Foothills Forage Association
Soil Carbon Monitoring Project

Prepared for:

I. McPherson
Executive Director
Foothills Forage Association
201, 5403 Crowchild Trail N.W.
Calgary, AB

Prepared by:
L. A. Leskiw M.Sc., P.Ag
J. P. Battigelli Ph.D., P.Ag
A. R. McLean M.Sc., A.Ag.

Paragon Soil and Environmental Consulting Inc.
14805 119th Avenue
Edmonton, AB T5L 2N9
(780) 434-0400

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1.0 INTRODUCTION

Paragon Soils and Environmental Consulting Inc. was contracted by the Foothills Forage Association to conduct a soil organic carbon monitoring project comparing soils under native range, new grassland (cultivated for 100 years and seeded to forage in 2006), and old grassland (cultivated for 75 years and reseeded to grassland 25 years ago). This report presents methodology, results, conclusions and recommendations based on the analyses of the data collected in 2006.

1.1 Background

Soil organic carbon (SOC) is an important factor in the quality of soils. Soil organic matter (SOM), which is comprised mainly of organic carbon, influences a range of soil properties and plant growth (Brady and Weil 1996). Both SOC and SOM refer to soil carbon with a conversion factor of SOC x 2 = SOM. Small amounts of SOM can dramatically increase the capacity of a soil to promote plant growth (Brady and Weil 1996). Typically, grasslands have high SOM contents, supplying essential plant nutrients, increasing soil aggregation, limiting erosion, increasing cation exchange capacity and water holding capacity (Conant *et al*. 2001). Maintenance of SOM is essential for sustaining grasslands (Conant *et al*. 2001).

Depending upon the type of vegetation grown and management practices, SOC can either be increased or decreased. Significant SOC losses due to conversion of native grassland to cultivated agriculture have been reported (Conant and Paustian 2002). The rate of SOC sequestration also varies with landscape, climate and depth to the local water table (Landi *et al.* 2003). Campbell *et al*. (1996) suggested that when grassland is first cultivated, the natural addition of organic matter ceases and subsequently less organic carbon is added to the soil. The greatest amount of SOC is lost during the first few decades of cultivation and the total levels of SOC stabilize at a new level lower than that of the preceding native grassland (McLauchlan *et al.* 2006). Organic carbon addition is also decreased when summer fallow and conventional tillage practices are implemented because less organic matter is incorporated into the soil and the organic matter in the soil is decomposed more rapidly because of higher soil moisture conditions (Campbell *et al*. 2000). Study showed that commercially-used grassland gained little organic carbon because of the removal of potential carbon sources (*i.e.* above-ground plant matter) (Campbell *et al*. 1996). When forage is removed, the amount of litter added to the soil is decreased. As well, with the removal of vegetation, the amount of growth of the root system decreases. Erosion associated with cultivation also affects the amount of SOC since carbon is transported with soils from eroded soils on topographic highs and concentrated in depositional areas in topographic lows (Janzen *et al*. 2002). However, this process can be minimized with management changes.

Within established grasslands, SOC can be increased through enhanced grazing management, fertilization, seeding with legumes and improved forage species and irrigation (Conant *et al.* 2001). Conversion of cultivated cropland to permanent grassland has also been shown to increase SOC (Conant and Paustian 2002). Landi *et al*. (2003) found that Chernozemic soils under natural grassland vegetation can sequester between 0.57 and 1.18 g SOC/m^2 per year. However, the rate of sequestration varies depending on topographic position (McLauchlan *et al*. 2006). (Campbell *et al.* 1996) Janzen et al. (2002) suggested that soil erosion leaves potential for higher amounts of SOC to be deposited in the soil. Lowland areas are subsequently enriched in SOC and upland areas, if reclaimed successfully, have a large storage capacity that may exceed the initial amount of SOC. While much research concerning SOC in soils under cultivation and various cropping systems has been conducted, little has been done in the area of perennial forage growth.

A major challenge in accurately measuring SOC is measuring small changes against high background levels. Conant *et al.* (2003) suggested that the amount of carbon sequestered can be in the order of one one-hundredth of the total amount of carbon in the soil. Background levels include organic and inorganic carbon. The amount of inorganic carbon in a soil depends on the type of soil, but increases the need for precision in detecting the amount of organic carbon (Ellert *et al.* 2002). There is considerable spatial variation over short distances in addition to possible measurement errors that can occur from sample collection through to laboratory analysis. This can be partially overcome by taking many samples and determining mean SOC levels within desired (95%) confidence limits.

Van den Bygaart (2006) suggested a sampling grid where cores are extracted in a regular grid. To compare SOC content over time, future cores are taken as close as possible to the initial locations, without re-sampling the initial location (Figure 1). Soil carbon content is measured as well as soil bulk density, the latter to correct for possible compaction and to express results in kg or T per ha.

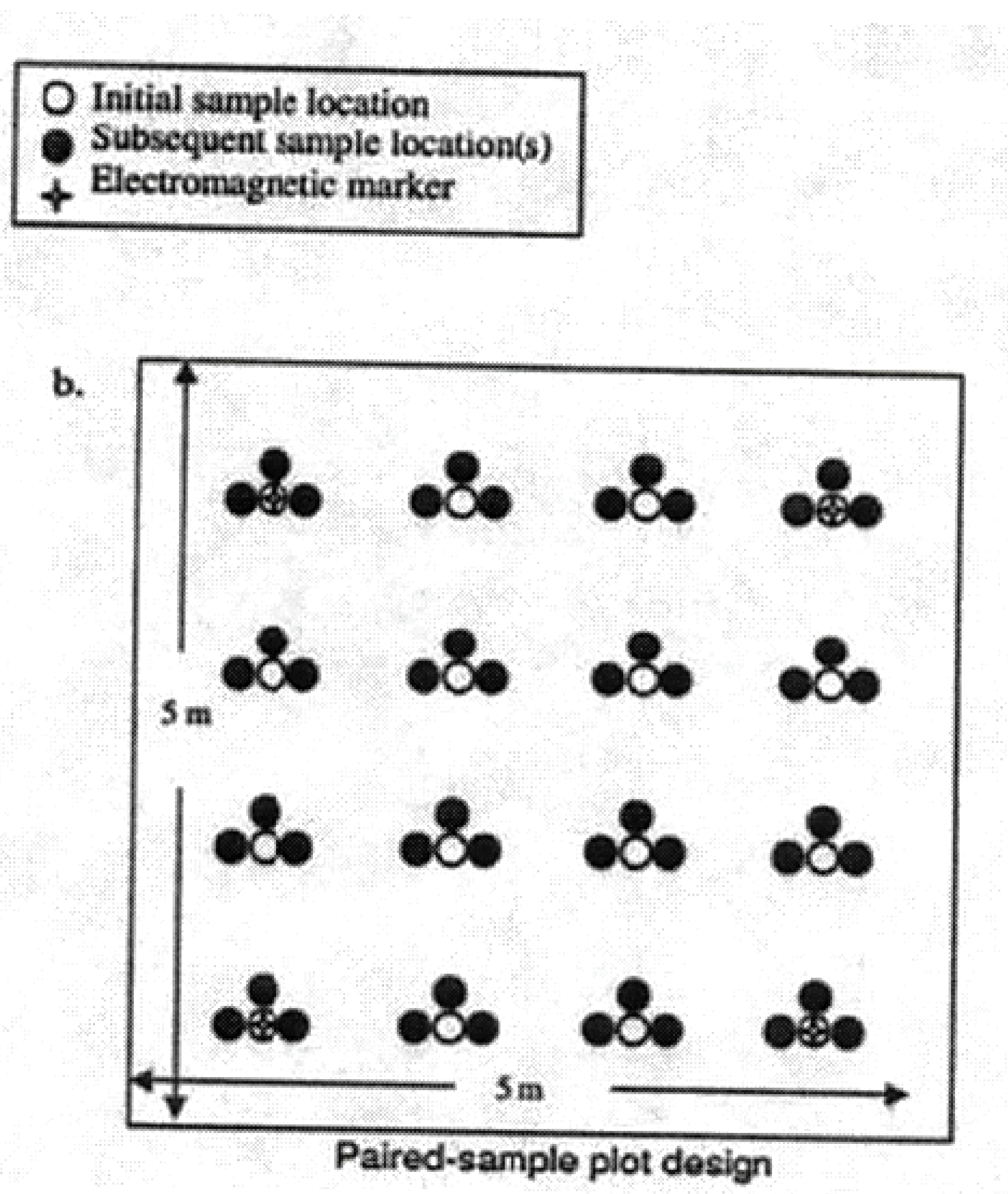

Figure 1: Suggested paired sample plot design for sampling soil organic carbon (Van den Bygaart 2006).

A soil zone perspective of topsoil depths, corresponding SOC mass and ranges is given in Table 1. There is considerable range in SOC content within soil zones. Similarly, topsoil (Ap horizon) depths also range considerably within soil zones. Minimum topsoil depth in Brown and Dark Brown Chernozems is about 10 cm, whereas in other soil zones, a minimum topsoil depth could be 15 cm.

Table 1: Summary of organic carbon contents in topsoil on mid-slopes in Alberta soil zones.

Eco-region (number of sites)	Dominant Soil Group	Topsoil Depth cm	SOC T ha^{-1} mean	SOC T ha^{-1} range
Peace Lowlands (10)	Dark Gray	12-20	77	37-137
Boreal Transition (8)	Dark Gray	15-23	58	29-130
Aspen Parkland (9)	Black	13-33	89	11-197
Fescue Grassland (2)	Black	19-20	78	66-89
Moist Mixed Grassland (5)	Dark Brown	10-18	41	24-67
Mixed Grassland (7)	Brown	10-24	19	13-28

Source: AB Benchmark sites. Note: Topsoil includes A horizons (Ap, Ah, Ahe)

In order to determine the minimum number of samples required for soils with increasing SOC levels, calculating the coefficient of variation (CV) is essential to examine the variability within and among plots. Table 2 estimates the number of samples required for measuring SOC in soils with various background levels of SOC with different CV values (10, 15 and 20 %) and different minimum detectable differences of SOC (1 and 0.5 T). Comparison of different sample numbers indicates that CV should be kept below 15% to keep sampling intensity reasonable. Reducing resolution from 0.5 T to 1 T/ha would reduce sample numbers for all soils, especially for those with > 50 T/ha SOC.

Table 2: Minimum number of samples required to detect various SOC changes (95% confidence) with varying coefficients of variation.

Background SOC (T/ha)	CV 10%				CV 15%				CV 20%			
	1 T		0.5 T		1 T		0.5 T		1 T		0.5 T	
	% Δ	n	% Δ	n	% Δ	n	% Δ	n	% Δ	n	% Δ	n
10	10	6	5	25	10	15	5	50	10	25	5	75
20	5	25	2.5	75	5	50	2.5	150	5	75	2.5	250
30	3.3	50	1.6	200	3.3	75	1.6	400	3.3	150	1.6	700
40	2.5	75	1.25	200	2.5	150	1.25	400	2.5	250	1.25	700
50	2	75	1	200	2	150	1	400	2	250	1	700
60	1.6	200	0.8	1600	1.6	400	0.83	1600	1.6	700	0.83	2500
70	1.4	200	0.71	1600	1.4	400	0.71	1600	1.4	700	0.7	3000
80	1.2	200	0.62	1600	1.2	400	0.62	2500	1.2	700	0.62	4000
90	1.1	200	0.55	1600	1.1	400	0.55	3000	1.1	700	0.55	5500
100	1.0	200	0.50	1600	1.0	400	0.50	3000	1.0	1600	0.5	5500

1.2 Objectives

In this project, three separate issues are addressed. First, SOC concentrations are compared among three fields under different management regimes (native range, new grassland and old grassland). The new and old grasslands were cultivated beginning about 1905 and reseeded to grassland in 2006 and 1981, respectively. Second, the rate of change of SOC with time is evaluated for the reseeded fields and compared to native range. Third, establish baseline conditions for 2006 so that changes in SOC can be monitored over time under each management practice.

To accurately assess soil quality, factors other than soil organic carbon also need to be considered. A soil may have a high SOC content; however, it may not be productive in terms of plant growth. Particle size analysis (PSA), cation exchange capacity (CEC) and nitrogen/phosphorus/potassium (NPK) concentrations are also determined for each field. There is a direct relationship between clay and SOC content (Campbell *et al.* 2000); clayey soils tend to sequester more carbon than sandy soils. Cation exchange capacity is the total number of cations a soil can adsorb (Brady and Weil 1996). If a soil has a low cation exchange capacity it generally does not support productive plant growth. Nitrogen, phosphorus and potassium are plant macronutrients. Without them, productive plant growth is not possible.

Another element of the soil ecosystem, besides soil chemical and physical properties, is the biological element of the soil. Specifically, soil arthropods are actively involved in decomposition, nutrient cycling and soil formation (Seastedt 1984). Mites (Acari) and springtails (Collembola) represent a numerically abundant and species-rich group of organisms in the soil. They respond quickly to changes in the soil habitat. These organisms may also provide a useful function as bioindicators of habitat disturbance and soil quality (Hogervorst *et al.* 1993, Pankhurst *et al.* 1995, van Straalen & Verhoff 1997) since changes to faunal assemblages may be detected prior to changes in physical or chemical properties (Garay & Nataf 1982).

These further analyses in conjunction with soil carbon content provide a better overall assessment of soil health for each production scenario.

2.0 METHODS

2.1 Field Methods

Three plots were located in midslope positions, in gently undulating terrain, on each of three adjoining fields representing the different land management practices. Plot corners were marked with a buried metal piece and a pigtail, and GPS coordinates were determined (see Figure 2-2). Grids were laid out using tape measures and sample plots were marked with pigtails. Subsequently soil cores were taken at each point.

2.2 Sample Numbers

Assuming a background SOC of 50 T/ha (for a thin black Chernozem) and a coefficient of variation of 10%, 75 soil samples per benchmark plot would be needed to detect a change of 1 T/ha of SOC (see Table 2). Based on the sample grid design outlined by Van den Bygaart (2006), the sample plot layout for this study consisted of 75 samples per field (3 plots, sample grids of 25 samples each at 5 m intervals), as shown in Figure 2. Sampling at this intensity should ensure statistical integrity, when carbon sequestration rates are examined in the future.

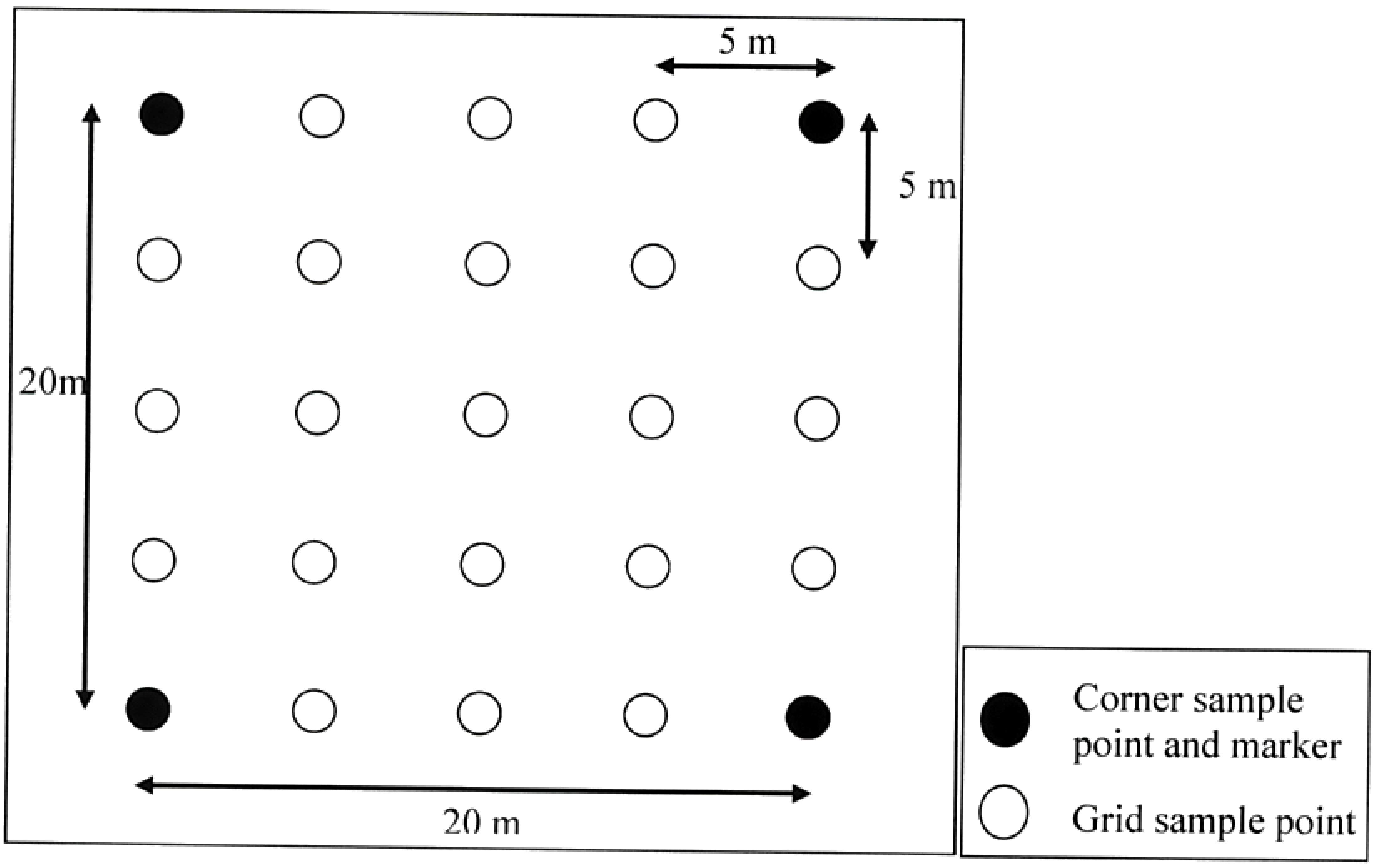

Figure 2: Sampling grid used at three plots per field.

2.3 Soil Sample Collection

Soil samples for measuring SOC and bulk density were collected using a soil corer (4.4 cm internal diameter). Care was taken to minimize sample compaction in order to reduce the influence on soil bulk density. Surface organic residue (*i.e.* crop residue, grasses etc.) was removed prior to sampling to prevent skewing of soil organic carbon concentrations. Soil cores were measured and placed directly into plastic bags and kept cool during transport to the laboratory. Sample points in the field were marked by placing a 5 cm section of PVC pipe into the core hole and filling the hole to the surface. In the future, new samples will be taken as close to the original sample core as possible. Three additional soil cores were randomly collected from each plot for soil fauna using the same soil corer.

2.4 Soil Sample Depth

Two sample depths were collected, based on soil horizon boundaries: A horizon and B or C horizon. The AB horizon was not included in sampling due to the high variability of organic carbon content within this transitional horizon. The SOC contents are based on actual depths of pure Ah or Ap materials. For B or C horizons, samples varied in thickness from 5 to 8 cm so values were adjusted to a standard 10 cm to allow comparisons. Therefore, reported SOC contents for B or C horizons are based on a 10 cm thickness. Soil fauna samples were 10 cm in length and divided into 0-5 cm and 5-10 cm samples for extraction in the lab.

2.5 Soil Profile Investigation

At one location in each field a soil pit was excavated, described and sampled for routine soil analyses. Soils were described according to the Canadian System of Soil Classification (Soil Classification Working Group 1998). Pedon descriptions, including parent geological material, pedological horizons and thicknesses, colour, texture, structure, consistence, and rooting characteristics, were observed and documented. Landscape description included slope position, drainage, stoniness, aspect, present erosion, and moisture regime of the plot.

2.6 Analytical Methods

Bodycote Laboratory in Edmonton, Alberta completed all analyses of soil chemical and physical properties. Table 3 outlines analyses completed on collected samples. Soil fauna samples were processed at Paragon. Fauna were extracted from the soil cores using a modified Merchant-Crossley extractor and identified to class, order and family levels depending on the group.

2.7 Statistical Methods

Exploratory analysis of the organic carbon data was the first step in the statistical analysis. Distribution of organic carbon content within each field and within each plot was examined graphically using box plots. This gives an indication of potential data outliers and variability in the data.

Next, one-way ANOVAs (analysis of variance) were conducted for each horizon (A and B or C). Separate ANOVAs were conducted to test if there was a significant ($\alpha=0.05$) difference in the mean organic carbon content between:

- Fields (native range, new grassland, old grassland);
- Plots (3 plots within each field).

If a significant difference among means was detected, Tukey's test (95% confidence limit) was used to determine where significant differences among means were located and how different they were.

Analyses of the soil fauna were carried out on density and relative abundance values using one-way ANOVA followed by the Homes-Sidak method if significant differences were observed. If the soil fauna data did not pass the assumptions of normality and equal variance, then the data were analyzed using the Kruskal-Wallis one-way ANOVA on Ranks method followed by Tukey's method if significant differences were observed.

Table 3: Laboratory analysis conducted on soil profile samples collected.

Parameter	**A**	**B or C**
Field Profiles		
Available NO_3-N, P, K, SO_4-S, NH_4-N (mg/kg)	1/field	1/field
Ca, Mg, K, Na (mg/kg)	1/field	1/field
Base saturation (%)	1/field	1/field
Exchangeable sodium percentage (%)	1/field	1/field
TEC (meq/100g)	1/field	1/field
Cation exchange capacity (meq/100g)	1/field	1/field
Carbon:Nitrogen	1/field	1/field
Organic carbon (%)	1/field	1/field
Total organic carbon (%)	1/field	1/field
Total Nitrogen (%)	1/field	1/field
PSA (% sand, silt and clay)	1/field	1/field
$CaCO_3$ equivalent	1/field	1/field
Monitoring Plots		
Soil organic carbon (%)	75/field	9/field
Total organic carbon (%)	75/field	9/field
Total inorganic carbon (%)	75/field	9/field
Bulk density (Mg/m^3)	75/field	9/field

3.0 RESULTS AND DISCUSSION

For the purposes of this study, the three fields examined for organic carbon content are hereafter referred to as:

1. Native range: never been under cultivation (Plots 1, 2 and 3);
2. New grassland: native range cultivated for the past 100 years and converted to grassland in 2006 (Plots 4, 5 and 6). Conventional tillage was used until about 1981 and conservation tillage was practiced since then;
3. Old grassland: native range cultivated for 75 years and converted to grassland 25 years ago (Plots 7, 8 and 9).

3.1 Soil Descriptions and Analytical Results

1. Native Range

Orthic Black Chernozem on till, well drained, slightly stony, gently undulating.

Soil Horizon	Depth of horizon (cm)	Description
Ah	0-10	Very dark grayish brown (10YR 3/2 d); moderate, fine, granular; friable; silt loam; abundant fine roots.
AB	10-15	Brown (10YR 4/3 d); moderate, fine, subangular blocky; friable; loam; abundant fine roots.
Bm	15-40	Dark yellowish brown (10YR 4/4 d); moderate, fine, subangular blocky; friable; silty clay loam; abundant fine roots.
Cca	40-60+	Grayish brown (10YR 5/2 d); weak, fine, subangular blocky; firm; silty clay loam; plentiful fine roots.

Note: Descriptors and horizons are based on the Canadian System of Soil Classification (Soil Classification Working Group 1998)

- Plot 1 has a 2% NW slope.
- Plot 2 has a 3% S slope.
- Plot 3 has a 3% N slope.
- Mean Ah thickness (25 sample points per plot): Plot 1 = 8.9 cm, Plot 2 = 7.8 cm, Plot 3 = 8.4 cm.
- Mean AB thickness (25 sample points per plot): Plot 1 = no data, Plot 2 = 6.6 cm, Plot 3 = 9 cm.
- The main vegetation cover was blue gramma grass, blue grass and sage.

2. New Grassland

Orthic Black Chernozem on till, well drained, slightly stony, gently undulating.

Soil Horizon	Depth of horizon (cm)	Description
Ap	0-12	Very dark grayish brown (10YR 3/2 d); weak, fine, subangular blocky to weak fine granular; friable; loam; plentiful fine roots.
Bm	12-20 to 25	Dark yellowish brown (10YR 4/4 d); weak, fine, prismatic to weak fine subangular blocky; friable; loam; few fine roots.
Cca	20-60+	Grayish brown (10YR 5/2 d); weak, fine subangular blocky; friable; clay loam; few fine roots.

Note: Descriptors and horizons are based on the Canadian System of Soil Classification (Soil Classification Working Group 1998).

- Plot 4 has a 2% S slope.
- Plot 5 has a 2% N slope.
- Plot 6 has a 3% W slope.
- Mean Ah thickness (25 sample points per plot): Plot 4 = 7.2 cm, Plot 5 = 8.7 cm, Plot 6 = 8.2 cm.
- Mean AB thickness (25 sample points per plot): Plot 4 = 3.8 cm, Plot 5 = 6.1 cm, Plot 6 = 5.5 cm.
- The main vegetation cover was "first year" alfalfa, vetch, sainfoin and brome grass with volunteer canola and wild oats. Stubble from the cover crop remained also.

3. Old Grassland

Orthic Black Chernozem on till, well drained, slightly stony, gently undulating.

Soil Horizon	Depth of horizon (cm)	Description
Ap	0-11	Very dark grayish brown (10YR 3/2 d); moderate fine granular; friable; loam; abundant fine roots.
AB	11-13	Brown (10YR 4/3 d); weak fine subangular blocky; plentiful fine roots.
Bm	13-20	Dark yellowish brown (10YR 4/4 d); weak fine subangular blocky; friable; silt loam texture; plentiful fine roots.
Cca	20-60+	Brown (10YR 5/3 d); weak fine subangular blocky; firm; clay loam; few fine roots.

Note: Descriptors and horizons are based on the Canadian System of Soil Classification (Soil Classification Working Group 1998).

- Plot 7 has a 2% S slope.
- Plot 8 has a 2% N slope.
- Plot 9 has a 3% NW slope.
- Mean Ah thickness (25 sample points per plot): Plot 7 = 8.8 cm, Plot 8 = 8.8 cm, Plot 9 = 8.5 cm.
- Mean AB thickness (25 sample points per plot): Plot 7 = 6.0 cm, Plot 8 = 5.8 cm, Plot 9 = 6.0 cm.
- The main vegetation cover was blue grass, meadow brome and alfalfa.

3.2 Analytical Results

Laboratory results for profiles sampled in each of the three fields are shown in Table 4. Careful examination of the results of the three profiles indicates changes in soil properties implying surface erosion of both new and old grasslands, which would have occurred during cultivation of these soils. The current topsoil is "lower" in the profile, incorporating the original AB horizon, and having characteristics more similar to the B horizon. Notably, in the cultivated soils SOC and total nitrogen contents in topsoils decreased, calcium levels increased, silt content decreased, clay content increased, potassium levels decreased, and available nitrogen levels decreased. Furthermore, the well defined AB horizon has diminished, probably being incorporated into the Ap horizon with cultivation. Overall, while still productive, the new and old grassland soils are inferior compared to the native range soil. This is based on the assumption that 100 years ago these soils were more or less the same.

Table 4: Soil chemistry and physical data for each field.

	1. Native Range				2. New Grassland			3. Old Grassland		
Horizon	Ah	AB	Bm	Cca	Ap	Bm	Cca	Ap	Bm	Cca
Sample Depth (cm)	0-10	10-15	15-40	40-60	0-12	12-20	20-60	0-11	13-20	20-60
Parameter										
Available NO_3-N (mg/kg)	8	22	8		1	<1		<1	<1	
Available P (mg/kg)	<5	<5	<5		16	<5		<5	<5	
Available K (mg/kg)	900	480	270		210	110		470	150	
Available SO_4-S (mg/kg)	7	14	6		5	8		6	5	
Available NH_4-N (mg/kg)	1.3	0.8	0.4		0.4	<0.3		0.5	0.5	
Ca (mg/kg)	3870	3670	3980		4690	4270		4810	4390	
Mg (mg/kg)	354	414	551		384	393		578	433	
K (mg/kg)	990	520	290		220	100		490	200	
Na (mg/kg)	10	20	20		20	20		<10	25	
BS (%)	80	79	91		106	103		99	108	
ESP (%)	0.2	0.2	0.3		0.3	0.3		<0.2	0.45	
TEC (meq/100g)	25	23	25		27	25		30	26	
CEC (meq/100g)	31.1	29.1	27.6		25.6	24.1		30.2	24	
C:N Ratio	11	11	9.6		10	8.6		9.9	9	
Organic Matter (%)	10	7	3		5	3		6	4	
Total Organic C (%)	5.02	3.4	1.71		2.32	1.52		3.2	1.84	
Total N (%)	0.46	0.32	0.18		0.23	0.18		0.32	0.21	
Texture	Silt Loam	Loam	Silty Clay Loam	Silty Clay Loam	Loam	Loam	Clay Loam	Loam	Silt Loam	Clay Loam
Sand (%)	30	30	13.8	14.6	33.8	25.2	33.8	36	25.4	28
Silt (%)	54	45.4	49	52.6	39.4	48.8	35.4	38.8	50.6	33.2
Clay (%)	16	24.6	37.2	32.8	26.8	26	30.8	25.2	24	38.8
$CaCO_3$ Equivalent (%)	0.3	0.3	0.2	13.1	0.5	0.4	20.4	0.9	0.6	19

Note: AB horizon of the Old Grassland was too thin to sample.

3.3 Organic Carbon – Results and Statistical Analysis

3.3.1 Box Plot Analysis

Based on the box plots (see Appendix A) created for the A horizon, SOC content within each field appears to have approximately equal variances and values were normally distributed. This satisfies the assumption of normality and equal variances necessary for among fields ANOVA.

Box plots created for plots 1 to 9 depict approximately normal distributions for SOC content in the A horizon. Variance of SOC content for native range plots (1, 2, and 3) was approximately equal. Variance of SOC in plot 4 was noticeably greater than plots 5 and 6. This indicates that plot 4 differs from plots 5 and 6, or there are anomalies in plot 4 data which requires more samples to be collected. Variance of SOC within old field plots (7, 8, and 9) differed. This is most evident in plot 8, which had greater variability than 7 and 9 suggesting that plot 8 may differ from plots 7 and 9 or there are anomalies in the plot 8 data and more samples are required.

Only three SOC samples per plot were collected for the B or C horizon. Box plots indicate that variability within plots was not equal and that the data was often not normally distributed. It is presumed that this is a reflection of insufficient sample numbers per plot.

3.3.2 ANOVA and Mean Comparisons

Mean SOC content in the A horizon differed significantly among fields (Figure 3). Native range had the highest mean soil organic carbon content (42.2 T/ha), followed by old grassland (35.7 T/ha) while the new grassland field was the lowest (27.4 T/ha).

This indicates that over 100 years of cultivation, there was a loss of 14.8 T/ha or about 0.15 T/ha per year of SOC based on the A horizon SOC levels. This relationship is probably not linear. One can speculate that losses were greater prior to about 1981 at which time conservation tillage practices were implemented on the cultivated field and grass was seeded on the old grassland field. Comparing the old grassland to the native range, there was a decline of 6.5 T/ha SOC over the 100 year period. This probably represents a decline over the first 75 years of cultivation with sequestration occurring during the last 25 years while under conservation tillage or grassland.

Using losses of 0.15 T/ha per year, if levels initially were the same then 42.2 T/ha minus 75 years x 0.15 T/ha per year = 11.2 T/ha lost bringing the level to 31 T/ha SOC. In the last 25 years gains of 0.15 T/ha per year should have increased levels by 25 x 0.15 = 3.8 T/ha, bringing the level up to 34.8 T/ha SOC. This value is very close to the 35.7 T/ha as measured in the old grassland field.

Interpretive Scenario 1 represents a linear SOC decline over the entire time under cultivation. An annual average SOC loss of 0.15 T/ha per year under cultivation with an accumulation of 0.15 T/ha per year under grassland could explain the results. This is considered to be a low rate scenario. Interpretive scenario 2 is considered to be more probable. This represents SOC decline for 75 years and accumulation for the last 25 years under cultivation due to adoption of zero-tillage practices and even greater SOC accumulation under grassland. Assuming annual sequestration rates averaging 0.3 T/ha/year under zero-tillage and 0.63 T/ha/year under grassland, the SOC trajectory would have been a decline (0.3 T/ha/year) from 42.2 T/ha (native range level), to 20 T/ha after 75 years followed by recovery (0.63 T/ha/year) on old grassland to 35.7 T/ha/year and recovery under zero-tillage (0.3 T/ha/year) to 27.4 T/ha/year.

These rates are speculative, within literature ranges reported for cultivated lands. Data on grassland sequestration is scarce. Results of this study clearly suggest SOC sequestration rates are higher under grassland than no-till, assuming the soils were the same originally and after 75 years of cultivation.

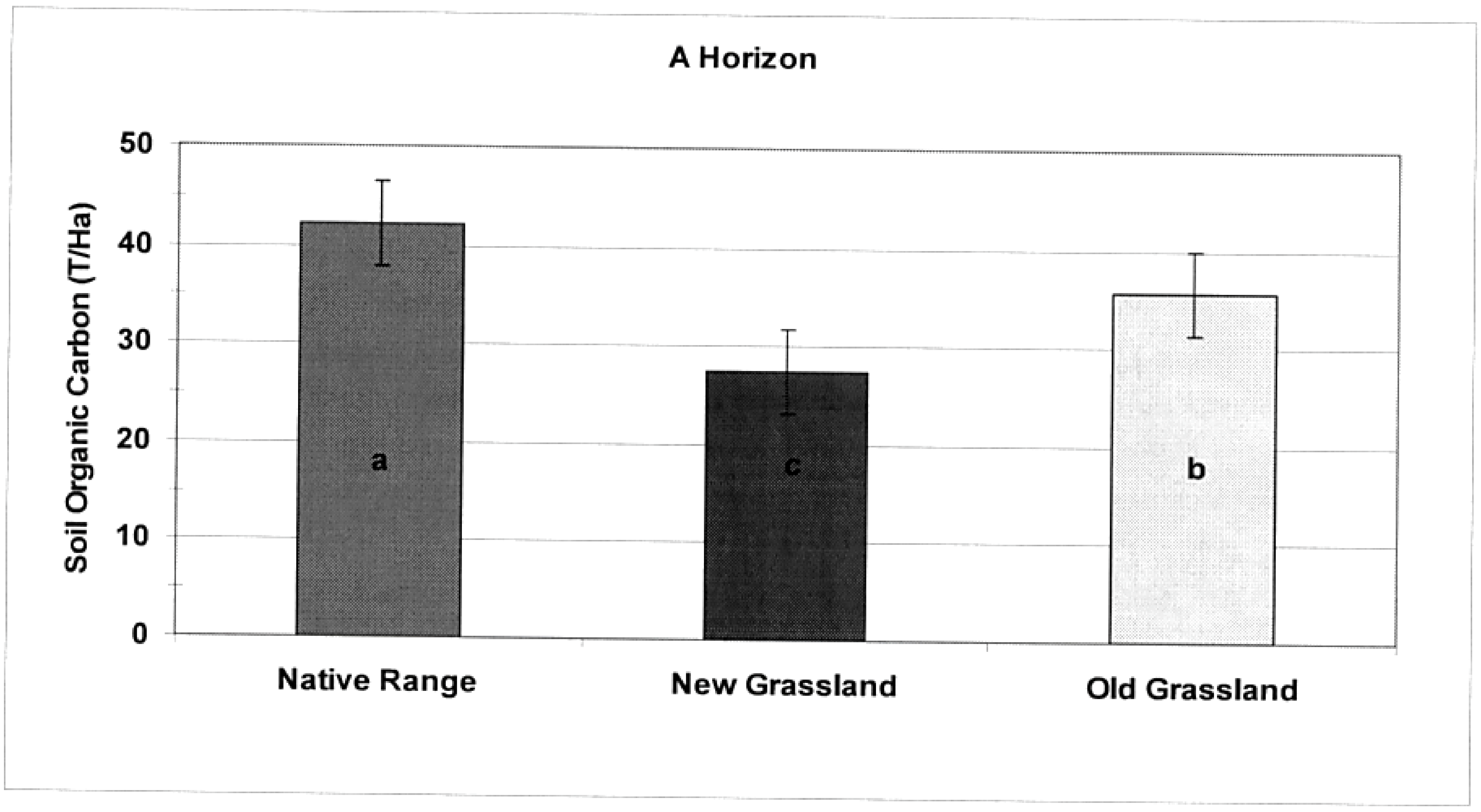

Figure 3: Mean SOC in the A horizon among fields.
<u>Note:</u> Different letters indicate a statistically significant difference.

Mean SOC for the A horizon by plot is presented in Figure 4. Plots within the fields were compared to determine variability within each field. In the native range, plots 1 and 3 were significantly higher than plot 2. In the new grassland, mean SOC values were significantly higher in plots 5 and 6 than plot 4. In the old grassland plots, mean organic carbon amounts were significantly higher in plot 9 than in plots 7 and 8. Mean values are variable across all plots.

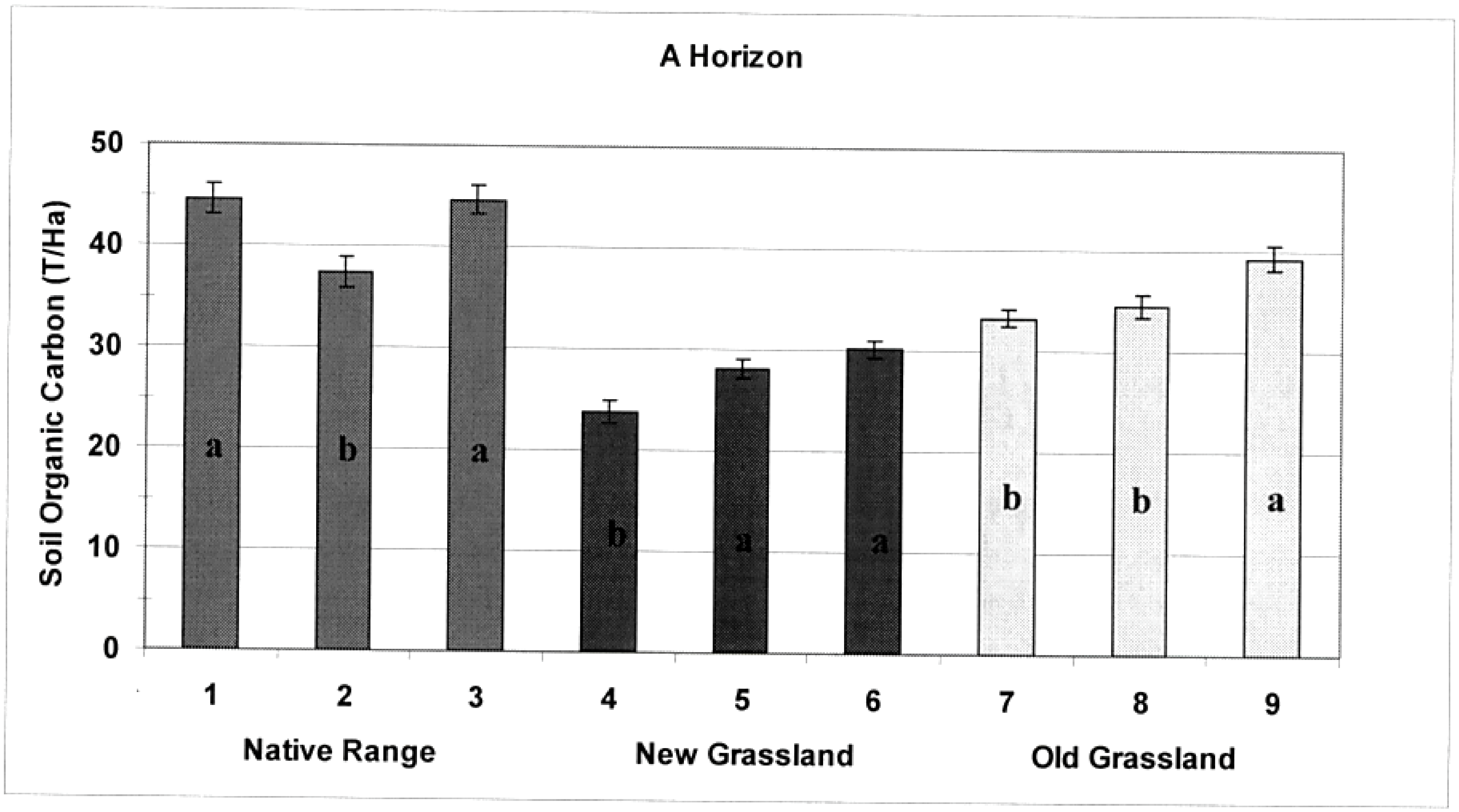

Figure 4: Mean SOC in the A horizon among plots.
Note: Different letters within field type indicates a significant difference among plots within field type only.

Mean bulk density in the A horizon differed significantly among fields (Figure 5). New grassland had the highest mean bulk density (1.3 g/cm^3), followed by old grassland (1.2 g/cm^3) while the native range field was the lowest (0.9 g/cm^3).

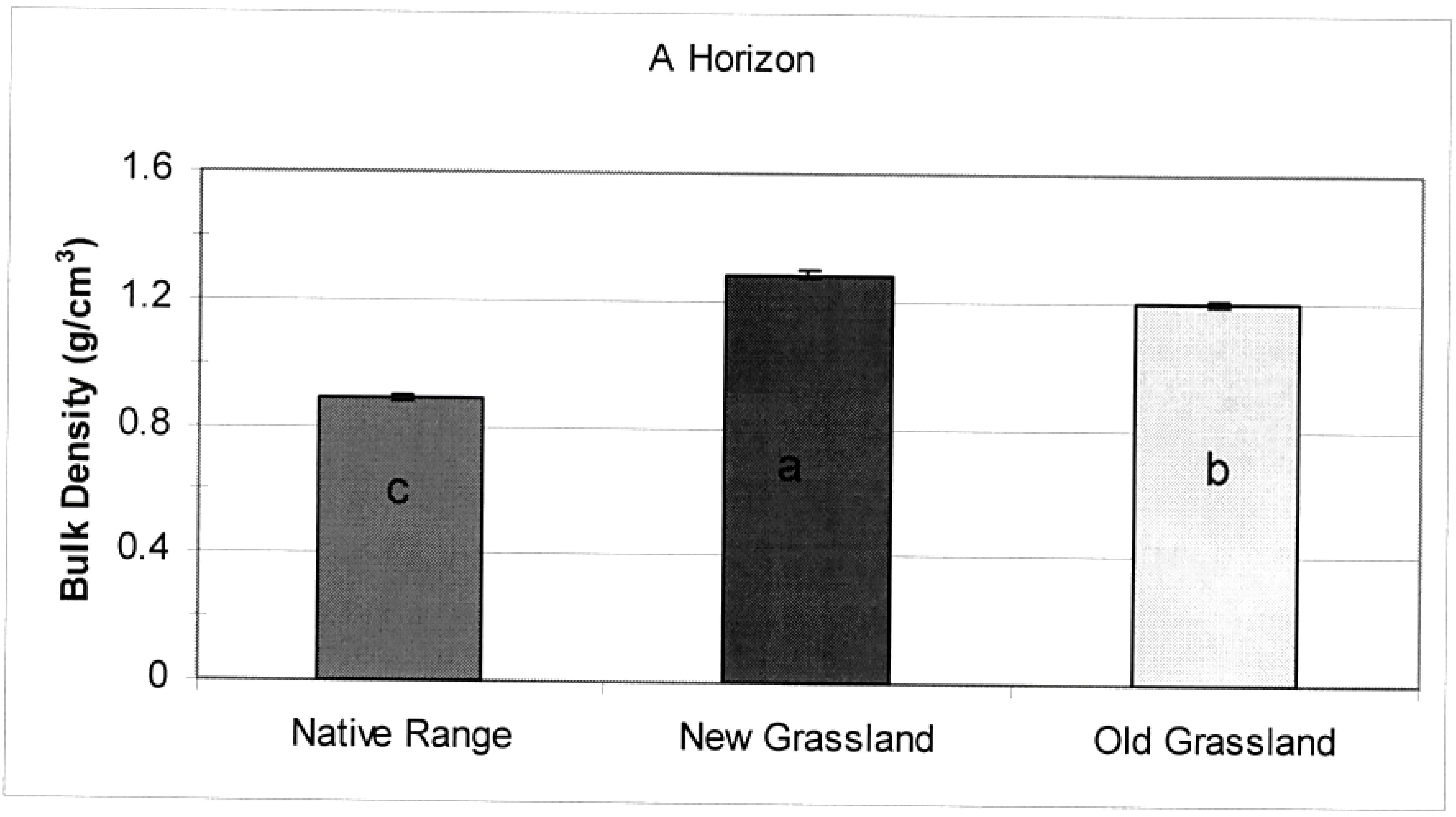

Figure 5: Mean bulk density in the A horizon among fields.
Note: Different letters indicate a significant difference as found by statistical analysis.

Mean bulk density for the A horizon by plot is presented in Figure 6. Plots within the fields were compared to determine variability within each field. In the native range, plots 1 and 3 were significantly different, while plot 2 was not significantly different from plots 1 and 3. In the new grassland, mean bulk density values were significantly higher in plots 5 and 6 than plot 4. In the old grassland plots, mean bulk density amounts were not significantly different.

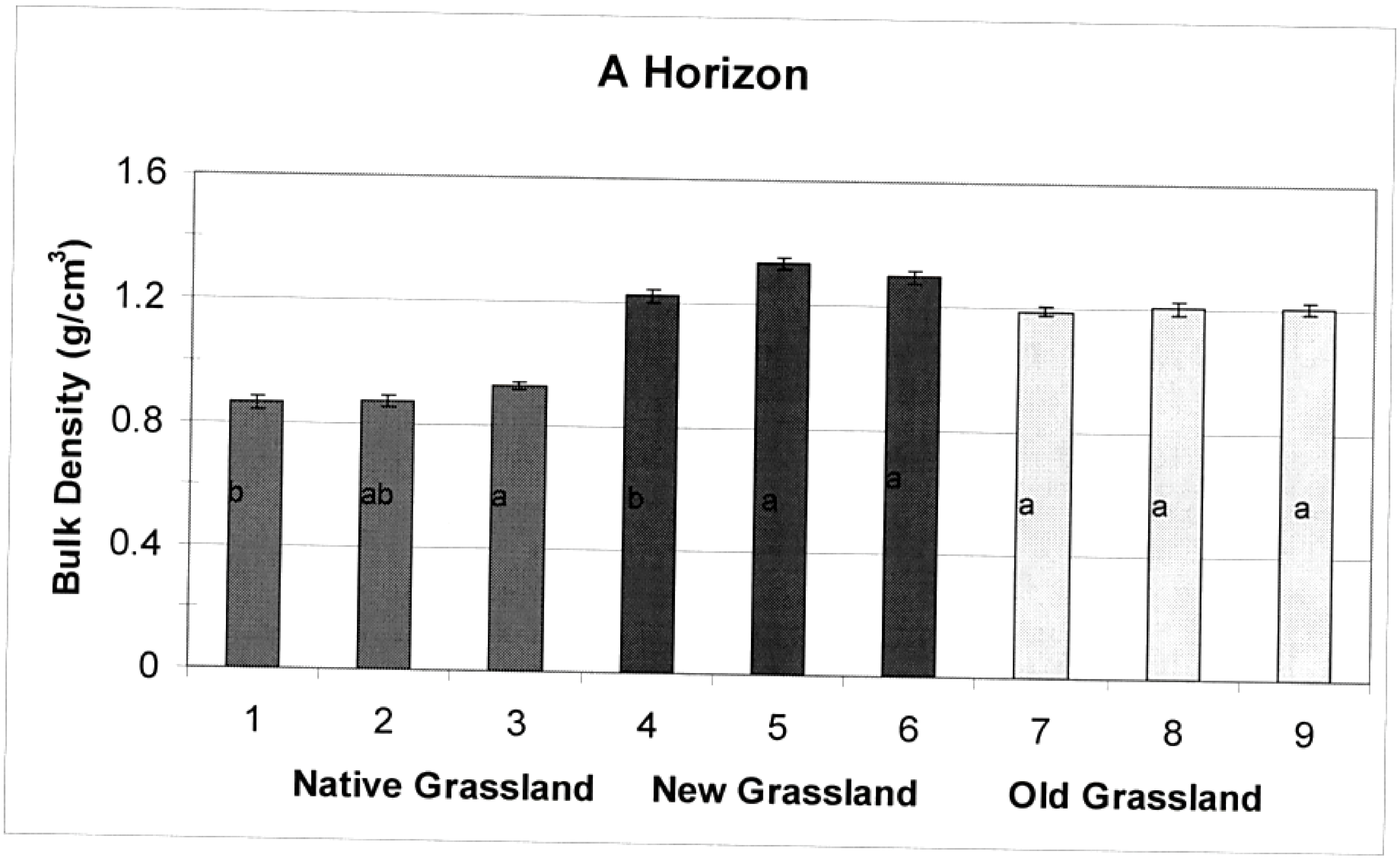

Figure 6: Mean bulk density in the A horizon among plots.
<u>Note:</u> Different letters within field type indicates a significant difference among plots within field type only.

Mean depth in the A horizon differed significantly among new grassland and old grassland (Figure 7). Old grassland had the highest mean depth (8.6 cm); followed by native range (8.4 cm) and the new grassland field (8.1 cm).

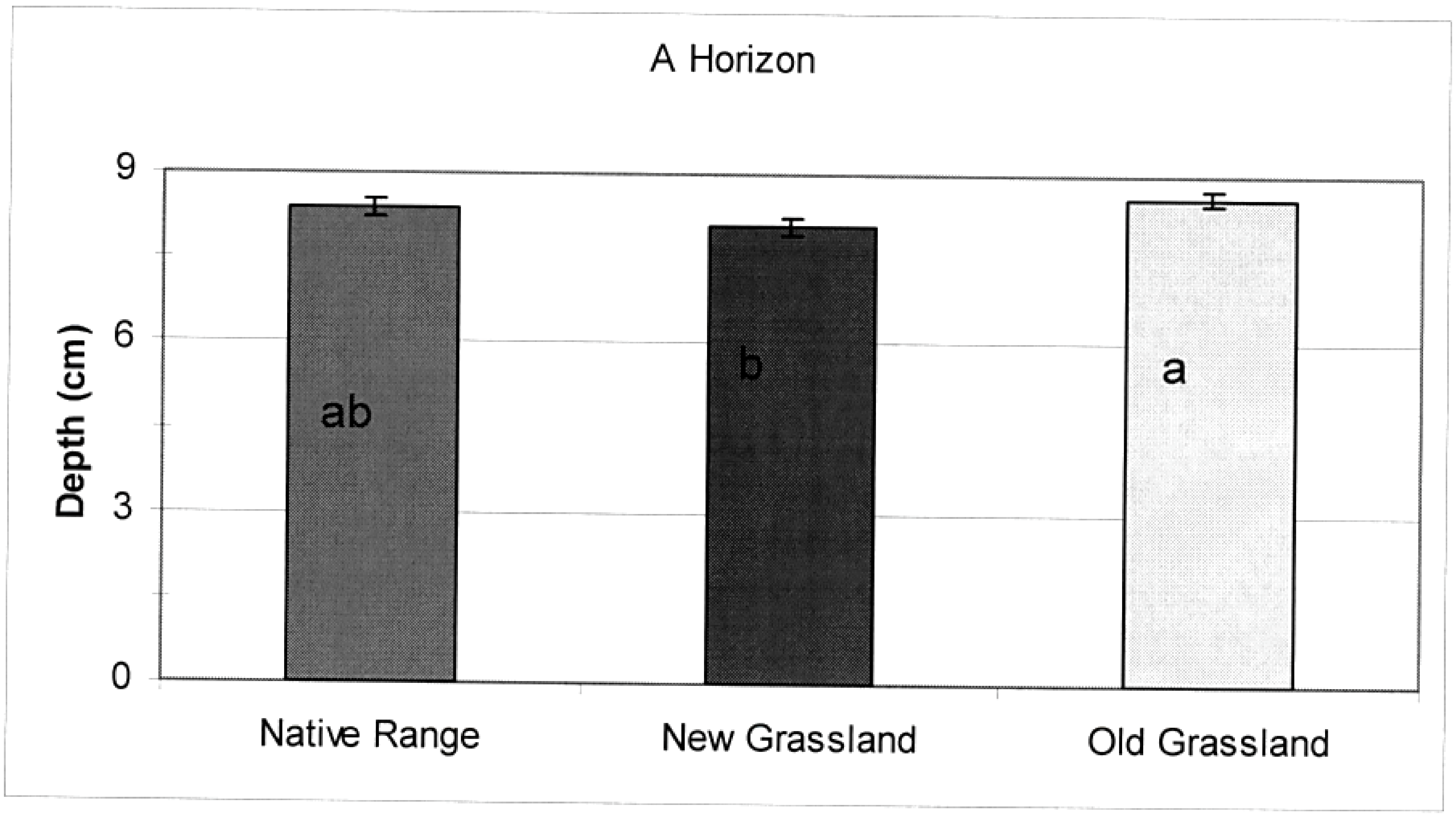

Figure 7: Mean depth in the A horizon among fields.
Note: Different letters indicate a statistically significant difference.

Mean depth for the A horizon by plot is presented in Figure 8. Plots within the fields were compared to determine variability within each field. In the native range, plot 1 was significantly higher than plot 3, and plot 2 was significantly lower than plot 3. In the new grassland, mean depth values were significantly higher in plots 5 and 6 than plot 4. In the old grassland plots, mean depth amounts were not significantly different. Mean values are variable across all plots.

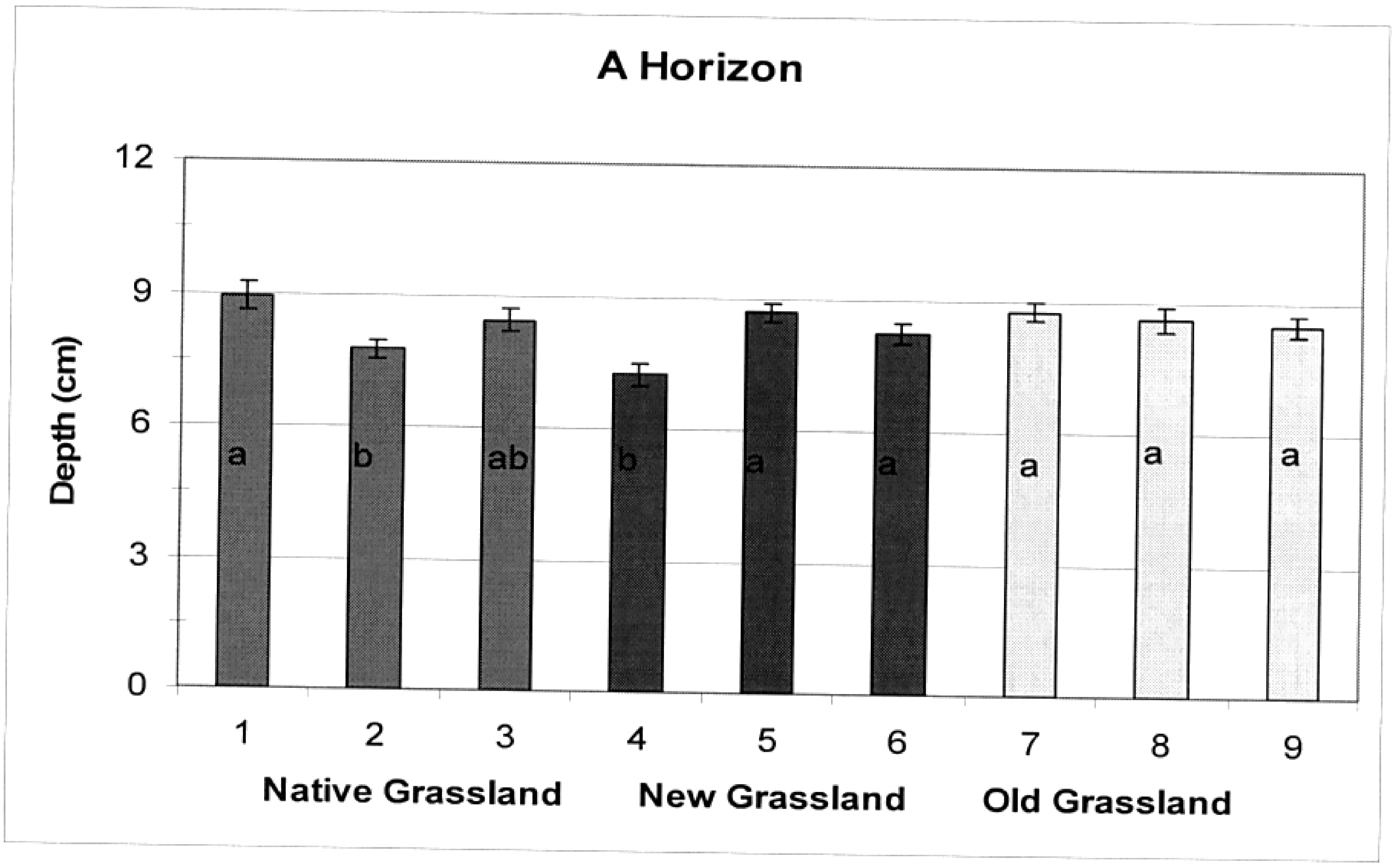

Figure 8: Mean Depth in the A horizon among plots.
<u>Note:</u> Different letters within field type indicates a significant difference among plots within field type only.

Figure 9 shows the comparison of SOC levels, standardized to 10 cm thick layers. Native range (25.5 T/ha) has a significantly higher SOC in the subsoil than the new grassland (20.8 T/ha) and the old grassland (18.6 T/ha).

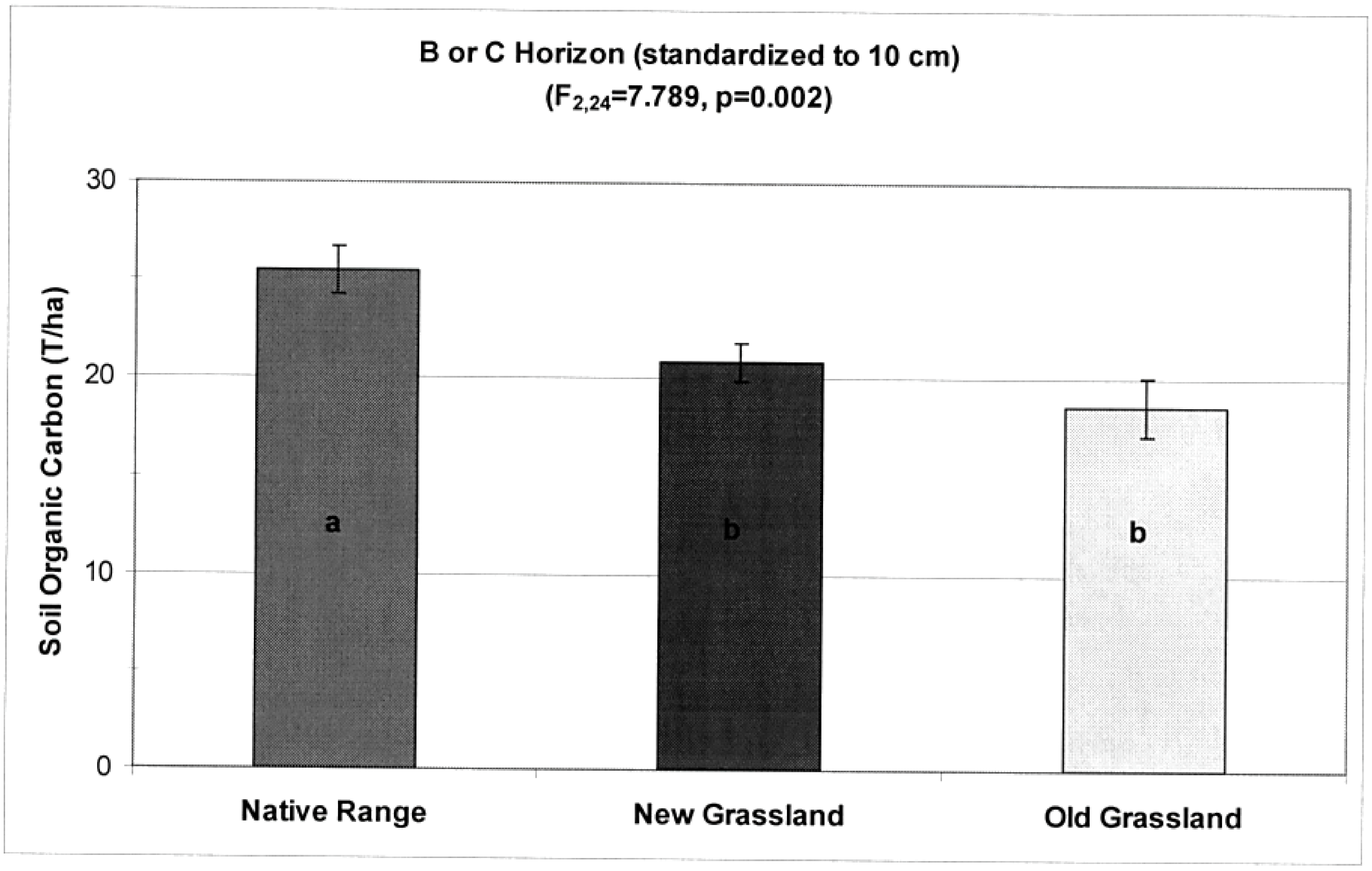

Figure 9: Mean SOC in the B or C horizon among fields.
Note: Different letters indicate a statistically significant difference.

While there was a great deal of variability in mean SOC of the B or C horizon among plots within each field, there were no significant differences in soil organic carbon content among plots within fields (Figure 10). However, comparisons in the B or C horizon may be compromised due to insufficient data since only 3 samples of B or C horizon were analyzed from each plot.

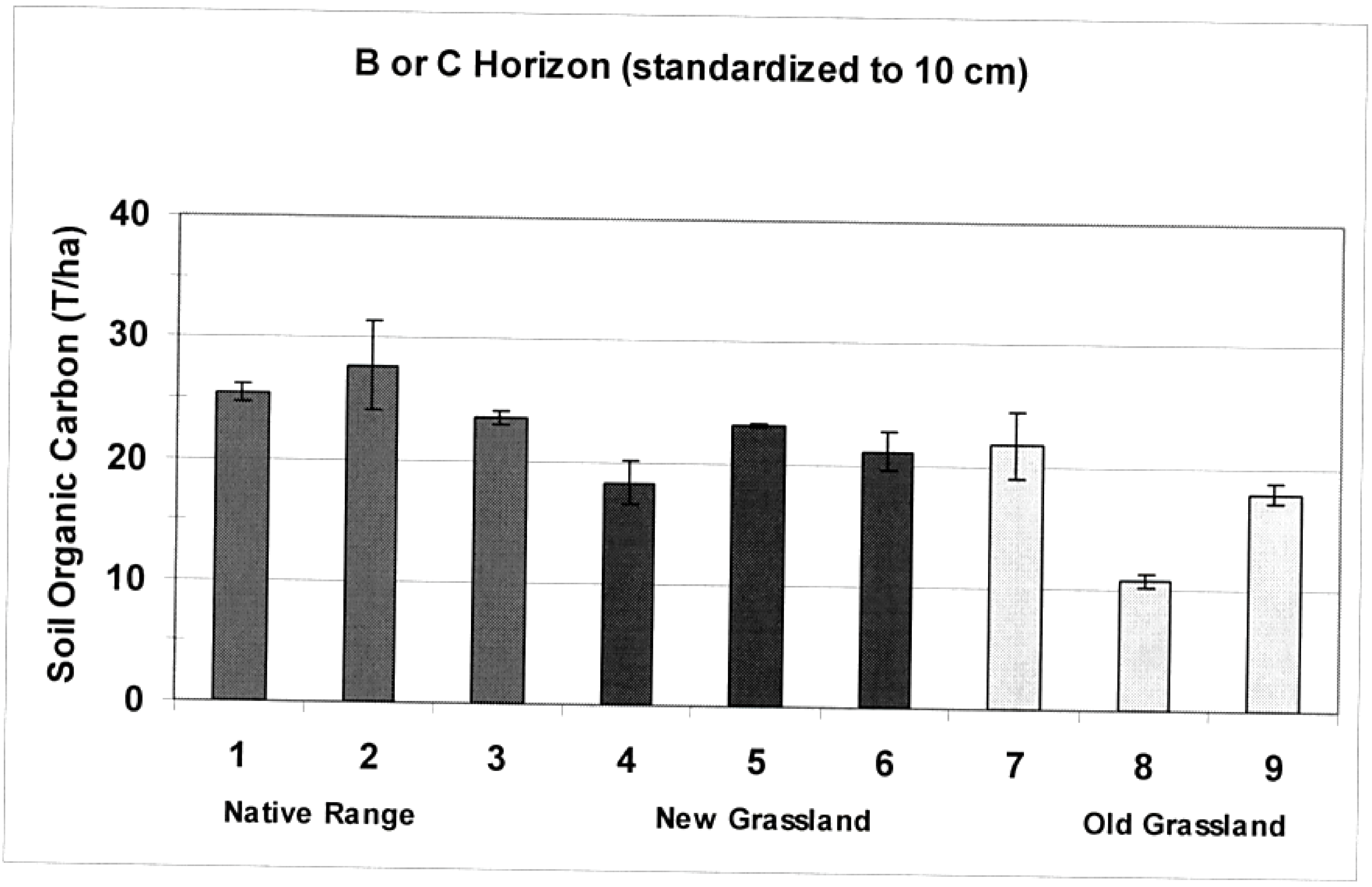

Figure 10: Mean SOC in the B or C horizon among plots.
Note: Different letters within field type indicates a significant difference among plots within field type only.

Mean bulk density in the B or C horizon was significantly higher in new grassland (1.30 g/cm^3) than native range (1.18 g/cm^3), but old grassland (1.23 g/cm^3) was not significantly different (Figure 11). There was variability in mean bulk density of the B or C horizon among plots within each field (Figure 12). However, comparisons in the B or C horizon may be compromised due to insufficient data since only 3 samples of B or C horizon were collected from each plot.

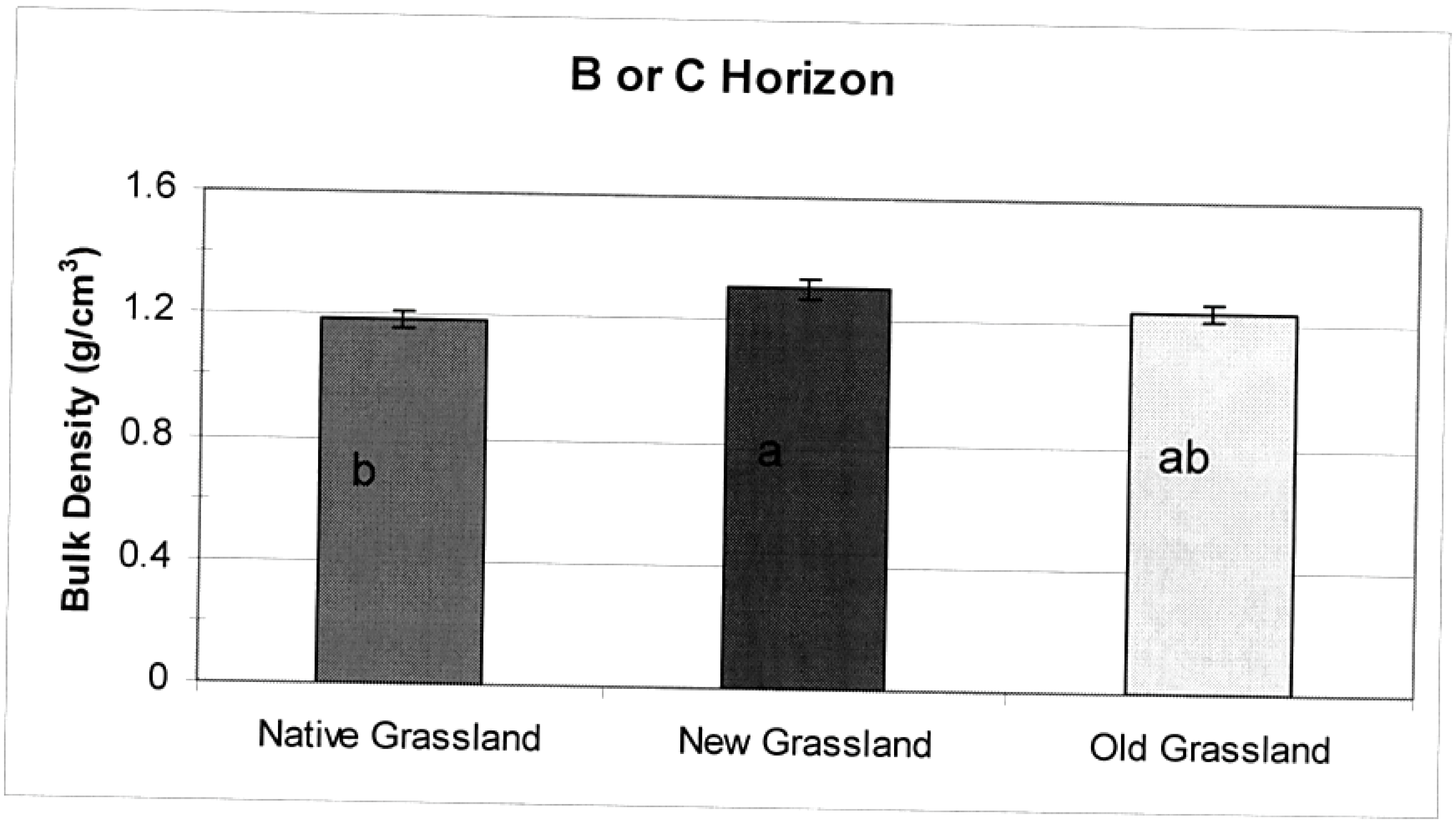

Figure 11: Mean Bulk Density in the B or C horizon among fields.
Note: Different letters indicate a significant difference.

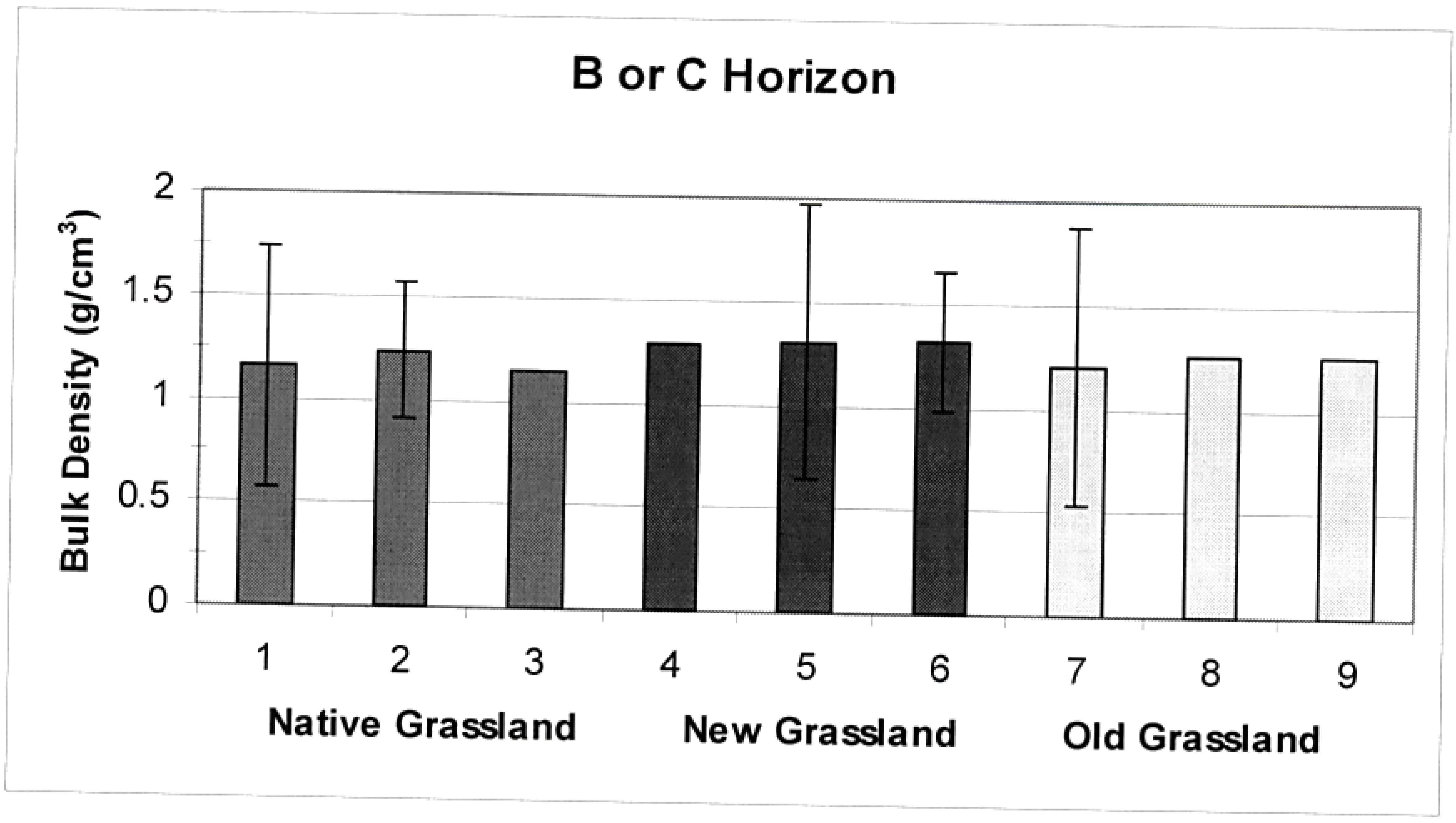

Figure 12: Mean Bulk Density in the B or C horizon among plots.
Note: Different letters within field type indicates a significant difference among plots within field type only.

3.3.3 Power Analysis

Using the data collected in 2006, different options for sample size and statistical power of the performed tests were examined. There is potential using the outlined sampling program to use composite samples to reduce the number of samples being sent to the lab. Comparisons examined included the original data using 75 (n=75) samples per field, grouped samples by 5 (n=15) and then grouped samples by 25 (n=3). In all three trials, statistical power exceeded the suggested value of 0.8 (1, 1, and 0.931, respectively).

The n=75 data failed the equal variance test for ANOVA resulting in the use of a Kruskal-Wallis One Way ANOVA on Ranks. Using this test, the differences in the median values among the treatment groups (natural, new and old) were significantly different ($p<0.001$). Tukey's test for a multiple comparison test showed that each plot differed significantly from each other. The n=15 data passed both normality and equal variance tests for ANOVA which indicated a significant difference of means values among the treatment groups ($p<0.001$). The Holm-Sidak method was used for the multiple comparisons which showed natural>old>new (42.2>35.7>27.4). The n=3 data also passed normality and equal variance tests for ANOVA which again showed a significant difference in mean values among the treatments ($p=0.006$). Again using the Holm-Sidak method to determine where the differences were among the treatments, only native range was significantly higher than new grassland (42.2 vs. 27.4).

The minimum detectable differences were:
- with n=75, 2.1 T/ha,
- with n=15 (composite of 5 samples), 3.2 T/ha, and
- with n=3 (composite of 25 samples), 8.9 T/ha

The data indicates that the current sampling design using n=75 gives the best resolution (2.1 T/ha). Using composite samples would increase the minimum detectable difference making it difficult to examine change given a low SOC input. In order to reduce the minimum detectable change to 1 T/ha approximately 200 samples would be needed from the natural grassland plots, 90 samples from the new grassland plots and 125 samples from the old grassland plots. This would require a total of 415 samples which is nearly twice as much as currently taken (215 samples).

3.3.4. Sample Size

Table 5 lists the minimum number of samples required to detect 2.0, 1.0, and 0.5 T/ha changes in SOC content at a confidence level of 95% using the method in Quinn and Keough (2002). The left-hand side of the table shows sample numbers calculated using the variance of the pooled data (n = 75); whereas, the right-hand side shows sample numbers calculated using plot specific data (n = 25). The coefficient of variation is about 20% for the 75 sample data set and ranges from 13 to 24 for the 25 sample plots. Owing to the high variability among plots, the total sample number required was higher with the plot specific analysis. In other words, when the data was analyzed for each plot within the main land use the total number of samples required to represent the whole field (at a given resolution) was generally higher than the pooled analysis. For instance, to detect a 2 t/ha change in SOC of a native grassland, 62 samples are adequate when the data pooled (based on the variance of 75 samples); whereas, to detect same amount of change, 157 samples are required during plot based analysis (i.e., based on the variance of 25 samples). Results show that the current sampling scheme allows detection of a change of 2 T/ha of SOC and the current sampling design is comparatively the most efficient.

Table 5: Coefficient of Variation (CV %) and sample numbers (n) required to detect small SOC changes.

Detectable difference for grouped data (n=75)				Detectable difference using plot specific data (n= 25)				
	2 T/ha	1 T/ha	0.5 T/ha			2 T/ha	1 T/ha	0.5 T/ha
	No. of samples required				CV%	No. of samples required		
Native Range CV = 19.0%	62	248	982	Plot 1	17.1	56	224	885
				Plot 2	19.9	53	213	844
				Plot 3	15.8	48	191	756
				Total		***157***	***628***	***2485***
New Grassland CV = 19.9%	29	114	453	Plot 4	23.9	31	125	494
				Plot 5	16.7	21	85	336
				Plot 6	13.2	15	61	242
				Total		***67***	***271***	***1072***
Old Grassland CV = 17.4%	37	148	584	Plot 7	13.2	19	75	296
				Plot 8	17.1	34	134	532
				Plot 9	16.6	41	165	652
				Total		***94***	***374***	***1480***

3.4 Soil Fauna

Soil fauna densities were significantly higher in both the native range and old grassland fields than the new grassland field (Figure 13). While not statistically significant, mean density of soil arthropods in the old grassland site was half that found in the native range field.

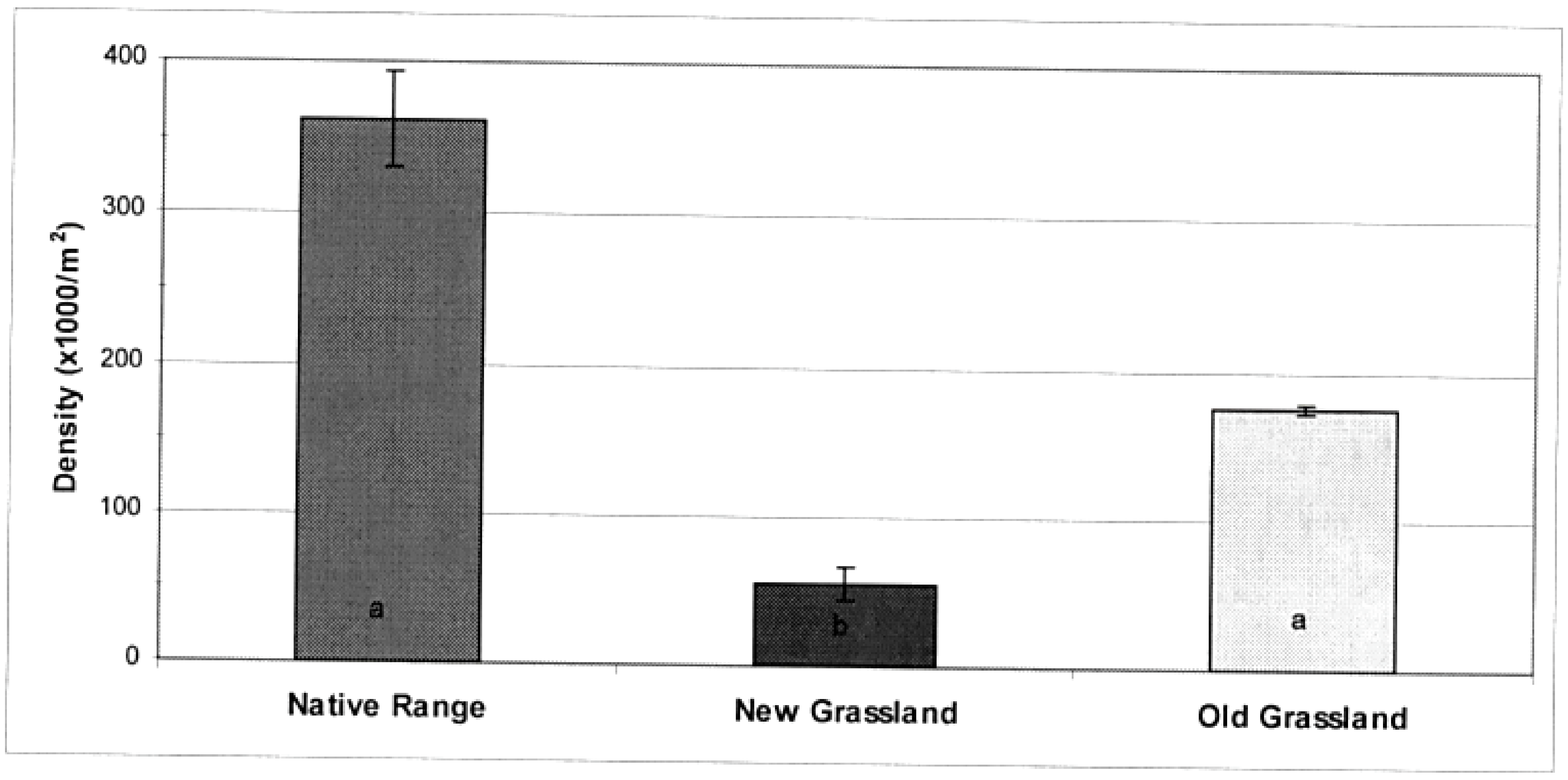

Figure 13: Mean density of soil micro arthropods among fields.
Note: Different letters indicates a significant difference in mean density among fields.

A similar pattern was observed in total Acari densities as well as the densities of all four suborders of mites (Table 6). While not statistically significant, densities of both Prostigmata and Oribatida from old grassland fields were half those found in the native range. Mesostigmata densities were similar between native range and old grassland while density of Astigmata in the old grassland field doubles that of the native range. Collembolan densities did not differ significantly among the fields.

Table 6: Mean density ($x1000/m^2$) of selected soil mesofauna groups.
Note: Different letters across rows indicates significant difference in mean density among fields.

	Native Range		-	New Grassland		-	Old Grassland		
Astigmata	8.66	±4.734	ab	1.40	±1.578	b	17.40	±0.526	a
Mesostigmata	6.43	±1.144	a	2.93	±0.381	b	6.01	±0.127	a
Oribatida	22.36	±2.722	a	3.21	±0.907	b	11.46	±0.302	ab
Prostigmata	273.72	±23.555	a	20.26	±7.852	b	115.48	±2.617	a
Total Acari	311.17	±26.843	a	27.81	±8.948	b	150.34	±2.983	a
Total Collembola	44.78	±6.425	a	25.01	±2.142	a	24.24	±0.714	a

Figure 14 shows the relative abundance of soil arthropods among the three fields. Only two differed significantly among the fields. The relative abundance of Collembola was significantly higher in the new grassland field than either the native range or old grassland fields. Conversely the relative abundance of Prostigmata was significantly higher in both the native range and old grassland field than in the new grassland field. This pattern also held true for the total proportion of Acari among the three fields.

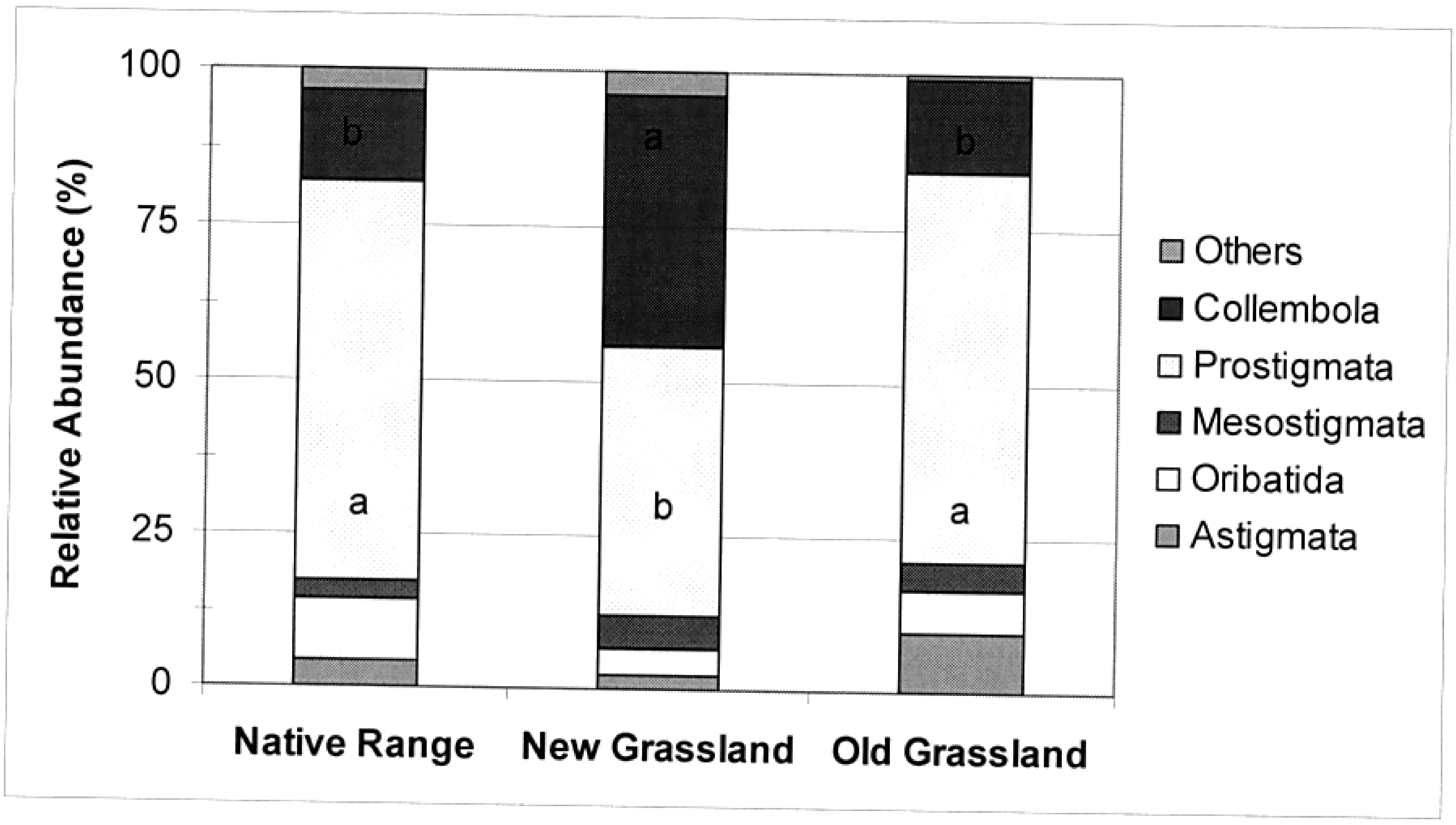

Figure 14: Mean relative abundance of soil mesofauna within fields.
Note: Different letters indicate a significant difference within mesofauna type. No letters indicates no significant difference among fields.

Figure 15 shows a positive relationship between soil organic carbon and soil mesofauna density among fields. With an $r^2 = 0.96$, there is a trend suggesting that higher densities of soil mesofauna are positively related to higher soil carbon amounts. This would influence decomposition rates, nutrient cycling and soil formation within the fields as densities of soil mesofauna increased.

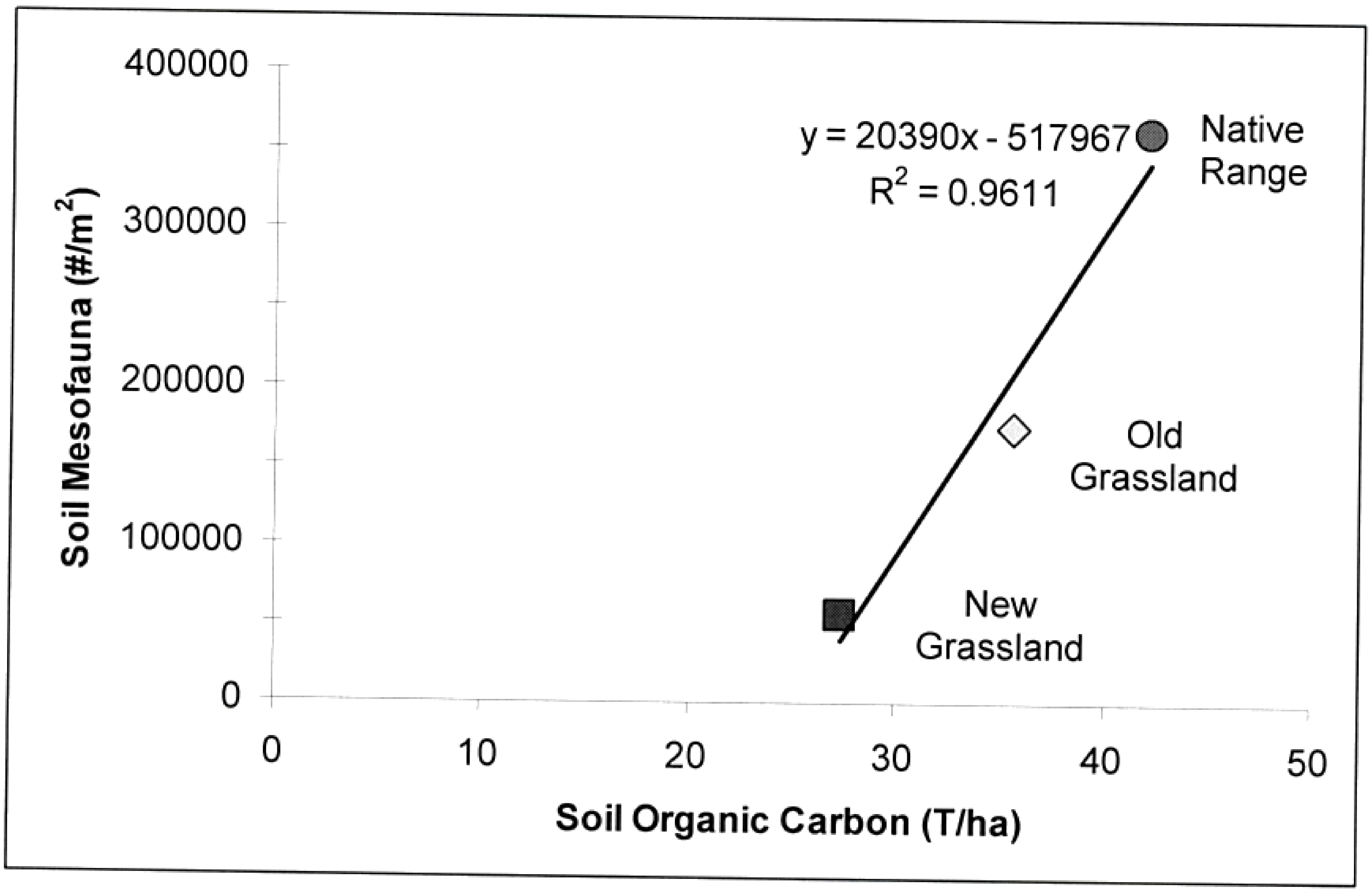

Figure 15: Relationship between soil mesofauna density and SOC among the three fields.

4.0 CONCLUSIONS AND RECOMMENDATIONS

A horizon:

The fields clearly differ with native range being superior followed by old grassland, then new grassland. However, plots within fields are also different indicating significant spatial variability in SOC within fields, even in what appeared to be very similar landscape positions. Some key findings are:

- The levels of SOC in A horizons in 2006 are as follows:
  native range (42.2 T/ha) > old grassland (35.7 T/ha) > new grassland (27.4 T/ha).
- The one-time sampling does not allow determination of SOC sequestration rates. Using conservative rates, sampling intervals should be spread over longer time intervals, for example 15 years, to detect statistically significant changes of at least 2 T/ha using the present approach, based on approximate annual sequestration rates of 0.15 T/ha.
- If sequestration rates under grassland are around 0.6 T/ha/year, then 4 or 5 year sampling intervals to detect an increase >2 T/ha are recommended using the present sampling regime.
- At a rate of 0.15 T/ha/year it would take about 99 years to sequester SOC in the cultivated soils to native range levels. If rates of 0.6 T/ha/year are attainable, it would take about 25 years to restore SOC levels.
- To detect the changes sooner, at a resolution of 1 T/ha, about twice as many samples are required due to the high coefficient of variation (about 20%).
- Bulk density of the A horizons is lowest (most favorable) in native range (0.9 g/m^3), followed by old grassland (1.2 g/m^3) and new grassland (1.3 g/m^3). The loss of SOC and degradation of soil structure attributable to years of cultivation contributes to the higher densities.
- The A horizon thicknesses varied somewhat among fields, however, average differences are less than 1 cm, a very small difference in practical terms. Note that cultivation in the old and new grassland fields would have affected the thickness of Ap horizon, maintaining its "thickness" by mixing in AB and B horizons as the surface eroded.

B horizon:

The study focused on the A horizon as it contains most of the SOC and is the layer where most rapid changes are expected. Nevertheless, three B or C horizons were sampled in each plot for comparison.

- The B or C horizon has about half the SOC that the A horizon contains.
- The B or C horizon in native range has the highest SOC levels (25.5 T/ha) followed by new grassland (20.8 T/ha), and old grassland (18.6 T/ha). The latter two amounts are not significantly different from each other but they are significantly lower than in the native range.
- Bulk densities of B or C horizons indicate the slight differences with more favorable conditions under old grassland, followed by native range and new grassland.

- To determine if the B or C horizon differs among fields more samples would be required in each plot. If further sampling of SOC in the B or C horizon is conducted, sampling should follow the lessons learned above from the A horizon data.
- Field observation indicated that native range plots contain a more pronounced AB transitional horizon compared to cultivated fields. As a result there is additional SOC in this layer in native range soils.
- Combining the total SOC in A and B or C horizons:
  - native range = 67.7 T/ha (100%)
  - old grassland = 56.5 T/ha (85% of native range)
  - new grassland = 46 T/ha (65% of native range)
  - note that there is additional SOC in the AB horizons and the losses in this layer are probably in a similar proportion.

Soil mesofauna:

Further work to examine the diversity of organisms in these different fields and their role in sequestering carbon in the soil is a critical component to sustainable soil ecosystem functioning. Maintaining a high biodiversity of soil life would support the desirable ecosystem services of soil fauna, such as improving soil structure, and making available plant nutrients via grazing that otherwise would stay locked away in the microbial biomass (Vetter *et al.* 2004). Future sampling should expand the number of samples collected within each field type as well as examining the species diversity of the fauna living in these different fields.

Developing productive native grassland alleviates some of the problems created by cultivated agricultural land. Native grassland increases the amount of SOC in a soil by increasing the amount of organic matter added, reduces decomposition times and decreases erosion. Introducing more organic matter increases the amount of organic carbon proportionally. As organic matter decomposition times are reduced, carbon and nutrients are released more slowly and are less susceptible to leaching. Continuous grass cover of native grassland decreases the amount of erosion and thereby decreases the movement of SOC from upland positions to lowland positions. The maximum amount of SOC that can be sequestered by a particular soil determines the duration of sequestration. It has been shown that the rate of sequestration decreases as the levels of accumulated SOC increase (McLauchlan *et al.* 2006).

Recommendations

Future work should include more field sites with different time periods of grassland development after cultivation and different farming practices (e.g. conventional, no-till, etc.). This would assist in defining the rates of SOC sequestration in grassland and cultivated farming systems. Critical to this would be access to documentation of farming practices on the fields including fertilizer, pesticide and herbicide application, grazing levels and crop production. Knowledge of annual and growing season precipitation would also assist in understanding the SOC sequestration process and rates.

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6.0 APPENDIX A: STATISTICAL DATA

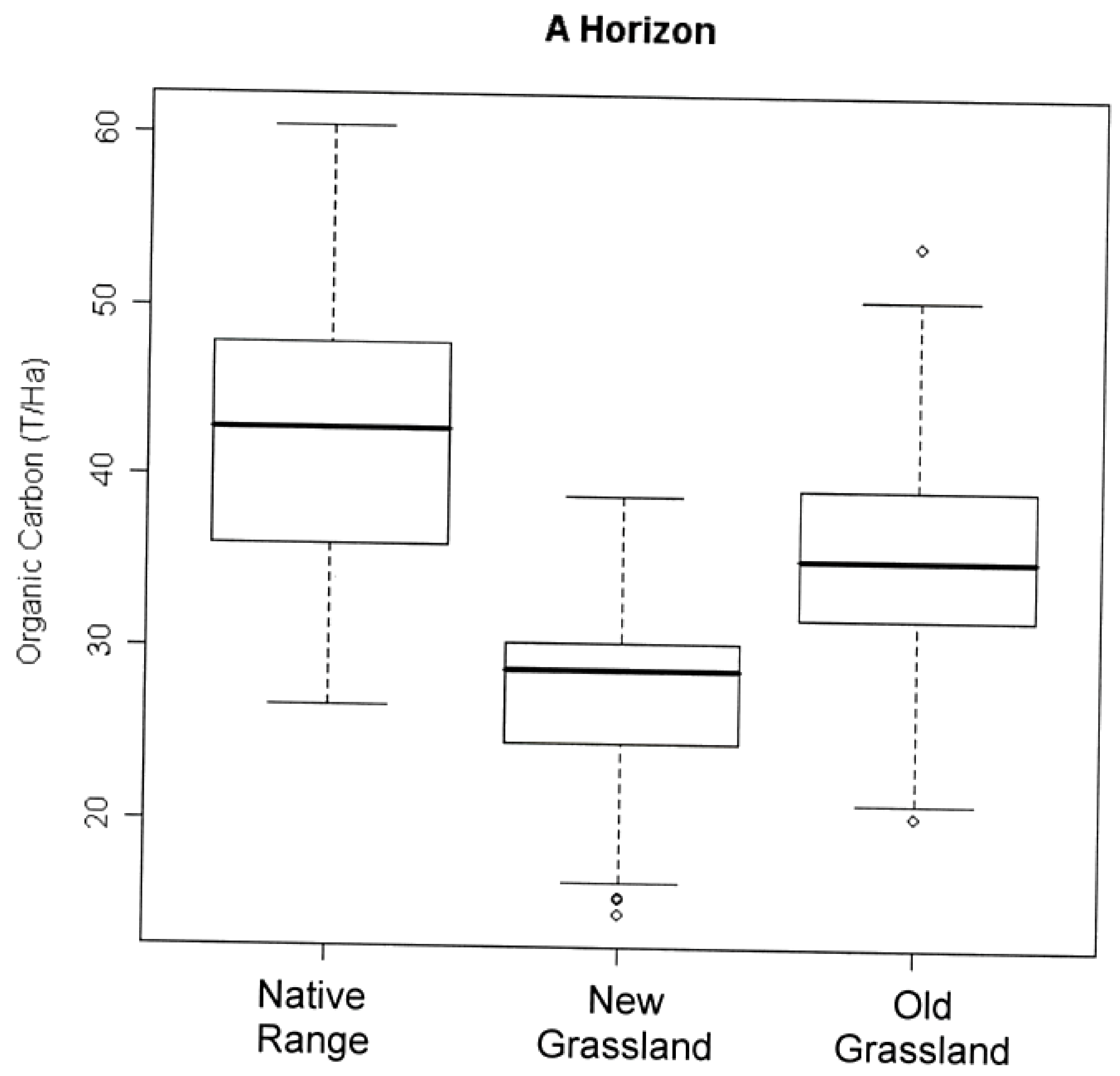

Figure 16: Box plots of SOC for A horizon by field.

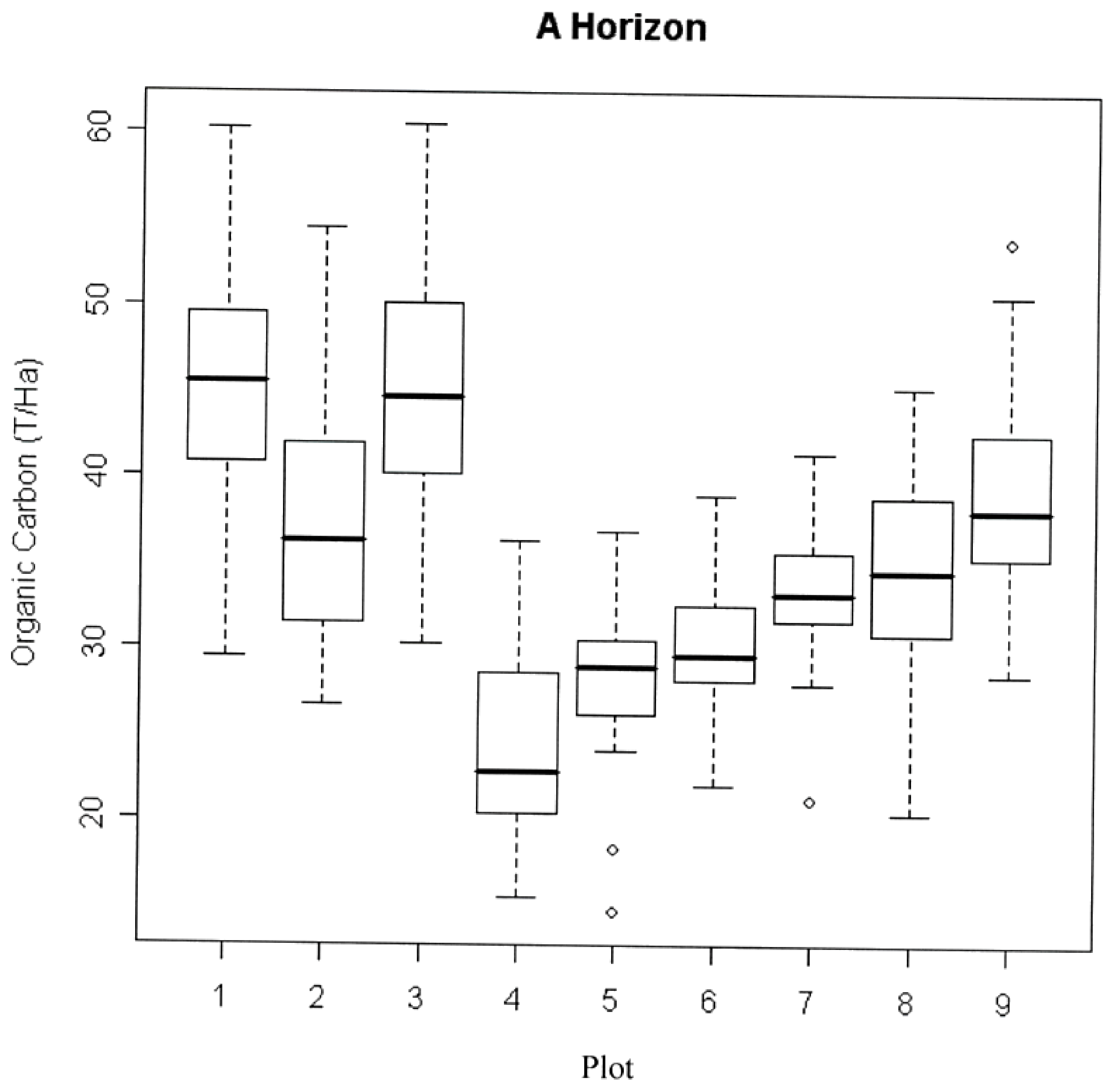

Figure 17: Box plots of SOC for A horizon by plot.

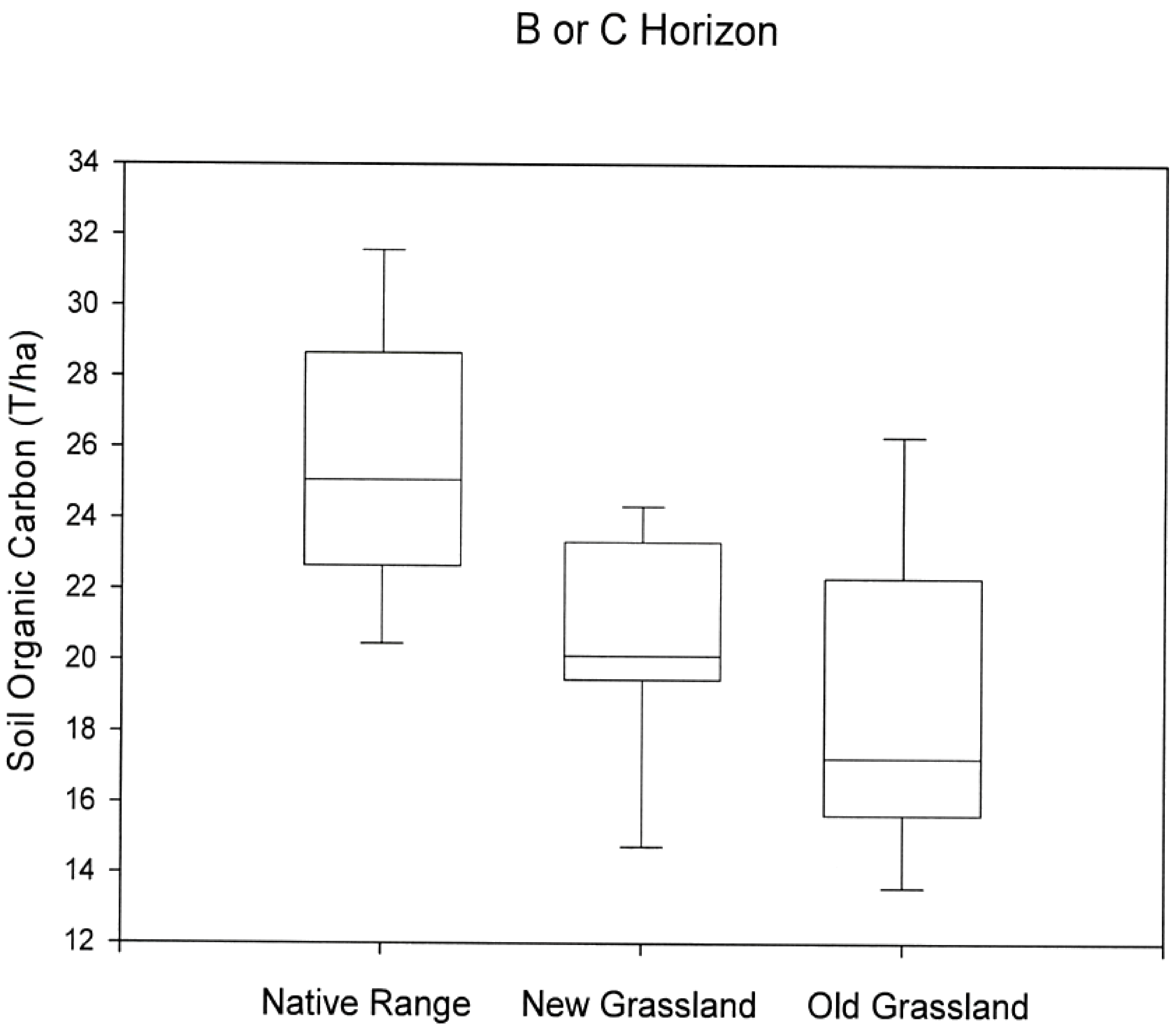

Figure 18: Box plots of SOC for B or C horizon by field.

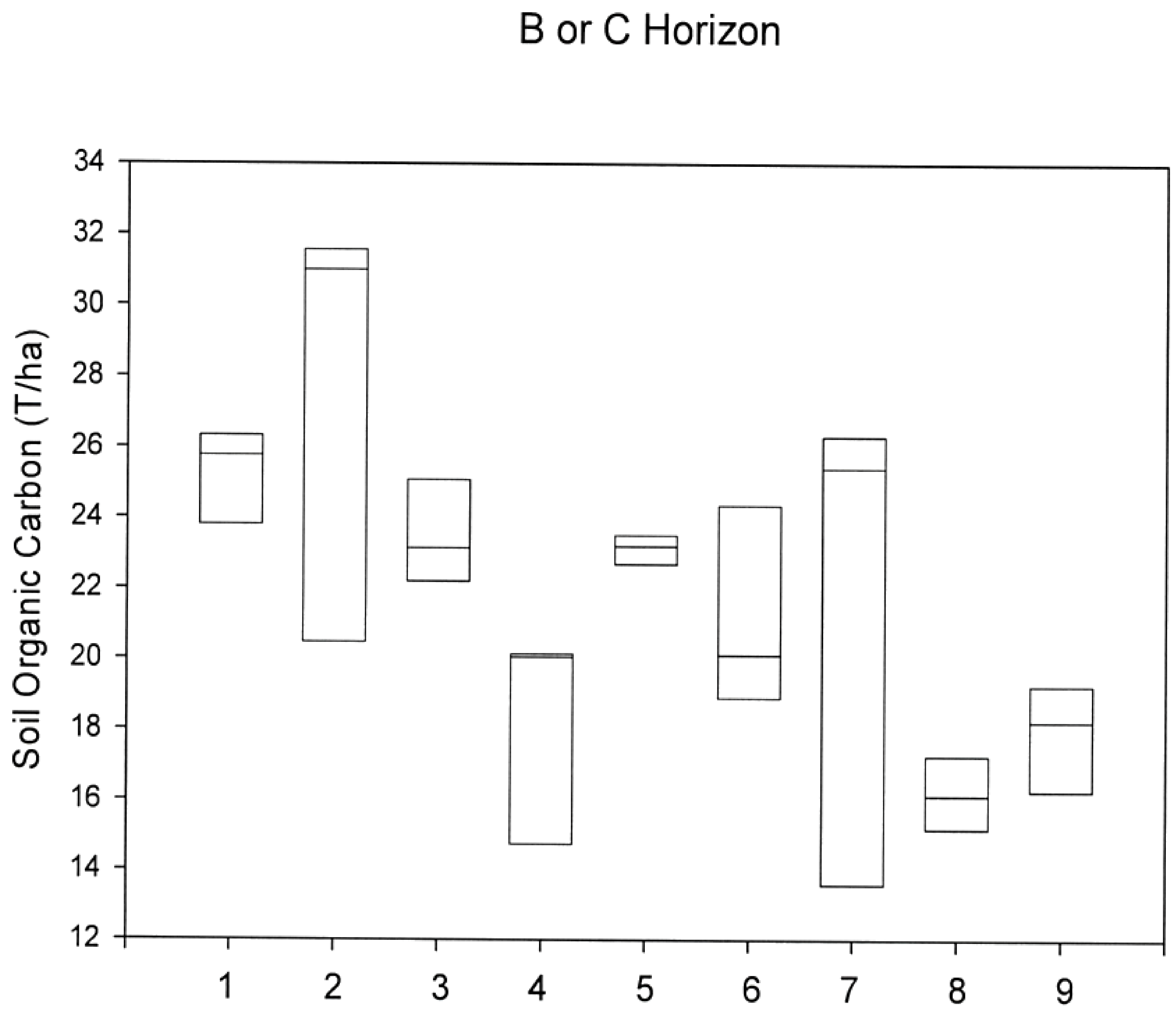

Figure 19: Box plots for SOC for B or C horizon by plot.

7.0 APPENDIX B: GPS DATA

Table 7: GPS coordinates for plot corners (NAD 83), Garmin GPS map 76

Plot	NE			SE		NW		SW	
No	Zone	Easting	Northing	Easting	Northing	Easting	Northing	Easting	Northing
1	12U	0307400	5588644	0307399	5588621	0307381	5588647	0307378	5588622
2	12U	0307477	5588623	0307477	5588602	0307458	5588623	0307457	5588604
3	12U	0307368	5588574	0307367	5588556	0307349	5588575	0307348	5588556
4	12U	0307227	5588540	0307226	5588521	0307205	5588544	0307206	5588522
5	12U	0307224	5588571	0307222	5588552	0307206	5588574	0307204	5588553
6	12U	0307129	5588480	0307129	5588458	0307112	5588481	0307110	5588460
7	12U	0307389	5587982	0307389	5587962	0307370	5587981	0307370	5587961
8	12U	0307339	5588044	0307337	5588024	0307319	5588044	0307316	5588024
9	12U	0307338	5588085	0307338	5588065	0307317	5588085	0307318	5588067

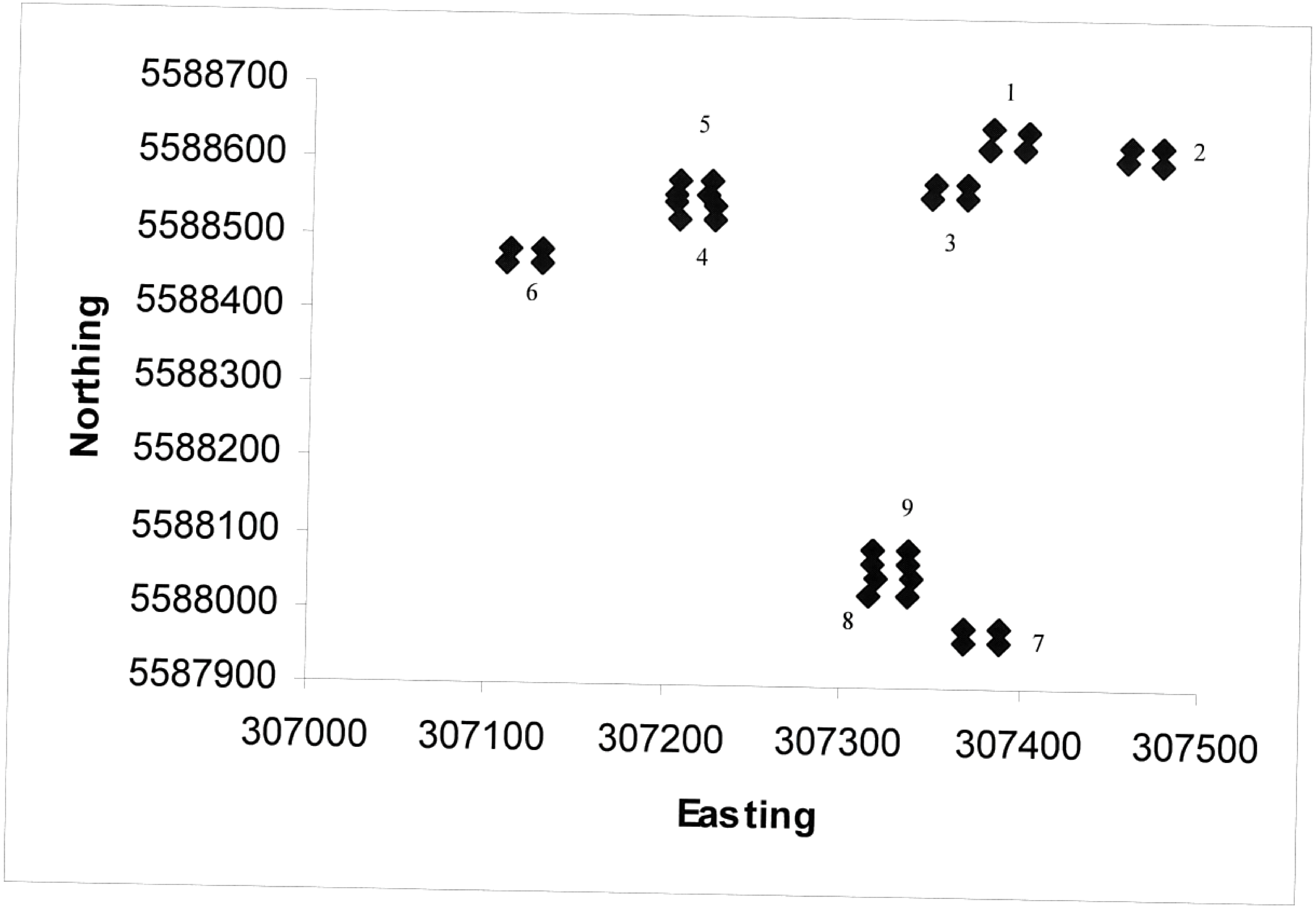

Figure 20: **Plot layout using GPS coordinates (NAD 83), Garmin GPS map 76.**

8.0 APPENDIX C: PICTURES

Figure 21: Native Range

Figure 22: New Grassland

Figure 23: Old Grassland

Figure 24: Soil profile

Figure 25: Ah horizon

Figure 26: AB horizon

9.0 APPENDIX D: RAW DATA

Table 8: Raw data for each sample collected from the A horizon.

Field	Plot	Grid Point	Horizon	Depth (cm)	Bulk Density (g/cm^3)	TOC (%)	SOC (T/ha)
nat	1	1	A	10	0.88	5.95	52.36
nat	1	2	A	10	0.9	5.76	51.84
nat	1	3	A	9	0.93	5.11	42.77
nat	1	4	A	9	1.06	4.92	46.94
nat	1	5	A	8	0.91	6.19	45.06
nat	1	6	A	7	0.78	6.47	35.33
nat	1	7	A	8	0.93	6.12	45.53
nat	1	8	A	7	0.79	6.35	35.12
nat	1	9	A	7	0.67	6.87	32.22
nat	1	10	A	10	0.86	5.76	49.54
nat	1	11	A	8	0.9	4.61	33.19
nat	1	12	A	8	0.96	5.46	41.93
nat	1	13	A	9	0.79	7.08	50.34
nat	1	14	A	8	0.72	7.77	44.76
nat	1	15	A	8	0.81	7.36	47.69
nat	1	16	A	10	0.85	5.12	43.52
nat	1	17	A	8	1.11	3.32	29.48
nat	1	18	A	10	0.85	6.45	54.83
nat	1	19	A	8	0.85	6	40.80
nat	1	20	A	8	0.67	6.94	37.20
nat	1	21	A	15	0.85	4.72	60.18
nat	1	22	A	10	0.91	5.27	47.96
nat	1	23	A	10	0.83	5.65	46.90
nat	1	24	A	10	0.82	6.5	53.30
nat	1	25	A	8	0.98	5.89	46.18
nat	2	1	A	8	1.08	4.14	35.77
nat	2	2	A	7	0.79	5.94	32.85
nat	2	3	A	8	0.84	8.09	54.36
nat	2	4	A	8	0.78	7.76	48.42
nat	2	5	A	9	0.91	5.97	48.89
nat	2	6	A	9	0.77	5.66	39.22
nat	2	7	A	7	0.78	6.63	36.20
nat	2	8	A	7	1.03	5.1	36.77
nat	2	9	A	10	0.84	5.64	47.38
nat	2	10	A	8	0.98	5.18	40.61
nat	2	11	A	9	0.93	5.15	43.11
nat	2	12	A	8	0.79	5.38	34.00

Field	Plot	Grid Point	Horizon	Depth (cm)	Bulk Density (g/cm^3)	TOC (%)	SOC (T/ha)
nat	2	13	A	7	0.82	5.88	33.75
nat	2	14	A	8	0.92	5.35	39.38
nat	2	15	A	8	0.91	5.93	43.17
nat	2	16	A	8	0.82	4.8	31.49
nat	2	17	A	7	0.93	4.1	26.69
nat	2	18	A	6	0.72	6.33	27.35
nat	2	19	A	6	0.79	6.54	31.00
nat	2	20	A	7	0.91	4.5	28.67
nat	2	21	A	7	0.94	4.21	27.70
nat	2	22	A	8	0.93	5.54	41.22
nat	2	23	A	7	0.91	5.63	35.86
nat	2	24	A	10	0.79	5.3	41.87
nat	2	25	A	7	0.87	4.88	29.72
nat	3	1	A	8	0.99	5.1	40.39
nat	3	2	A	8	0.8	6.84	43.78
nat	3	3	A	8	0.93	5.16	38.39
nat	3	4	A	8	0.84	5.86	39.38
nat	3	5	A	7	0.86	5.33	32.09
nat	3	6	A	8	1.03	5.48	45.16
nat	3	7	A	8	0.9	6.33	45.58
nat	3	8	A	8	0.81	6.6	42.77
nat	3	9	A	8	0.86	5.52	37.98
nat	3	10	A	8	0.81	6.93	44.91
nat	3	11	A	8	0.9	5.68	40.90
nat	3	12	A	8	0.9	6.56	47.23
nat	3	13	A	8	0.97	5.17	40.12
nat	3	14	A	10	0.96	5.58	53.57
nat	3	15	A	9	0.98	5.92	52.21
nat	3	16	A	10	0.94	5.32	50.01
nat	3	17	A	10	1.03	5	51.50
nat	3	18	A	8	0.96	4.96	38.09
nat	3	19	A	10	1.05	4.66	48.93
nat	3	20	A	5	0.86	7.03	30.23
nat	3	21	A	8	1	5.58	44.64
nat	3	22	A	10	0.93	6.5	60.45
nat	3	23	A	8	0.98	5.38	42.18
nat	3	24	A	10	0.93	5.6	52.08
nat	3	25	A	10	0.96	5.5	52.80
new	4	1	A	7	1.38	3.02	29.17

Field	Plot	Grid Point	Horizon	Depth (cm)	Bulk Density (g/cm^3)	TOC (%)	SOC (T/ha)
new	4	2	A	8	1.16	3.08	28.58
new	4	3	A	9	1.18	3.07	32.60
new	4	4	A	7	1.33	3.21	29.89
new	4	5	A	7	1.31	2.99	27.42
new	4	6	A	6	1.25	2.78	20.85
new	4	7	A	6	1.31	2.92	22.95
new	4	8	A	6	1.28	2.77	21.27
new	4	9	A	10	1.27	2.85	36.20
new	4	10	A	7	1.25	2.91	25.46
new	4	11	A	8	1.26	2.72	27.42
new	4	12	A	7	1.06	2.76	20.48
new	4	13	A	7	1.09	2.79	21.29
new	4	14	A	7	1.14	2.55	20.35
new	4	15	A	6	1.1	2.76	18.22
new	4	16	A	6	1.22	2.24	16.40
new	4	17	A	7	1.04	2.37	17.25
new	4	18	A	7	1.08	2.49	18.82
new	4	19	A	9	1.28	2.58	29.72
new	4	20	A	7	1.26	2.54	22.40
new	4	21	A	9	1.08	2.6	25.27
new	4	22	A	7	1.33	2.44	22.72
new	4	23	A	6	1.24	2.08	15.48
new	4	24	A	10	1.32	2.34	30.89
new	4	25	A	5	1.34	2.29	15.34
new	5	1	A	8	1.42	2.63	29.88
new	5	2	A	8	1.35	2.22	23.98
new	5	3	A	9	1.39	2.18	27.27
new	5	4	A	9	1.37	2.22	27.37
new	5	5	A	8	1.29	2.51	25.90
new	5	6	A	9	1.37	2.5	30.83
new	5	7	A	10	1.28	2.48	31.74
new	5	8	A	9	1.46	2.26	29.70
new	5	9	A	10	1.33	2.17	28.86
new	5	10	A	10	1.32	2.43	32.08
new	5	11	A	10	1.4	2.63	36.82
new	5	12	A	9	1.4	2.42	30.49
new	5	13	A	9	1.36	2.41	29.50
new	5	14	A	10	1.42	2.37	33.65
new	5	15	A	8	1.27	2.57	26.11

Field	Plot	Grid Point	Horizon	Depth (cm)	Bulk Density (g/cm^3)	TOC (%)	SOC (T/ha)
new	5	16	A	7	0.94	2.76	18.16
new	5	17	A	5	1.27	2.28	14.48
new	5	18	A	8	1.42	2.32	26.36
new	5	19	A	9	1.3	2.28	26.68
new	5	20	A	8	1.39	2.31	25.69
new	5	21	A	9	1.38	2.32	28.81
new	5	22	A	9	1.37	2.37	29.22
new	5	23	A	8	1.21	2.6	25.17
new	5	24	A	9	1.28	2.61	30.07
new	5	25	A	9	1.33	2.85	34.11
new	6	1	A	9	1.31	3.3	38.91
new	6	2	A	9	1.18	3.07	32.60
new	6	3	A	9	1.16	3.27	34.14
new	6	4	A	8	1.26	2.75	27.72
new	6	5	A	8	1.35	2.76	29.81
new	6	6	A	8	1.28	2.69	27.55
new	6	7	A	10	1.35	2.76	37.26
new	6	8	A	7	1.42	2.92	29.02
new	6	9	A	9	1.26	2.88	32.66
new	6	10	A	9	1.26	3.24	36.74
new	6	11	A	6	1.23	3.09	22.80
new	6	12	A	8	1.25	2.9	29.00
new	6	13	A	10	1.06	2.91	30.85
new	6	14	A	8	1.31	2.68	28.09
new	6	15	A	10	1.15	2.82	32.43
new	6	16	A	8	1.34	2.76	29.59
new	6	17	A	8	1.36	2.78	30.25
new	6	18	A	9	1.36	2.23	27.30
new	6	19	A	7	1.33	2.75	25.60
new	6	20	A	6	1.38	2.66	22.02
new	6	21	A	9	1.36	2.63	32.19
new	6	22	A	8	1.39	2.62	29.13
new	6	23	A	8	1.37	2.71	29.70
new	6	24	A	8	1.16	3.13	29.05
new	6	25	A	7	1.48	2.8	29.01
old	7	1	A	10	1.23	3.25	39.98
old	7	2	A	10	1.05	3.35	35.18
old	7	3	A	10	1.16	3.07	35.61
old	7	4	A	10	1.18	3.02	35.64

Field	Plot	Grid Point	Horizon	Depth (cm)	Bulk Density (g/cm^3)	TOC (%)	SOC (T/ha)
old	7	5	A	9	1.11	3.31	33.07
old	7	6	A	9	1.13	3.48	35.39
old	7	7	A	7	1.33	3.21	29.89
old	7	8	A	9	1.27	2.9	33.15
old	7	9	A	10	1.1	3.63	39.93
old	7	10	A	8	1.32	2	21.12
old	7	11	A	8	1.21	2.97	28.75
old	7	12	A	9	1.04	3.46	32.39
old	7	13	A	8	1.21	3.77	36.49
old	7	14	A	7	1.26	3.16	27.87
old	7	15	A	8	1.17	2.98	27.89
old	7	16	A	8	1.14	3.34	30.46
old	7	17	A	9	1.16	3.39	35.39
old	7	18	A	8	1.19	3.42	32.56
old	7	19	A	8	1.13	3.52	31.82
old	7	20	A	8	1.18	3.37	31.81
old	7	21	A	8	1.3	3.03	31.51
old	7	22	A	10	1.12	3.69	41.33
old	7	23	A	9	1.24	3.42	38.17
old	7	24	A	9	1.26	2.94	33.34
old	7	25	A	10	1.28	2.63	33.66
old	8	1	A	10	1.18	3.27	38.59
old	8	2	A	8	1.26	3.15	31.75
old	8	3	A	8	1.24	3.18	31.55
old	8	4	A	10	1.2	3.14	37.68
old	8	5	A	10	1.24	3.16	39.18
old	8	6	A	8	1.22	3.97	38.75
old	8	7	A	8	1.17	3.29	30.79
old	8	8	A	10	1.05	3.28	34.44
old	8	9	A	10	1.21	3.6	43.56
old	8	10	A	8	1.18	3.2	30.21
old	8	11	A	8	1.1	3.41	30.01
old	8	12	A	8	1.18	3.65	34.46
old	8	13	A	7	1.25	2.81	24.59
old	8	14	A	8	1.16	3.32	30.81
old	8	15	A	8	1.2	3.39	32.54
old	8	16	A	10	1.18	3.38	39.88
old	8	17	A	10	1.26	3.07	38.68
old	8	18	A	10	1.13	3.56	40.23

Field	Plot	Grid Point	Horizon	Depth (cm)	Bulk Density (g/cm^3)	TOC (%)	SOC (T/ha)
old	8	19	A	7	1.26	2.93	25.84
old	8	20	A	8	1.42	2.98	33.85
old	8	21	A	8	1.35	3.28	35.24
old	8	22	A	8	1.16	3.74	34.71
old	8	23	A	5	0.91	4.46	20.29
old	8	24	A	10	1.25	3.61	45.13
old	8	25	A	10	1.34	3.02	40.47
old	9	1	A	7	1.31	3.5	32.10
old	9	2	A	10	1.38	3.6	49.68
old	9	3	A	6	1.23	4.85	35.79
old	9	4	A	6	1.22	4.06	29.72
old	9	5	A	8	1.08	4.7	40.61
old	9	6	A	8	1.18	4.23	39.93
old	9	7	A	10	1.11	3.46	38.41
old	9	8	A	10	1.16	3.46	40.14
old	9	9	A	9	1.13	3.54	36.00
old	9	10	A	9	1.22	3.21	35.25
old	9	11	A	9	1.14	3.67	37.65
old	9	12	A	8	1.39	3.09	34.36
old	9	13	A	8	1.3	2.73	28.39
old	9	14	A	8	1.26	4.22	42.54
old	9	15	A	10	1.21	4.15	50.22
old	9	16	A	8	1.2	4.43	42.53
old	9	17	A	8	1.04	4.35	36.19
old	9	18	A	8	1.16	3.68	34.15
old	9	19	A	8	1.43	3.45	39.47
old	9	20	A	8	1.13	4.21	38.06
old	9	21	A	10	1.24	3.76	46.62
old	9	22	A	8	1.15	3.76	34.59
old	9	23	A	8	1.22	3.78	36.89
old	9	24	A	10	1.07	5.01	53.61
old	9	25	A	10	1.19	4.24	50.46

Table 9: Raw data for each sample collected from the B or C horizon.

Field	**Plot**	**Grid Point**	**Horizon**	**Depth (cm)**	**Bulk Density (g/cm^3)**	**TOC (%)**	**SOC (T/ha)**	**SOC (T/ha) for 10 cm**
nat	1	9	B	7	1.19	2	16.66	23.80
nat	1	14	B	6	1.13	2.33	15.80	26.33
nat	1	22	B	5	1.15	2.24	12.88	25.76
nat	2	7	B	6	1.27	2.44	18.59	30.99
nat	2	8	B	6	1.17	2.04	14.32	20.46
nat	2	13	B	7	1.27	2.13	18.94	31.56
nat	3	7	B	6	1.01	2.29	13.88	23.13
nat	3	11	B	6	1.15	2.18	15.04	25.07
nat	3	15	B	6	1.29	1.72	13.31	22.19
new	4	5	B	6	1.26	1.59	12.02	20.03
new	4	11	C	6	1.29	1.56	12.07	20.12
new	4	24	C	6	1.32	1.49	11.80	14.75
new	5	10	B	8	1.26	1.38	13.91	23.18
new	5	14	B	6	1.39	1.69	14.09	23.49
new	5	16	B	6	1.26	1.8	13.61	22.68
new	6	11	C	6	1.26	1.61	12.17	24.34
new	6	19	B	5	1.18	1.92	11.33	18.88
new	6	22	B	6	1.5	1.34	12.06	20.10
old	7	10	B	6	1.2	1.51	10.87	13.59
old	7	21	C	8	1.27	2	20.32	25.40
old	7	23	C	8	1.14	1.73	15.78	26.30
old	8	3	B	6	1.3	1.24	9.67	16.12
old	8	8	C	6	1.25	1.38	10.35	17.25
old	8	22	B	6	1.22	1.66	12.15	15.19
old	9	13	B	8	1.38	1.32	14.57	18.22
old	9	14	B	8	1.3	1.25	13.00	16.25
old	9	18	B	8	1.08	1.78	15.38	19.22