doi:10.2489/jswc.66.3.183

Landscape position effect on selected soil physical properties of reconstructed prairies in southcentral Iowa

J.G. Guzman and M.M. Al-Kaisi

Abstract: Changes in land use and alteration of the ecosystem can significantly affect soil physical, chemical, and biological properties. In this study, changes in soil organic carbon (SOC), root biomass, bulk density (ρb), water stable aggregates (WSA), and infiltration rates were examined in reconstructed prairies varying in age and landscape position. The objective of the study was to determine the potential of landscape position effect on these selected soil properties in reconstructed prairies. Findings show that SOC increased as years since prairie establishment increased and had a positive correlation with infiltration rate and WSA. The opposite was true for ρb, where it decreased as prairie age increased and negatively correlated with SOC. However, the effects of SOC and ρb on infiltration rates varied by landscape slope position and age of prairie establishment. Root biomass, SOC, and WSA had decreased, while ρb increased at the midslope compared to the summit and toe-slope positions resulting in lower infiltration rates. Although the summit and the toe-slope positions had similar soil properties, infiltration rates were much greater in the toe-slope position. This was ascribed to the toe-slope position's superior WSA, due to greater SOC concentrations. In general, this study shows that over time, increases in SOC did promote aggregate formation and lower ρb, creating more permeable soil surfaces in these reconstructed prairies. However, better soil conservation practices that reduce soil surface water runoff in the midslope in particular are needed during the first few years of prairie establishment.

Key words: infiltration—prairie—soil carbon

Changes in land use and alteration of the ecosystem can significantly affect soil physical, chemical, and biological properties status. Under similar conditions, permanent grasslands tend to have greater soil organic carbon (SOC) at the surface than cultivated cropland, due to slowly decomposing plant debris. This is mainly due to tillage management increasing rapid microbial oxidation of plant residue (above- and below-ground), which could have been stored as soil organic matter (Paustian et al. 2000; Al-Kaisi and Yin 2005). In addition, tillage also reduces aggregate formation, shown to be critical for carbon (C) accumulation (Six et al. 2002; Jones and Donnelly 2004). Thus, cropland and disturbed land have been targeted as possibilities to sequester C and are considered a partial means for slowing further increases in greenhouse gas concentrations in the atmosphere through soil C sequestration under no-tillage and organic management regimes (Lal et al. 1999; West and Post 2002). Many studies have already shown increases in SOC after prairie reconstructions on previously cultivated cropland, especially over the first decade since prairie establishment (McLauchlan et al. 2006; Kucharik 2007; Guzman and Al-Kaisi 2010). However, little information is known about the linkage of SOC increases with overall soil quality parameters, such as bulk density (ρ_b), aggregate stability, and water infiltration in reconstructed prairies as affected by landscape slope position and age of established prairie system.

Although conversion of crop and marginal lands to reconstructed prairies has been gaining momentum in recent years due to the prairies' aesthetic and environmental values, modest attention has been given to the above- and below-ground biogeochemical processes that can contribute to potential reduction of surface water runoff and erosion (Davie and Lant 1994). Losses of SOC in the summit and midslope positions can occur when soil erosion is high and deposited in the toe-slope position, where SOC accumulates (Gregorich et al. 1998). This is imperative considering that SOC depends not only on the potential C input from vegetation in prairies but also the gain and losses of C from soil erosion and re-deposition in lower lands. The severity of soil erosion depends upon water infiltration into a soil environment and it is an important soil quality indicator that is strongly affected by land management and landscape slope position (Sauer et al. 2005; Jiang et al. 2007). Although many studies have described spatial variability in surface runoff in hydrologically active areas (Dunne and Black 1970; Bernier 1985) and more recently including water infiltration rates as affected by vegetation cover (Bhark and Small 2003; Bautista et al. 2007). Little is known on the interaction effects of landscape hydrology and soil surface properties on water infiltration rates. Soil proprieties such as ρ_b (Karlen et al. 1999; Murphy et al. 2004), aggregate formation (Jastrow 1987, 1996), SOC (Brye and Kucharik 2003), and root biomass (Baer et al. 2002) have all been shown to be significant in creating a more permeable soil environment, thus reducing surface runoff.

The objective of the study was to link changes in SOC with overall soil quality parameters, such as ρ_b and water stable aggregate (WSA), with water infiltration rates to indentify times and landscape positions effects on water intake in reconstructed prairies. The hypothesis of this research is that water infiltration rates will vary by landscape position and years since prairie establishment due to differences in aggrading soils.

Materials and Methods

Site Description and Experimental Design. This study was conducted in Jasper and Warren counties in 2005 and 2006. The sites contained different soil series with different properties at the summit (table 1), midslope (table 2), and toe-slope positions (table 3). Average annual temperature was 10.3°C

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Table 1
Summit parameters: establishment year, current plant species, slope, and selected soil properties for each site at the top 15 cm soil depth.

Characteristic	NT-2003	P-2003	P-1998	P-1993	P-remnant
Ecosystem	Row crop	Prairie	Prairie	Prairie	Prairie
Establishment year	1870s, no-till since 2003	2003	1998	1993	Native remnant
Dominant plant species	*Zea mays* L.	*Andropogon gerardii* *Schizachyrium scoparium* *Elymus canadensis*	*Andropogon gerardii*	*Andropogon gerardii* *Schizachyrium scoparium* *Solidago canadensis* *Trifolium pratense*	*Andropogon gerardii* *Schizachyrium scoparium* *Sorghastrum nutans* *Solidago canadensis* *Chamaecrista fasciculata*
Slope	0% to 1%	0% to 2%	0% to 6%	3% to 4%	2% to 4%
Soil properties					
Soil association	Otley-Mahaska	Otley-Mahaska	Otley-Mahaska	Otley-Mahaska	Ladoga-Gara-Armstrong
Soil type	Mahaska	Mahaska	Tama	Mahaska	Sharpsburg
Sand	5%	2%	2%	2%	2%
Silt	67%	69%	70%	71%	69%
Clay	28%	29%	28%	27%	29%
pH	7.1	6.4	7.2	6.8	6.7

Notes: NT = no-till. P = prairie.

Table 2
Midslope parameters: establishment year, current plant species, slope, and selected soil properties for each site at the top 15 cm soil depth.

Characteristic	NT-2003	P-2003	P-1998	P-1993	P-remnant
Ecosystem	Row crop	Prairie	Prairie	Prairie	Prairie
Establishment year	1870s, no-till since 2003	2003	1998	1993	Native remnant
Dominant plant species	*Zea mays* L.	*Schizachyrium scoparium* *Sorghastrum nutans*	*Andropogon gerardii*	*Andropogon gerardii* *Schizachyrium scoparium* *Sorghastrum nutans*	*Schizachyrium scoparium* *Solidago canadensis* *Bouteloua curtipendula* Shrubs
Slope	10% to 16%	5% to 8%	6% to 9%	4% to 10%	10% to 14%
Soil properties					
Soil association	Otley-Mahaska	Otley-Mahaska	Otley-Mahaska	Otley-Mahaska	Ladoga-Gara-Armstrong
Soil type	Otley	Otley	Otley	Otley	Adair-Sharpsburg
Sand	2%	2%	2%	3%	21%
Silt	71%	68%	68%	70%	56%
Clay	26%	30%	30%	27%	23%
pH	6.8	6.8	6.7	7.1	6.6

Notes: NT = no-till. P = prairie.

Table 3
Toe-slope parameters: establishment year, current plant species, slope, and selected soil properties for each site at the top 15 cm soil depth.

Characteristic	NT-2003	P-2003	P-1998	P-1993	P-remnant
Ecosystem	Row crop	Prairie	Prairie	Prairie	Prairie
Establishment year	1870s, no-till since 2003	2003	1998	1993	Native remnant
Dominant plant species	*Zea mays* L.	*Silphium laciniatum* Various other forbs	*Spartina pectinata*	*Spartina pectinata* Various other forbs	*Helianthus grosserratus*
Slope	0% to 1%	1% to 5%	0% to 1%	4% to 5%	1% to 4%
Soil properties					
Soil association	Otley-Mahaska	Otley-Mahaska	Otley-Mahaska	Otley-Mahaska	Ladoga-Gara-Armstrong
Soil type	Shelby	Shelby	Shelby	Shelby	Colo-Ely
Sand	11%	3%	3%	3%	28%
Silt	63%	68%	68%	70%	49%
Clay	26%	29%	29%	27%	23%
pH	7.0	6.6	6.9	7.1	6.0

Notes: NT = no-till. P = prairie.

(50.5°F) and precipitation was 956 mm (37.6 in). Soils in both Jasper County and Warren County, Iowa, formed in loess under native vegetation of tallgrass prairie (Bryant and Woster 1978; Nestrud and Woster 1979). All of the reconstructed prairie sites were located in the Neal Smith National Wildlife Refuge (NSNWR) (41°35' N, 93°14' W). The remnant prairie was located approximately 95 km (59 mi) southwest in Rolling Thunder Prairie (41°10' N, 93°43' W) in Warren county. Historical backgrounds on the conversion of row crop production, reconstructed prairie in NSNWR sites, and present vegetative conditions of all sites were summarized in tables 1 to 3.

All soil and plant sampling plots were located on summit, midslope, and toe-slope positions of all sites (tables 1 to 3). There were three reconstructed prairie sites varying in establishment year—1993, 1998, and 2003—categorized as P-1993, P-1998, and P-2003, respectively. The row crop production site was a no-till corn–soybean crop rotation since 2003 (NT-2003) adjacent to prairie sites of the same soil association. A prairie remnant (P-remnant) site was included to identify the upper limits for selected soil properties. The experiment was designed so that each site varying in year of establishment was the main treatment, replicated three times along each slope position in plots approximately 4 m^2 (43 ft^2) and 30 m (98 ft) apart. To measure the effects of slope position and years since establishment of different sites on ρ_b, SOC, root biomass, WSA, and infiltration rate, each plot was treated as an experimental unit for a total of 45 observations and treatment means for comparisons (three replicated plots × three slope positions × five locations). Detailed assessments of soil texture, ρ_b, vegetation growth, and other related properties were determined to characterize site-to-site variability and to incorporate differences into the analyses and interpretations when differences occurred between sites.

Soil Organic Carbon, Bulk Density, and pH. Ten to twelve soil cores 1.7 cm (0.67 in) diameter were randomly taken to a depth of 15 cm (6 in) in each plot and then homogenized into a single sample. Soil samples were sieved 2 mm (0.8 in) and then air dried before analyzed for pH (1:1; soil to water), using an AR15 pH meter (Accumet Research, Fisher Scientific International); SOC was determined by dry combustion using a LECO CHN analyzer (LECO, St. Joseph, Michigan). Three ρ_b samples were randomly collected using a 1.7 cm (0.67 in) diameter soil probe in each plot. Soil cores were taken at 15 cm (6 in) soil depth, and then oven dried at 105°C (221°F) for 24 hours and weighed. The ρ_b (g cm^{-3}) was calculated as the dried soil mass divided by the soil core volume (Blake and Hartge 1986).

Root Biomass. Using a soil core sampling method, a 10.5 cm (4.1 in) diameter golf course hole cutter was used to collect root biomass samples to a 15 cm (6 in) depth in three replications for each plot. Samples were collected in late August of each year. All samples were frozen until analysis could be performed. Soil cores were processed by sieving and flotation of roots using a hydropneumatic elutriation system (Gillison's Variety Fabrication) equipped with 530 µm (0.02 in) screens (Smucker et al. 1982). Removal of any nonroot debris was conducted during this process. The roots were then oven dried at 65°C (149°F) until all water was evaporated, and roots were dry and brittle, and the sample was weighed to determine dry matter weight.

Aggregate Stability. Soil samples were taken using a 10.5 cm (4.1 in) diameter golf course hole cutter to a soil depth of 15 cm (6 in) in three replications for each plot. Samples were then gently passed through 8 mm (0.3 in) sieve to remove any undesirable plant residue and rocks. Soil samples were then air dried and stored for analysis. The WSA–size distributions were determined following the procedure from Kemper and Rosenau (1986) with some modifications. A soil sample of 100 g (0.2 lb) was used for wet sieving for 5 min in deionized water at 21°C (70°F). By lowering and then raising the sieves with a stroke length of 20 mm (0.8 in) and a frequency of 90 strokes min^{-1}, using a custom made sieving machine where 20 cm (7.9 in) diameter sieves could fit. Seven aggregate size fractions were collected, >4 mm (>0.16 in), 2 to 4 mm (0.08 to 0.16 in), 1 to 2 mm (0.04 to 0.08 in), 0.5 to 1 mm (0.02 to 0.04 in), 0.25 to 0.5 mm (0.01 to 0.02 in), and 0.053 to 0.25 mm (0.002 to 0.01 in). For the remaining sample that passed through the last sieve, 0.053 mm, it was considered <0.053 mm. Each soil sample was first misted with a spray bottle and then submerged in water in the top sieve for at least 5 min before wet sieving began to slake off air dried soil. In addition, this prewetting reduces buildup of air pressure in pores resulting in less air escaping with minimal aggregate disruption. Following wet sieving, soil sample of each aggregate fraction was transferred by washing it into tubs and then oven dried at 65°C (149°F) until all water was evaporated. Dry weight of each fraction size was recorded. In addition, WSA dry weights were then adjusted to soil moisture corrections from air-dried subsamples of WSA. The aggregate stability for each soil sample was then expressed by mean weight diameter (MWD) (Youker and Mcguiness 1957):

$$MWD = \sum_{i=1}^{7} \bar{x}_i w_i \,, \tag{1}$$

where x_i is the mean diameter (mm) of size fraction and w_i is the weight of each size fraction of aggregates of total sample.

Water Infiltration. Water infiltration rates were measured using a Cornell Sprinkle Infiltrometer (Cornell University, Ithaca, New York) (Ogden et al. 1997). This system consisted of a portable rainfall simulator placed on a single 24.1 cm (9.5 in) inner diameter ring inserted 7 cm (2.8 in) into the soil and aboveground vegetation was clipped. The ring was equipped with an overflow tube to determine the time to runoff and runoff rate. Rainfall simulator intensity rate of 0.5 cm min^{-1} (0.2 in min^{-1}) were used. Every three minutes, runoff was measured until steady water infiltration occurred. Water infiltration rate (i_t) (cm min^{-1}) was calculated by using the following equation:

$$i_t = r - r_{ot} \,, \tag{2}$$

where r is rainfall intensity (cm min^{-1}), and r_{ot} is surface runoff rate (cm min^{-1}). In addition, to account for three-dimensional flow in the bottom of the ring, Reynolds and Elrick (1990) developed a model to estimate Field-Saturated Infiltrability (using single ring rain simulators), which takes into account soil type and ring insertion depth effects on infiltration rate. They determined empirical correction factors for different soil texture and insertion depths to adjust field measurements of infiltration rates. In this study, rings were inserted to a soil depth of 7 cm (2.8 in) in silt loam soils. Therefore, a conversion factor of 0.80 was used to take into account of horizontal flow at the bottom of the ring:

$$i_{fs} = i_t \times 0.80 \,, \tag{3}$$

where i_{fs} is field-saturated infiltrability.

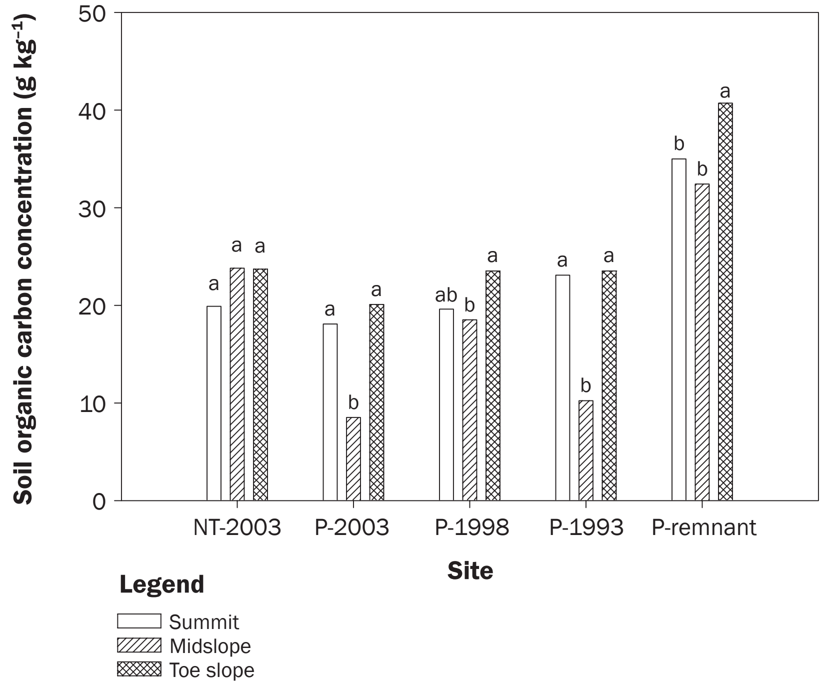
Statistical Analysis. In general, data was analyzed using the general linear procedure (GLM) (SAS Institute 2002). Statistical significance was evaluated at $p \leq 0.1$. Additionally, correlations were done using PROC CORR procedure in SAS (SAS Institute 2002). Multiple backwards elimination regression analysis was done using JMP (SAS Institute 2002). Focus on two-way interactions that included years since prairie establishment and selected soil properties by slope position were given. This was done to address the objective of this study of examining the effects of slope position and age since establishment of reconstructed prairies on SOC, root biomass, ρ_b, and aggregate stability effects associated with water infiltration.

Results and Discussion

Landscape Slope Position and Age of Established Prairie Effects on Selected Soil Properties. The greatest SOC concentrations generally occurred at the toe-slope positions, followed by the summit and the least at the midslope positions (figure 1). This can be attributed to SOC distribution and losses due to soil erosion and deposition effects by slope position (Gregorich et al. 1998). Furthermore, the reconstructed prairies have lower SOC concentrations in the midslope compared to the NT-2003 and P-remnant sites. The P-remnant site had the greatest SOC concentrations, followed by the NT-2003 site, P-1993, and P-1998 reconstructed prairie sites, respectively, averaged across all slope positions. However, SOC concentration at the P-2003 site was significantly lower than that of all sites. Although direct measurements of soil erosion were not taken in this study, lower concentrations of SOC in the P-2003 site might primarily be due to the midslope position having a higher risk of soil erosion (Gregorich et al. 1998) and lower vegetation present (figure 2) decreasing soil productivity (potential C input from above- and below-ground). This findings stress the importance of early establishment of vegetation especially in the midslope position when soil is most vulnerable to erosion during transition from row crop production to prairie. During the first few years of prairie establishment, with poor vegetation establishment like patchy spots, often leave bare soil with little or no C inputs and high risk of soil erosion. In the NT-2003 site, where contour planting and residue cover practices are used

Figure 1

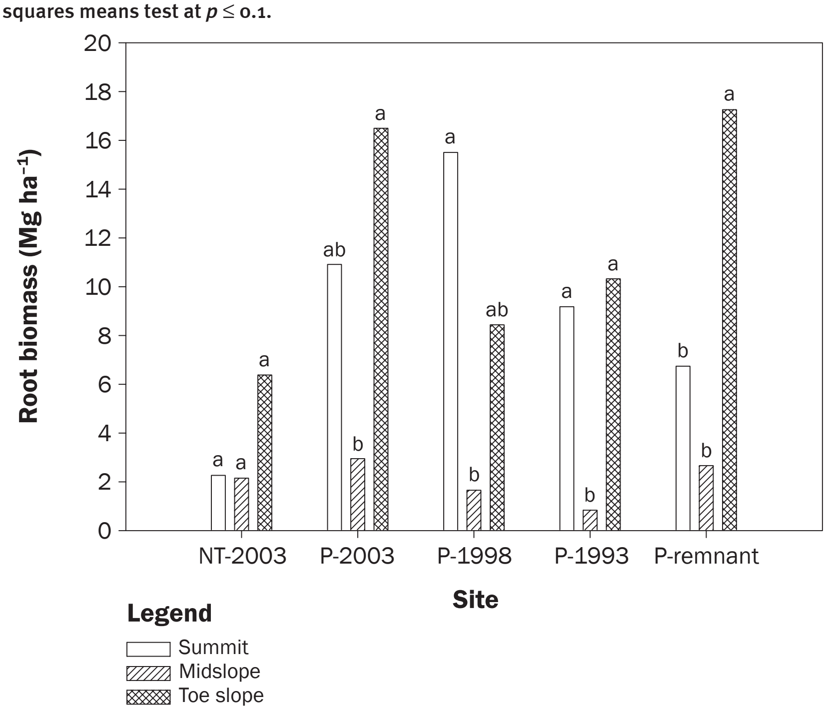
Slope position effect on soil organic carbon concentration in the top 15 cm soil depth for each site. Treatments within the same site with the same letters are not significantly different according to the least-squares means test at $p \leq 0.1$.



Notes: NT = no-till. P = prairie.

Figure 2

Slope position effect on root biomass in the top 15 cm soil depth for each site. Treatments within the same site with the same letters are not significantly different according to the least-squares means test at $p \leq 0.1$.



Notes: NT = no-till. P = prairie.

Table 4

Correlations between soil organic carbon (SOC) concentration, root biomass (RB), bulk density (ρ_b), mean weight diameter (MWD), infiltration rate (i_t), infiltration rate the first three minutes (3-min i_t), and years since establishment.

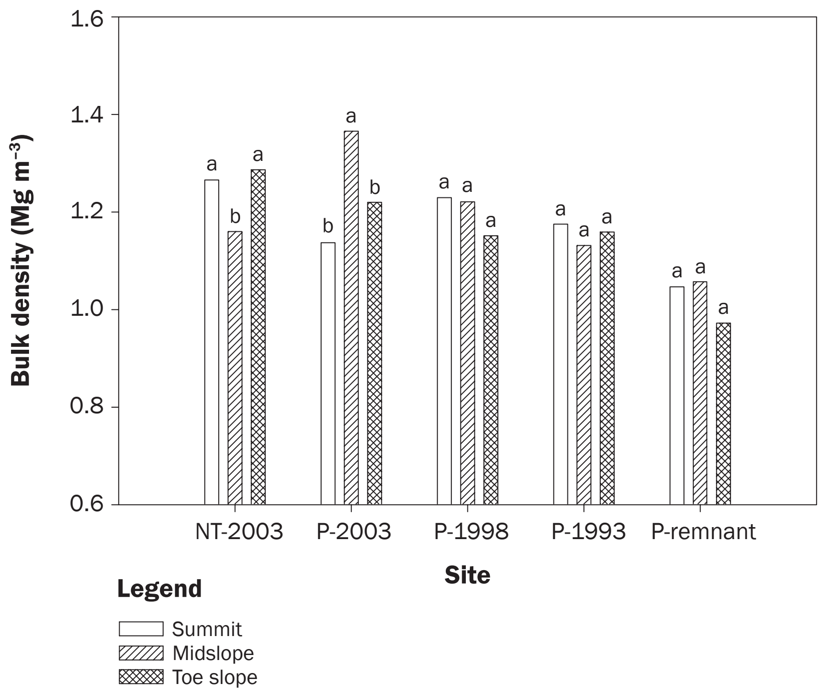
	SOC		RB		ρ_b		MWD		i_t		3-min i_t	
	r	*p*-value	*r*	*p*-value	*r*	*p*-value	*r*	*p*-value	*r*	*p*-value	*r*	*p*-value
Years*	0.80	<0.0001	0.03	0.8548	–0.66	<0.0001	0.17	0.3258	0.53	0.0008	0.60	0.0001
SOC	—	—	0.13	0.4497	–0.69	<0.0001	0.08	0.6341	0.58	0.0002	0.63	<0.0001
RB	0.13	0.4497	—	—	–0.25	0.1461	0.24	0.1642	0.09	0.5830	0.20	0.2500
ρ_b	–0.69	<0.0001	–0.25	0.1467	—	—	–0.29	0.0895	–0.53	0.0009	–0.70	<0.0001
MWD	0.08	0.6341	0.24	0.1642	–0.29	0.0895	—	—	–0.02	0.8876	0.30	0.0764

Notes: The significance level is $p \leq 0.05$.

* For the P-remnant site, 150 years was assumed for establishment year in model.

Figure 3

Slope position effect on bulk density in the top 15 cm soil depth for each site. Treatments within the same site with the same letters are not significantly different according to the least-squares means test at $p \leq 0.1$.



Notes: NT = no-till. P = prairie.

to reduce soil erosion, lower SOC concentration in the midslope were not observed.

With exception of the NT-2003 site, there was a significant reduction in root biomass at the midslope position compared to the summit and toe-slope positions (figure 2). This can be attributed to differences in vegetation densities at the midslope position compared to the summit and toe-slope positions (tables 1 to 3) and the loss of soil productivity due to high potential of soil erosion, as previously mentioned. Years since prairie establishment and SOC, ρ_b, and MWD were not well correlated with root biomass (table 4). However, increases in root biomass have long been known to enhance aggregate formation and reduction in ρ_b, due to root exudates acting as binding agents for soil particles (Tisdall and Oades 1982; Oades and Waters 1991).

In general, ρ_b values averaged across slope positions, tended to decrease as years since establishment increased (figure 3). Slope position was not a significant determinant for ρ_b, due to site variability of natural and anthropogenic parameters (tables 1 to 3). Decreases in ρ_b can be attributed to increases in soil organic matter, soil structure, and root biomass, as age since establishment of reconstructed prairies increased (table 4). Other studies have reported similar findings (Jastrow 1987; Baer et al. 2002; and McLauchlan et al. 2006), where they found a strong linkage between SOC, root biomass, and soil aggregation, which have major influences on ρ_b.

In general, the slope position effect on WSA distributions was similar across all sites; therefore, results were presented by averaging WSA fraction of each size across sites to show the main effect of slope position on WSA fractions distribution (figure 4). In these prairie sites and the row crop production site, 1 to 2 mm (0.04 to 0.08 in) was the dominant size fraction at approximately 24% and the <0.053 to 0.025 mm (<0.002 to 0.01 in) size fraction at approximately 8%. At the midslope position, a lower distribution of WSA greater than 2 mm (0.08 in) compared to those at the summit and toe-slope positions across all sites were observed (figure 4). Consequently, the midslope position had slightly greater distributions of less than 1 mm (0.04 in) size fraction across all sites. For the summit and toe-slope positions, similar WSA distributions were observed when averaged across sites. The MWD calculations show the same trend with midslope position having a significantly lower MWD compared to the summit and toe-slope positions (data not shown). This might be attributed to lower root biomass and soil organic matter, due to soil erosion effect on the midslope position. Differences among sites were also observed, where the two most recent established sites had significantly lower MWD values compared to the longer established reconstructed and remnant prairie sites (figure 5). This suggests that similar WSA distributions can be reached within a decade of prairie establishment (or cessation of tillage) and the rate of increase is much greater during the early years of prairie establishment than long-established prairies. These results agree with Jastrow's (1996) study that soil aggregates can reach their maximum size around 10 years after cessation of tillage.

Selected Soil Physical Properties Effects on Infiltration Rate. Landscape slope position effect on infiltration rate showed that summit and midslope positions had lower infiltration rates compared to the toe-slope position (figure 6), as Sauer et al. (2005) found in their study. Using simple correlations between infiltration rate and selected soil properties (table 4) showed that year since prairie establishment, SOC concentrations, and ρ_b were significant parameters in determining infiltration rate. This can be attributed to the increases in SOC concentration and decrease in ρ_b as age of prairie establishment increases, resulting in a more permeable environment for water. Additionally, MWD and root biomass were also major factors in explaining much of the differences that occurred in the first three minutes of infiltration rate after initial soil runoff (table 4). When infiltration rates were grouped across sites by slope position (figure 6), the P-remnant site had among the highest infiltration rate across all slope positions, followed by the P-2003 site, with the exception of the midslope position.

Further analysis focusing on two-way interactions between several soil properties (SOC concentration, root biomass, ρ_b, MWD) and years since prairie establishment to predict infiltration rate by slope position using a multiple backwards elimination regression analysis was used (table 5). At the summit position, none of the selected soil properties correlated well with steady state infiltration rate. At the toe-slope position, SOC concentration did have a positive correlation, while ρ_b had a negative correlation with infiltration rate. This might be attributed to the toe slope having greater SOC and lower bulk density compared to the summit and midslope positions. There were two-way interactions observed between years since prairie establishment and ρ_b, and years since prairie establishment and MWD at the midslope position (table 5). The effect of prairie age on the interaction of SOC, ρ_b, and MWD with infiltration rate during the first three minutes after initial runoff was observed in the summit and midslope positions (table 6). In general, these findings suggest that infiltration rate was affected differently by SOC and other soil surface parameters measured in this study at different slope positions and years since prairie establishment.

Figure 4
Slope position effect on wet aggregate stability distribution at the top 15 cm soil depth across all sites. Treatments with the same letters are not significantly different according to the least-squares means test at $p \leq 0.1$.

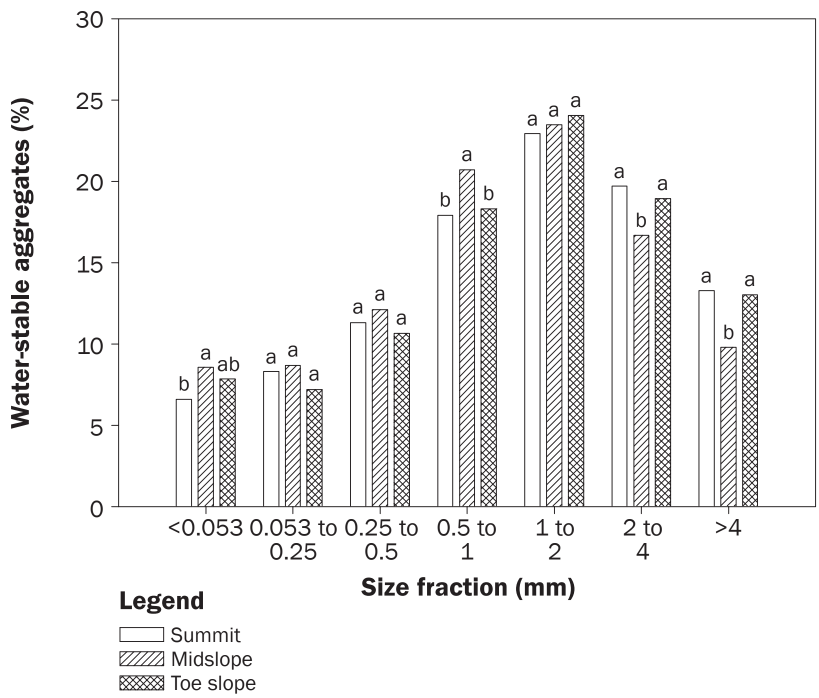
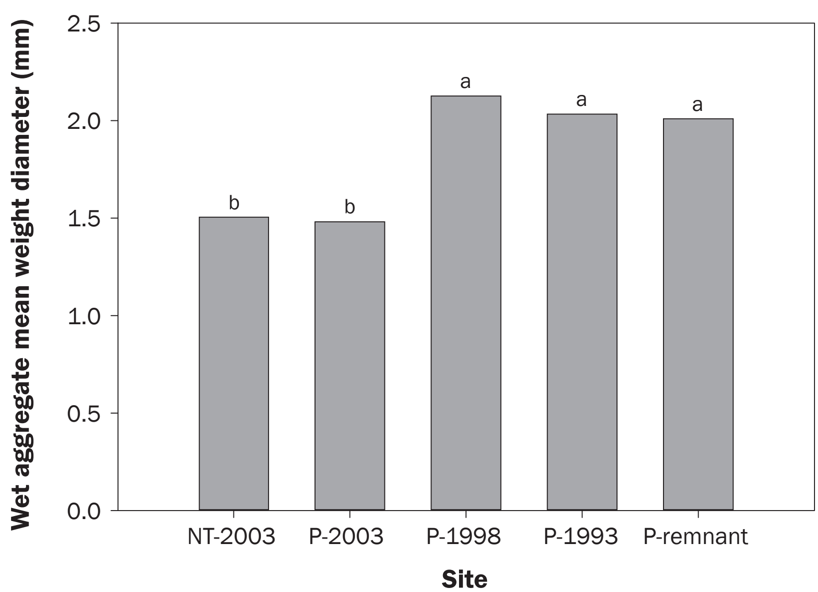


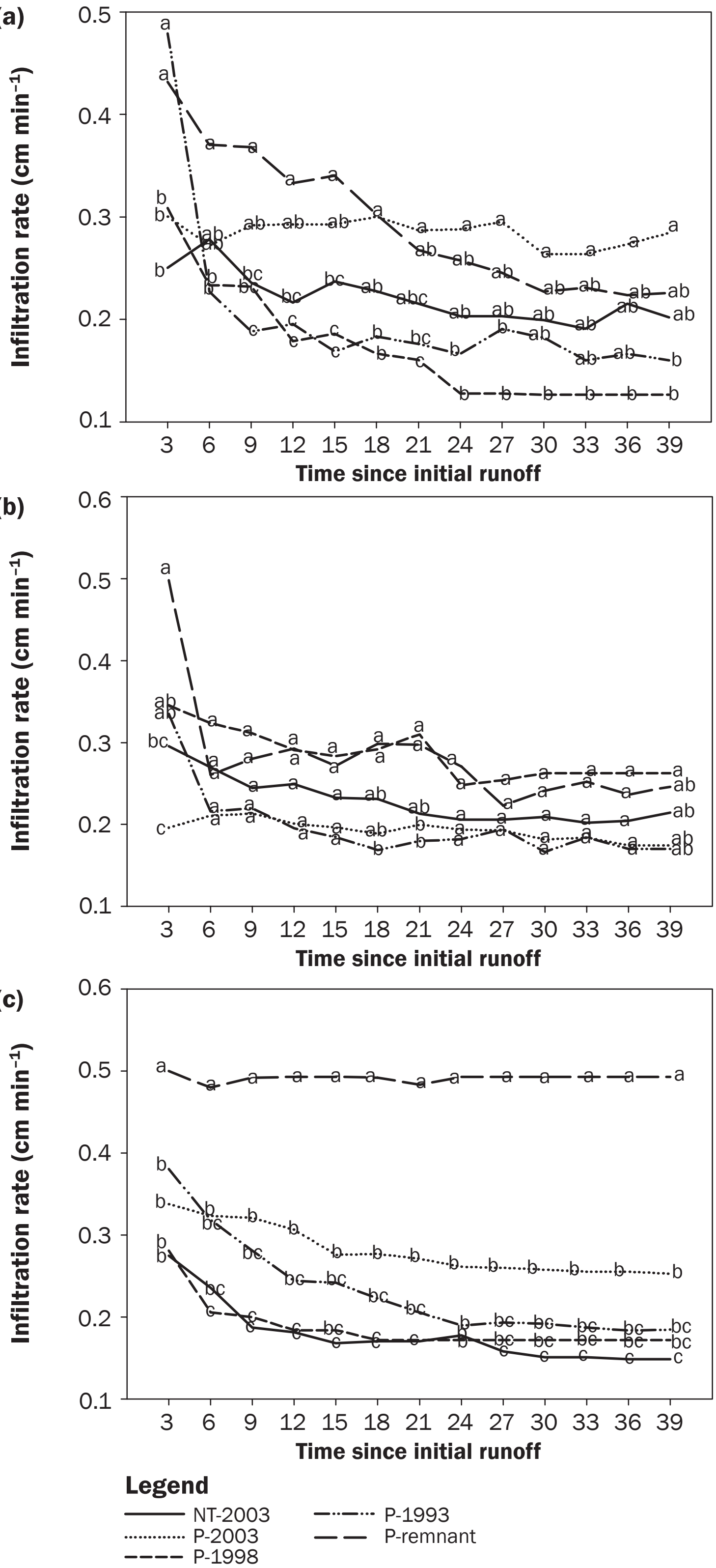
Figure 5
Mean weight diameter of all sites across slope positions. Treatments with the same letters are not significantly different according to the least-squares means test at $p \leq 0.1$.



Notes: NT = no-till. P = prairie.

Figure 6

Infiltration rates of different slope positions: (a) summit, (b) midslope, and (c) toe slope. Treatments with the same letters at each time of measurement are not significantly different according to least-square means test at $p \leq 0.1$. Simulated rainfall rates used were 0.5 cm min^{-1}.



Notes: NT = no-till. P = prairie.

For the most part, this can be explained by slope position effect on soil organic matter pool size (Gregorich et al. 1998; Hook and Burke 2000). All of the soil properties measured in this study (SOC concentration, root biomass, ρ_b, WSA, and MWD) were significantly lower at the midslope position with an exception of ρ_b, which was greater than that of the summit and toe-slope positions. This can be attributed to the potential of greater soil erosion and soil degradation at the midslope position, which, in turn, may result in low biomass productivity. Additionally, SOC as well as silt and clay fractions that are eroded due to surface runoff are then deposited down at the toe slope, where accumulation occurs. This resulted in greater infiltration rate in the toe-slope position, due in part, to the development of soil aggregation (figure 4) and porosity (figure 3).

At the midslope position where the lowest SOC concentrations and MWD occurred, steady state infiltration rate was reached quicker than at the summit and toe-slope positions (figure 6). In this case, soil surface properties such as SOC concentration, root biomass, and MWD might play a less significant role in infiltration rate than distinctive hydraulic and pedological features, such as slope steepness and the curvature of the land surface (Pennock et al. 1987) and porosity of the soil (figure 3, table 5). Vegetation cover (Bhark and Small 2003; Bautista et al. 2007) then might played a bigger role in reducing water runoff and soil erosion in the midslope, especially during the first years of prairie establishment. In these reconstructed prairies, difficulties in early establishment of vegetation in the midslope position might have left this soil vulnerable to water erosion from surface runoff in particular due to greater land slope.

At the summit position, which has relatively less potential for soil erosion and deposition compared with the midslope and toe-slope positions, steady state infiltration rate were similar to that of the midslope positions, even though the summit position had higher root biomass, SOC concentration, and MWD. Similar findings were also reported in another study (Sauer 2005), although reasons are unclear. However, the summit position did have greater infiltration rate and longer time to reach steady state than the midslope position (figure 6). In addition, SOC and MWD were good indicators of infiltration rate during the first three minutes after initial

Table 5

Correlations (using multiple backwards elimination regression analysis) between steady state infiltration rate and soil organic carbon (SOC) concentration, root biomass (RB), bulk density (ρ_b), mean weight diameter (MWD), and years since prairie establishment for each slope position.

	Steady state infiltration rates					
	Summit		Midslope		Toe slope	
Term	Estimate	Prob > ltl	Estimate	Prob > ltl	Estimate	Prob > ltl
Intercept	—	—	2.66	0.0113	0.6909	0.0176
Years*	—	—	–0.0121	0.0304	—	—
SOC	—	—	—	—	0.0843	0.0076
SOC × years	—	—	—	—	—	—
ρ_b	—	—	–2.6972	0.0181	–0.5572	0.0076
ρ_b ×years	—	—	–0.0761	0.0233	—	—
MWD	—	—	0.4139	0.0499	—	—
MWD × years	—	—	0.0094	0.0844	—	—
RB	—	—	—	—	—	—
RB × years	—	—	—	—	—	—
r^2 adj	0.00		0.33		0.78	
Mean	0.24		0.23		0.27	

Notes: The significance level is $p \leq 0.05$. When no data are shown (—), the factor was eliminated in the model. Prob > ltl = *p*-value associated with the *t*-test.

* For the prairie-remnant site, 150 years was assumed for establishment year in model.

Table 6

Correlations (using multiple backwards elimination regression analysis) between first three minutes after initial runoff infiltration rate and soil organic carbon (SOC) concentration, root biomass (RB), bulk density (ρ_b), mean weight diameter (MWD), and years since prairie establishment for each slope position.

	First three minutes after initial runoff infiltration rates					
	Summit		Midslope		Toe slope	
Term	Estimate	Prob > ltl	Estimate	Prob > ltl	Estimate	Prob > ltl
Intercept	–0.2054	0.0950	0.7694	0.2120	1.0819	<0.0001
Years*	–0.0022	0.0374	0.0072	0.0032	—	—
SOC	0.1145	0.0017	–0.3231	0.0815	—	—
SOC × years	0.0023	0.0080	—	—	—	—
ρ_b	—	—	0.1878	0.6821	–0.6108	0.0001
ρ_b × years	—	—	0.0331	0.0235	—	—
MWD	0.1806	0.0049	—	—	—	—
MWD × years	—	—	—	—	—	—
RB	—	—	—	—	—	—
RB × years	—	—	—	—	—	—
r^2 adj	0.80		0.57		0.67	
Mean	0.33		0.37		0.37	

Notes: The significance level is $p \leq 0.05$. When no data are shown (—), the factor was eliminated in the model. Prob > ltl = *p*-value associated with the *t*-test.

* For the prairie-remnant site, 150 years was assumed for establishment year in model.

run off in the summit position in this study (table 6).

Summary and Conclusions

In general, this study shows that over time, increases in SOC did promote aggregate formation and lower ρ_b creating greater preferential flow in soil in these reconstructed prairies in the summit and toe-slope positions. In the midslope position, SOC concentration, root biomass, and WSA had decreased, while ρ_b had increased, compared to the summit and toe-slope positions. However, the midslope and the summit positions had lower infiltration rate than the toe-slope position. This was attributed to the toe-slope positions superior SOC concentration and lower ρ_b, which were highly correlated with infiltration rate. The findings of this study showed that infiltration rate in these reconstructed prairies and the row crop production site were influenced by SOC concentration, root biomass, ρ_b, and MWD, although vary by slope position and time since prairie establishment. The implication of this research documents the need for more effective management practices when establishing new prairies, especially on the midslopes to reduce soil surface water runoff during the first few years of prairie establishment until full vegetation establishment.

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