Effects of cultivation and recovery on soil organic matter and N mineralization in shortgrass steppe

Submitted by

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We hereby recommend that the thesis prepared under our supervision by Tamiko Ihori entitled "Effects of cultivation and recovery on soil organic matter and N mineralization in shortgrass steppe" be accepted as fulfilling in part the requirements for the degree of Master of Science.

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Abstract

EFFECTS OF CULTIVATION AND RECOVERY ON SOIL ORGANIC MATTER AND N MINERALIZATION IN SHORTGRASS STEPPE

Understanding cultivation effects on soil organic matter (SOM) and available nutrients to plants is important, because SOM is an important storage of C globally and available nutrients are an important factor in plant growth. It is also important to understand recovery from disturbance such as cultivation. I conducted two studies: one on total SOM and the other on in situ N mineralization in native, cultivated, and recovering abandoned fields in the shortgrass steppe of northeastern Colorado.

I examined total C and N content in 30 cm depth soil of native fields, abandoned fields that were historically cultivated and then abandoned about 50 years ago, and cultivated fields that were cultivated more than 50 years, at 13 sites in the Pawnee National Grasslands. Both total C and N were highest in native, intermediate in abandoned, and lowest in cultivated fields. An average loss from cultivation for total C was 26% and for total N was 29%. Precipitation had a significant effect on SOM content in native fields, but did not have an effect on C and N losses from cultivation. C/N ratio differences among native, abandoned, and cultivated fields were not significant in 30 cm depth soil. I estimated recovery of SOM using the CENTURY model. During 50 years of abandonment of lands, I estimate that 25 g/m^2 of C has recovered, but we could not detect N recovery.

In situ net mineralization in 15 cm depth soil was also examined among three land management treatments (native, abandoned, and cultivated) and two microsites (under individual *Bouteloua gracilis* plants and between individual plants).

Total C, N, and C/N ratios were highest in native, intermediate in abandoned, and lowest in cultivated fields, and higher under plants than between plants. *In situ* net N mineralization, % N mineralization, and moisture content in soils were highest in cultivated fields, but there was no difference between native and abandoned fields. *In situ* net N mineralization, % N mineralized, and soil moisture content were not significantly different between microsites. A ratio of field net N mineralization to lab net mineralization was highest in cultivated fields, but differences between native and abandoned fields were not significant. This ratio tended to be higher between plants than under plants, but there was not a significant difference. Because this ratio may be an index of environmental limitation to N mineralization, I infer that cultivated fields and between plant locations have less environmental restriction than native fields or under-plant locations.

I concluded from these results that nitrogen availability to plants is recovered in abandoned fields from the results of _in situ_ N mineralization. However total C has recovered only 25 g/m^2, and total N did not show recovery in abandoned fields.

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Chapter 1

Effects of cultivation and recovery on soil organic matter in the Pawnee National Grasslands

Introduction

A large proportion of the US Central Grassland region has been cultivated since the late 1800's (Klipple and Costello 1960). In the 1930's, many farmers abandoned their lands, because drought and high wind made it difficult to continue cultivation (USDA,1985). The effect of historical cultivation on depleting soil organic matter is well-documented (Russel 1929; Haas et al. 1957; Schimel et al. 1986; Aguilar et al. 1988; Burke et al. 1989). However, the process of recovery is not well understood, and these abandoned croplands provide a good opportunity to assess the recovery of soil organic matter.

Soil organic matter content depends on the long term balance of decomposition and primary production. This balance is determined by many factors, including temperature, moisture, and chemical and physical structure of the organic matter (Meentemeyer 1984, Burke et al. 1989). In cultivated lands, litter was removed historically and decomposition was increased by plowing because of more contact between litter and microbes (Haas et al. 1957; Coleman et al. 1984); thus inputs to soil organic matter decrease and outputs from soil organic matter increase. Losses of soil organic matter have been demonstrated to be related to climate, soil texture (Cole et al. 1989; Parton et al. 1987; Burke et al. 1989), and topographic location (Aguilar and Heil. 1988 a; Schimel et al. 1985; Yonker et al. 1988). Highest losses tend to occur in areas with high temperature, high precipitation, and coarse soil texture, and in areas susceptible to erosion such as exposed slopes.

Soil organic matter (SOM) represents an important storage of carbon globally (Coleman et al 1984; Schlesinger 1990). According to Schlesinger (1990), C stored in SOM is $1.5 * 10^{18}$g. As degradation of soil organic matter increases due to cultivation, CO_2 is emitted from the soil to the atmosphere. There are some indications that soil C loss could represent a significant input to atmospheric CO_2 (Burke et al. 1991).

A close examination of the recovery of soil organic matter in previously cultivated grasslands has not been conducted. An understanding of recovery from disturbance is important to predict the effects of current and future land management decisions on systems.

The objective of this study was to evaluate the effect of cultivation and release from cultivation on soil organic matter across a climatic gradient. I proposed several hypotheses for the effects of cultivation and recovery on soil organic matter:

1. Total N and C are highest in native land, intermediate in historically cultivated and then abandoned land, and lowest on continuously cultivated land. This occurs because cultivated lands are subjected to highest rates of decomposition, erosion,

and lowest litter inputs over the largest time interval.

2. Total soil N and C are highest in sites with highest precipitation, because as precipitation increases, production increases more than decomposition rate does.
3. Losses of total soil C and N due to cultivation increase as precipitation increases, because of higher decomposition rates and more rapid erosion.
4. C/N ratios are lowest in cultivated soils, intermediate in abandoned soils, and highest in native soils, because C declines from cultivation more rapidly than N.

Methods

Site Description

This study was conducted in the Pawnee National Grasslands (PNG) of northeastern Colorado, a 78,100 ha area, and an adjacent study site, the Central Plains Experimental Range (CPER) of the United States Department of Agriculture-Agricultural Research Service. The CPER, 6280 ha in area, is located to the west of the Pawnee National Grasslands, approximately 60 km northeast of Fort Collins (40°49′N latitude; 107°47′ W longitude). Mean annual temperature varies from 8.4°C to 9.7°C (Burke et al. 1990, Siemer 1977), and annual precipitation ranges from 350 to 400 mm across the

PNG, with a gradient of increasing precipitation from west to east (Burke et al., 1990). The vegetation of the PNG is shortgrass steppe, dominated by *Bouteloua gracilis* (H.B.K.) Lag.ex Griffiths, and *Buchloe dacyloides* (Nutt.) Englem. *B. gracilis* accounts for 75% of the net primary production in the shortgrass steppe of northeastern Colorado (Hanson 1955, Milchunas et al. 1989). A number of succulents, half shrubs, forbs and annual grasses are also present.

About 20-30% of PNG was cultivated in the late 1800's, and abandoned by 1937 because of unreliable precipitation and economic difficulties (USFS 1964; USDA 1985). Other lands in this area have been cultivated continuously since the late 1800's.

Sample Collection

Aerial photographs were used to locate thirteen study sites across the PNG and one at the CPER (Coffin et al., submitted). Each site had an uncultivated field (native), a field that was abandoned in 1938, and five sites had a cultivated field that was identified as being plowed continuously since 1930. Native land and abandoned land were adjacent to each other, and cultivated fields were located within 1 km of native and abandoned land on the same soil series according to the Weld County Soils maps (USDA 1982).

In both the native and adjacent abandoned fields, I located two transects, 50 m apart. These transects were 198 m long (99 m in native, 99 m in abandoned) and perpendicular to the boundary between native land and abandoned land. Similar transects were located in cultivated fields. For sampling soil cores, I divided the transect into 6 equal units, and one sample was collected from a random location within each of the two units that were closest and furthest from the boundary within each transect. Soil samples were collected to a depth of 30 cm using a coring device with a 5.2 cm diameter.

Laboratory and Statistical Analysis

Soil samples were air dried and sieved through a 2 mm screen. For total nitrogen content in the soil, four subsamples were ground and digested using a micro-Kjeldahl procedure (Bremner et al. 1982) followed by colorimetric analysis (EPA 1979). Four subsamples were analyzed for total carbon using the method of Snyder and Trofymow (1984). Soil texture was determined using the hydrometer procedure described by Day (1965).

Average climate data for each site were generated by interpolating weather station data in northeastern Colorado using a geographic information system (GIS) (Burke et al. 1990).

Analysis of variance was used to test for the effects of site and treatment on total N and C with a covariate of sand content (SAS INC 1988). The covariate was used because texture was not consistent across treatments within sites and sand content is known to influence both dependent variables (Parton et al. 1987, Burke et al. 1989). I used a probability level of 0.05 and Scheffe's range test. To calculate losses of total C and N from cultivation, I statistically adjusted values of total N and total C for sand content based on the statistical model. To evaluate the relationship of precipitation and sand content to soil organic matter and soil organic matter losses, I conducted linear regressions for native soils only.

Results and Discussion

Total N and total C were significantly different among all treatments (P=0.0001). They were highest in native land, intermediate in abandoned land, and lowest in cultivated land (Fig. 1.1). An average loss from cultivation (native minus cultivated) for total C was 26% and for total N was 29%. On cultivated land, since plant residue is removed (Haas et al. 1957) and remains have more contact with soil microbes from plowing and mixing residue into the soil surface (Coleman et al. 1984), decomposition of soil organic matter increases. Moreover, soil erosion increases under cultivation because soil aggregates are broken by tillage (Elliott 1986). Inputs to soil organic matter decrease and outputs from soil organic matter increase due to plowing. There are two possible explanations why abandoned fields have intermediate soil

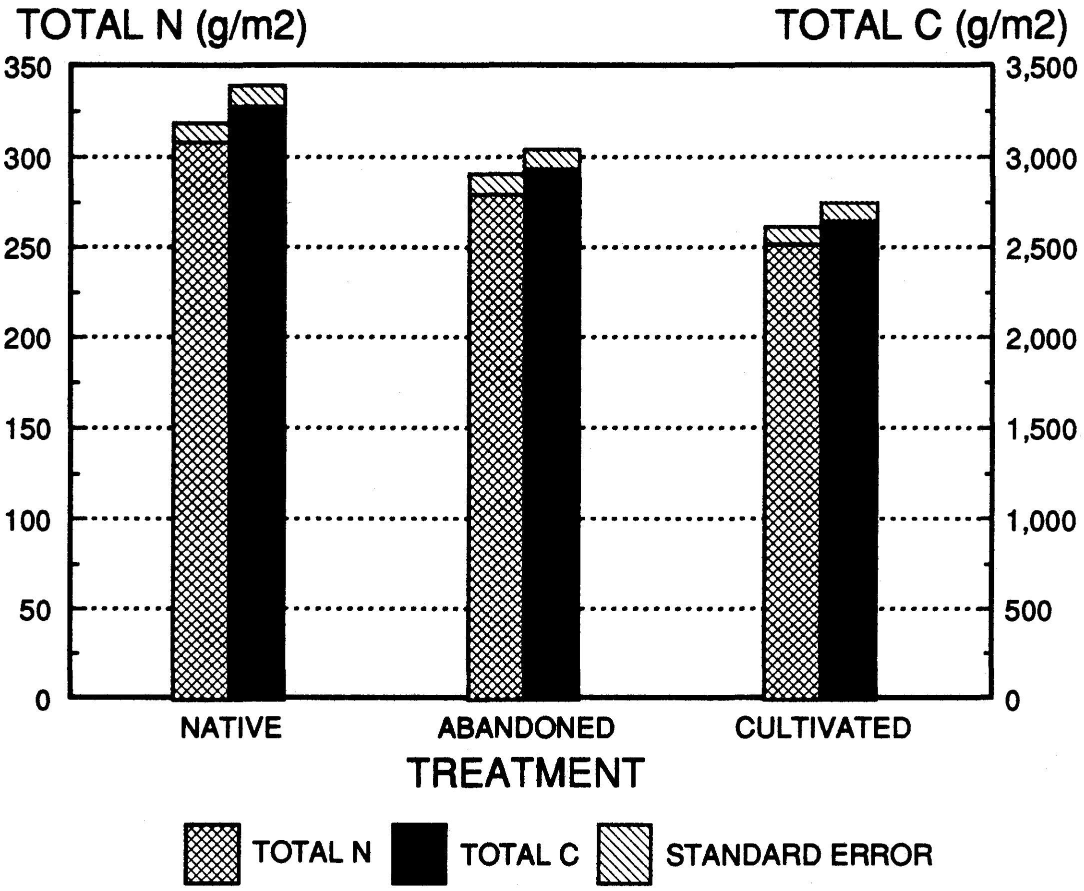

Fig. 1.1. Average soil carbon and nitrogen for 13 sites that have native, abandoned, and cultivated fields (5 sites in cultivated fields), located in the Pawnee National Grasslands in northeastern Colorado. All treatments are significantly different (P = 0.0001).

organic matter content. One is that soil organic matter has recovered after 50 years of abandonment of fields, and the other is that abandoned fields had not been cultivated as long as currently cultivated fields, and so lost less of their original content of C and N.

Not only sand content (Fig. 1.2), but also precipitation and temperature have effects on soil organic matter (Burke et al. 1989). Since in this study, the temperature gradient was limited (8.5-9.8°C), I considered precipitation to be the major climatic gradient. Precipitation had significant effects on total C ($P=0.0024$), and total N ($P=0.0058$) (Fig. 1.3) in native fields. When precipitation is high, both total C and N are high, because plant production increases as precipitation increases. However, precipitation only accounted for a small proportion of the variance in total C and N ($R^2 = 0.16$ for C $R^2 = 0.13$ for N). This result suggests that local spatial variability of soil organic matter content due to other factors is greater than the effect of precipitation on soil organic matter. The source of local variability may be historical grazing management.

C and N losses, which were calculated as differences between native and cultivated fields, were not significantly related to precipitation ($P = 0.22$, $R^2 = 0.44$, and $P=0.41$, $R^2 = 0.23$, respectively). Precipitation also did not have a significant effect on % losses of total C and total N (Fig. 1.4, $P = 0.33$, $R^2 = 0.31$, and $P = 0.51$, $R^2 = 0.16$, respective-

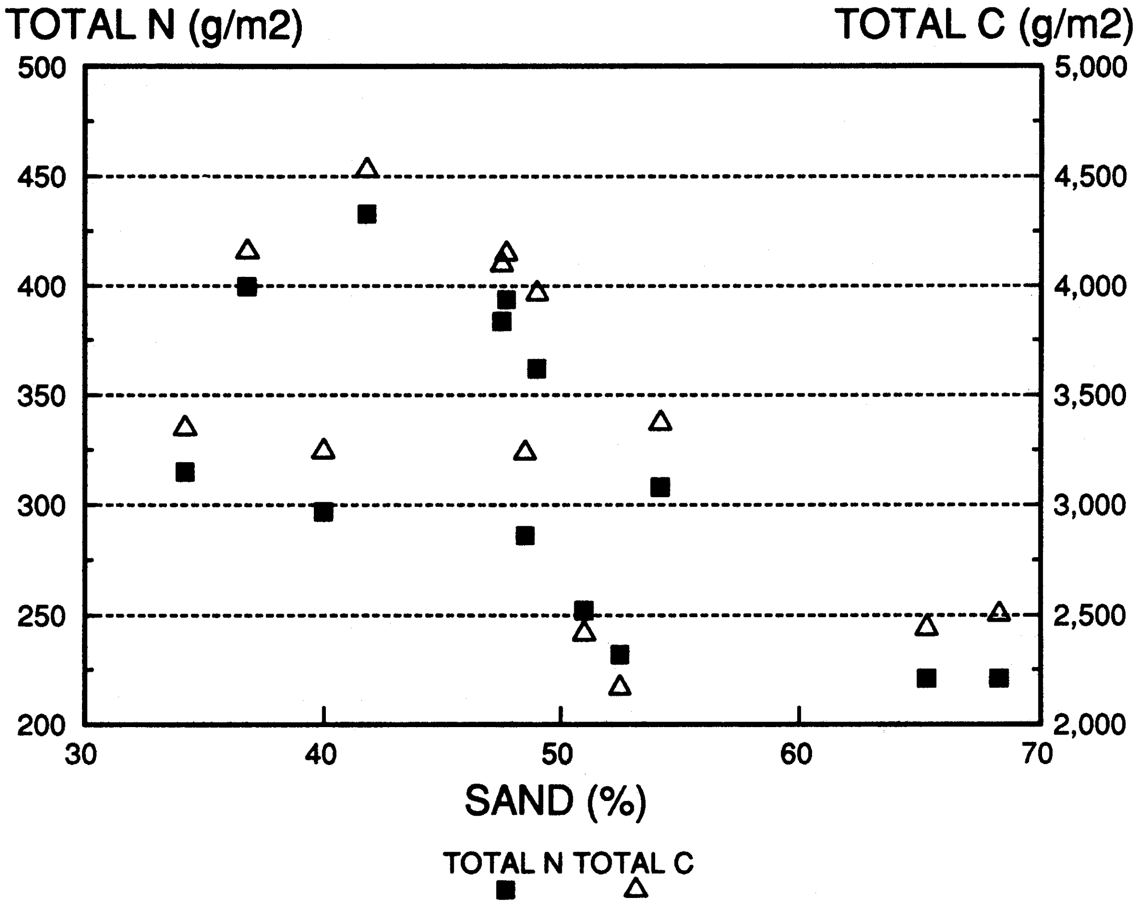

Fig. 1.2. Relationship of soil C and N to sand content in native soils of Pawnee National Grassland. $R^2 = 0.63$, $P = 0.0001$ for C, and $R^2 = 0.62$, $P = 0.0001$ for N.

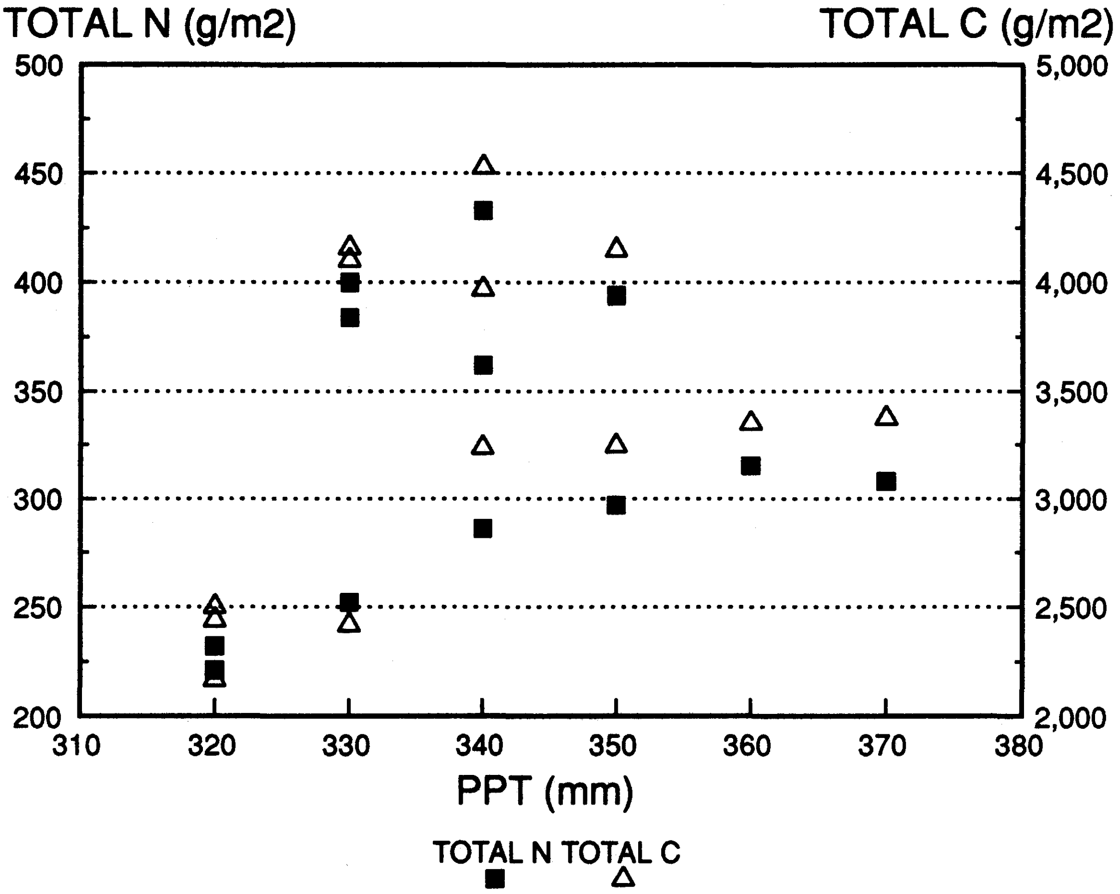

Fig. 1.3. Relationship between soil C and N in native soils to precipitation in the Pawnee National Grasslands. $R^2 = 0.16$, $P = 0.0024$ for C and $R^2 = 0.13$, $P = 0.0058$ for N.

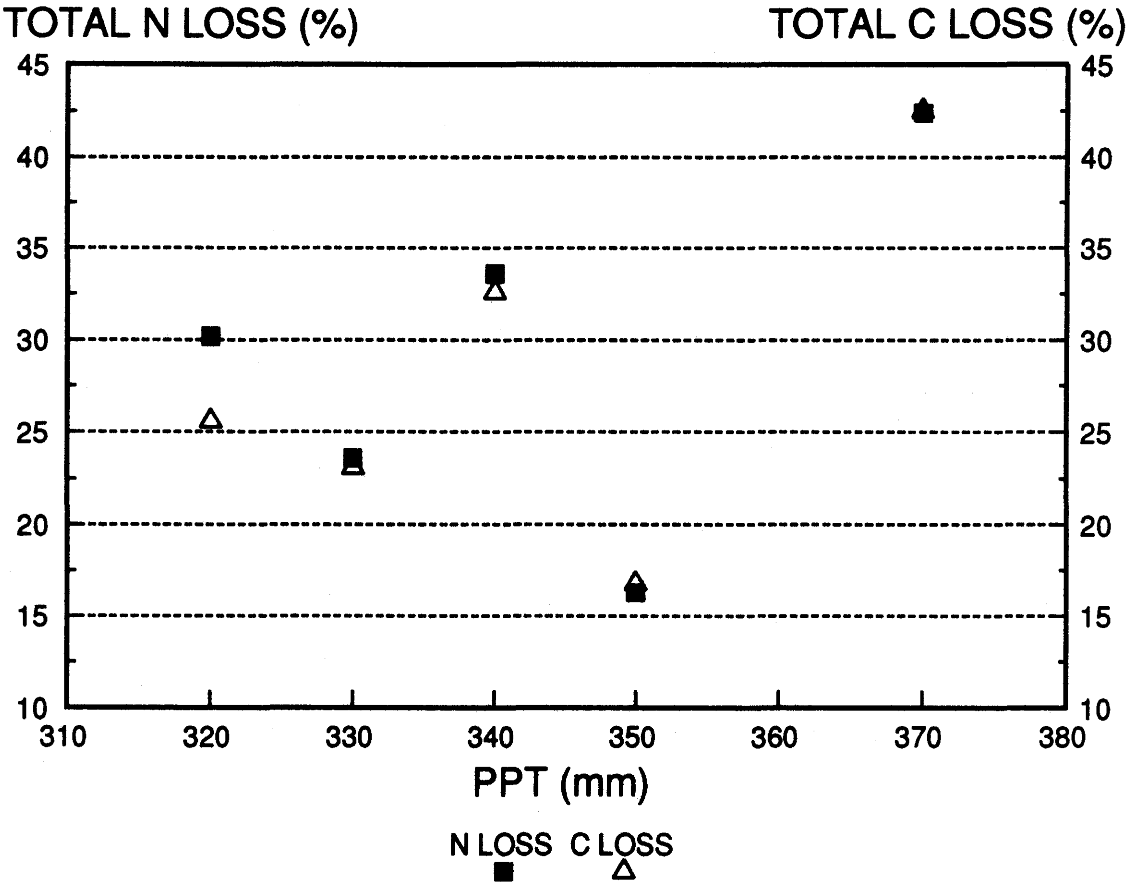

Fig. 1.4. Relationship between annual precipitation and % losses of total C and N from cultivation. R^2 = 0.31, P = 0.33 for C, and R^2 = 0.16, P = 0.51 for N.

ly). It is possible that the precipitation range (320-380 mm) was not large enough, and/or the number of sites was too small to detect the influence of precipitation on soil organic matter losses. This suggests that local variability of soil organic matter losses due to historical management is greater than the influence of precipitation on soil organic matter losses in this study. There were no significant relationships between sand content and losses of total C and N (P=0.56 for C and P=0.57 for N).

There were no significant differences in C/N ratios among treatments, but there were differences among sites (P=0.02). This result indicates that carbon loss was the same as nitrogen loss for the 0 - 30 cm depth of soil during cultivation. This result differs from earlier work (Haas et al. 1957, Burke et al. 1989) that showed relatively greater C losses than N as a result of cultivation, and narrower C/N ratios in cultivated fields than in native fields. Differences in losses between N and C are probably diluted in the 0 - 30 cm depth soil, since cultivation effects are most significant in surface soils (Aguilar et al. 1988, Schimel et al. 1985). Precipitation did not have a significant effect on C/N ratio (P=0.64).

Observed total C and total N in native fields were compared to expected N and expected C derived from regressions reported by Burke et al (1989) for soils across the entire U.S. Central Grasslands, and to predicted C and N from the CENTURY grassland model (Parton et al. 1988). The CENTURY model was parameterized for the soils and climate conditions at each site, and run until organic matter levels reached steady state (3000 years). I ran the model assuming 10 % forage removal, to represent native grazing. I modified estimates of the soil water holding capacity by using equations from Cosby et al.(1984), because the equations in CENTURY tended to underestimate water holding capacity.

These comparisons between the two models and the field data were made for several reasons. First, they provide a reasonable test of both the regression model and the simulation model for native grassland conditions. Second, if the models adequately estimate native conditions, I could use them to assess the soil organic matter loss and recovery for these sites.

C and N data from this study showed significant correlation with predictions from the regression equation data by Burke et al (Fig. 1.5 R^2=0.57 for both C and N, P=0.003 for C, and 0.002 for N). This result indicates that mean annual temperature, mean annual precipitation and soil texture explained more than half of the variation of soil organic matter. However, CENTURY estimates showed no significant correlation to observed data (R^2=0.21 and P=0.12 for C, R^2=0.16 and P=0.18 for N). Prediction by regression tended to underestimate SOM and prediction by CENTURY tended to overestimate SOM. Since the regression model estimates soil

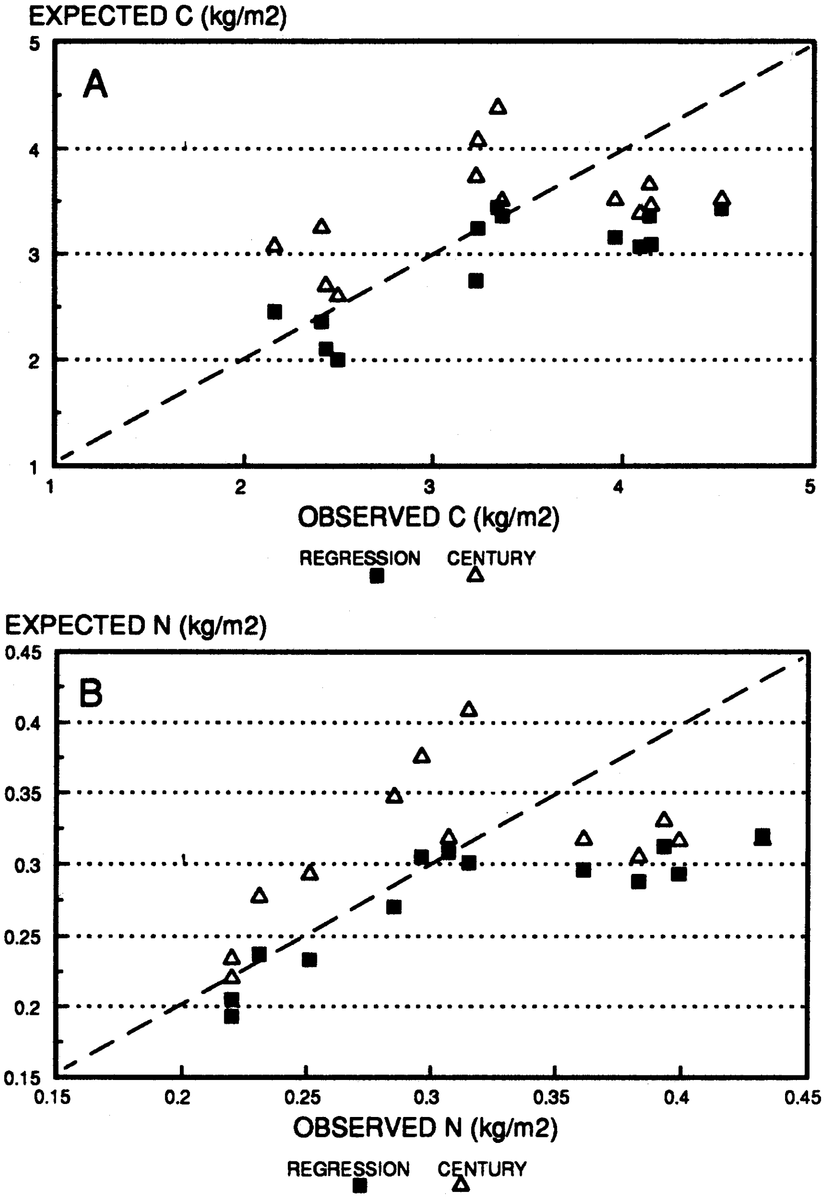

Fig. 1.5. Relationship between observed C and expected C (A) and observed N and expected N (B) in native fields. Expected C and N were derived from regression equations reported by Burke et al. (1989) for the Central Grassland region and the CENTURY soil organic matter model. (A) $R^2 = 0.57$, $P = 0.003$ for the regression equation and $R^2 = 0.21$, $P = 0.092$ for the CENTURY model. (B) $R^2 = 0.57$, $P = 0.002$ for the regression equation and $R^2 = 0.16$, $P = 0.19$ for the CENTURY model.

organic matter to a 20 cm depth and observed data are for 30 cm depth soil, the model tended to underestimate total C and total N. Because we did not parameterize CENTURY to include historical (during the past 150 years) grazing impacts, CENTURY tended to overestimate total C and total N in native fields.

Observed total C and total N losses and % losses from cultivation were plotted against expected C and N losses from the regression equation (Figs. 1.6, 1.7). The relationships were not significant (R^2=0.3 for C and R^2=0.1 for N); the equation tended to underestimate the losses of C and N. This implies the across region patterns of Burke et al. (1989) do not work well within this small area.

In addition, C and N losses were estimated by running the CENTURY model (Fig. 1.6). I ran the CENTURY model for 30 years of continuous wheat and 170 years of wheat and fallow systems to approximate historical conditions in Weld County (Greb et al. 1979). During the continuous wheat system, cultivation events were implemented twice per one year and during the wheat-fallow system, cultivation events were implemented four times in 2 years. Straw was not removed from the system, during the entire run.

I assumed that currently cultivated fields had been cultivated for 70 years, and plotted 70 years of losses from cultivation in CENTURY against observed losses from cultivation (Fig. 1.6). Because the CENTURY model output addresses

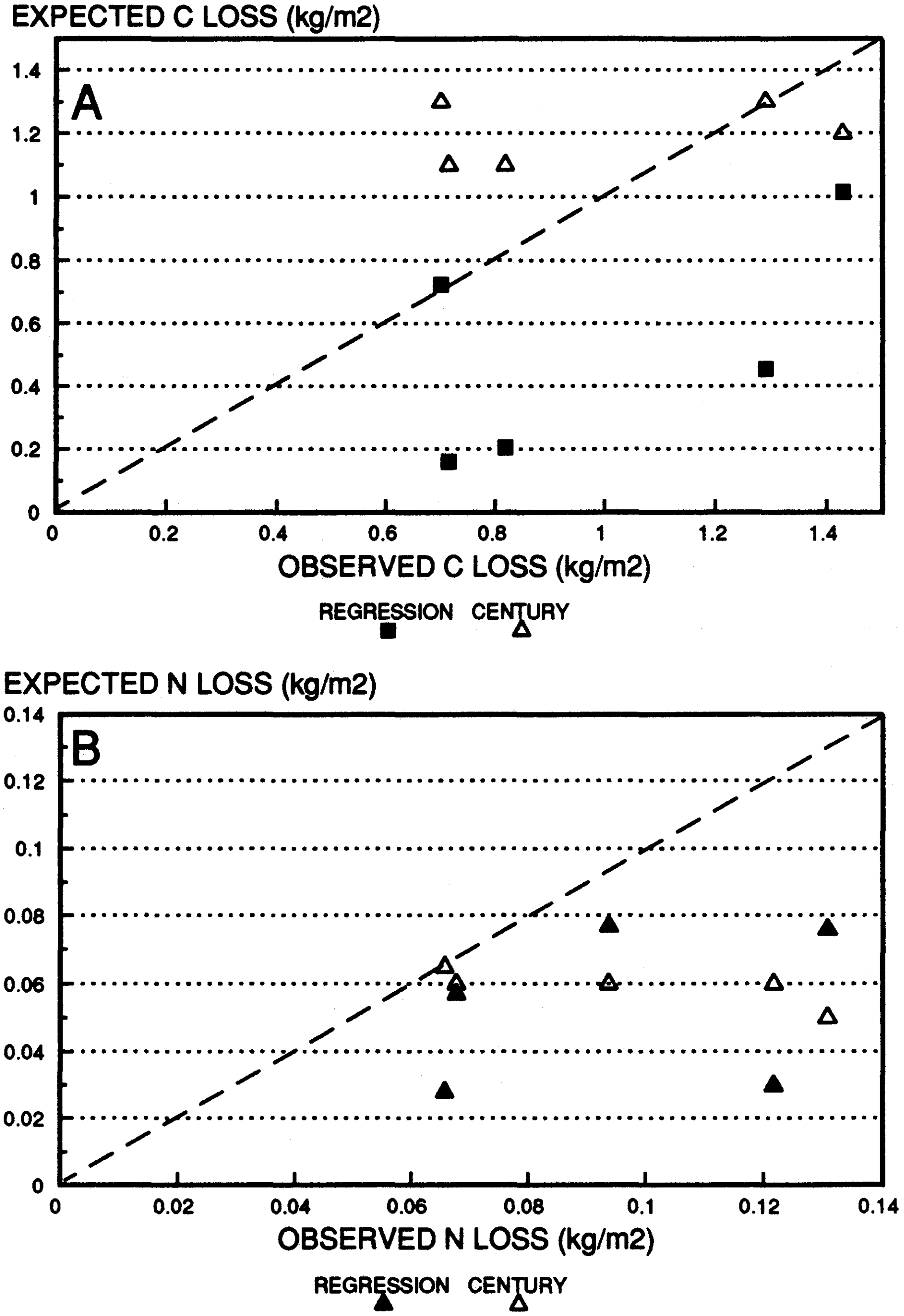

Fig. 1.6. Relationship of observed C losses from cultivation to expected C losses derived from regression equations by Burke et al. (1989) and the CENTURY model (A), and relationship of observed N losses and expected N losses (B). $R^2 = 0.34$, $P = 0.3$ for C loss and $R^2 = 0.08$, $P = 0.65$ for N losses in the regression model. $R^2 = 0.11$, $P = 0.58$ for C and $R^2 = 0.58$, $P = 0.14$ for N in the CENTURY model.

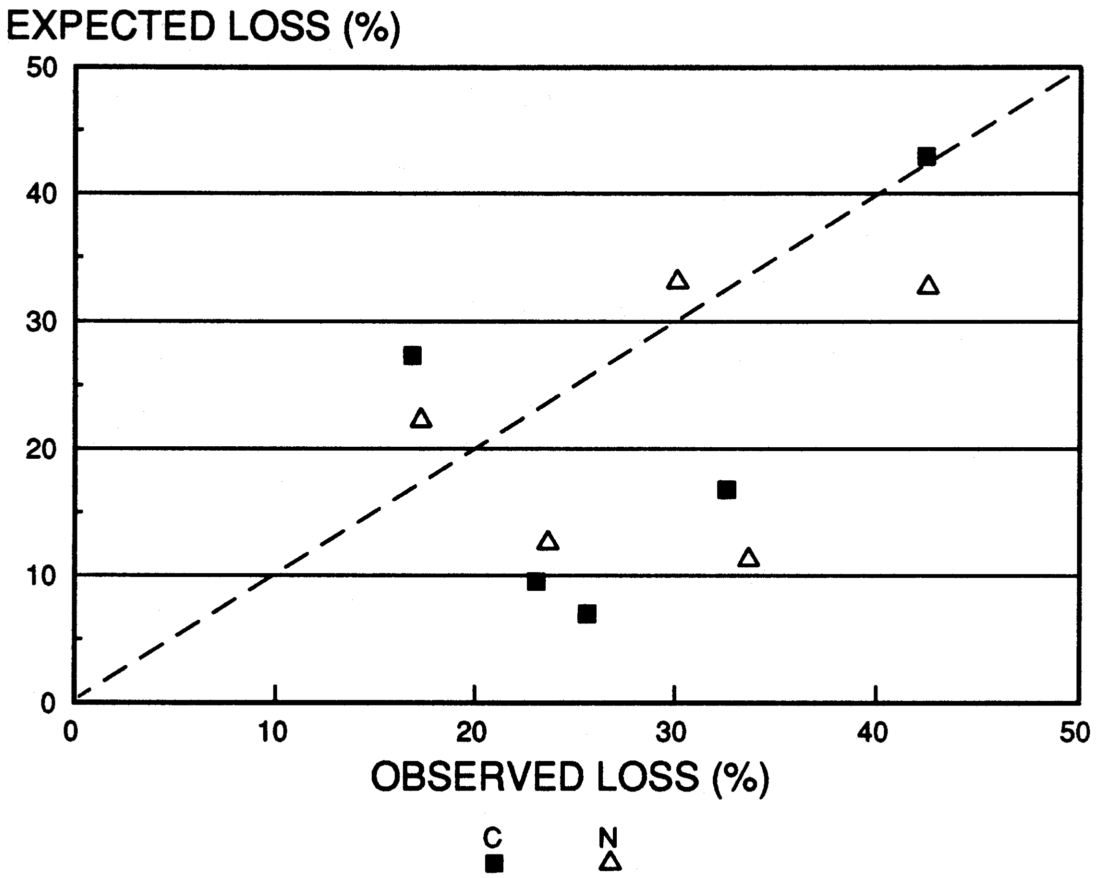

Fig. 1.7. Relationship of observed C and N % losses from cultivation to expected C and N % losses derived from the regression equation by Burke et al. (1989). $R^2 = 0.30$, $P = 0.34$ for C and $R^2 = 0.14$, $P = 0.53$ for N.

the surface 20 cm of soil and not the 30 cm we sampled, and because most losses occur in the top 20 cm, total losses are a more appropriate index for comparison than relative losses or the value of SOM in native, cultivated, or abandoned fields. CENTURY did not show variability in SOM losses from cultivation across sites. C losses in CENTURY tended to overestimate observed C losses, and N losses in CENTURY tend to underestimate observed N losses (Fig. 1.6)

Because I do not know how much soil organic matter was there when the fields were abandoned and how long these had been cultivated, it is hard to evaluate how much and how fast soil organic matter has recovered. Even though CENTURY predictions did not fit the data in native fields perfectly, it is the only available tool for estimating the recovery of soil organic matter in abandoned fields. It is likely that the fields were first plowed between 1910 and 1920, and they were abandoned in 1937 when the government purchased them (USDA, 1985). I assumed that abandoned fields had been cultivated 20 years before abandonment, and plotted total C and N losses from 20 years of cultivation estimated from CENTURY against the difference of total N and C in native fields and in abandoned fields (Fig. 1.8). These results showed that there were few variations in total C and N losses from 20 years of cultivation at each site in CENTURY estimations, even though the model estimated large variations among sites in native SOM. Since we did not have information on

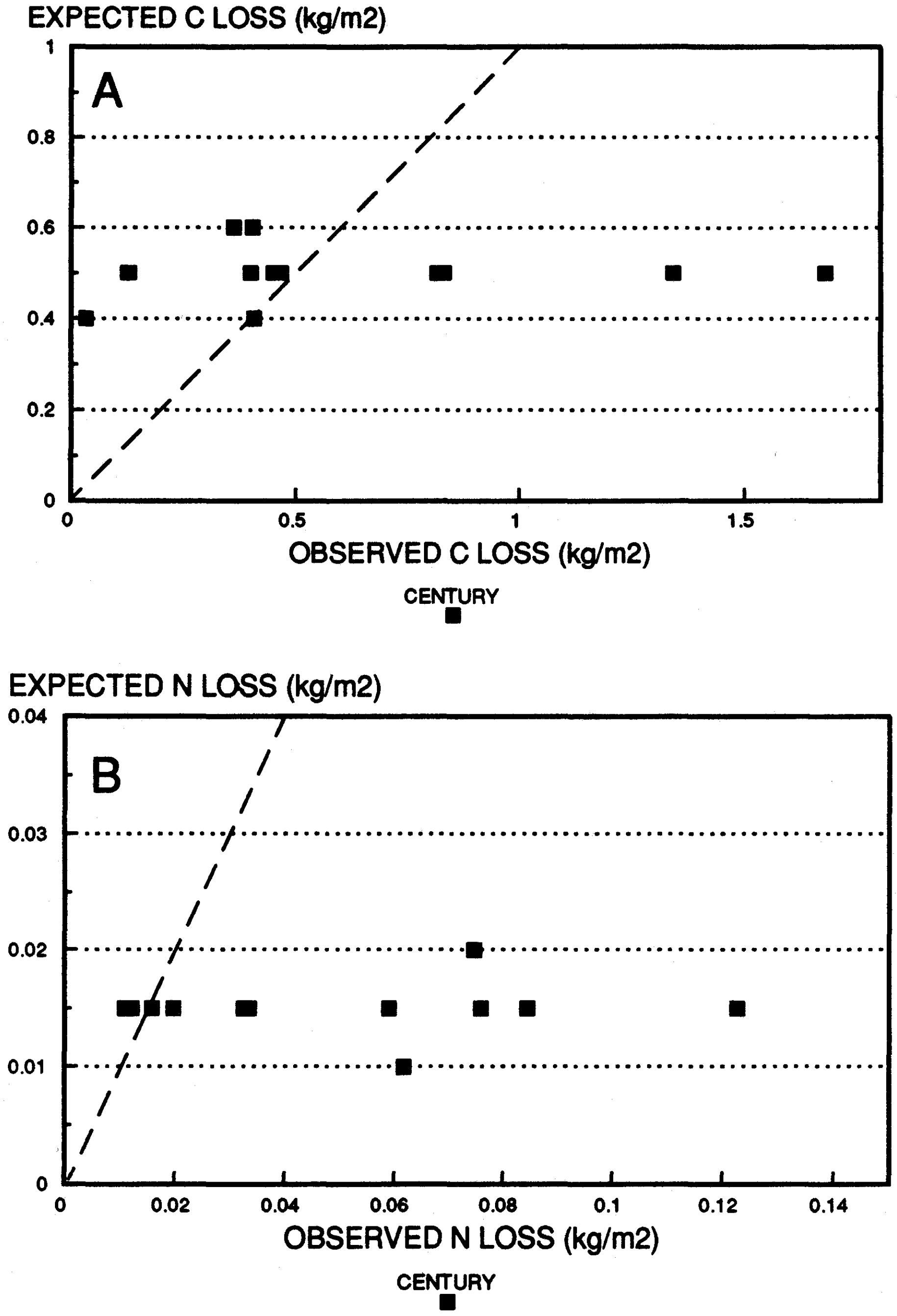

Fig. 1.8. Relationship of total C and N losses estimated from the CENTURY model during 20 years of cultivation to the difference in C and N between native and abandoned fields.

how management varied among sites, the model did not represent historical management differences. These results suggest that the length and the intensity of cultivation may have varied significantly among sites.

I also assumed the abandoned fields had been cultivated for 30 years before abandoned, and plotted the SOM losses from 30 years of cultivation against the SOM differences in native and abandoned fields (Fig. 1.9). These results have the same trends as losses from 20 years of cultivation, but C losses were overestimated in more sites.

I ran CENTURY for the average climatic, soil texture, and water holding capacity of all the sites in this study (Fig. 1.10). In CENTURY, C losses from 70 years of cultivation overestimated observed average C losses at all the sites by 11 %, while C losses from 20 years of cultivation underestimated the average C losses of abandoned fields by 30 %, estimated as the difference between native and abandoned fields. Simulated N losses from both 70 years and 20 years of cultivation underestimate average N losses of all the sites (27% of underestimate for 70 years and 69 % for 20 years). C losses from 30 years of cultivation in CENTURY overestimate the average C losses abandoned fields by 4.3 %, and N losses from 30 years of cultivation underestimate N losses in abandoned field by 49 %.

If 30 years is a reasonable estimate of how long the fields were cultivated before abandonment, and if CENTURY's

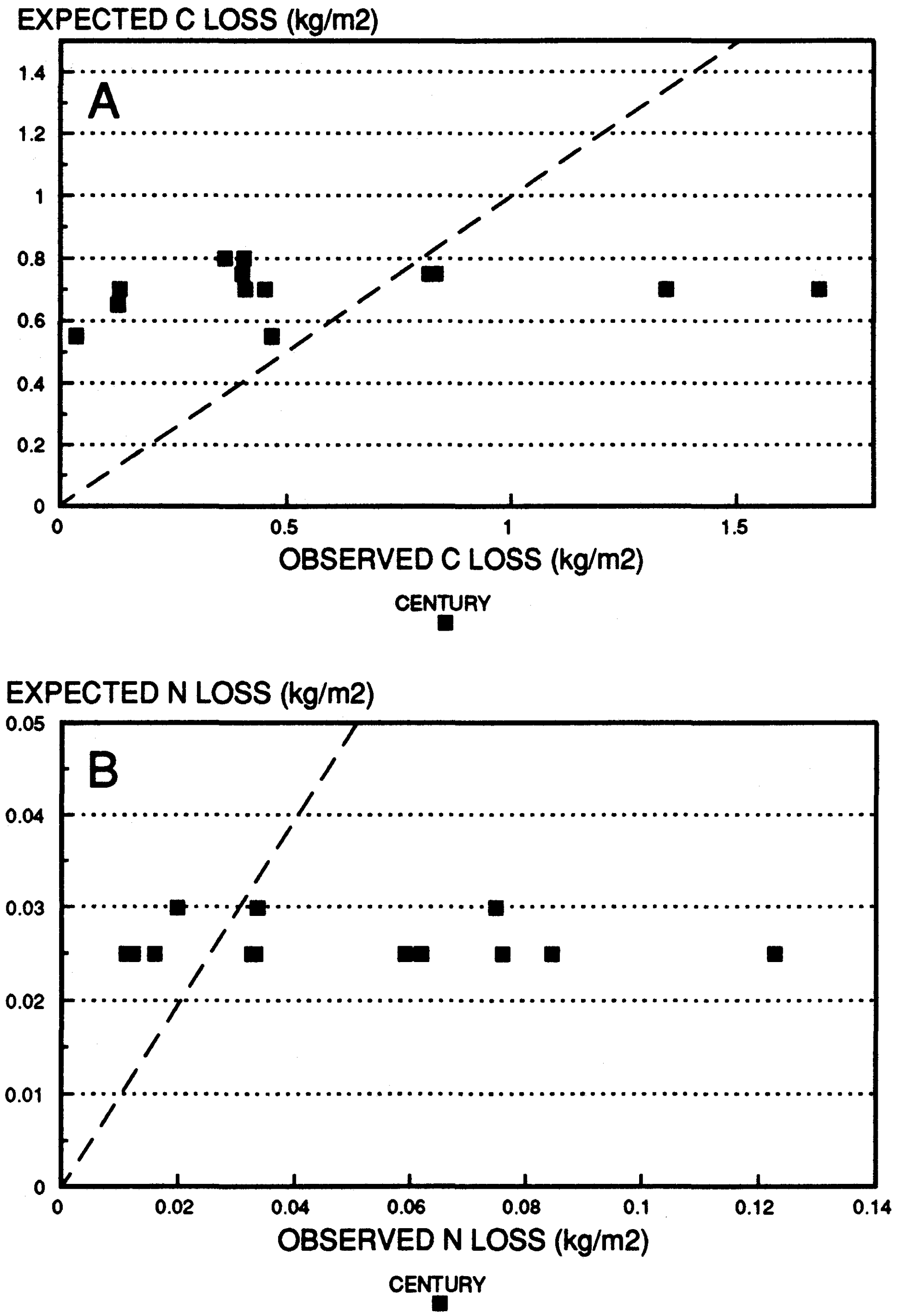

Fig. 1.9. Relationship of total C losses in the CENTURY model during 30 years of cultivation to the difference of C and N in native and abandoned fields.

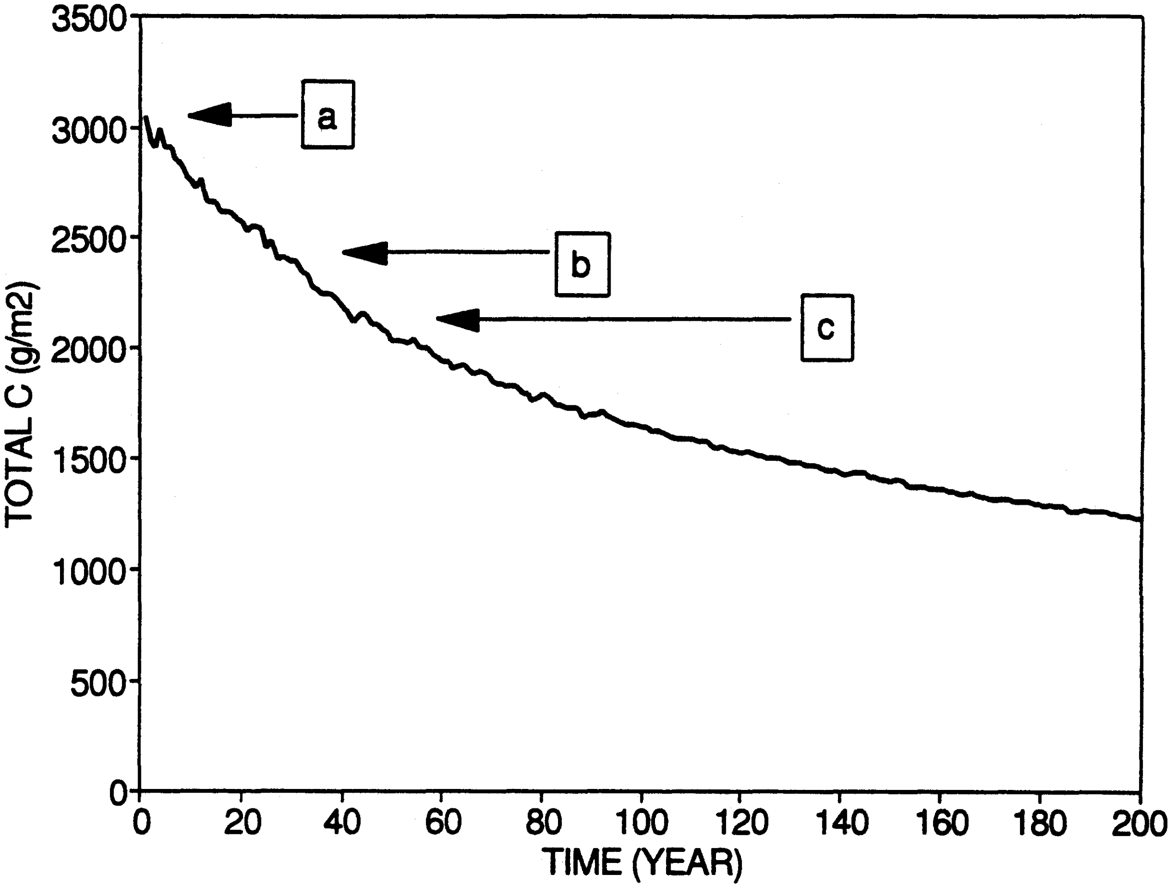

Fig. 1.10. Soil C losses from 200 years of cultivation predicted by CENTURY model from average climate and soil parameters of 13 sites in the Pawnee National Grasslands. a: observed average for all native fields. b: observed average for all abandoned fields. c: observed average for all cultivated fields.

prediction is an overestimate of SOM losses at the time of abandonment, this difference can be considered to represent an estimate of the recovery of SOM during the 50 years after abandonment. The estimate of C recovery is about 25 g/m^2. However, because CENTURY underestimates N losses from 30 years of cultivation, total N recovery was not considered to occur in this study. These results suggest that total C recovery is faster than total N recovery.

In this study, I found that cultivation reduces soil organic matter. However, it is difficult to evaluate recovery of soil organic matter, because we do not know initial conditions at the time the field was abandoned and how long the field had been cultivated before it was abandoned. Analysis using the CENTURY model suggests that site management was highly variable across the sites. In addition, analysis by the CENTURY model indicates that as much as 25 g C/m^2 of SOM has accumulated since the fields were abandoned.

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Chapter 2

Effects of cultivation and recovery on nitrogen mineralization in the Pawnee National Grasslands

Introduction

That cultivation has significant effects on soil organic matter is known well. In chapter 1, I focused on cultivation and abandonment effects on soil organic matter. The results showed that soil organic matter decreased as a result of cultivation, as has been shown by previous work (Russel 1929, Haas et al. 1957, Schimel et.al. 1986, Aguilar et al.1989, Burke et al. 1989, Burke et al. submitted).

In a related study, the effects of cultivation and abandonment on potential N mineralization rate were tested by using a laboratory incubation method (Burke et al. submitted). They reported lower potential N mineralization rates in cultivated fields than in native and abandoned fields, and similar rates in native and abandoned fields. However, potential N mineralization rates do not indicate directly available nutrients for plants, since conditions are not ideal for microbes in the field.

Microsites, such as under plants and between plants have been demonstrated to affect potential N mineralization rates (Hook et al. 1991, Burke et al. submitted). Potential mineralization rates are higher under individual plants in shortgrass steppe than between plants. Since more carbon is available under plants, microbial activity is higher under plants under ideal moisture and temperature conditions such as in the laboratory (Hook et al. 1991, Burke et al submitted). In the field, plant uptake and different levels of microbial activity occur, changing environmental conditions, and thus mineralization patterns in the field may be different from in the laboratory.

The objective of this chapter is to evaluate the influence of cultivation and abandonment, and of plant microsite, on in situ N mineralization. I am also interested in testing whether in situ mineralization patterns are the same as the results of laboratory incubations, and in using this comparison to evaluate environmental restriction across management treatments and microsites.

Methods

Site Description

We conducted this study in the Pawnee National Grasslands (PNG) of northeastern Colorado. The PNG is 78,100 ha in area and is located approximately 50 km northeast of Fort Collins. Annual precipitation across the PNG is 350-400 mm increasing toward the east (Burke et al. 1990). Mean annual temperature ranges from 8.4 to 9.7°C (Burke et.al. 1990, Simmer,1977). The vegetation of PNG is shortgrass steppe, with *Bouteloua gracilis* (H. B. K.) Lag.ex Griffiths, and *Buchloe dacyloides* (Nutt.) Englem. as dominant species. A number of succulent, half shrubs, forbs, and annual grasses are also present (Coffin and Lauenroth 1988).

In the late 1800's, 20 - 30% of PNG was cultivated but, because of economic difficulty, drought, and high winds (USFS

1964, USDA 1985) these areas were abandoned and returned to grassland through federal programs. Interspersed among these abandoned fields there are privately owned fields that have been cultivated since the late 1800's.

In Situ Incubation

Three sites that had an uncultivated field (native), a field that was abandoned in 1938 (abandoned), and a currently cultivated field, were chosen in PNG (Coffin et al. submitted, Burke et al. submitted, Ihori et al. in prep). Native fields and abandoned fields at each site were adjacent to each other and the cultivated field was located within 1 km of native and abandoned fields on similar soils. In both native and abandoned fields, we located two transects which were 50 m apart from each other. Transect length was 200 m (100 m in native, and 100 m in abandoned), and these were perpendicular to the boundary between native and abandoned land. I located samples every 25 m along the transect, for a total of eight sample sets in each field. At each sample location, I stratified soils by two types of microsite, under individual *B. gracilis* plants and between *B. gracilis* plants. At each microsite, I collected one soil core (5.2 cm and 15 cm depth) for initial analysis and left one core in place in the native and abandoned fields from June 15th to July 14th in 1991. We collected cores twice on June 15th and July 14th in the cultivated fields with same type of core that was used in native and abandoned fields, because we could not leave cores in the cultivated fields. Cultivated fields were in the fallow phase, and there were no plants actively growing.

Laboratory and Statistical Analysis

Soil water content was determined by oven-drying 10 g subsamples to constant weight at 85°C. To determine NO_3-N and NH_4-N, wet soil samples were extracted using 2-M KCl including 5 mg/L phenyl-mercuric acetate to retard microbial activity. Extracts were analyzed by colorimetric methods (EPA 1979). Net N mineralization was calculated by subtracting initial NO_3-N plus NH_4-N from final concentrations.

Air-dried and sieved samples were analyzed for total N and total C content. For total N content, three subsamples from each core were digested using a micro-Kjeldahl procedure (Bremner et al. 1982) followed by colorimetric analysis (EPA 1979). For total C content, three subsamples were analyzed using the methods of Snyder and Trofymow (1984). Mineral N, total N and total C were averaged for each site, treatment, and microsite.

I used Analysis of Variance (SAS INC 1988) to test for the effects of site, treatment, and microsite on mineralized N, total N and C, and C/N. A probability level of 0.05 was used to evaluate significance. A Scheffe test was used for mean separation.

Results and Discussion

Total C and N

Both total soil C and total N were significantly influenced by site (P=0.0001 for both C and N), treatment (P=0.0001 for both C and N), and microsite (P = 0.0006 for C, P = 0.0453 for N). Total C and N were highest in native fields and lowest in currently cultivated fields (Fig. 2.1) as Ihori et al. (in prep) and Burke et al. (submitted) showed.

Many authors have demonstrated losses of soil organic matter (SOM) as a result of cultivation (Russel 1929, Haas et al. 1957, Schimel et al. 1986, Aguilar et al. 1989, Burke et al. 1989, Burke et al. submitted). These losses are attributed to disruption of soil aggregates that protect SOM from decomposition, increases in soil erosion, and reduction in plant residue input. There are two possible reasons SOM in abandoned fields was intermediate. One is that SOM in abandoned fields has recovered since early intensive cultivation. The other explanation is that abandoned fields were not cultivated as long as currently cultivated fields.

B. gracilis is the dominant bunchgrass species in the Pawnee National Grasslands and good indicator of vegetation recovery (Coffin et al. submitted). In each treatment, both total N and total C were always higher under *B. gracilis* than between *B. gracilis* (Fig. 2.1); this was also found by Burke et al.(submitted). This probably occurs because under

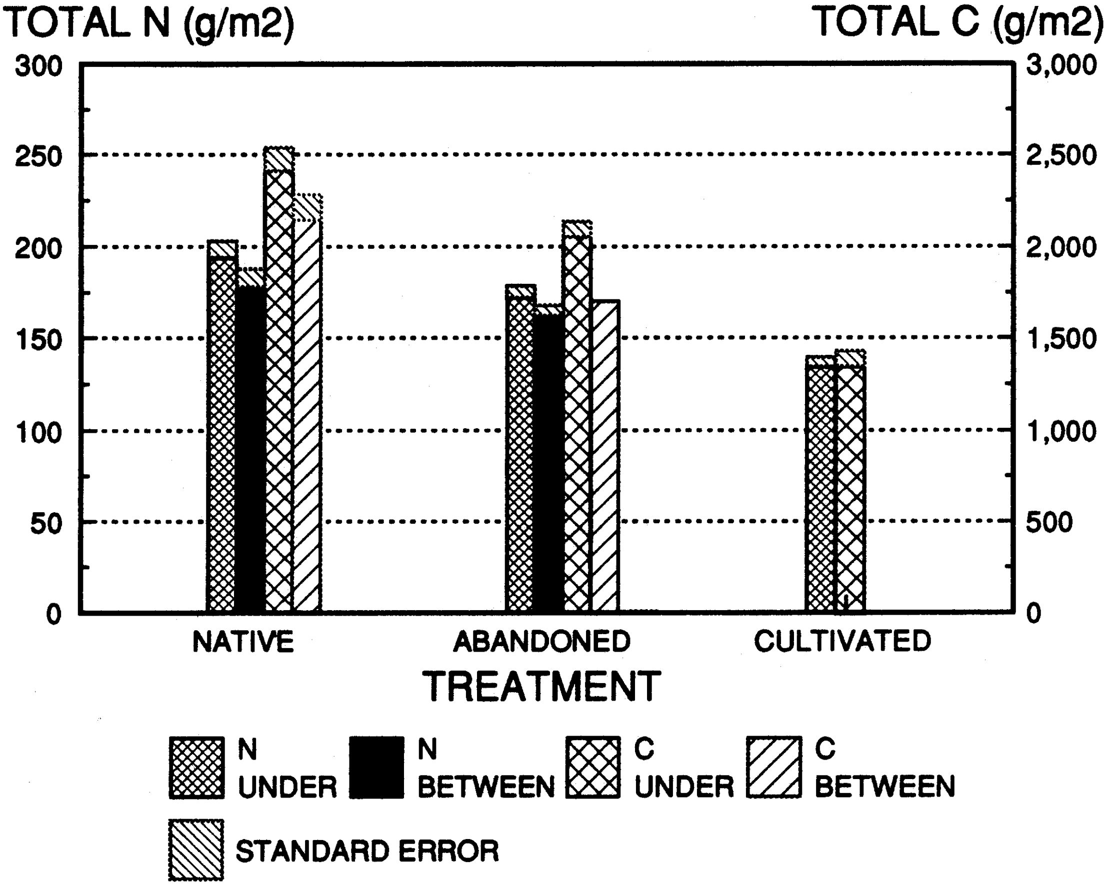

Fig. 2.1. Total N and total C in soils (0 - 15 cm) from Pawnee National Grasslands in northeastern Colorado. Soils were collected from native, abandoned, and cultivated fields and two kinds of microsites, under and between individual *Bouteloua gracilis* plants.

plants there is more above and belowground input to SOM than between plants. This suggests that soil organic matter recovery is higher under plants than between in abandoned fields. Thus, plant recovery dynamics may play an important role in patterns and rates of soil organic matter accumulation (Bruke et al. submitted).

C/N ratios were significantly affected by both treatment and microsite effects (Fig. 2.2, P=0.0001). C/N ratios were highest in native fields, intermediate in abandoned fields, and lowest in cultivated fields (Haas et al. 1957, Burke et al. submitted). Since soil C is more easily lost via decomposition as a result of cultivation than is soil N, C/N ratio narrows with cultivation. C/N ratios were intermediate in abandoned fields. This could either reflect fewer losses from these fields than cultivated fields, or could suggest C input during recovery. Under *B. gracilis*, C/N ratios were higher than between plants. This is likely because there is more plant material above and below ground under *B. gracilis,* and plant material has a higher C/N ratio than SOM.

N Mineralization

In situ net mineralization rates were significantly highest in cultivated fields, but differences between native and abandoned fields were not significant (Fig. 2.3). Moisture content was also significantly higher in cultivated fields (Fig. 2.4). This occurred because we took samples

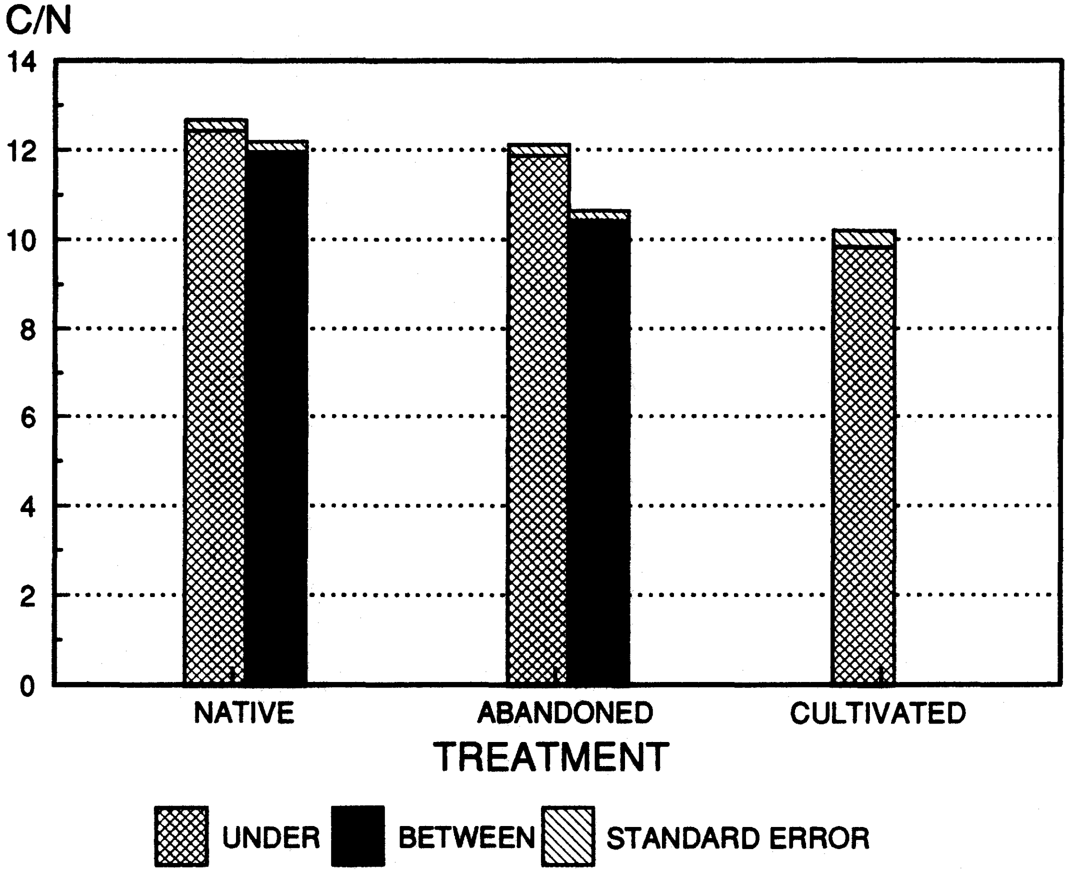

Fig. 2.2. Average C/N ratios in three native, abandoned, and cultivated fields and two microsites (under and between plants) in soil (0 - 15 cm) from the Pawnee National Grasslands in northeastern Colorado.

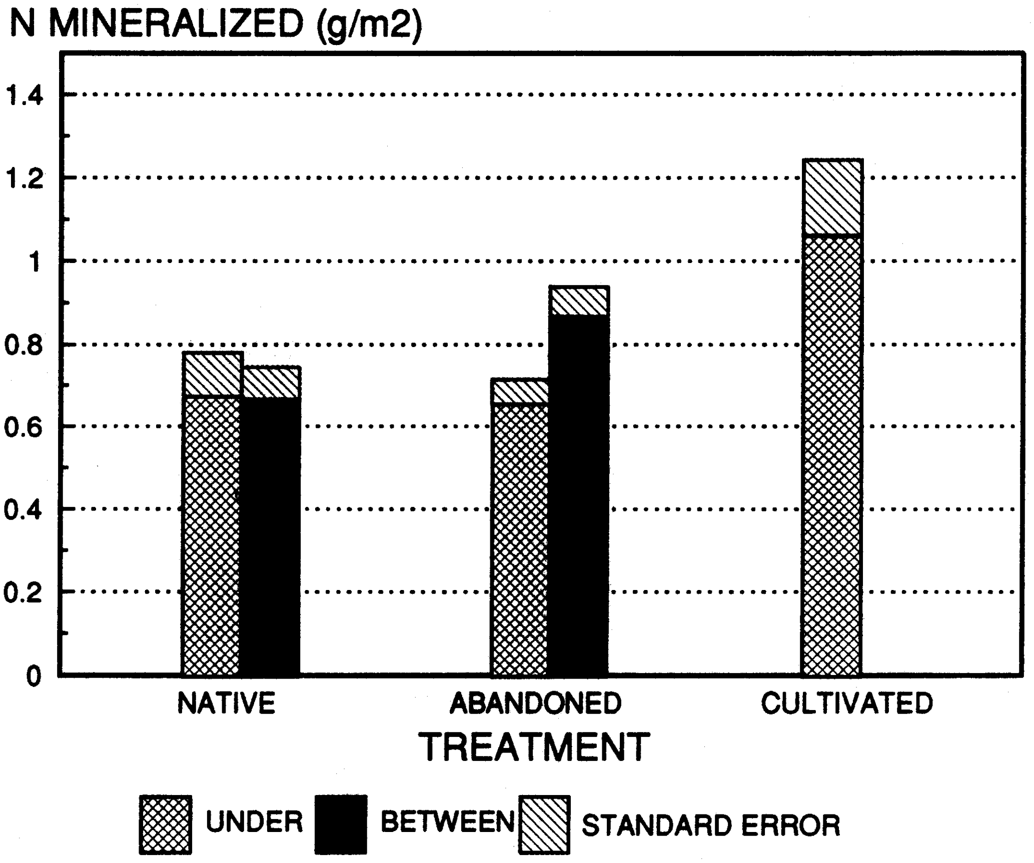

Fig. 2.3. Net N mineralization in 30-day in situ incubations of soils (0 - 15 cm) from the Pawnee National Grasslands in northeastern Colorado. Soils were collected from native, abandoned, and cultivated fields, and two microsites, under and between plants.

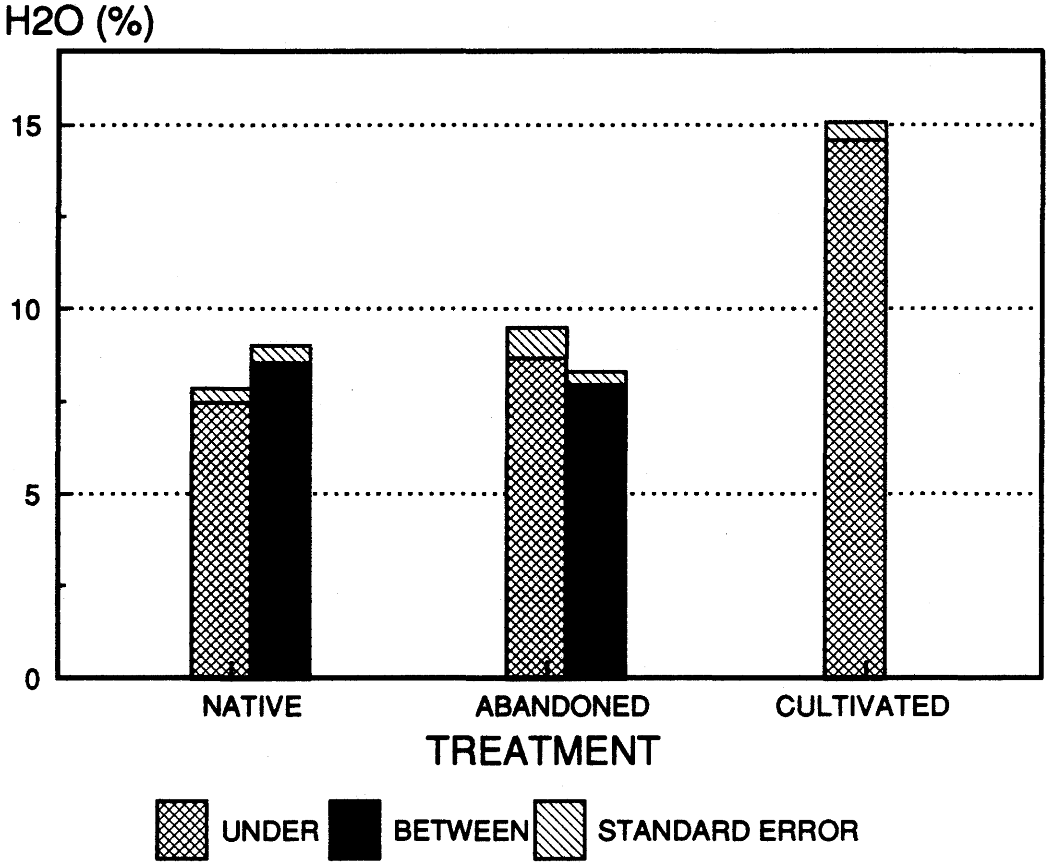

Fig. 2.4. Average of initial and final moisture content of *in situ* incubated soils (0 - 15 cm) in the Pawnee National Grasslands in northeastern Colorado. Soils were collected from native, abandoned, and cultivated fields, and two microsites, under and between plants.

from fallow fields, and there were no living crops to take up water from soil. Soil moisture is one of the important factors controlling N mineralization (Burke 1989), and this may be one of the reasons for higher net in situ N mineralization in cultivated fields. In addition, C/N ratios were lower in cultivated fields. When C/N ratio is about 10, microbial immobilization is low and when C/N ratio is higher than 10 higher immobilization occurs (Paul and Clark 1989). This could be one of the reasons why N mineralization was higher in cultivated fields than in native and abandoned fields, since the C/N ratio in cultivated fields was about 10 and in other treatments was higher than 10.

Since in the laboratory incubations conducted Burke et al. (submitted), plant materials were removed, but not in the field incubations, immobilization in native and abandoned fields is higher in in situ incubation than in laboratory incubation. Because there were fewer plant materials in cultivated fields than in native and abandoned fields in in situ incubations, immobilization rates may be lower in cultivated fields than native and abandoned fields.

Differences of in situ mineralization between plant microsites were not significant (Fig. 2.3), even though higher N mineralization in laboratory incubations under plants than between plants has been reported for shortgrass steppe (Hook et al. 1991) and these sites (Burke et al. submitted). This lack of pattern in in situ cores may be a function of the method used to estimate N mineralization. Live plants were located within the cores that were located "under" plants in the fields. Thus, plant uptake could significantly reduce the estimated rates of N mineralization. In the laboratory, plant uptake did not occur. Higher microbial C under plants (Burke et al. submitted) also indicates higher mineralization under plants under optimum condition for N mineralization.

The percentage of mineralized N per unit total soil N (Fig. 2.5) was significantly highest in cultivated fields, but the difference in this percentage between native and abandoned fields was not significant. This ratio indicates the amount of "active" SOM (sensu Parton et al. 1987) relative to the total, and suggests that there is a higher proportion of active N in cultivated fields than native and abandoned. This is likely because total N has been reduced more than active SOM-N.

Results of higher N mineralization and % N mineralization in cultivated fields indicate that the potential N losses are higher in cultivated fields than native and abandoned fields. High concentrations of nitrate and ammonium may leach from the system, or be subjected to volatile losses via ammonia volatilization (760 g NH_4 N ha^{-1} y^{-1}) (Schimel et al. 1988) or denitrification (104 g N_2O N ha^{-1} y^{-1}) (Parton et al. 1988). Both % mineralized and net N mineralized in abandoned field had a tendency that N

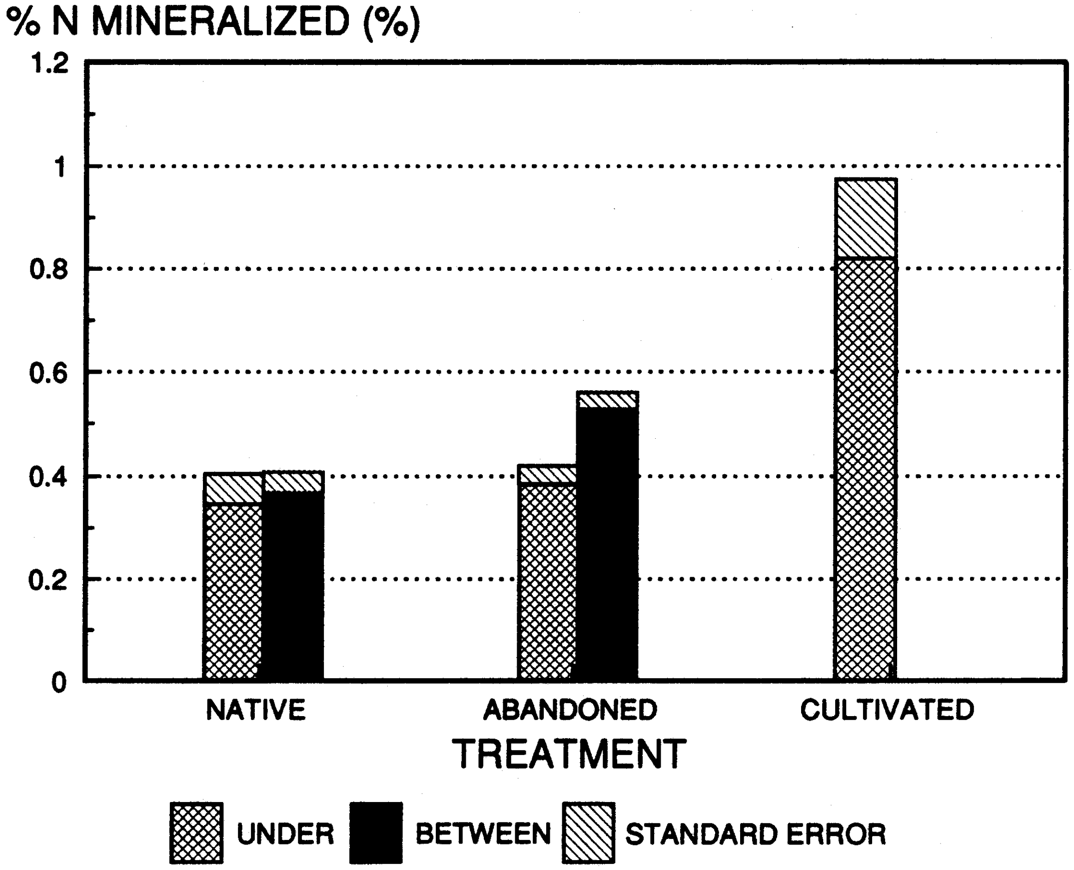

Fig. 2.5. Percentage of N mineralized of total N in soils (0 - 15 cm) from the Pawnee National Grasslands in northeastern Colorado. Soils were collected from native, abandoned, and cultivated fields, and two microsites, under and between plants.

mineralization between *B. gracilis* was similar to N mineralization in cultivated fields, and under *B. gracilis* was similar to native fields. This can be interpreted as evidence that, in abandoned fields, faster recovery occurs under plants than between plants. Microsite effects on percent N mineralized were not significant.

Field N mineralization rates from this study were divided by laboratory N mineralization rates from the same sites from a separate study (Burke et al. submitted). This ratio may be considered to represent an index of environmental limitation to N mineralization in the field (the lower the ratio, the greater the environmental limitation), since laboratory incubations are conducted under relatively optimum temperature and moisture. The ratio was significantly higher in cultivated fields than native fields, but the difference between native and abandoned fields and the difference between abandoned and cultivated fields were not significant (Fig. 2.6). This result suggests that cultivated fields tended to have less environmental restriction in the field than native fields. This interpretation is supported by soil moisture data (Fig. 2.4). Since there were no plants in cultivated fields, moisture level was higher and mineralization rates were higher.

The ratio of field net mineralization to lab net mineralization tended to be lower under plants than between plants, though this was not a significant difference (P =

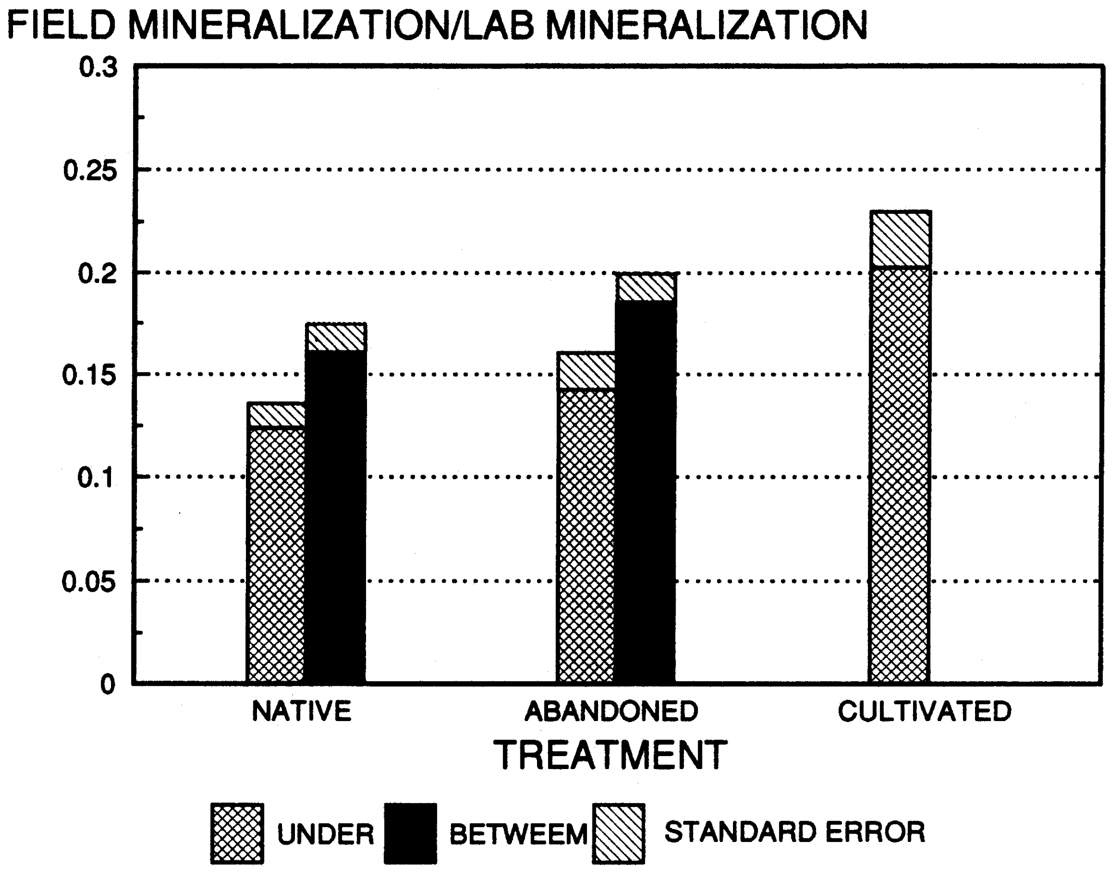

Fig. 2.6. N mineralized in field / N mineralized in the laboratory from soils from the Pawnee National Grassland in northeastern Colorado. Soils were collected from native, abandoned and cultivated fields and two kinds of microsites, under and between plants.

0.063). Under plants, immobilization is likely higher due to higher microbial C (Burke et al. submitted) and a higher C/N ratio (Fig. 2.2). In addition, because of the core method, plants probably took up mineralized N from soil in the fields. Therefore, to evaluate effects of cultivation and abandonment on in situ N mineralization, it may be better to use N mineralization data from between plants.

I found that in situ estimates of available N for plants in native fields and abandoned fields were not significantly different, which suggests that N supply capacity for plants in abandoned fields has recovered. Similar results were documented by Burke et al. (submitted). However, the total nutrient pool (total C and N) had not recovered yet, since decomposing soil organic matter is slow to accumulate. My data, and results of many others suggest that cultivation decreases active pools responsible for nutrient supply, and more slow or passive soil organic matter pools (sensu Parton et al. 1987). However, recovery over 50 years may only significantly affect active soil organic matter, such that N mineralization is equal between native and abandoned fields. We may need to consider longer recovery effects on slow or passive soil organic matter.

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