm	66.4	11.8	21.9					165-195cm	79.1	9.2	11.7

Appendix C (continued)

Depth	%sand	%silt	%clay	Depth	%sand	%silt	%clay	Depth	%sand	%silt	%clay
|--------------Rangeland 1----------------|				|----------------Rangeland 2----------------|				|----------------Rangeland 3----------------|			
0-15cm	62.4	16.7	20.9	0-15cm	30.6	23.1	46.2	0-15cm	58.4	15.3	26.3
15-30cm	51.1	19.7	29.2	15-30cm	20.4	22.5	57.1	15-30cm	49.0	17.8	33.1
30-45cm	52.9	19.7	27.4	30-45cm	49.8	21.7	28.5	30-45cm	68.3	14.0	17.6
45-60cm	52.9	15.2	32.0	45-60cm	24.6	24.0	51.4	45-60cm	60.5	10.9	28.6
60-75cm	63.1	10.1	26.8	60-75cm	32.1	23.8	44.1	60-75cm	68.0	6.7	25.2
75-90cm	68.2	10.1	21.8	75-90cm	31.4	25.7	42.8	75-90cm	59.6	10.9	29.4
90-105cm	69.3	7.5	23.2	90-105cm	32.3	22.0	45.7	90-105cm	63.8	9.3	27.0
105-135cm	66.4	10.1	23.5	105-135cm	36.7	18.8	44.5	105-135cm	70.0	4.1	25.9
135-165cm	73.2	5.9	21.0	135-165cm	30.5	27.1	42.4	135-165cm	73.3	6.7	20.0
165-195cm	66.2	6.8	27.1	165-195cm	35.5	18.7	45.8	165-195cm	80.0	0.0	20.0

Appendix C (continued)

Depth	%sand	%silt	%clay	Depth	%sand	%silt	%clay	Depth	%sand	%silt	%clay
Wheat-Fallow 1				Wheat-Fallow 2				Wheat-Fallow 3			
0-15cm	67.5	10.0	22.5	0-15cm	59.5	13.5	27.0	0-15cm	81.7	7.5	10.8
15-30cm	59.4	16.9	23.7	15-30cm	54.3	16.9	28.8	15-30cm	78.5	9.0	12.4
30-45cm	50.3	18.0	31.7	30-45cm	41.9	20.5	37.6	30-45cm	72.4	15.1	12.5
45-60cm	62.1	11.8	26.1	45-60cm	74.8	0.0	25.2	45-60cm	55.3	19.4	25.3
60-75cm	53.0	11.8	35.2	60-75cm	70.3	6.6	23.1	60-75cm	78.4	11.7	10.0
75-90cm	64.9	2.5	32.6	75-90cm	74.8	4.2	21.0	75-90cm	83.3	9.2	7.5
90-105cm	62.2	4.2	33.6	90-105cm	65.0	10.0	25.0	90-105cm	87.3	9.1	3.6
105-135cm	68.2	3.4	28.5	105-135cm	38.5	17.1	44.4	105-135cm	85.1	8.3	6.6
135-165cm	65.3	8.3	26.5	135-165cm	37.6	22.8	39.7	135-165cm	88.4	6.7	5.0
165-195cm	69.9	6.7	23.4								