Effects of Corn Crop Residue Grazing on Soil Physical Properties and Subsequent Soybean Production in a Corn–Soybean Crop Rotation

A.S. Leaflet R1837

Justin Clark, research assistant in animal science
Jim Russell, professor of animal science
Douglas Karlen, soil scientist, USDA–National Soil Tilth Laboratory
Darrell Busby, southwest Iowa area livestock extension specialist
Brian Peterson, USDA–Natural Resource Conservation Service
Larry Pellack, USDA–National Soil Tilth Laboratory
Dallas Maxwell, Armstrong Research Farm staff

Summary

For three years beginning in 1999, a 96-acre field near Atlantic, Iowa was used to study the effects of corn residue grazing by beef cows on soil characteristics and soybean yields in subsequent years. Each winter, cows were allowed to graze corn crop residues inside selected paddocks in four sub-fields over five monthly periods. To compare the effects of grazing, one paddock was left as an ungrazed control. At the end of grazing in the spring, soil bulk density, moisture content, and penetration resistance were measured inside and 15 ft outside twelve grazing exclosures in each paddock. Soil surface roughness, texture, and type were also measured in twelve locations in each paddock. Corn crop residues were collected for yield, cover, and composition at the initiation, middle and termination of grazing. Precipitation and soil temperature also were recorded throughout the grazing season. Each following year, soybeans were planted in replicated subfields with disking or no tillage and harvested using a combine equipped with a yield monitor and global positioning system (GPS).

Cattle grazing corn crop residue has shown no effect on soil bulk density, but there has been a measurable effect on penetration resistance in paddocks grazed in October and November ($P < 0.05$). There is an increase in soil surface roughness during certain periods of cattle grazing where 75% of the variation can be contributed to increase in the amount of time soil temperature is above freezing. Cattle grazing had no effect on soybean plant population. However, 36 and 38% of the variation in soybean yield can be attributed to penetration resistance and soil surface roughness.

Introduction

The highest cost to beef cow–calf producers is the feeding of stored feeds in winter months. To lower feed costs, many producers attempt to extend the grazing season into winter. The primary resource for winter grazing in the Midwest is corn crop residue. On average, one acre of grazed corn crop residues will reduce the amount of hay needed to maintain cows by approximately a half-ton over winter. Although corn crop residue grazing is quite effective in reducing feed costs, some producers are concerned that it will have an adverse effect on soybean yields planted the following year in a corn and soybean rotation because of soil compaction. Studies have shown that use of large machinery in wet conditions causes soil compaction and reduces subsequent corn grain yields from 6–10%. Similarly, an increase in soil bulk density can occur in overstocked pastures in wet conditions. It is the purpose of this study to determine whether and when corn crop residue grazing affects soil properties and grain crop yields in subsequent years.

Materials and Methods

Experimental design

For three years beginning in 1999, a 96-acre field belonging to Bill Pellet near Atlantic Iowa was equally divided into two fields for a corn-soybean rotation. Corn was planted in 30-inch rows and soybeans were drilled in 7-inch rows. Prior to corn planting in 1999, fields were chisel-plowed to initiate the experiment on equal tillage treatments. After corn grain harvest, fields were divided into four 12-acre blocks to determine the effects of cornstalk grazing on the yields of soybeans planted with no tillage or tillage once with a disk the year following grazing. Each block contained a lane leading to a common watering and supplementation site for the field. Blocks were divided into six paddocks. One paddock in each block was randomly selected as an ungrazed control. Remaining paddocks were strip-grazed at 28-day intervals to evaluate the interactions of corn crop residue grazing and weather conditions on soil characteristics and soybean yields. Prior to grazing, twelve9-ft^2 grazing exclosures were placed in each grazed paddock in two transects at approximately 90-ft intervals for comparison of grazed and ungrazed areas within each paddock.

On October 18, 16, and 23 in 1999, 2000, and 2001, each block was stocked with three Angus cows (mean body weights; 1366, 1310, and 1335 in 1999, 2000, and 2001) at an allowance of .67 acres/cow/28 days. Hay was supplemented as large round bales to cows as necessary by a herdsman.

Soil Measurements

Soils were core-sampled prior to grazing in 1999 and 2000 in twelve locations in each paddock for visual determination of classification, clay content, and subsoil depth.

Each year 12 soil samples per paddock were collected at the 0 to 4- and 4 to 8-inch depths to determine any differences in soil bulk density present prior to initiation of grazing. Upon completion of the grazing season, soil bulk density was again measured by taking soil samples at the 0 to 4- and 4 to 8-inch depths within and 15 feet outside of each grazing exclosure in the same corn residue interrow. Post-grazing bulk density measurements for each grazing exclosure within a grazed paddock were expressed as a ratio of the measurements outside to those inside grazing exclosures for each of the depths. Bulk density data were expressed as ratios to account for variations in soil properties within paddocks that may affect bulk density. Grazing exclosures were not used in control paddocks and, therefore, bulk density ratios in control paddocks were 1. Soil moisture contents were determined from the same soil samples used for determination of soil bulk density.

After grazing in each year, soil penetration resistance was measured as the kg of force required to push a rod with a 0.505-inch cone into the ground using a penetrometer. Similar to bulk density measurements, penetration resistance was measured at the 0 to 4- and 4 to 8-inch depths at 12 locations within and 15 feet outside of the grazing exclosures in the same interrow. Penetration resistance was also expressed as a ratio of the measurements outside to inside the grazing exclosures in grazed paddock and as 1 in the control paddocks.

After grazing in each year, soil surface roughness was measured by two methods within each grazed and control paddock. In the first method, roughness was measured as the percentage of change in the length of a 2-m long chain after being forced to take the contour of the bare soil surface in a straight line at 12 locations in each paddock. In the second method, roughness was measured as the standard deviation in the lengths of 40 pins in a 2-m long pin meter, determined by image analysis, in six locations in each paddock.

Corn Crop Residue Measurements

Corn crop residue cover was measured at the initiation and termination of grazing and after soybeans were planted in the spring. Measurements were taken at six locations within a paddock by counting proportion of 100 points on a 50 ft rope that were above corn residue.

For determination of crop residue mass and composition, corn crop residue samples were collected from a minimum of one 4-m^2 site within each grazed or ungrazed paddock and composited by grazing and block (minimum of three samples per block) at pre-, mid-, and post-grazing). Crop residue samples were analyzed for organic matter (OM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and in vitro organic matter disappearance (IVOMD).

Environmental measurements

Throughout the grazing period, soil temperatures were measured with HOBO® series H8 data loggers programmed to take soil temperatures at the 4-inch depth every 30 minutes at two locations per block. All damaged data loggers or erroneous data was discarded and the remaining measurements were averaged. Precipitation measurements for the daily average precipitation of the grazing period and the maximum 24-hour precipitation event were obtained daily from the Atlantic, IA station of the National Climatic Data Center (NCDC).

Soybean measurements

Upon emergence of the soybean plants in the spring, plant populations were measured by averaging the number of plants on each side of a yardstick tossed randomly six times per paddock taken times a factor of 3890 for the 7 ½ inch rows. Soybeans were harvested in the fall using a combine equipped with a global positioning system (GPS) and yield monitor to measure yield within each paddock.

Herd Data Records

Cattle were weighed and visually scored for body condition on a nine-point scale at the initiation and termination of the grazing season. Supplemental hay was weighed as fed.

Statistics

Soil physical property and pre- and post-grazing crop residue cover data were analyzed as a randomized block design using the GLM procedure of SAS to test the effects of month of grazing within a year. Post-planting corn residue cover and soybean emergence and yield measurements were also tested for the effects of tillage treatments. For variables with significant treatment effects, contrasts were conducted to determine differences between paddocks that were ungrazed or grazed in a specific period. To quantitate the effects of soil properties, corn residue, and environmental measurements on soybean yields, regression analysis was conducted predicting soybean yields within and between both tillage treatments from all soil, crop residue and environmental measurements. Also to determine the effects of environmental factors on soil penetration resistance and surface roughness, regression analysis was used to predict penetration resistance ratio or surface roughness from the maximum 24 hour precipitation event and percentage of time the soil is below freezing during the period that each paddock was stocked as well as the soil moisture content at the termination of the grazing season. Changes in forage masses and composition of grazed and ungrazed corn crop residues were calculated by regression analysis with time and analyzed for the effects of grazing by the GLM procedure within years.

Results and Discussion

Soil Measurements

Soil classifications, taken prior to the grazing season, were not different between paddocks for all three years. Main soil types were Marshall, Minden, and Corley. Measurements of soil clay content and subsoil depth have also shown no significant difference between paddocks grazed and the control paddocks for all three years (Table 1).

Neither the initial soil bulk measurements nor the post-grazing soil bulk density ratios (Table 2) of paddocks grazed in any month have differed from the ungrazed paddocks in the three-year studied. However, post-grazing penetration resistance ratios (PR) for the upper 4 inches of soil in grazed paddocks have been greater ($P < 0.05$) than ungrazed paddocks typically in the first two paddocks grazed in each year (Table 2). The second paddock grazed in 1999 PR increased by 29%. In the first and second paddocks grazed in the 2000 season PR increased by 28 and 21%. In the 2001 season, PR increased in the first, second and last paddocks grazed by 44, 39, and 25%. These increases may be a result of grazing during periods when soil temperatures were above freezing (Table 3). For the 2000 and 2001 seasons, there was a strong quadratic relationship ($r = 0.39$ and 0.48) between PR and the amount of time the soil was below freezing temperature (%SF). For all years combined the correlation ($r = 0.17$) was not as strong, but was still significant (Table 4). In general, as the %SF decreased PR increased, suggesting that trampling effects on compaction will be minimized when the ground is frozen. Penetration resistance ratios for the 4 to 8 inch depths did not differ between grazed and ungrazed paddocks for all three years.

Post-grazing soil moisture contents did not differ between grazed and ungrazed paddocks in all three years. This, along with a lack of significant correlation to penetration resistance discounts post-grazing soil moisture as the cause of variation in PR, and therefore, any effects seen were a result of trampling.

Soil surface roughness, as measured by a 2-m chain, in the third and fifth month of grazing in 1999 and the second and fifth month of grazing of 2001 were greater ($P<0.05$) than ungrazed paddocks (Table 5). Similarly, soil surface roughness, measured with a 40-pin meter, in the fifth month of grazing in 1999 was greater ($P<0.05$) than ungrazed paddocks. The difference between the two soil surface roughness measurements may be caused by a difference in sensitivity. It is believed that the 2-meter chain method is more sensitive due to direct contact with the soil surface at every chain link, whereas the 40-pin meter only makes direct contact at the 40 pinpoints.

Regression analysis for the 2-m chain method showed a quadratic relationship ($r = 0.86$) between the soil surface roughness and %SF for the 1999 season (Table 6). Likewise, regression analysis for the 40-pin meter showed quadratic relationships to %SF ($r = 0.35$ to 0.75) for the 1999 and 2001 seasons, and when all years were combined ($r = 0.27$; Table 7). Typically, soil surface roughness will increase as %SF increases from 0 to 60% and decrease as %SF increases from 60 to 100%, with similar levels of surface roughness for 0 and 100 %SF. This trend indicates soil is most susceptible to increased roughness if grazed during periods when the soil is only frozen half the time. According to soil temperature measurements, this most likely to occurred in late winter when the last paddock grazed was most likely saturated from melting snow cover. Likewise, this may also explain why surface roughness increased in some paddocks grazed though there was no increase in PR. The water content of the soil may have been high enough to exceed the plastic limit. As water saturation increases in the soil, it becomes more susceptible to compaction. However, as the water content of the soil reaches the plastic limit, particle displacement is more likely to occur rather than compaction. On this project, soil moisture was not measured on a daily basis but water content may still have caused soil particles to displace around the hoof rather than compacting, if soil was above freezing. Another factor that may contribute to surface roughness is increased equipment traffic in some areas of the field at the time of corn harvest. Unfortunately, surface roughness measurements are unable to differentiate between cattle grazing and implement tracts.

Corn Crop Residue Measurements

Pre-grazing residue covers did not differ between ungrazed and grazed paddocks in any of the three years (Table 5). Post-grazing residue covers were lower ($P<0.05$) in the first two paddocks grazed during 2000 and in all paddocks grazed during 2001 than control paddocks. This result is likely caused by residue removal by the beef cows although changes in organic matter mass in the second season indicate otherwise (Table 8). Post-planting residue covers were lower ($P<0.05$) in the second and last two paddocks grazed than ungrazed paddocks in fields planted with no tillage in 2000.

Initial residue organic matter yields and composition of corn crop residues did not differ between ungrazed and grazed for all three years (Table 8). During the first and last years the rate of decrease in crop residue organic matter mass during the grazing was greater ($P<0.05$) in grazed paddocks than ungrazed paddocks, which is a typical result of cornstalk grazing. However, daily changes in the concentrations of CP, NDF, ADF, or IVDOM over the grazing season did not differ between ungrazed and grazed paddocks in all three years. This result indicates that the amount of nutrient loss from grazing is comparable to that lost from weathering effects.

Soybean Measurements

Soybean plant population measurements in the spring following the grazing season did not differ between grazed or ungrazed paddocks for any of the three years (Table 9). This signifies although cattle grazing on corn crop residue may have an effect on soil physical properties, it has no measurable effect on the emergence of soybean plants. Similarly, soybean yields did not differ between ungrazed and grazed paddocks in fields planted with disking or no tillage in 1999 and 2000 (Table 10). Likewise, soybean yields in paddocks that were ungrazed or grazed and planted by disking did not differ in 2001. However, soybean yields in the paddock grazed in the second period were 8% lower ($P<0.05$) than ungrazed paddocks in fields planted with no tillage in 2001. With data from all years combined, conventional tillage and no-tillage showed a quadratic relationship between soybean yields and soil surface roughness, as measured by the standard deviation of pin length from a 40-pin meter, where soil roughness accounts for up to 22 to 38% of the variation in soybean yields, respectively (Table 11). For the no-tillage system as soil surface roughness increases soybean yields decrease. However, for the conventional tillage system as soil surface roughness increases soybean yield decreases but then began to increase again when surface roughness became greater. It is not clear why this relationship exists between soybean yields and surface roughness in the conventional tillage system. When regression analysis was calculated solely for the 2001 season, no-till soybean yields showed a strong negative linear relationship to PR ($r = 0.36$) and an even stronger positive quadratic relationship to %SF ($r = 0.72$; Table 12).

It has been shown that %SF has a direct effect on soil surface roughness and PR. Likewise, both soil surface roughness and PR along with %SF has been shown to negatively effect soybean yields. Therefore the effects of grazing corn crop residue by beef cattle on soil physical properties and subsequent soybean yields will be reduced if grazing is restricted to periods of below freezing soil temperatures.

Herd Data Records

In the initial grazing season, cows began with an average BCS of 5.52 and a weight of 1,366 lbs. When the cows were removed on March 1, they had an average BCS of 5.08 and weight of 1,455 lbs. per cow. Over the season, the cows had consumed supplemental hay totaling 14,330 lbs., and equaling 8.78 lbs./cow/day. In the second season, cows began with an average BCS of 5.46 and a weight of 1310. When the cows were removed on March 5, they had an average BCS of 5.25 and weight of 1390 lbs. Over the season, the cows had consumed supplemental hay totaling 49240 lbs., and equaling 29.30 lbs./cow/day. In the third season, cows started at 1335 lbs and a BCS of 5.58 and finished at 1453 lbs and 5.5 BCS on March 12. They consumed 19 lbs/head/day totaling 31980 lbs for the entire group of 12 cows over 140 days.

Assuming that a cow would require approximately 30 lb hay per day for maintenance, the hay savings from corn crop residue grazing were 911, 25, and 451 lb/acre grazed in 1999, 2000, and 2001. Although the hay savings in 1999 were close to those observed in our previous experiments, hay savings in 2000 and 2001 were considerably less than previously attained. While this difference may be partially the result of inclement weather during the winter of 2000, the high condition scores of cows observed at the termination of grazing in 2000 and 2001 imply that the reduced hay savings likely resulted from excessive supplementation.

Implications

Grazing of cattle on corn crop residue has shown to impact soil surface roughness. Up to 86 % of the variation in surface roughness can be contributed to the status of soil temperature, where an increase in soil temperature will result in increased likely hood of a rough surface. The effects of corn residue grazing of cattle on soybean production is not as clear. It has been shown to have no effect on soybean plant emergence indicating any effects grazing has on soil does not result in a lower plant population the following spring. However, in the third year of the experiment the second paddock grazed showed an 8% reduction in soybean yields for the no-tillage system. In the 2001season, when the effect on soybean yield was seen, penetration resistance accounted for up to 36% of the variation, while percent of time the soil is below freezing can be attributed to 72% of the variation in soybean yield for that year. Likewise, when soybean yield data was combined for all three years, up to 38% of the variation in yield was attributed to soil surface roughens. Sense penetration resistance and soil surface roughness are largely impacted during long periods of above freezing soil temperatures, soybean yields should not be effected if cattle grazing is restricted to periods of below freezing soil temperature.

Table 1. Soil clay content and subsoil depth.

Table 2. Post grazing soil penetration resistance ratio[a] and soil bulk density ratio[b].

		Initiation date of 28-day grazing period				
Soil depth	Control	1	2	3	4	5
1999-2000		Oct. 18	Nov. 10	Dec. 08	Jan. 05	Feb. 02
Penetration ratio						
0 – 4 in.	1.00	1.11	1.29*[c]	1.07	1.08	1.15
4 – 8 in.	1.00	1.05	0.98	1.00	1.02	1.08
Bulk density ratio						
0 – 4 in.	1.00	1.11	1.10	1.08	1.03	1.11
4 – 8 in.	1.00	1.05	0.98	1.02	1.01	1.02
2000 - 2001		Oct. 16	Nov. 13	Dec. 11	Jan. 08	Feb. 05
Penetration ratio						
0 – 4 in.	1.00	1.28*	1.21*	1.16	1.20	1.23
4 – 8 in.	1.00	1.09	0.98	0.94	1.08	1.02
Bulk density ratio						
0 – 4 in.	1.00	1.11	1.07	1.06	1.09	1.04
4 – 8 in.	1.00	0.92	1.07	1.09	0.99	1.03
2001 - 2002		Oct. 23	Nov. 20	Dec. 18	Jan. 15	Feb. 12
Penetration ratio						
0 – 4 in.	1.00	1.44*	1.39*	1.13	1.06	1.25*
4 – 8 in.	1.00	1.22	1.16	1.06	1.11	1.18
Bulk density ratio						
0 – 4 in.	1.00	0.91	0.95	0.91	0.93	0.91
4 – 8 in.	1.00	0.94	1.00	0.94	1.01	0.94

[a]Average force required to push a rod with a 0.505 in. cone through the upper 4 inches and 4 to 8 inches of soil expressed as a ratio of the measurements taken 15 ft outside the grazing exclosures to inside the grazing exclosures in the given paddock.
[b]Average bulk density of upper 4 inches and 4 to 8 inch depths taken 15 ft outside the grazing exclosure to inside the grazing exclosures in the given paddock.
[c]Means in the same row with an asterisk (*) are different from the mean of the control paddocks ($P<0.05$).

Table 3. Percentage of below freezing soil temperature and average daily precipitation.

	Initiation date of grazing period				
	1	2	3	4	5
1999-2000	Oct. 18	Nov. 10	Dec. 08	Jan. 05	Feb. 02
% time < 32^o F	0	0	3.4	100	72.5
Daily average precipitation, in.	0.038	0.033	0.025	0.012	0.053
Maximum 24h precipitation, in.	0.82	0.52	0.29	0.11	0.60
2000 – 2001	Oct. 16	Nov. 13	Dec. 11	Jan. 08	Feb. 05
% time < 32^o F	1.7	61.2	100	92.5	100
Daily average precipitation, in.	0.043	0.081	0.041	0.055	0.095
Maximum 24h precipitation, in.	1.69	0.49	0.15	0.85	0.98
2001 – 2002	Oct. 23	Nov. 20	Dec. 18	Jan. 15	Feb. 12
% time < 32^o F	2	0	79	99	69
Daily average precipitation, in.	0.008	0.054	0.008	0.048	0.037
Maximum 24h precipitation, in.	0.12	0.6	0.22	0.48	0.34

Table 4. Penetration resistance ratio regression equation with % of time soil temperature < 0 Celsius as the dependent variable.

Year	Equation	Significance	R^2
2000 - 2001	$Y = 1.42 - 0.17X - 0.167X^2$	0.02	0.39
2001 - 2002	$Y = 1.41 - 0.087X - 0.28X^2$	<0.01	0.48
All years combined	$Y = 1.26 + 0.13X - 0.32X^2$	<0.01	0.17

Table 5. Crop residue cover and soil surface roughness.

	Crop residue cover					Surface roughness	
			Post-planting				
Initial date of grazing	Pre-grazing	Post-grazing	Pooled Tillage [a]	No - till	Tilled	40-pin meter[b]	2 meter chain[c]
1999–2000							
Control	87.5	82.3	63.2	79.7	46.8	1.12	2.88
Oct. 18	84.3	90.3	62.8	81.7	44.0	1.19	3.56
Nov. 10	86.3	90.3	62.1	78.6	45.5	1.27	3.98
Dec. 08	87.6	90.6	62.9	78.4	47.4	1.33	4.85* [e]
Jan. 05	88.1	88.5	62.3	77.3	47.3	1.24	3.02
Feb. 02	88.2	89.6	61.5	75.3	47.6	2.10*	9.48*
2000–2001							
Control	91.2	86.7	59.6	78.9	40.3	2.11	2.90
Oct. 16	95.5	82.4*	56.5	76.7	36.4	2.20	4.40
Nov. 13	90.9	82.0*	57.3	76.0*	38.5	2.06	2.50
Dec. 11	93.8	85.4	54.5	77.7	31.4	2.11	4.40
Jan. 08	90.6	86.4	51.5*	74.9*	28.1	2.04	3.40
Feb. 05	91.3	86.2	50.6*	74.1*	27.2	2.30	2.40
2001-2002							
Control	87.5	91.7	78.4	87.6	69.2	2.00	5.92
Oct. 23	88.3	86.4*	79.0	87.0	70.9	1.72	6.77
Nov. 11	87.3	86.9*	78.9	83.7	74.2	1.76	9.65*
Dec. 12	87.5	87.3*	77.7	84.4	71.0	2.04	7.21
Jan. 15	88.8	83.6*	74.9	84.8	65.0	1.86	8.60
Feb. 12	88.1	84.1*	75.4	82.6	68.3	2.26	11.60*

[a]Includes both no-tillage and conventional tillage systems.
[b]Standard deviation in pin length, cm.
[c]Reduction in chain length, %.
[d]Means in the same column with an asterisk (*) are different from the mean of the control paddocks ($P<0.05$).

Table 6. Soil surface roughness when measured by a 2-meter chain with % of time soil temperature < 0 Celsius as the dependent variable.

Year	Equation	Significance	R^2
1999 - 2000	$Y = 3.79 + 30.55X – 31.33X^2$	0.001	0.86

Table 7. Soil surface roughness when measured by 40-pin meter with % of time soil temperature < 0 Celsius as the dependent variable.

Year	Equation	Significance	R^2
1999 - 2000	$Y = 1.22 + 4.33X - 4.30X^2$	0.001	0.75
2001 - 2002	$Y = 1.72 + 1.99X - 1.88X^2$	0.03	0.35
All years combined	$Y = 1.55 + 1.97X - 1.64X^2$	<0.01	0.27

Table 8. Organic matter yields and composition initially and daily change in ungrazed and grazed paddocks.

		Daily change	
	Initial value	Ungrazed	Grazed
1999-2000			
Organic matter yield, lbs/acre	6219	17.59[a]	-4.12[b]
IVDOM (% of OM)	46.8	0.019	0.02
NDF (% of OM)	71.9	0.003	0.036
ADF (% of OM)	45.6	0	0.02
CP (% of OM)	4.4	-0.002	-0.006
2000-2001			
Organic matter yield, lbs/acre	7914.9	-1.48	-10.19
IVDOM (% of OM)		-0.08	-0.06
NDF (% of OM)	75.4	0.03	-0.01
ADF (% of OM)	45.7	0.06	0.06
CP (% of OM)	5.5	0	0.002
2001- 2002			
Organic matter yield, lbs/acre	3823.48	31.32[a]	15.62[b]
IVDOM (% of OM)	49.1	-0.024	-0.037
NDF (% of OM)	67.9	0.03	0.02
ADF (% of OM)	43.3	0.03	0.02
CP (% of OM)	5.5	-0.003	0.001

[ab]Means without common superscript differ ($P<0.05$).

Table 9. Soybean plant population counts post planting.

	Soybean plant populations, plants per acre		
	Pooled tillage	No – till	Tilled
1999–2000			
Control	91901	92387	91415
Oct. 18	96227	103085	89470
Nov. 10	86552	102113	70992
Dec. 08	84121	101140	67102
Jan. 05	100167	101140	99195
Feb. 02	90442	106003	74882
2000–2001			
Control	158031	159490	156572
Oct. 16	137608	132260	142957
Nov. 13	126425	117672	135177
Dec. 11	149278	170187	128370
Jan. 08	139553	143930	135177
Feb. 05	139067	153655	124480
2001-2002			
Control	151223	140040	162408
Oct. 23	133719	139067	128370
Nov. 11	139068	141013	137123
Dec. 12	141985	114755	169215
Jan. 15	141499	120590	162408
Feb. 12	162894	136150	189637

Table 10. Soybean yields by tillage method.

		Paddock according to initiation date of 28-day grazing period				
Tillage method	Control	1	2	3	4	5
1999-2000		Oct. 18	Nov. 10	Dec. 08	Jan. 05	Feb. 02
No – till, bu/acre	56.11	55.52	54.61	56.29	56.69	55.13
Tillage	54.29	56.90	56.95	55.37	56.81	58.21
Combined tillage	55.20	56.20	55.78	55.83	56.75	56.67
2000 - 2001		Oct. 16	Nov. 13	Dec. 11	Jan. 08	Feb. 05
No – till	46.10	51.00	50.60	48.80	49.00	48.10
Tillage	56.70	58.10	56.20	55.80	53.30	53.70
Combined tillage	51.38	54.54	53.39	51.97	51.17	90.93
2001 - 2002						
No – till	51.40	49.90	47.35*[a]	51.95	52.05	51.00
Tillage	53.55	52.45	49.05	51.70	52.40	49.60
Combined tillage	52.47	51.18	48.20*	51.82	52.22	50.30

[a]Means in the same row with an asterisk (*) are different from the mean of the control paddock (P<0.05).

Table 11. Soybean regression equations for all three years combined when compared to surface roughness, measured by standard deviation of 40 - pin meter.

Independent variable	Regression equation	Significance	R^2
No - tillage	$Y = 72.15 - 18.33X + 3.70X^2$	<0.01	0.38
Conventional tillage	$Y = 83.14 - 33.79X + 9.34X^2$	0.02	0.22
Tillage methods combined	$Y = 80.24 - 29.4X + 7.51X^2$	<0.01	0.21

Table 12. Soybean yield regression equations for 2001 - 2003 season, no – till only.

Dependent variable	Equation	Significance	R^2
Penetration resistance ratio	$Y = 55.41 - 3.92X$	0.04	0.36
% of the time soil temperature < 0 C	$Y = 48.53 + 5.2X - 1.71X^2$	0.01	0.72