CONSERVATION INNOVATION GRANTS

Final Report

Grantee Name: David Clay	
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Project Director: David Clay / Cheryl Reese	
Contact Information: David Clay Cheryl Reese	Phone Number: Clay:605-688-5081; Reese:605-688-6309 E-Mail: David.Clay@sdstate.edu Cheryl.Reese@sdstate.edu
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Summary

The NRCS-CIG grant Agreement Number: 9-148 was funded from October 2009 to September 2012. A no-cost extension was granted in August 2012 due to poor weather. In South Dakota, cover crops following wheat are becoming a standard practice and the analysis of data collected in this project indicate that winter cover crop will either increase or not impact the following crops yields. In-season cover crops produced mixed results. If planted too early, cover crop reduced yields. In-season cover crop seeded at V4-V6 did not influence the corn crop and gene regulation. However, in-season cover crops did help protect the soil.

In the Northern Great Plains, climate variability is influencing crop yields and saline and sodic soil development. Findings from this study indicate that cover crops following wheat can reduce these risks. Winter cover crops either did not influence soil nitrate concentrations or reduced spring nitrate concentrations. Spring nitrate reductions should reduce the risk of nitrate leaching and denitrifications. Spring soil ammonia concentrations were not impacted by winter cover crops. These results are attributed to the ammonia being released from the soil organic matter after the cover crop dies. Winter cover crops influenced the soil microbial community. Soil nitrate and ammonia concentrations were not impacted one year after the cover crop. Cover crop and landscape position influenced the apparent microbial community structure. However additional work is needed to confirm these findings. This project met or exceeded the project goals related to the number of workshops sponsored (4), number of curricula developed (2), the number of fact sheets developed (2), and the number of field days sponsored (4). It is estimated that over 400 farmers attended the workshops and field days.

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Submitted to new book on Precision Conservation

Chapter 1: Determining C Budgets and Estimating the Potential Impact of Precision Conservation and Cover Crops on Soil Organic Carbon Maintenance.

David E. Clay, Gregg Carlson, Jiyul Chang, Graig Reicks, Sharon A. Clay, and Cheryl Reese
South Dakota State University, Brookings, South Dakota, 57007. USA
Correspondence: David E. Clay. E-mail: david.clay@sdstate.edu

Cover crops can increase the soil organic C content, which in turn can increase the soils long-term productivity and yield potential. Estimating the impact of precision conservation and cover crops on soil organic C (SOC) starts with developing a carbon budget. Carbon cycling across watersheds can be determined using three fundamentally different techniques. The first approach is to determine net productivity using a carbon flux tower. Carbon flux towers are most appropriate for small watersheds where a common management has been implemented. This may not be the case in precision conservation. The second approach is to link physical measurement with modelling, while the third approach is to determine carbon, nitrogen, and water budgets for specific points by plant and soil sampling. This technique may be most appropriate in precision conservation because SOC turnover may high spatial dependency. However, C budget calculations require estimates of below ground biomass, which is difficult to measure. In many situations point measurements can be augmented with results from simulation models. Once the carbon budgets are understood, this information can be used to assess the value of implementing precision conservation. This chapter provides examples on how to convert point carbon budget measurements into an assessment of precision conservation.

Introduction

Precision conservation is designed to target conservation activities to landscape areas that disproportionally impact the environment and the fields' long-term resilience (Ortega et al., 2002; Wilhelm et al., 2004; Varvel 2006; Vanden Bygaart et al., 2003; Sisti et al., 2004; Russell et al., 2005; Clay et al., 2012). Examples of precision conservation might include, identifying and planting adapted plants in waterways, identifying and using no-tillage or reduced tillage techniques in highly erodible areas, as well as matching rotations, N rates, and cover crops to landscape problems. Today's precision tools make precision conservation feasible. For example, GPS controlled sprayers and fertilizer applicators can be turned off when they drive over water ways and planters can seed different cultivars at different landscape positions. Ultimately, precision conservation can result in cool season grasses being seeded into summit/shoulder areas, traditional row crops being no-tillage seeded into backslope positions and salt tolerant native plants being seeded into footslope positions.

A key component for the long-term sustainability of precision conservation is soil carbon maintenance. Soil organic carbon (SOC) maintenance requires that the amount of carbon added to the system equals the amount of relic carbon mineralized (Barber 1971, 1978; Anderson 1982; Barber and Martin, 1976; Balsedent et al., 1988; Allmaras et al., 2004; Bradford et al., 2005; Clapp et al., 2000; Causarano et al., 2006; Clay et al., 2010, 2012a) . Precision conservation can increase SOC by reducing tillage intensity in erodible area, which in turn can lead to reduced erosion and increased soil carbon levels (Clay et al., 2012b).

Higher SOC levels have many benefits including increased productivity, higher cation exchange capacities, and more plant available water (Morachan et al., 1972; Figure 1). In soil, where yields are controlled by available water, Figure 1 suggests that there is a feedback loop between soil organic carbon and productivity. As SOC increases, the soil productivity increases, which in turn increases SOC.

Carbon Inputs and Outputs

The carbon cycle is driven by photosynthesis that produces organic biomass that is respired by microorganisms (Frye and Blevins, 1997). Developing a carbon budget starts with accurate carbon output and input measurements. In carbon budgets, outputs are the amount of carbon dioxide (CO_2) released to the atmosphere, while inputs are the amount of organic carbon added to the soil. CO_2 releases can be measured directly or indirectly. For direct measurements CO_2 is measured continuously. For indirect measures, changes in SOC at the beginning and end of the study are measured. Input measurements require accurate measurements of above and below ground biomass. Obtaining good measures of above ground biomass is relatively easy and is typically accomplished by weighing the amount of biomass returned to soil or estimating non-harvested C (NHC) from the harvest index (grain/all above ground biomass). However, obtaining accurate measures of below ground biomass and exudates is very difficult (Dwyer at al., 1996; Rochette et al, 1997, 1999; Kuzyakov and Domanski, 2000; Huggins et al., 1998; Amos and Walters, 2006; Mamani-Pati et al., 2010; Bolinder et al., 2007; Ehleringer et al., 2000). The three basic approaches used to estimate below ground biomass are modeling (Gilmanov et al., 1997; Molina et al., 2001), estimation, and measurement.

Modeling Below Ground Biomass

Models have the capacity to account for climate, soil, and vegetation differences. The Century model estimates cereal root growth as a function of precipitation and plant age (.http://www.nrel.colostate.edu/projects/century5/). For example, at emergence, 60% of the fixed carbon is allocated to roots, which decreases linearly with time and 3 months after planting the amount allocated to roots is 10%. If 60% of the fixed carbon is allocated to roots the associated root-to-shoot ratio would be 1.5 and if 10% of fixed carbon is allocated to roots the associated root-to-shoot ratio would be 0.11. The RothC model does not estimate plant growth.

Care must be used when comparing modeling results with field studies because the experiment may define roots differently. For example, the Century model, allocates C to roots as a function of time and of total C fixed, while many field studies report roots as a ratio between roots and shoots (roots/shoots). In addition, some studies include the root crown in the root sample, while other studies do not. For carbon budgets, roots must be clearly defined and all sources of C must be considered. Plant growth simulation models may improve the accuracy of C input estimates by improving below ground biomass estimates.

Measurement of Below Ground Biomass

Measuring roots is complicated by roots not equally distributed below the plant. Follett et al. (1974) collected 10 monoliths (91 cm deep) centered over the corn row at silking. In these monoliths, 73% of the root biomass, not including crowns, was contained in the surface 20.3 cm. Laboski et al. (1998) reported that over a three year period, in soil with a subsurface (15-60cm) bulk density of 1.57 Mg m^{-3}, 94% of the roots were within the surface 60 cm with 85% of the roots in the upper 30 cm. Dwyer et al. (1996) reported that root mass density with depth could be explained by the equation, $Y = Y_0 e^{-BX} + C$, where Y is the root mass density (mg cm^{-3}), Y_0 is the root mass density extrapolated to X=0, B is the shape coefficient, C represents the root mass in the deepest increment, and X is soil depth (cm).

Within the plant, C is allocated to many different parts including roots, exudates, crown, stover, grain, and cobs (Table 1) (Lloyd and Taylor, 1994; Herbert et al., 2001; Hanson et al., 2000; Kuzyakov and Cheng, 2001; Kuzyakov and Larionava 2005, 2006; Melnitchouck et al., 2005; Wichern et al., 2008). Nearly all below ground biomass estimates do not consider exudates. Exudates, may represent 5 to 21% of all carbon fixed by the plant (Marschner, 1995), and they have a range of roles. They can be used to help regulate microbial communities, change the chemical and physical conditions of the root, and inhibit the growth of competing plants. Exudates need to be included in carbon budget calculations. In Table 1, it was assumed that 50% of the roots were exudates. When exudates were included in the calculations, the root to shoot ratios [(stover + grain + cob)/(roots+exudates+crown)] ranged from 0.47 to 0.61 (Table 1). Following harvest, most of the below ground (crown, and roots 0-15 cm), stover, and cobs would be added back to the surface soil. In South Dakota experiments, 67% of the roots+exudates+crown were in the surface 15 cm, 83% of all biomass returned to the soil (roots, exudates, crown, stover, and cob) was in the surface 15 cm, and 12% of the ear was cob.

Table 1. Corn allocated into different components at 4 sites. The root to shoot (R/S) ratio includes roots and exudates in the calculations. For exudates it was assumed that exudates equal roots. Corn growing degree days (GDD) were calculated based on a base temperature of 10^{o} C (modified from Chang et al., 2013)

					Roots + Exu.									
Site	Year	GDD	Latitude	Longitude	0-15	15-30	30-60	60-75	Root crown	Stover	Grain	Cob	R/S ratio	Leaf area silking
					kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha		m^2/m^2
1	2009	1134	44.314670	-96.65292	3370	1510			3360	5780	10640	1370	0.47	3.61
2	2009	1315	44.485624	-98.78180	2180	810	870	250	2550	5860	7870	1010	0.46	3.06
3	2010	1478	44.161507	-98.53577	3980	1590	1290	510	1390	7880	9030	1420	0.48	3.94
4	2010	1469	44.517730	-98.83958	5720	1390	1460	540	2180	6850	10300	1450	0.61	3.68

Table 2. The calculated percentages of SOC, using the non-isotopic approach that must be returned annually to maintain soil organic carbon. Root to shoot ratios for corn, soybean, and wheat were identical to the values reported in Johnson et al. (2006). SOC was from the 0-15 cm soil depth.

Location		Tillage	Landscape Position/soil	SOCi kg SOC/ha	%SOC Returned	Reference and notes
Rosemont, MN		no-till		55,600	5.35	Allmaras et al. (2004)
		Chisel			9.41	
		Plow			23.31	
Lafayette	Indiana	Plow		34,900	18.3	Barber (1978)
Morris, MN		Plow		48,400	15.9	Wilts et al. (2004)
Iowa		Plow		26,750	16	Larson et al. (1972)
Kentucky		Plow		28,270	17.7	Frye and Blevins (1997)
Moody, SD		Strip till	Footslope	47,100	9.9	Clay et al. (2005)
			Lower backslope	46,700	9.9	
			Backslope	44,000	9.9	
			Upper backslope	43,600	9.9	
			Shoulder/summit	46,700	9.9	
Colorado	Sterling	No-tillage	Footslope	14,210	8.72	Peterson and Westfall (1997)
			Backslope	12,980	8.26	
			Summit	18,530	8.54	SOCi estimated from the
			Backslope	14,500	9.26	0-15 cm depth were calculated
			Summit	13,570	9.66	by multiplying the 0-5 depth by
			Footslope	6,180	8.54	2
			Summit	16,810	8.04	
Brazil	Southern Brazil	No-tillage/ plowed	Oxisol	40,180	5.4	Sisti et al. (2004)

Differences Between Roots and Shoots

Stover, crowns, and roots may have different mineralization rates (Wilts et al., 2004). Gale and Cambardella (2000) reported that in no-tillage, 75% of the new C incorporated into SOC was root derived, while a large percentage of surface residue was released as CO_2. Barber and Martin (1976) had similar results and reported that 50% of the root derived C was retained in SOC while only 13% of shoot derived C was retained in SOC. Differences between surface and root residue may be related to greater biochemical recalcitrance of root biomass, physical protection of root biomass, and lower O_2 concentrations with increasing soil depth. Tillage is likely to reduce differences between shoot and root mineralization rates.

Comparing Initial and Final SOC Amounts

The ability to accurately determine carbon turnover depends on an accurate measurement of the SOC content at the beginning and end of the experiment. To convert gravimetric SOC values to volumetric values the concentration is multiplied by the bulk density. Changes in management resulting from precision conservation are likely to change bulk densities, which in turn will impact the relative depth sampled. To minimize changes in bulk density-derived sampling error, two approaches can be used. The first approach is to use a bulk density adjusted sampling protocol. In this approach, the depth at the final sampling is adjusted to account for changes in bulk density. The ratio, $\frac{\text{Sampling depth 1}}{\text{Sampling depth 2}} = \frac{\text{Bulk density 1}}{\text{Bulk density 2}}$, defines the relationship between depth and bulk density. This ratio can be rearranged into, $\text{Sampling depth 2} = \frac{(\text{Bulk density 2} \times \text{sampling depth 1})}{(\text{Bulk density 1})}$. In this approach, a soil sample is collected for bulk density analysis, which is then used to define the final sampling protocols. In the second approach, the carbon budget in the entire soil column is determined at the beginning and end of the experiment. In these calculations, the entire soil column is sampled and the associated bulk densities of each zone and C concentration determined. Techniques for measuring bulk density are available at Grossman and Reinsch (2002).

Determining Carbon Turnover

Carbon turnover can be estimated using a simulation model or point or calculated using the input and output measurement described above. For simulations, the Century or RothC models are routinely used. The Century model (http://www.nrel.colostate.edu/projects/century5/) divides plant material, based on the lignin to N ratio into structural or metabolic pools and SOC into active, slow, and passive soil carbon pools. The active pool represents microbial biomass with a turnover time of days to years. The slow pool represents more recalcitrant material with turnover times in years to decades. The passive pool is humified carbon stabilized on mineral surfaces with turnover times of hundreds to thousands of years. Each pool has different rate constants. It is difficult to estimate the size of different pools based on only field derived information.

The Rothamsted Carbon Model (RothC) uses a five pool structure, decomposable plant material (DPM), resistant plant materials (RPM), microbial biomass, humified organic matter, and inert organic matter to assess carbon turnover (Coleman and Jenkinson, 1996; Skjemsted et al., 2004; Guo et al., 2007). The first 4 pools decompose by first order kinetics. The decay rate constants are modified by temperature, soil moisture, and indirectly by clay content. RothC does not include a plant growth sub-module, and therefore NHC inputs must be known, estimated, or calculated by inverse modeling.

Many scientists have attempted to use chemical extraction techniques to quantify the sizes of these C pools used by the Century and RothC models (Wolf et al., 1994; Olk and Gregorich, 2006; Olk, 2006; Zimmermann et al., 2007). These efforts have had mixed results. Olk and Gregorich (2006) stated that, “Each procedure has its strengths and weaknesses; each is capable to some degree of distinguishing labile SOM fractions from nonlabile fractions for studying soil processes, such as the cycling of a specific soil nutrient or anthropogenic compound, and each is based on an agent for SOM stabilization”. In general, low density soluble SOC materials turns over faster (i.e. has a higher k value) than high density mineral-associated SOC, and hydrolyzable SOC turns over faster than non-hydrolyzable SOC (Martel and Paul, 1974; Six and Jastrow, 2002).

Direct Measurement of Carbon Turnover

Direct calculation of C turnover can be based on non-isotopic and isotopic techniques. In these calculations average SOC and NHC mineralization rates, based on only field derived information, is determined. This approach does not determine the mineralization rates of the different C pools as defined by either the Century or RothC models. In non-isotopic and isotopic experiments, carbon inputs are modified and the temporal changes in SOC are measured (Larson et al., 1972). In the past, direct measurement has been underutilized, and many studies have reported the SOC at the end of the study and have failed to report the initial conditions. If the initial and final values are known, the SOC rate constants can be determined.

Determining rate constants is complicated by changes in method to measure SOC content. For example, samples collected in the 1950's could use a Walkley-Black analysis, while samples collected in 2010 could determine total C based on combustion at 1000^o C. To convert SOC values from one method to another, appropriate constant should be used. For example, soil organic matter can be converted to SOC by dividing by 1.72, and Walkley-Black C can be converted to SOC by multiplying Walkley-Black C by 1.34 (Clay et al., 2010). However, it should be noted that the conversion factors are sensitive to soil and revisions.

Soil organic C budgets can be based on the relational diagram shown in Figure 2. In this diagram, non-harvested crop residues (NHC) represent the annual additions of organic carbon added to soil. A portion of NHC is converted into soil organic carbon. The rate constants (k_{NHC} and k_{SOC}) represent the annual rate that carbon is transformed from NHC into SOC or SOC to CO_2. Based on the relational diagram, several equations can be defined. The first equation is $\delta SOC/\delta t = 0$ at the equilibrium point. For this equation, the amount of NHC (non-harvested C) transformed into SOC is equal to the amount of SOC transformed into CO_2. Mathematically this is expressed as,

$$k_{SOC} \bullet SOC_e = k_{NHC} \bullet NHC_m, \qquad [1]$$

where SOC_e is the amount of SOC at equilibrium, NHC_m is the non-harvested C maintenance requirement (the amount of crop residues that must be returned to maintain current SOC levels), and k_{SOC} and k_{NHC} are first order rate constants. The second equation is,

$$\frac{dSOC}{dt} = k_{NHC}\left[NHC_a - NHC_m\right], \qquad [2]$$

where NHC_a is the amount of non-harvested C applied. This equation can be rearranged into the form,

$$\frac{dSOC}{dt} = k_{NHC} NHC_a - k_{NHC} NHC_m. \qquad [3]$$

which is converted into a linear equation, y=mX – b, by defining $\frac{dSOC}{dt}$ as y, NHC_a as x, and k_{NHC} as m (Figure 3). This derivation provides the theoretical basis for Johnson et al. (2006), and shows that the y-intercept is the product of the non-harvested carbon first order mineralization rate constant (k_{NHC}) and the non-harvested carbon (NHC_m) maintenance requirement, whereas the slope is the non-harvested carbon rate constant (k_{NHC}). The maintenance requirement is calculated by dividing the y-intercept by the slope.

Clay et al. (2006) proposed an alternative approach were both k_{NHC} and k_{SOC} are calculated. The derivation of this approach is as follows. First, equations 1 and 2 were integrated into the equation, $NHC_a = NHC_m + (NHC_a - NHC_m)$, which resulted in,

$$\frac{NHC_a}{SOC_e} = \frac{k_{SOC}}{k_{NHC}} \bullet \frac{SOCe}{SOCe} + \left[\frac{dSOC}{dt} \bullet \frac{1}{k_{NHC} \bullet SOC_e}\right] \qquad [4]$$

This was accomplished by replacing (NHC_a – NHC_m) with $\frac{dSOC}{dt} \bullet \frac{1}{k_{NHC}}$ and NHC_m with $\frac{k_{soc}}{k_{NHC}} \bullet SOC_e$, and dividing both sides by SOC_e. After cancelling units, the equation

$$\frac{NHC_a}{SOC_e} = \frac{k_{SOC}}{k_{NHC}} + \frac{dSOC}{dt}\left[\frac{1}{k_{NHC} \bullet SOC_e}\right] \quad [5]$$

was derived. This equation was solved by defining SOC_i (initial SOC) as SOC_e, $\frac{NHC_a}{SOC_i}$ as y, and $\frac{d\mathrm{SOC}}{dt}$ as x. SOC_e was replaced with SOC_i because as time approaches infinity, SOC_i approaches SOC_e, and the assumption is that when the experiment was initiated SOC_i approached SOC_e. The resulting y-intercept is $\frac{k_{SOC}}{k_{NHC}}$ and the slope is $\frac{1}{k_{NHC} \bullet SOC_i}$. Based on these values, maintenance requirement and first order rate constants are determined with the equations,

$$NHC_m = b \bullet SOC_i \quad [6]$$

$$k_{NHC} = 1/(m \bullet SOC_i) \quad [7]$$

$$k_{SOC} = b/(m \bullet SOC_i) \quad [8]$$

The advantages of this solution are that site-specific rate constants are calculated which can be used to calculate the impact of management on carbon turnover (Clay et al., 2006). For example, based on equation [5], if $k_{SOC} = 0.011$, $k_{NHC} = 0.13$, and NHC = 4000 kg C (ha yr)$^{-1}$, then SOC_e is 47,300 kg C ha^{-1} [47,300 = (0.13/0.011)(4000)]. If NHC is reduced to 2000 kg C (ha yr)$^{-1}$ then SOC decreases to 23,600 kg ha^{-1}. The disadvantages with this approach are that it assumes that: 1) above and below ground biomass make equal contributions to SOC; 2) the amount of below ground biomass is known; 3) SOC is near the equilibrium point; and 4) the rate constants are constant. Based on this solution, rate constants were calculated for a large number of historical studies (Table 2).

SOC maintenance calculations are very sensitive to the root-to-shoot ratio (Figure 4), which are impacted by crop type. Johnson et al. (2006) used root to shoot ratios of 0.82, 0.55, and 0.62 for wheat (*Triticum aestivum*), corn, and soybean (*Glycine max*), respectively, whereas Amos and Walters (2006) reported that root to shoot ratios increased with N and P deficiencies and decreased with increasing water stress, population, shade, and soil compaction. Sensitivity analysis showed that the amount of corn stover that could be harvested increased with root to shoot ratio. If roots were not considered in the NHC value, then the estimated amount of above ground biomass that could be safely harvested was 35%, whereas if the root to shoot ratio was 1.00 then 70% of the above ground biomass could be harvested. These findings are attributed to a relative increase in importance of the below ground biomass. For accurate SOC maintenance estimates, NHC should be allocated to the appropriate soil zone and the relative importance of surface and subsurface NHC on SOC maintenance requires additional research

Drainage class, tile drainage, soil characteristics, tillage, and initial SOC levels can also impact SOC maintenance requirements (Arrouays and Pelissier, 1994; Zach et al., 2006; Clay et al., 2007). Tillage and installing tile drainage generally increases the SOC mineralization (West and Post, 2002; Clay et al., 2006, 2012). Landscape position

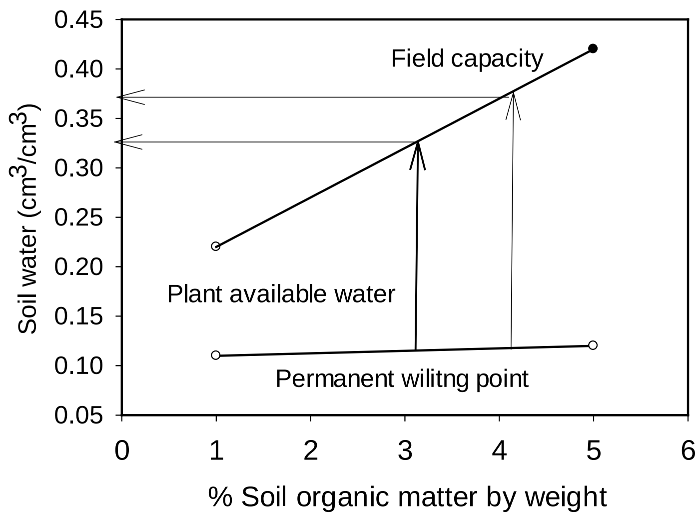


Figure 1. Relationship between soil carbon centent and plant available water for a silt loam soil (modified from http://soils.usda.gov/sqi/assessment/files/available_water_capacity_sq_physical_indicator_sheet.pdf).

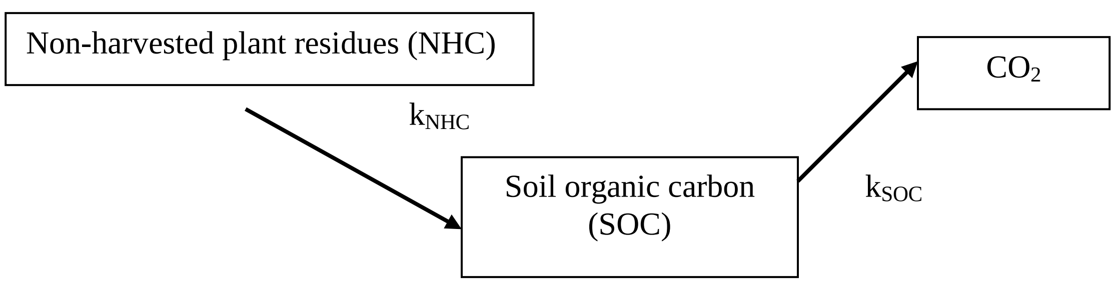


Figure 2. A relational diagram showing the relationship between three carbon pools and the associated rate constants.

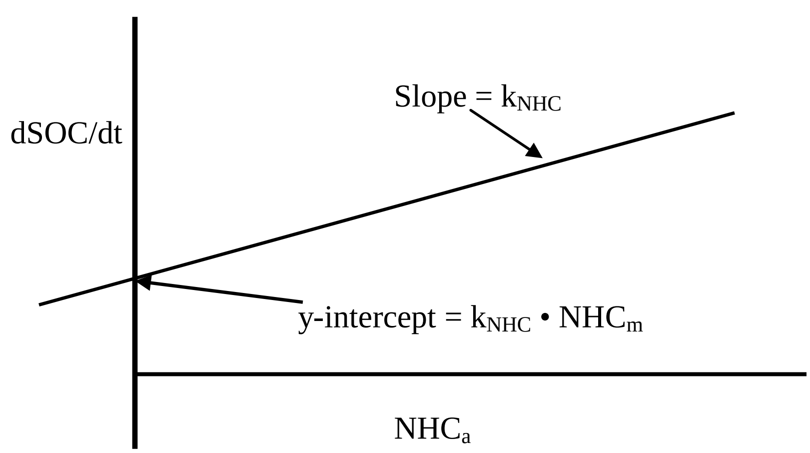


Figure 3. Graphical representation showing the relationship between the change in soil organic carbon with time (dsoc/dt) and amount of non-harvested carbon returned to soil.

also impacts carbon turnover by influencing the amount of carbon contained in the soil, soil water contents, productivity, and the relative age of the SOC (Campbell et al., 2005). Campbell et al. (2005) reported that in Colorado, soil organic C gains increased with cropping intensity and tended to be highest in the lowest evaporation sites. Others have reported that footslope areas may have higher turnover rates than summit shoulder areas (Campbell et al., 2005, Soon and Malhi, 2005; Clay et al., 2005). Landscape differences can result from two interrelated factors, higher soil water contents and larger SOC concentrations in footslope than summit/shoulder areas (Clay et al., 2001). In addition, C contained in summit/shoulder areas may be more resistant to mineralization than C from footslope areas (Clay et al., 2005, Figure 5). Similar contour maps can be developed for mineralized carbon and the amount of relic carbon remaining in the soil after mineralization. Based on these maps, the data can be aggregated into landscape positions (Table 3) and precision conservation management recommendations implemented.

Figure 4. Relationship between root to shoot ratio and the amount of above ground biomass that can be harvested and still maintain the SOC level at the current level.

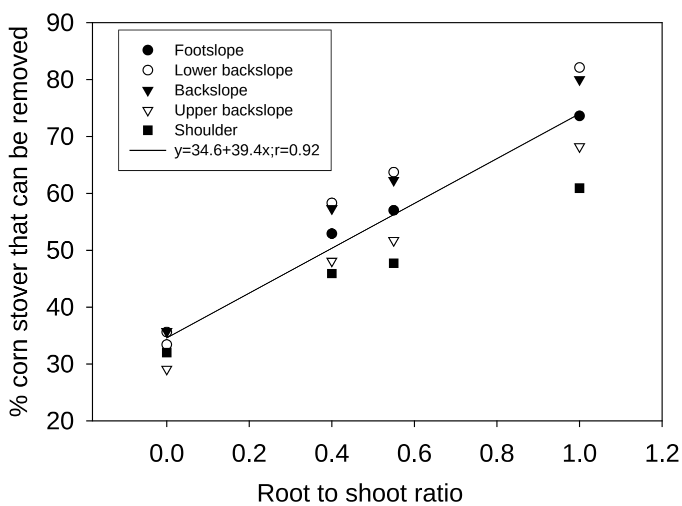
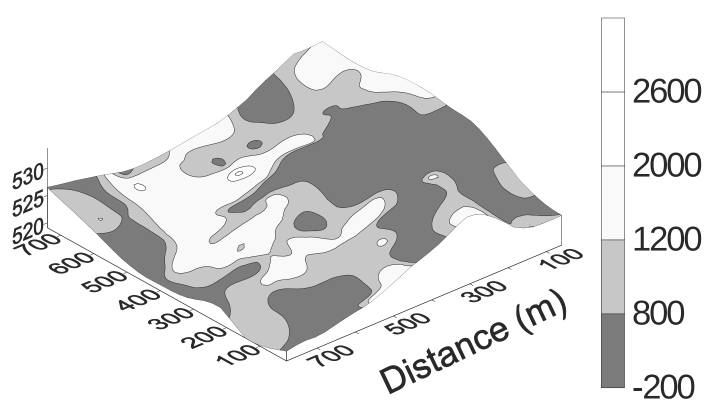


Figure 5. Landscape position influence on annual carbon additions from 1995 to 2003 (Clay et al., 2005).

Annual New C Incorporated (kg C $ha^{-1}yr^{-1}$)



Isotopic Source Tracking

A common technique for assessing C turnover in production fields is the ^{13}C natural abundance approach (Ågren et al., 1996; Balesdent and Mariotti, 1996; Follott et al., 1997; Nadelhoffer and Fry, 1988; Collins et al., 1999; Kuzyakov, 2001; Baisden et al., 2002; Ekblad et al., 2002; Fernandez and Cadisch, 2003; Griebler et al., 2004; Cheng et al., 2005; Böstrom et al., 2007, 2008). The ^{13}C isotopic approach is based on soil, C_4, and C_3 plants having different δ^{13}C signatures. The ^{13}C isotopic natural abundance C-budget approach can be used to determine the amount of NHC remaining in soil, SOC half-lives, and SOC turn-over because relic SOC and new plant material additions have different isotopic values. When making these calculations, it is important to consider that aboveground and belowground carbon inputs may have different isotopic signatures. For

Table 3. The influence of landscape position and ^{13}C fractionation on calculated half-lives of SOC at the Moody field (modified from Clay et al., 2007).

	^{13}C fraction considered	
Landscape position	No	Yes
	years	years
Footslope	49.8	89.1
Lower backslope	56.1	87.8
Backslope	113.1	232
Upper backslope	181	341
Shoulder/summit	78.9	151

Table 4. The potential impact of not considering ^{13}C fractionation during SOC mineralization on amount of relic carbon remaining in the soil and the incorporation of plant carbon (PCR) into the SOC. The soil contained at the end of the experiment contained 50,000 kg/ha.

	PCR	soil initial	soil final	SOC retained	PCR/ SOC	PCR incorporation	Relic carbon
	‰	‰	‰	‰	kg/ha	kg/ha	kg/ha
no-fract	-13	-16.50	-15.50	-16.25	0.29	14,286	35,714
fract	-13	-16.50	-15.50	-16.25	0.23	11,538	38,462

Table 5. The impact of landscape position on SOC and associated half life (modified from Clay et al., 2007). These values were calculated using the ^{13}C isotopic fractionation approach. The 523.4-527.3 m zone was the lower backslope while the 532.2-532.2 m zone was the shoulder area.

Elevation zone	SOC	Half-life	k
m	Mg/ha	years	g/(g year)
523.4-527.3	52.2	97.8	0.007087394
532.2-532.2	49.1	341	0.00203269

example, plant roots are often ^{13}C-enriched compared to plant leaves (Badeck et al., 2005, Bowling et al., 2008). Furthermore, mycorrhizal fungi are frequently ^{13}C-enriched compared to host plant leaves, probably because mycorrhizal fungi receive ^{13}C-enriched carbon from host plants (Böstrom et al., 2008).

An important benefit of the isotopic approach is that below ground biomass values are not required. The ^{13}C natural abundance isotopic carbon budget approach is based on C_3 plants having lower $\delta^{13}C$ value than C_4 plants (Ehleringer, 1991; Clay et al., 2006) and that the signatures can be tracked by placing C_3 plant residue into a soil derived from C_4 plants or visa versa. In these calculations, the delta ^{13}C value is calculated with the equation,

$$\delta^{13}C = [R(sample)/R(standard)-1] \times 1000‰ \qquad [9]$$

where, R(sample) is the ratio of ^{13}C and ^{12}C in the sample, and R(standard) is the ratio of ^{13}C and ^{12}C in a limestone fossil of *Belamnitella Americana* for the Cretaceous Pee Dee formation in South Carolina. This standard has been assigned the $\delta^{13}C$ value of 0‰ and has been reported to have an R value of 0.0112372 (Craig, 1957). Using mass balance relationships, the $\delta^{13}C$ values in a soil sample and total carbon in soil can be defined by the equations,

$$\delta^{13}C_{soil\ final} = \frac{\left[PCR_{incorp}\left(\delta^{13}C_{PCR}\right) + SOC_{retained}\left(\delta^{13}C_{SOC\ retained}\right)\right]}{\left(PCR_{incorp} + SOC_{retained}\right)} \qquad [10]$$

$$SOC_{final} = PCR_{incorp} + SOC_{retained}, \text{ and} \qquad [11]$$

$$SOC_{initial} = SOC_{retained} + SOC_{lost} \qquad [12]$$

In these equations, $SOC_{initial}$ was the SOC in the soil at the beginning of the experiment, SOC_{final} was SOC at the end of the study, $\delta^{13}C_{soil\ final}$ was the $\delta^{13}C$ value of SOC when the experiment was completed, PCR_{incorp} was the new plant carbon incorporated into SOC, $\delta^{13}C_{PCR}$ was the $\delta^{13}C$ value of the plant material retained in the soil after mineralization, $SOC_{retained}$ was the amount of relic C ($SOC_{initial}$) retained in the soil at the end of the study, and $\delta^{13}C_{SOC\ retained}$ was the associated $\delta^{13}C$ value. The equations,

$$SOC_{retained} = \frac{\left[SOC_{final}\left(\delta^{13}C_{soil\ final} - \delta^{13}C_{PCR}\right)\right]}{\left(\delta^{13}C_{SOC\ retained} - \delta^{13}C_{PCR}\right)}, \text{ and} \qquad [13]$$

$$PCR_{incorp} = \frac{SOC_{final}\left(\delta^{13}C_{soil\ final} - \delta^{13}C_{SOC\ retained}\right)}{\left(\delta^{13}C_{PCR} - \delta^{13}C_{SOC\ retained}\right)} \quad [14]$$

were derived by simultaneously solving these equations. Equations 13 and 14 have been modified by making a variety of assumption. The first assumption is that ^{13}C fractionation during SOC and PCR mineralization is minimal, i.e., $\delta^{13}C_{\text{SOC retained}} = \delta^{13}C_{\text{soil initial}}$ and $\delta^{13}C_{\text{PCR}} = \delta^{13}C_{\text{plant}}$. Based on these assumption, the equation

$$PCR_{incorp} = \frac{SOC_{final}\left(\delta^{13}C_{soil\ final} - \delta^{13}C_{soil\ initial}\right)}{\left(\delta^{13}C_{plant} - \delta^{13}C_{soil\ initial}\right)} \quad [15]$$

was derived. Solving equation 15 required that soil and plant material be collected at time zero ($\delta^{13}C_{\text{soil initial}}$ and $\delta^{13}C_{\text{plant}}$) and at the end of the experiment (SOC_{final} and $\delta^{13}C_{\text{soil final}}$). Equation 15 can be reorganized into,

$$\frac{PCR_{incorp}}{SOC_{final}} = \frac{\left(\delta^{13}C_{soil\ final} - \delta^{13}C_{soil\ initial}\right)}{\left(\delta^{13}C_{plant} - \delta^{13}C_{soil\ initial}\right)} \quad [16]$$

Equation 16 can be modified by replacing $\delta^{13}C_{\text{soil initial}}$ with δ_{c3}, $\delta^{13}C_{\text{plant}}$ with δc_4, and $\delta^{13}C_{\text{soil final.}}$ Based on these modifications the equations,

$$p = \frac{\delta - \delta_{c3}}{\delta_{c4} - \delta_{c3}} \quad [17]$$

$$\delta = p\ \delta_{c4} - (1\text{-}p)\ \delta_{c3} \quad [18]$$

reported by Wolf et al. (1994) were derived. The p and δ equations are based on the assumption that ^{13}C discrimination during SOC and non-harvested biomass mineralization is minimal. Extreme care must be used when using equations 16, 17, and 18 because they assume that ^{13}C fractionation during SOC and PCR mineralization is insignificant (Stout et al., 1981; Ehleringer et al., 2000; Clay et al., 2007). Research has shown that these assumptions can produce large errors (Clay et al., 2007, 2008). This error increases with the length of the experiment, and is the result of biological processes discriminating against the ^{13}C isotope.

The assumption of ^{13}C fractionation in fresh biomass may be appropriate. Boutton (1996) stated that, "Direct measurements indicate that the $\delta^{13}C_{PDB}$ of plant tissue remains relatively constant during the early stages of decomposition (1-7 years)." The apparent lack of ^{13}C enrichment during the early stages of non-harvested biomass mineralization may result from two independent processes cancelling each other out. The first factor is that many SOC consumers tend to accumulate ^{13}C. The second factor is that resistant materials (waxes and lignin) tend to be depleted in ^{13}C (Lichtfouse et al., 1995; Boutton, 1996; Huang et al., 1999; Conte et al., 2003).

If ^{13}C fractionation during SOC mineralization occurs, not accounting for fractionation when C_4 plant materials are added to soil can result in over-estimating the importance of C_4 plant material and underestimating the half life of the relic carbon. For C_3 plants, the reverse was true. There are three approaches to account for ^{13}C isotopic fractionation. The first approach is to use a model such as Century to calculate the amount of fractionation (http://nrel.colostate.edu/projects/century5/reference/html/Century/labeled-C.htm).

The second approach is to include no-plant control areas where the fractionation is measured and ultimately integrated into the calculations. The third approach is to estimate fractionation based on previously measured values (Clay et al., 2006). ^{13}C fractionation during SOC mineralization can be integrated into equations 13 and 14 using the equation,

$$\delta^{13}C_{SOC\ retained} = \delta^{13}C_{soil\ initial} + \varepsilon_{SOC} \bullet \ln(SOC_{retained} / SOC_{initial}) \qquad [19]$$

where, ε_{SOC} was the Rayleigh fractionation constant for the relic SOC. If fractionation occurs during fresh biomass mineralization, a similar equation can be used. The Rayleigh fractionation constant of the soil organic carbon (ε_{SOC}) is calculated from plots where plant growth is prevented. This equation has been used to explain ^{13}C fractionation in a variety of systems (Balesdent and Mariotti, 1996; Accoe et al., 2002; Fukada et al., 2003; Spence et al., 2005; Wynn et al., 2005). Once ^{13}C isotopic fractionation is determined, carbon budgets are determined by using Equation 19 to calculate $\delta^{13}C_{SOC\ retained}$ which is then used to calculate plant C remaining (PCR) in the soil (Equation 15).

Table 5. The influence of landscape position and ^{13}C fractionation on calculated half-lives of SOC at the Moody field (modified from Clay et al., 2007).

	^{13}C fraction considered	
Landscape position	No	Yes
	years	years
Footslope	49.8	89.1
Lower backslope	56.1	87.8
Backslope	113.1	232
Upper backslope	181	341
Shoulder/summit	78.9	151

After the temporal changes in the size of different soil organic C components are determined, the first order rate constant (k), half-life, and mean residence time can be calculated using the equations,

$$k = -\frac{\ln\left(SOC_{remaining} / SOC_{initial}\right)}{number\ of\ \ years} \qquad [20]$$

$$t_{half-life} = -\frac{\ln(2)}{k} \qquad [21]$$

$$\text{Mean residence time} = \frac{1}{k} \qquad [22]$$

It is important to remember that assuming that isotopic fractionation does not occur can result in large errors in the calculated amount of plant carbon retained in the soil (PCR) and the amount of relic carbon retained in the soil (Table 5, 6).

Matching Residue harvesting to SOC Maintenance Requirements

Carbon budget information can be used to predict the impact of a range of management practices, including precision conservation on soil health. Precision conservation can be used to improve soil health because SOC has high spatial dependency. Across the United States crop residues are being harvested for either livestock feed or bedding. In addition to these uses, crop residues can be harvested for ethanol production or fuel. The wide scale harvesting of crop residues, for whatever purpose, can have detrimental impact on soil health and result in increased erosion (Delgado and Berry, 2008; Cruse and Herndl, 2009; Peterson and Westfall, 1997). Crop residue protects the soil by increasing water infiltration and aggregate stability, while reducing erosion. The impact of residue removal on soil productivity and erosion is related to many factors including soil erodibility, slope, and landscape position (Thomas et al., 2011; Meki et al., 2011). Predicting the impact of any specific management practice on erosion and carbon sequestration is complicated by spatial variability.

In many fields, SOC has high spatial dependency with shoulder soils contain less SOC than lower footslope soils (Ritchie et al., 2007). SOC patterns can be produced by differential erosion, different amounts of carbon returned to the soil annually, management, and differential mineralization rates (Ritchie et al., 2007). For example, Clay et al. (2006, 2007) reported that in a South Dakota field soils in the lower backslope position (523.4-527.3 m) has higher SOC and shorter SOC half live than soil from the summit area (Table 5). Differences between the landscape positions were attributed to drainage that was installed in the footslope area and a lower SOC mineralization rate constant in shoulder than lower backslope soils.

Similar results were reported by Clay et al. (2011) for long-term studies conducted in Colorado (Sherrod et al., 2003). At Stratton, soil from the summit had a half life of 26.8 years, while SOC from the footslope had a half life of 20.1 years. Differences in SOC contents and k values resulted in higher maintenance requirements in the toeslope (2,597 kg/(ha year)) than the summit [1,373 kg/(ha year)]. Landscape differences in SOC and mineralization rates complicate the development of sustainable management plans across watersheds and suggest that the SOC maintenance requirement is higher in footslope than lower backslope areas. We believe that to improve sustainability both erosion and SOC maintenance must be considered. In many fields, this means that the SOC level from soil with a high erosion risk must be increased. This is accomplished by apply more NHC than the SOC maintenance requirement.

Example 1 Estimating Carbon Turn-over

The rate of SOC increase can be estimated by measuring the current SOC level and making several assumptions. For example, if SOC is 25 Mg ha^{-1} and k_{SOC} is 0.02 g (g SOC· $year)^{-1}$ and k_{NHC} is 0.2 g (g SOC· $year)^{-1}$, and the amount of non-harvested carbon returned to the field annually is 5,000 kg ha^{-1}, then 500 kg C [(5,000·0.2) – (25,000·0.02)]will be added to the SOC. Applying less NHC than the maintenance requirement results in decrease in SOC.

Example 2 Using Precision Conservation to Maintain SOC

Prior research has shown that landscape position influenced SOC turn over. In this example, calculate SOC maintenance for shoulder and lower backslope positions based on the following data. The maintenance requirement can be calculated with the equation, NHC_m = (SOC)×(k_{SOC} / k_{NHC}).

	Shoulder	Lower backslope
k_{SOC}	0.014 g (g×year)$^{-1}$	0.017 g (g ×year)
k_{NHC}	0.20 g (g×year)$^{-1}$	0.20 g (g×year)$^{-1}$
SOC	20,000 kg SOC ha^{-1}	25,000 kg SOC ha^{-1}
$SO_{maintenance}$	=20,000×(0.014/0.2)=1,400	=25,000×(0.017/0.20)=2,125

These calculations suggest that the maintenance requirements for the two landscape positions are different. However, this calculation does not consider the importance of increasing SOC in the shoulder area. The failure to protect the soil surface and maintain the SOC can produce severe consequences.

Summary

Even though sensitivity analysis of carbon budget maintenance equations shows that below ground biomass estimates influence SOC maintenance rate calculations, most experiments do a poor job of estimating below ground biomass. The minimum data required to estimate SOC maintenance requirements is $SOC_{initial}$, SOC_{final}, and the amount of non-harvested carbon returned to the soil during the study period. This minimum data set is not available for most studies. Below ground biomass is generally estimated using root to shoot ratios. The impact of the root to shoot ratios on calculated maintenance requirements is important because root to shoot ratios are highly variable and almost always underestimate below ground biomass. Amos and Walters (2006) reported that the net below ground C deposition in corn at physiological maturity was 29 ±13% of the shoot biomass (leaves, stems, husks) in 41 studies. The use of these values is further complicated by the use of different definitions for root to shoot ratio. Converting Amos and Walters (2006) units to units used by Johnson et al. (2006) would reduce the reported values from 0.29 to 0.15 (harvest index 50%).

For ^{13}C isotopic approaches accurate measurements of ^{13}C fractionation in the bulk soil are needed. ^{13}C isotopic discrimination can be measured in no-plant control areas. These plots are used to measure ^{13}C enrichment of the relic carbon during the experimental timeframe. Once the carbon budgets and rate constants are known, this information can combined in measured spatial variability to estimate the impact of precision conservation on changes in SOC.

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Chapter 2: Global food security through enhanced resilience of northern Great Plains soils.

David Clay, Sharon Clay, Kurt Reitsma, Barry Dunn, Gregg Carlson, David Horvath, Daniel Clay, and James Stone

The adoption of non-sustainable row crop production practices in US Great Plains produced extensive erosion and a loss of productivity during the 1930's. U.S. Great Plains farmers partially solved this problem by converting eroded croplands back to grasslands, integrating cover crops into their rotations, and by adopting more sustainable row crop production practices. High grain prices are providing an economic incentive to increase crop production by converting grasslands in semi-arid regions to row crop production. The objective of this paper was to discuss the sustainability of increasing maize and soybean production in the northern Great Plains semi-arid environment. This was accomplished by determining regional changes in the northern Great Plains crop production practices and the impact of these practices on crop productivity, soil organic C, and erosion. Analysis showed that: 1) in South Dakota from 1974 to 2012 there was a 2.6 M ha increase in the amount of land seeded to corn and soybean and a decreases in the amount of land seeded to wheat, minor crops, hayland, pasture, and native prairie; 2) across the Great Plains, maize (*Zea mays*) water use efficiency increased at a rate of 0.23 kg grain $(ha \times cm \times year)^{-1}$ while in South Dakota a wide scale adoption of reduced and no-tillage systems which when combined with higher yields resulted in a 24% increase in surface soil organic C (SOC) from 1985 to 2010 and a 34% decrease in erosion (wind, rill, and sheet) from 1982 to 2007; and 3) maize, soybean (*Glycine max*), and wheat (Triticum *aestivum*) profitability has improved and in 2012 the return for investment was 1.24, 1.34, and 1.07, respectively. In two drought years with similar rainfalls (28.2 cm), maize (+4.3 Mg ha^{-1}), soybean (+0.67 Mg ha^{-1}), and wheat (+1.84 Mg ha^{-1}) yields increased from 1974 to 2012. For maize, soybean, and wheat 22, 61, and 41% of the yield increases, respectively, were attributed to increased available water resulting from improved soil management. Regional assessments of SOC and erosion suggest that in spite increasing crop production in this semi-arid environment that contains many fragile lands, the soil resistance and resilience to extreme events has improved . However, even with genetic and management enhancements, the conversion of grasslands to croplands contains risks in semi-arid areas containing high climate variability. Worldwide, targeted research should be conducted to identify the long-term ramification on landuse changes on fragile soils located in semi-arid regions.

Abbreviations: non-harvested carbon (NHC); soil organic carbon (SOC);

1. Introduction

The conversion of grasslands to croplands have been reported at numerous semi-arid locations including the United States northern Great Plains (Wright and Wimberly, 2013), Africa (Maitima et al., 2009), Argentina, and Uruguay (Vega et al., 2009). This conversion is driven by high grain prices and equipment and genetics improvements. Under normal climatic conditions, the conversion of grassland to row crop production might be sustainable; however, extreme climatic events might be the tipping point that converts an apparent sustainable system to a non-sustainable system. Evidence for a non-sustainable system include yield reductions, a decrease in soil organic C, and increased erosion.

2. A brief history of sustainability

Non-sustainable management practices such as the use of practices that gradually increase soil salinity or increase erosion can produce a long-term gradual decline in soil resilience and productivity. Extreme events such as drought, flooding, fires, and pest population explosions can provide the tipping point that converts a gradual decline to a rapid decline in productivity. Over the long-term, gradual and rapid declines in resilience are serious and can produce cataclysmic results. For example, people between the Tigris and Euphrates rivers in the Middle East domesticated hogs (*Sus scrofa),* cattle (*Bos taurus*), emmer wheat (*Triticum dicoccoides),* and wild barley (Hordeum vulgare), and developed irrigation systems about 7000 years ago. The development of these technologies resulted in the development of city states of Eridu, Nippur, Lagash, Kish, and Ur. However, soils in this region were poorly drained, which when irrigated, resulted in a gradual accumulation of salts. In response to salinization, the amount of land seeded to barley, which is salt tolerant increased, whereas the amount of land seeded to wheat, which has lower salt tolerance, gradually decreased. The impact of gradual yield declines on food production was partially solved by abandoning saline soils and bringing new fields into production. Eventually, this solution diminished their ability to produce food required by their civilization (http://archive.unu.edu/unupress/unupbooks/80858e/80858E04.htm).

Rapid catastrophic failure occurred during the U.S. Dust Bowl in the Great Plains during the 1930s. At the time, the farmers used extensive tillage to prepare a seed bed and control weeds. These practices reduced the soil resilience by harvesting more nutrients than what was returned, as well as reducing SOC and aggregate stability. These practices when combined with drought, high winds, and limited ground cover resulted in severe wind erosion and in many cases crop failure. This failure is attributed a a multi-year drought that change a gradual loss of productivity to a catastrophic event. Farm mechanization that occurred in the United States after 1890 allowed for easy plowing, which when combined with high grain prices during World War 1, and federal policies that required breaking the sod led to widescale seeding wheat into the Great Plains prairies. Important lessons from the Tigris and Euphrates rivers in the Middle East and the United States Great Plains were that soil and crop failure can occur many years after the new technology is adopted. Slow changes in soil properties that diminish its ability to grow crops or unforeseen climatic events can provide tipping points that converts a sustainable system to a non-sustainable system.

In many situations, new technologies can convert a non-sustainable system to a sustainable system. Indications that the sustainability has improved might include increased productivity, improved soil health, reduced erosion more nutrients returned than removed, and reduced pest pressure. There are many different techniques that can be used to increase long-term sustainability. The Incan Empire on the Peruvian coast in South America used a multi-step process that included: 1) increasing crop diversity by domesticating many plants including maize, squash (*Cucurbita),* beans (*Phaseolus vulgaris*) and other plants; 2) reducing erosion by installing terraces at highly erodible sites; 3) and using waru waru to lengthen the growing season. The integration of these technologies allowed the Incas to thrive in watersheds containing highly erodible soils and extreme climatic variability (Mamani-Pati et al., 2011). In addition, the Incas trained experts (agronomists) who worked with local communities to improve crop productivity. Today, the indigenous peoples of this region are rediscovering and putting these traditional solutions back into practice.

A second example of a sustainable farming technology was associated with increased agricultural intensification and improved nutrient budgets. During the European middle ages (1500 to 700 years ago) many farmers used a 3-year sequence consisting of a cereal (oats, Avena sativa; rye, Secale cereale; wheat*;* and barley), a legume (peas, Pisum sativum*;* and beans), and fallow (Knox, 2004). In many areas, fallow was used to rest the soil every other year. The productivity of this system was low and it provided little feed for livestock other than oxen, which were used to plow the fields. . The manure from the oxen was generally applied to gardens, which resulted in a negative nutrient balance in many fields. In the 1700's, the Viscount Charles "Turnip" Townshend proposed that crop rotations be changed from a 3 year sequence to a 4-year rotation that included wheat, barley, turnips (*Brassica rapa*) and ryegrass (Lolium *multiflorum*) or clover (Trifolium*)*. This rotation eliminated fallow and provided forages (turnips, clover and ryegrass) for grazing by livestock. This change improved nutrient recycling, increased the amount of land devoted to food production by 33%, and increased yields. The net result was that from 1750 to 1860 wheat yields were increased 68%, pulse yields (annual leguminous crop) were increased 44% higher pulse . In addition, stocking densities for milk cows, sheep, and swine increased 46, 25, and 43%, respectively (Broadberry et al., 2010). This rotational change: 1) powered the Industrial Revolution, 2) provided resources that grew the English population from 5.7 million in 1750 to 16.6 million people in 1850, and 3) provided the theoretical basis for the organic agricultural industry today. In conventional agriculture, the importance of this rotational sequence was reduced in the 1950's by the wide scale availability of inexpensive N fertilizer. The lessons learned from Europe and South America showed that long-term sustainability and productivity can be improved by controlling soil loss and improving nutrient budgets.

In the Great Plains, two technologies, equipment and genetic improvements have and are changing agriculture (Fig. 1; Marra et al., 2004; Clay et al., 2012). To explore linkages between these technologies, a better understanding of each technology is needed (Tripplet and Dick, 2008). Civilization, as we know it, required the development of efficient techniques to plant seeds and control weeds. Over 10,000 years ago ancient Babylonians used simple tools to place and cover seeds**.** Over time, seeding and seedbed preparation techniques were slowly improved. The introduction of the moldboard plow in England during the 18th century revolutionized farming by decreasing the time and labor needed for seedbed preparation and increasing the amount of land a grower could farm. This technology resulted in both positive and negative impacts on crop production and the environment. In the 1950's other equipment, such as plows, disk-harrow, and cultivators, were widely used to create seedbeds and control weeds. A disadvantage with using plow-type technology is that it can increase wind and water erosion. Recently, improvements in no-till drills make it feasible to skip tillage completely.

Plant genetics improvements have been accelerated by the use molecular biology. Molecular biological techniques provide the ability speed up the breeding process (marker assisted selection) and transfer genes from plants or other organisms to the target organism. The results to-date include plants that have increased drought and pest resistance, as well as the production of plants resistant to nonselective herbicides (e.g. glyphosate) that allowed for easier weed control. Linkage between better planters and improved genetics has made many tillage practices unnecessary (Marra et al., 2004). Benefits from reduced tillage are reduced erosion, reduced water loss through evaporation, and improved soil health. However, since these benefits are slowly realized, in most cases, numerous demonstrations and careful research are needed to further new practice acceptance. The adoption of new technologies are dependent on: 1) management and labor requirements; 2) expected return on investment ; 3) management flexibility; 4) few or easily overcome management and production barriers; 5) the ease of integrating the new technology into current production systems (Carpenter, 2010; Fernandez-Cornejo and Casewell, 2006); and 6) synergistic relationships among the proposed practices (ASA 2001; Brookes and Barfoot, 2011; Frisvold et al., 2007; Givens et al., 2009; Mensah, 2007a, 2007b; Pekrun et al., 2005; Young, 2006).

In addition to equipment and genetic improvements, farming system profitability has changed. For example, from 1974 to 2012 the return for investment ratios for major grain crop increased and in 2012 the total gross value/total costs ratio for maize, soybeans, and wheat were 1.24, 1.34, and 1.07, respectively (http://www.ers.usda.gov/data-products/commodity-costs-and-returns.aspx). These increases were driven by higher yields and selling prices. On many farms, economic considerations have a major impact when deciding what to seed, and the lower return for investment ratio for wheat than corn or soybeans may be responsible for an annual decline in the amount of land [175,000 $(\text{ha} \times \text{year})^{-1}$] seeded to wheat between 1974 and 2012 in Nebraska, South Dakota, and North Dakota. The long-term ramification replacing wheat with maize and soybean in northern Great Plains rotations is unknown.

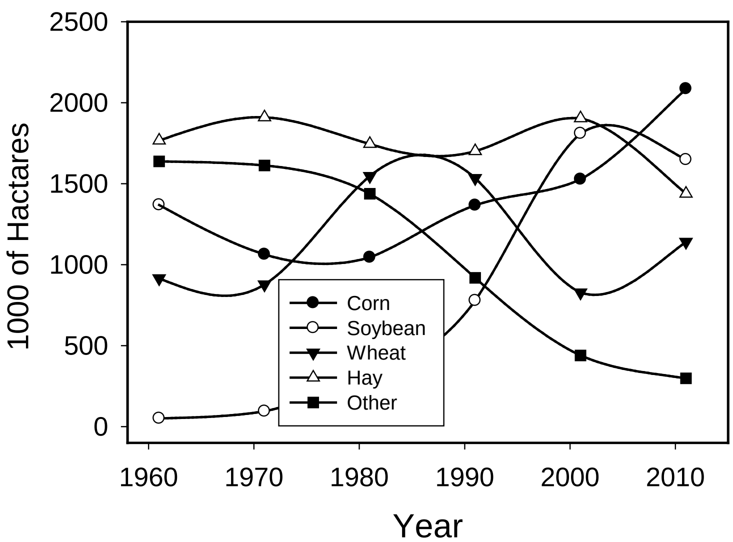

Figure 1. The change in acres seeded to corn, soybean, wheat, hay, and other crops in South Dakota from 1960 to 2010 (NASS 2000, 1985-2012).

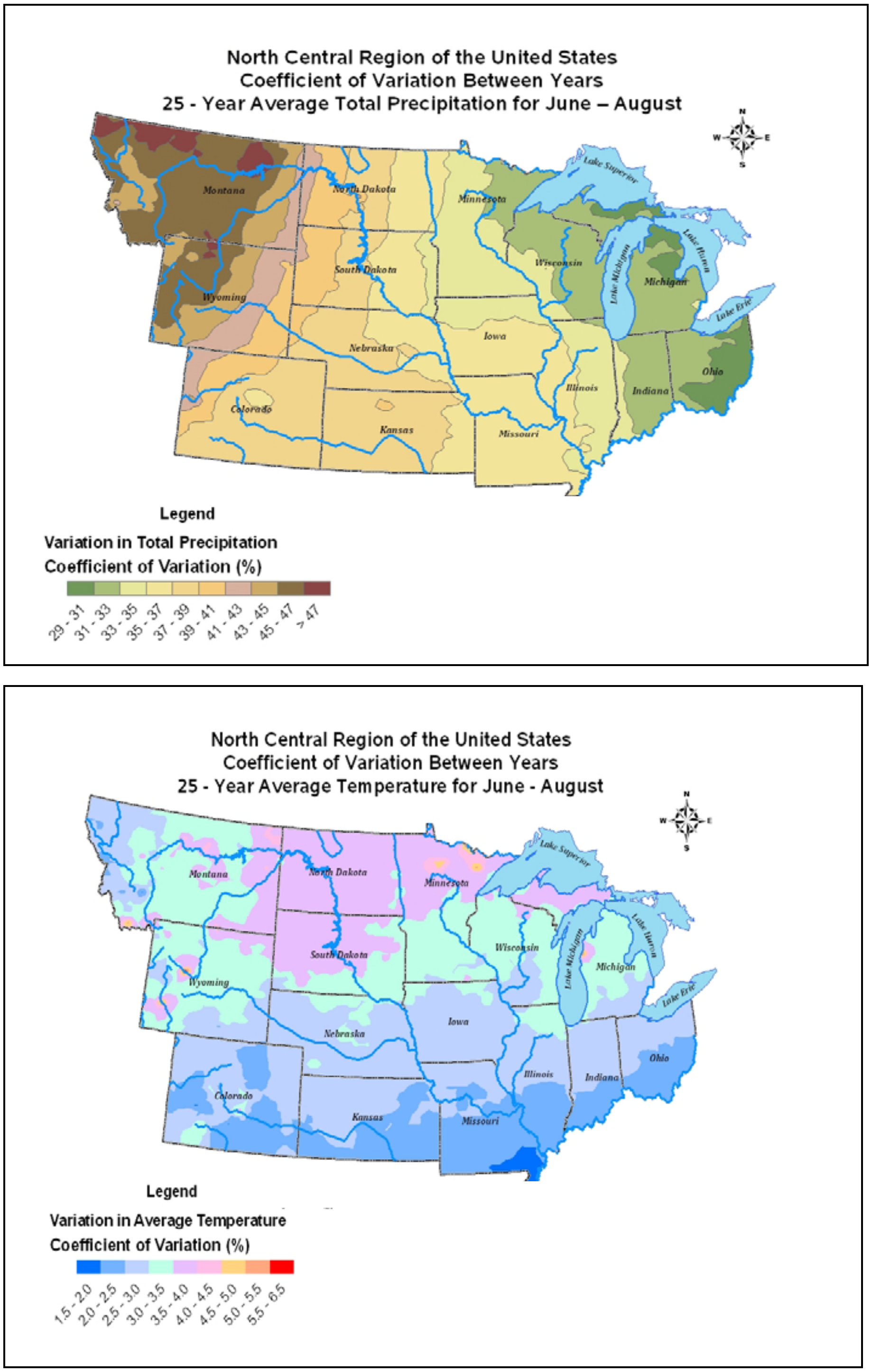

Figure 2. The 25 year precipitation (a) and temperature (b) coefficient of variation for the north central region of the United States. These maps are based on data collected from 1640 weather stations between 1982 and 2006. The data source was the U.S .National Weather Service.

3. Assessing agricultural system resilience against extreme climatic events

The northern Great Plains is a semi-arid area of the United States containing high climate variability (Fig. 1). In this region, farmers are routinely challenged by droughts, frosts, floods, high wind, and hail. In spite of these difficulties, the percentage of land seeded to corn and soybeans have increased in South Dakota while land seeded to hay, wheat, and other crops declined (Fig. 2). Landuse changes can impact yields, soil organic C, erosion, and long-term sustainability. In addition, extreme climatic events can convert an apparently sustainable practice to a non-sustainable practice. To assess the regional sustainability of management and landuse changes a series of assessments were conducted. These regional assessments considered yields and economic returns, soil health (SOC), tillage changes, and erosion. The lessons learned in the northern Great Plains are applicable to semi-arid regions worldwide.

Table 1. A comparison between rainfall and corn, wheat and soybean yields in 1974 and 2012 (NASS, 1973, 1974, 2011, 2012; http://www.ncdc.noaa.gov/temp-and-precip/time-series/index.php?parameter=hdd&month=11&year=2012&filter=7&state=39&div=0). A Palmer Drought Severity of -2 is characterized as a moderate drought and a -4 value is extreme drought. The South Dakota heating degree days was calculated using a base 18.3^{o}C.

Year	SD Palmer Drought Severity	SD Heating degree day	Eastern SD Rainfall	all wheat	Soybean	Corn
		C	cm	kg/ha	kg/ha	kg/ha
1974	-2.18	1091	28.2	1234	1341	2065
2012	-3.35	1048	28.2	3071	2012	6321
2012-1974			0	1837	671	4256

Table 2. The amount of South Dakota land seeded to corn, soybean, and wheat in 1974 and 2012. The table also provides selling prices, state yields, and increased income (based on 2012 selling prices) from higher yields.

	Harvested		Selling price		Yields		Return		$ return in 2012 from higher yield
Crop	1974	2012	1974	2012	1974	2012	1974	2012	
	ha×1000	ha×1000	$/Mg	$/Mg	Mg/ha	Mg/ha	$/ha	$/ha	$/ha
Corn	943	2,145	135	277	2.07	6.34	279.45	1756.18	1,183
Soybean	149	1,906	269	518	1.35	2.02	363.15	1046.36	347
Wheat	1,252	904	179	302	1.24	3.08	221.96	930.16	556
Total	2,344	4,955							

3.1 Comparing yields with similar droughts

In the first assessment, yields in years with similar droughts were compared. Yield is an important criterion because it integrates climate, management and genetic changes . South Dakota yields and economics from 1974 and 2012 were selected because the annual rainfall and heat units in 1974 and 2012 were similar (Table 1). Over this time period, South Dakota maize yields increased by 4.26 Mg grain ha^{-1} whereas soybean and wheat yields increased by 0.671 and 1.84 Mg grain ha^{-1}, respectively. Based on the 2012 crop selling prices the net impact of higher maize, soybean, and wheat yields was $1,183, 347, and 556 per hectare (Table 2). These yield increases were attributed to the implementation of locally-based adaptive management practices that leveraged genetic improvements with crop and soil management practices.

3.2 Changes in soil organic C

In the second assessment, changes in soil organic carbon (SOC) and plant available water were compared. Soil carbon is important because it is related to soil water holding capacity, nutrient cycling, biological activity, and yield potential (Fig. 3; Cardwell, 1982). For this comparison, a benchmark is needed. One study that developed soil C benchmarks for South Dakota was Clay et al. (2012). This study used 34,704 production surveys and 95,214 producer composite soil samples collected and analyzed for soil C from 1985 to 2010. During this time period, surface soil organic C (SOC) levels increased 24% (Clay et al., 2012). This increase was attributed to a gradual increase in the amounts of non-harvested C returned to soil and increased use of reduced tillage systems.

SOC is directly related to plant available water. Plant available water, represents the maximum amount of water that can be extracted from a soil, and it is the difference between the amount of water held at the permanent wilting point (-1500 kPa) and field capacity (-33 kPa). Based on Figure 3, the 24% increase in SOC should increase plant available water 0.61 cm $\{15cm\times[(0.39-0.142)-(0.34-0.134)]\}$ in the surface 15 cm . This comparisionsuggests that from 1974 to 2012, soil resilience and drought tolerance improved.

3.3 Management changes

In the third assessment, changes in tillage were compared. From 1974 to 2010 many South Dakota farmers switched from clean tillage to no-tillage (Clay et al., 2012). In clean tillage little residue is left on the soil surface, while in no-tillage most of the residue is left on the soil surface. Similar changes occurred in North Dakota and Nebraska (Hansen et al., 2012). Associated with this change, was a decrease in the amount water lost to evaporation and runoff (Smika, 1983; Hatfield et al., 2000; Pryor, 2006; Su et al., 2007; Triplett and Dick, 2008; Salado-Navarro and Sinclair, 2009; Klocke et al., 2009; Baumhardt et al., 2010; Mitchell et al., 2012). Based on Pryor (2006) a South Dakota water savings resulting from a reduction in evaporation was estimated with the equation, δ(soil water, cm) = 1.3 (cm/tillage pass)×(δ in # of tillage passes) (Tables 3 and 4). Based on this equation, it was estimated that annual evaporation decreased 5.2 and 2.6 cm in the no-tillage and reduced tillage systems, respectively. The combined impact of reduced evaporation and increased plant available water was highest in the is South-central (SC) region (Table 3).

Table 3. The impact of SD NASS region on no-tillage adoption and estimated increase in plant available water (Clay et al., 2012). The no-tillage estimates are based on 34,704 production surveys.

SD NASS region	No-tillage 2004-2007	No-tillage 2008-2010	No-tillage 2004-2010	Water increase in the surface 15 cm: No-till	Con. till	SOC	Total
	% adoption			cm	cm	cm	cm
NC	97	69	85	4.42	0.39	0.61	5.42
C	68	57	63	3.28	0.96	0.61	4.85
NE	20	11	16	0.83	2.18	0.61	3.63
EC	11	5	8	0.42	2.39	0.61	3.42
SE	29	33	31	1.61	1.79	0.61	4.02
NW	40	ns	nc	2.08	1.56	0.61	4.25
SC	88	ns	nc	4.58	0.31	0.61	5.50
CW	82	ns	nc	4.26	0.47	0.61	5.34
Ave.	54	35	41				4.55

ns the sample did not contain adequate samples and nc is not calculated.

Table 4. The impact of increased plant available water on net economic return for corn, soybean, and wheat grown in South Dakota in 2012 (NASS, 2012). The selling prices for maize, soybean, and wheat was \$277/Mg, \$518/Mg, and \$302/Mg, respectively. The water use efficiency for maize, soybean, and wheat was 217 kg of grain $(cm\times ha)^{-1}$, 95.1 $(cm\times ha)^{-1}$, and 302 $(cm\times ha)^{-1}$, respectively.

NASS Region	Water increase	Harvested maize	Harvested soybean	Harvested wheat	Total yield maize	Total yield soybean	Total yield wheat	$ return due to man
	cm	ha	ha	ha	Mg	Mg	Mg	$
NC	5.42	487,647	450,011	137,593	573,541	231,955	114,846	314,079,090
C	4.85	348,435	240,384	145,930	366,710	110,873	108,995	192,165,957
NE	3.63	368,265	373,121	53,580	290,086	128,806	29,953	156,307,287
EC	3.42	403,836	397,402	5,220	299,703	129,252	2,750	150,989,862
SE	4.02	372,311	397,402	29,927	324,782	151,928	18,527	174,465,985
NW	4.25	81,625	2,023	114,041	75,279	818	74,640	43,869,379
SC	5.50	73,936	34,317	99,229	88,243	17,950	84,047	59,185,895
WC	5.34	61,148	0	56,575	70,857	0	46,525	33,724,833
Total		2,197,204	1,894,660	642,095	2,089,201	771,581	480,282	1,124,788,289

An additional water savings resulted from increased plant available water (Clay et al., 2012). For South Dakota, total water savings from reduced evaporation and increased plant available water was calculated (Table 3). Yield increases from improved soil management were determined by multiplying water savings by the water use efficiency values for maize (Kim et al., 2008), soybeans (Monsanto Company, 2010), and wheat (Kharel et al., 2011). These calculations suggest that increases in plant available water derived from improved management could account for 22, 63, and 36% of the maize, soybean, and wheat yield increases from 1974 to 2012, respectively. State wide, improved soil management had a 1.1 billion dollar impact on net agricultural returns in 2012 (Table 4). These findings are conceptually in agreement with Norwood (1999).

3.4 Changes in erosion

In the forth assessment, changes in management and soil erosion in Nebraska, South Dakota, and North Dakota were compared (Table 5). From 1982 to 2007 the amount of developed land gradually increased while the amount of cropland, range land, and pasture gradually decreased in South Dakota, North Dakota, and Nebraska (NRCS, 2007). In addition, wind, sheet, and rill erosion decreased 25% over this time period. Erosion decreases are attributed to a reduction in tillage intensity and higher SOC contents. Of these three states, the erosion reductions were highest in South Dakota (34%) and lowest in North Dakota (20%). The wind + sheet and rill erosion reduction was 23% in Nebraska. These data suggest that in the northern Great Plains yields have increased while erosion has decreased. In fact the opposite results were observed. Extreme caution must be used in extending these findings to the local level because land-use changes are likely to occur first in highly productive soils (land capability classes 1, 2, and 3) and then proceed to less productive sites (land capability class 4, 5, 6, and 7).

4. Potential for further yield increases

High maize and soybean grain prices and improved tillage practices and better genetics are driving landuse changes in the northern Great Plains. A rarely discussed component of this question is, are their opportunities to further increase maize, soybean, and wheat yields using current genetics and management? If further genetic or management improvements are probable, then it is likely that increases in land devoted to maize and soybean production will continue to increase.

4.1 Identifying yield benchmarks

To assess this question accurate benchmarks are needed. Over the past 40 years, maize hybrids and soybean and wheat cultivars have been tested in South Dakota crop testing program. This database shows that maize (Fig. 4) and soybean (data not shown) have increased faster in the testing program than the South Dakota state average. For example, in 1974 the South Dakota dryland crop testing maize yields were 30.6% higher than the yields in eastern South Dakota, while in 2012 the testing program had yields that were 46.5% higher. For dryland corn production in Nebraska similar results have been reported (Dobermann and Shapiro, 2004). Although the factors responsible for an apparent widening gap are unknown, it could be attributed to maize management not keeping pace with genetic improvements. Techniques to reduce the yield gap might include using variable seeding rates, improving hybrid selection, or using in-season N applications. The yield gap was not attributed to soil and climate differences because: 1) the testing sites were strategically located to represent the major maize growing regions in the state, 2) yield variation across the test sites was very large; and 3) genetic improvements have similar impacts on maize grown over a range of climatic conditions (Duvick and Cassman, 1999; Kim et al., 2008).

Table 5. The influence of year on land use and erosion in South Dakota, Nebraska, and North Dakota (modified from NRCS, 2007).

	Land use					Erosion		
Year	Developed	Rural	Cropland	Range	Pasture	Wind	Sheet + rill	Wind + sheet
	ha*1000	ha*1000	ha*1000	ha*1000	ha*1000	Mg/(ha· y)	Mg/(ha· y)	Mg/(ha· y)
1982	370	18,050	8,668	7,850	785	8.9	7.2	16.1
1987	374	18,037	8,712	7,659	717	8.9	6.6	15.4
1992	384	18,004	8,148	7,590	702	6.9	5.4	12.4
1997	403	17,977	8,256	7,536	657	6.3	4.7	11.0
2002	410	17,961	8,193	7,585	660	7.2	4.8	12.0
2007	417	17,954	8,130	7,597	682	7.2	4.8	12.0

4.2 Narrowing the gap between the achievable and measured yields

It may be possible to narrow the yield gap between the plants achievable and observed yield by using management practices (higher population or an appropriate yield goal) that allows the genetic potential to be expressed (Duncan, 1954; Dobermasnn and Shapiro, 2004; Butzen, 2011;). This may involve better management of the available resources (fertilizer, pesticides, and genetics) (Stewart et al., 2005; Bundy et al. 2011). In the northern Great Plains, most of the cropland currently is fertilized (Fig. 5) while most rangelands are not fertilized. These data suggest that large yield increases on crop land will not be achieved by implementing a fertilizer program on current crop lands. However, yield increases resulting from applying fertilizer on converted pasture or rangelands are possible.

In the future, it may be possible to narrow the yield gap through better problem diagnosis. The traditional approach to diagnose problems is based on visual interpretation or soil and plant sampling. This approach can lead to miss-diagnoses, the recommendation that do not consider synergistic or antagonistic relationships between abiotic and biotic stresses, and problems that are identified too late for corrective treatments. New molecular biology techniques provide an opportunity to improve our understanding on how crops respond to stress and reduce diagnosis delays and errors. For example, Clay et al. (2009) used transcriptome analysis to assess how plant population affected light, water, and N utilization. They showed that modern maize hybrids, in response to increasing population pressure, down-regulated many genes associated with photosynthesis. The net result was shorter plants with a reduced per plant yield and a greater yield per hectare. This response is the opposite than what is generally considered the shade response, where the plants become etiolated (Horvath et al., 2007; Moriles et al., 2012). The success of skip row seeding configurations under water stress may be based on maize down regulating photosynthesis in response to increasing plant population.

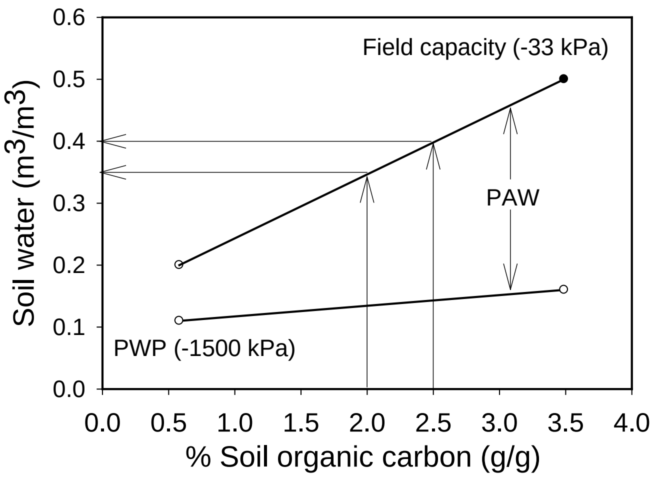

Figure 3. Relationship between soil orgnaic carbon (SOC) and plant available water (modified from http://soils.usda.gov/sqi/assessment/files/available_water_capacity_sq_physical_indicator_sheet.pdf). In the chart, PWP is permanent wilting point and PAW is plant available water. Percent organic matter was converted to SOC by dividing soil organic matter by 1.72. Based on Clay et al. (2012). SOC was estimated to be approximately 2% in 1974 (100×38,000/188,000,000). A 24% increase would increase SOC to 2.48%.

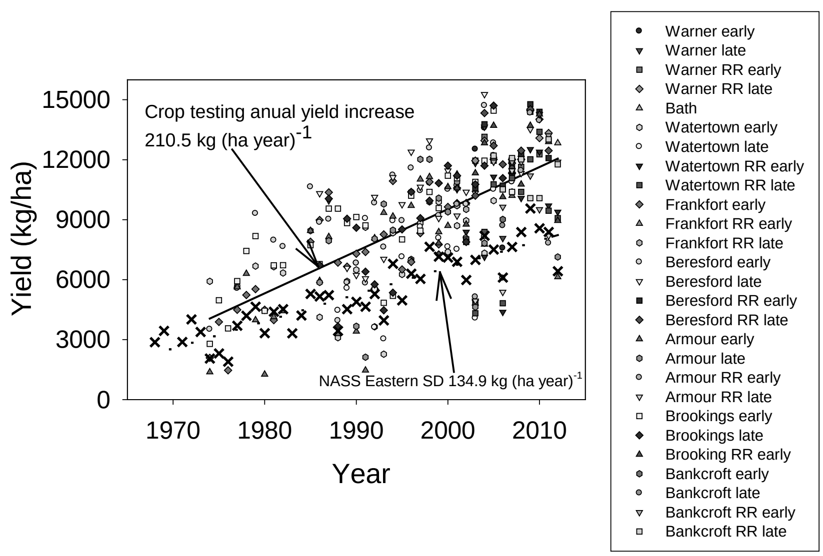

Figure 4. Corn yields on the eastern side of the state and the average annual yield increase (YI) from 1970 through 2012 in the South Dakota crop testing program, at various locations (Bonneman 1969-1986; Hall et al., 1987-2012; NASS, 2000; NASS 1985-2012). The corn testing sites were located in the eastern third of the state. Differences between the two curves represent the widening yield gap (Bonnemann, 1969-1986; Hall et al., 1987, 1988; Hall and Bonnemann, 1989-1992; Hall, 1993-1999; Hall and Kirby, 2000-2004, 2006; Hall et al., 2005, 2007-2012). In 1974 and 2012, the crop testing yielded 31% and 46% more than the eastern side of the state average, respectively.

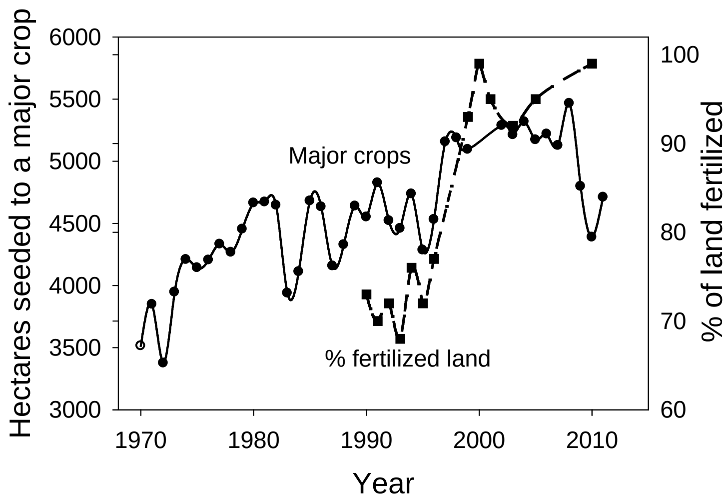

Figure 5. The amount of South Dakota land seeded to major crops and the percent of land fertilized (NASS 2000, 1995-2012).

4.3. Increasing yields through improved resource use efficiency

The ability to produce future yield increases depends on our ability to improve resource use efficiency (water, nutrients, and light) and pest management. For maize, previous yields increased were derived from improved soil health, improved tillage, and increased water use efficiencies (Norwood, 1999; Fig. 6). Water use efficiency has been defined using many different equations, and in this paper, it is the ratio of grain production divided by evaportranpiration (ET) (Kim et al., 2008; Payero et al. 2009). Based on this definition, the easiest way to increase WUE is to reduce evaporation. This can be accomplished through the use of no-tillage. However, the ability to convert water savings into greater yield is dependent on many factors including temperature, soil drainage and location (DeFelice et al., 2006).

Higher WUE could also be related to improved stress tolerance (Gaskell and Pearce, 1983; O'Neillet al., 2004; Lorenz et al., 2010). Gaskell et al. (1983) reported that different maize hybrids with relatively high CO_2 exchange capacity tend to have higher stomatal frequency and lower resistance. Hammer et al. (2009) suggested that WUE is influenced by root architecture (Hammer et al., 2009), while Lee and Tollenaar (2007) suggested that the increased yields could be linked to more erect leaves, higher population, and the selection of leaves that stay green longer. Others have reported that modern maize hybrids have higher photosystem II quantum efficiency (O'Neill et al., 2006), and improved photosynthesis and reduced transpiration under water stressed conditions (Nissanka et al., 1997). Nissannka et al. (1997) also reported that: 1) recovery from water stress was slower in the hybrid released in 1959 than 1988; 2) CO_2 losses through respiration were less for the hybrid released in 1988, and 3) water use efficiency (CO_2 fixed/transpiration) was less for Pride 5 than Pioneer 3902 when exposed to water stress. Tollenaar and Wu (1999) attributed corn yield increases to increased leaf longevity, a more active root system and a higher assimilate supply to demand ratio during grain filling. This analysis is in agreement with a meta analysis of water use efficiency (WUE) studies conducted over the past 60 years (Fig. 6).

Results from these studies suggest that WUE has increased. However, over this time period, there are a few studies that conduced side by side comparisons of maize hybrids released over the last 60 years. Studies reported by Monsanto Company (2011) and Pioneer (2009) did investigate this question. These studies indicate that WUE has increased over the past 50 years and that the improvements can be attributed solely to genetic improvements. A genetic-based increase in WUE when combined with tillage induced reductions in evaporation provides an opportunity to grow maize in more water limited environments (Fig. 6).

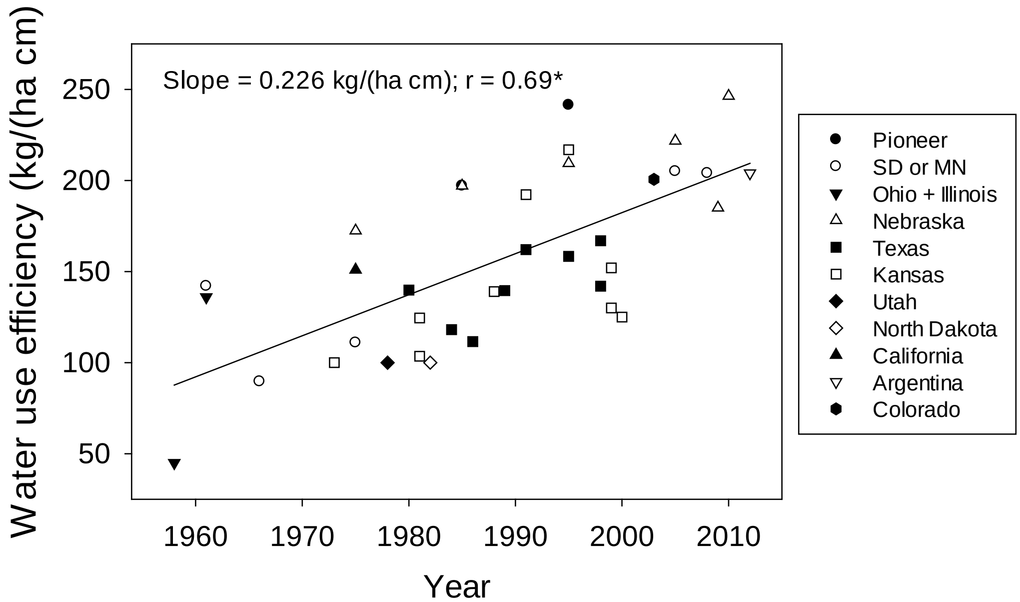

Figure 6. Relationship between year of published research and maize water use efficiency in studies conducted across the US Great Plains. Based on Dreibelbis and Harold (1958), Gard, et al. (1961) only no-irrigated treatments; Holt and Van Daren (1961), Timmons et al., (1966), Hillel and Guron (1973), Stewart et al. (1975), Hanks et al. (1978), Musick and Dusek (1980), , Stegman (1982), Eck (1984), Unger (1986), Hattendorf et al., (1988); Howell et al., (1989), Steiner et al. (1991), Scheekloth et al. (1991); Howell et al. (1995), Lamm et al. (1995), Howell et al. (1998); Tolk et al. (1998); Trooien et al. (1999); Norwood (1999, years 92-95); Norwood (2000); Al-Kaisi and Yin (2003); Sharratt and McWilliams (2005); Kim et al. (2008), Payero et al. (2009), Monsanto (2010), Pioneer (2009); and Barbieri et al. (2012). Where possible dryland, fertilized, and seeded at an appropriate rate were selected for comparisons. Experiments were only included if they contained adequate measurements.

4.3 Increasing yields with rotational diversity

In the future it may be possible to increase yields further by adopting more diverse rotations. Rotations provide protection from pests, and in any given year, can reduce pest pressures from 0 to 100% (Chang et al., 2004; Oerke, 2005). In semi-arid landscapes, where crops are grown on soils with land capability classifications ranging from 3 to 6, effective crop rotations can reduce the pest severity and risk of pest resistance to control practices. In addition, crops grown in semi-arid landscapes can have yields reduced by water stress, which in turn can increase its susceptible to pest problems. For example, drought acts as a predisposing stress factor for charcoal rot and Northern stem canker in soybean, as well as, stalk rots of maize (Schoenweiss, 1975). Research conducted in maize showed that under drought conditions, many pest defense genes were down-regulated, which may increase the importance of *prophylactic* pest management (Hansen et al., 2013). These results suggest that interactions between the abiotic and biotic stresses can influence our ability to control pests (Bockus et al., 2001).

It may be possible to reduce the pest risks in highly erodible soils by using cover crops or by adopting a more diverse or stacked rotation. A stacked rotation is a crop sequence where one crop may follow itself for several years followed by a longer period of time where the crop is not seeded (maize-maize-soybean-soybean-wheat-wheat). The advantage of a stacked rotation is that the total pest selection pressure is reduced by increasing the length of time between seeding the same crop (Beck, 1999; Derksen et al., 2002).

Crop rotations have a direct impact on SOC. Soil C can be increased by a sowing cover crop, increasing the amount of non-harvested C returned to soil, and reducing the tillage intensity (Clay et al., 2012). Of the three major crops grown in the northern Great Plains, maize returns more non-harvested C to soil than either wheat or soybeans. Depending on the cover crop(s) chosen, soil aeration, nutrient recycling, and other benefits can be obtained (Midwest Cover Crops Council, 2012).

7. Summary

Over the past 40 years no-tillage and the amount of maize and soybeans in the rotation has increased in the northern Great Plains. These changes were made possible by genetic enhancements and management improvements. Associated with the changes were higher yields across the region, reduced erosion across the regino, and improved soil organic C in South Dakota. For example, in two years with similar rainfalls, maize, soybean, and wheat yields were much higher in higher in 2012 than 1974. For maize, soybeans, and wheat 22, 61, and 41% of the yield increases, respectively, were attributed to increased available water resulting from improved tillage and soil management. Maize yield increases were attributed to improved WUE, which were linked to reduced evaporation and/or physiological improvements that increased the ratio between fixed carbon stored in grain and water transpired. Analysis of yields from 1974 and 2012 indicate that drought resilience has improved which reduced the need for federal drought assistance, reduced insurance payments, and provided critical raw materials for rural communities. This research suggests that a roadmap to improved food security should invest in both genetic and management improvements and genetic improvements can only be achieved by defining the management options that allows the genetics to be expressed.

SOC increased from 1985 to 2010, while erosion losses decreased from 1982 to 2007. These improvements are attributed to the combined impact of improved soil health, better genetics, and enhanced management techniques. A regional assessment suggests that genetic, soil, and management improvements have provided a short term opportunity to increase the amount of land used to produce maize and soybeans and that research needs to be conducted to determine the sustainability of land-use changes in the northern Great Plains . We believe that the long-term sustainability of converting grassland systems that have a land use capability classifications that range from 3 to 7 to crop production contains significant risks. In many of the worlds semi-arid regions similar questions exists and research is needed to identify fields that should be protected from conversion to crop land.

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Chapter 3: Cover Crops in Rotations with Soybeans

(will be published in the SD Soybean production manual)

Cheryl L. Reese (Cheryl.Reese@sdstate.edu)
Sharon Clay (Sharon.Clay@sdstate.edu)
Dan Forgey (dcforgey@venturecomm.net)
David Clay (David.Clay@sdstate.edu)

Cover crops, grown during or after cash crops, are used to improve soil health, increase organic matter, increase water infiltration, reduce erosion, reduce nutrient deficiencies, increase fertilizer efficiency, and increase available forage for livestock. Cover crops include a wide array plants including but not limited to: brassicas (sugar beet, turnips, radish) (Fig. 5.1); grasses (barley, winter wheat, rye); and legumes (chickling vetch, lentils, peas). The ability to benefit from cover crops depends on your ability to fit the cover crop into your rotation. This chapter provides background material using cover crops in rotations containing soybeans.

Figure 5.1. Brassicas (radishes and turnips) planted into spring wheat stubble after early August harvest. Photo taken in November, about 10 weeks after planting (11/10/2010). These radishes provide forage for livestock and help reduce soil compaction. (Photo, Cheryl Reese, SDSU)

Economic benefits from cover crops

Cover crops have been advertised as a one-step solution to many problems associated with row crop production. For example, they have been linked to increased fertilizer efficiency, improved soil quality, increased carbon sequestration, and reduced erosion. Cover crops can reduce nutrient losses. If using legumes, these crops may increase soil nitrogen, if N levels are low, by fixing atmospheric N. Brassica crops with large tap roots can help break compaction zones and increase water infiltration.

Cover crops also add organic matter, which improves soil quality, reduces erosion, and reduces runoff. Some cover crops also provide glucosides, which act as a biofumigant, and may reduce disease organisms.

While some of these benefits are more obscure than others, in a practical sense cover crops must have economic value within your rotation. Economic benefits from cover crops may include increased yields in row crops, increased fall and winter forage, reduced fertilizer requirements, improved soil yield potential, and under some conditions reduced iron deficiency chlorosis (IDC) in soybean (Chapter 26).

The definitive impact of cover crops on crop yields is often indirect. For example, research suggests that under some conditions cover crops can increase soybean yields by reducing iron deficiency chlorosis (IDC) (Chapter 26, Kaiser et al., 2011). This hypothesis is based on the plant releasing the negatively charged bicarbonate ion (HCO_3^-) when it takes up the negatively charged nitrate ion (NO_3^-). The bicarbonate ion then reacts with iron to form a relatively insoluble complex that cannot be taken up by the plant. Kaiser et al. (2011) suggests that cover crops can reduce the risk of IDC by decreasing the soil nitrate concentration and forcing the soybean to fix N.

Steps for introducing cover crops into a rotation

In the northern Great Plains, cover crops can be used fill specific and general needs within rotations. For example, a specific need might be to improve nutrient recycling while a general need is to increase the long-term yield potential by increasing soil organic matter content. The requirements for both systems are similar, yet slightly different. Implementing an effective cover crop program requires following several key steps (Table 5.1).

Table 5.1. Steps for integrating cover crops into your rotation.

1. Develop a cover crop plan.
2. Identify specific objectives.
3. Identify crop rotational requirements.
4. Determine agronomic requirements:
    a. desired species (single or mix), seeding rates, and landscape positioning (if any) for specific cocktails (i.e., seed mix);
    b. examine herbicide labels to determine if herbicide residuals will limit selected species growth.
5. Determine costs (seed, planting, future control, if needed) and expected returns.

Developing a cover crop plan and objectives

Developing a cover crop plan is critical for justifying your use of limited farm resources. Cover crop management objectives may include extending fall grazing, scavenging nutrients, reducing pests, wildlife habitat, and/or decreasing soil compaction. Each field is likely to have a different set of objectives. One producer might target increasing the soil organic matter content while a different farmer might target providing forage for fall grazing.

Selecting the appropriate seeding data and plant species to use for a cover crop is critical for achieving your goals. Often a mix of species, i.e., a cover crop “cocktail,” is used. Mixing many species allows for many goals to be addressed by a single planting, and often enhances the opportunity for successful establishment of at least one species. In South Dakota, considerable success has been achieved by seeding a cover crop after winter or spring wheat harvest in August. Other opportunities for seeding cover crops include following a failed crop (e.g., late frost or hail damage) or after the critical weed-free period in a row crop (about V4 to V5 in corn). Questions that should be considered when selecting a cover crop cocktail include:

1. Did prior herbicide use (or environmental conditions) result in carryover or residuals that will prevent successful cover crop establishment?
2. Will the soil chemical characteristics influence plant establishment? For example, in salty soils cocktails should include salt tolerant plants (Chapter 48).
    a. Salt tolerant plants include barley, sugarbeets, tall wheat grass, canola, and wheat grass.
    b. Soybeans is moderate tolerant, while corn is moderately sensitive.
3. Will the cover crop cocktail increase or decrease pests in the cash crop (insects, weeds, and diseases) the following spring? For example, grass species like barley, rye, oats, or corn can act as a secondary host for the wheat curl mite which vectors wheat streak mosaic virus. Planting these grasses may provide a ‘green bridge’ for this pest to over winter and cause significant disease problems in wheat planted the following spring.
4. Does the cocktail influence future management? For example, will the cover crop need to be killed? If a cover species is planted that can potentially over winter, make sure to apply needed treatments in the spring to cease the cover crop growth so that it does not interfere with the season’s intended cash crop.
5. How will the cover crop cocktail influence fertilizer requirements? For example, legumes like clover may increase soil N or deep rooted brassicas will alleviate soil compaction.

Crop rotations and cover crops

There are many crop rotations that could be enhanced by including cover crops (Chapter 4). This chapter concentrates on three rotations: (1) corn grain followed by soybean; (2) corn for silage followed by soybean, and (3) soybean, wheat, and corn for grain (Table 5.2). Fall cover crops in South Dakota are difficult and risky to establish after harvest of both soybean and corn due to the cold, short, and often dry growing season remaining in September and October.

Table 5.2. Three crop rotations with cover crops and possible risk for successful cover crop emergence.

	Year 1		Year 2		Year 3	
Rotation	Crop	Fall Cover Crop Risk	Crop	Fall Cover Crop Risk	Crop	Fall Cover Crop Risk
Corn (Grain)/ Soybeans/ Corn (Grain)	Corn (Grain)	High	Soybeans	Moderate to High	Corn (Grain)	High
Corn (Silage)/ Soybeans/ Corn (Grain)	Corn (Silage)	Moderate to Low	Soybeans	Moderate to High	Corn (Grain)	High
Soybeans / Wheat/ Corn (Grain)	Soybeans	Moderate to High	Wheat	Low	Corn (Grain)	High

Planting a cover crop into growing corn or soybeans in July and August (Figure 5.2) has produced mixed results (Mutch and Martin1998, http://www.covercrops.msu.edu/pdf_files/covercrop.pdf; authors unpublished data). These crops are often seeded aerially with an airplane and moisture is crucial for germination.

In South Dakota, research where a cover crop was seeded at the corn V5-V6 growth period showed that the cover crop has a minimal impact on the corn crop yield. For this application, cover crop cocktails should include plants that germinate and grow well under shade, such as red clover. If corn has been treated with atrazine, there may be few cover crops that will establish during the season, especially if conditions that minimize breakdown (dry or abnormally cool conditions) have occurred.

Drilling the cover crop between rows has produced a more consistent stand (Fig. 5.3) than broadcast applications (Fig. 5.2 and 5.4); however, either technique can be successful if growth characteristics, seeding requirements, and water are available. When cover crops are seeded in-season, the cover crop usually remains quite small until the main crop starts to senesce and approaches maturity, at which time growth accelerates. Following corn harvest, the cover crop can be fall and winter grazed.

In soybean, the canopy may be too dense to allow for good establishment of in-season cover crops and planting may need to be delayed until leaf senescence.


Figure 5.2. Aerial seed application of cover crops into August corn crop. (Photo courtesy Dan Forgey)

Figure 5.3. Crimson clover drilled into corn at V6 on June 30, 2011. Photo 09/15/2011, Trail City, SD. (Photo, Cheryl Reese, SDSU)

Figure 5.4. Crimson clover broadcast seeded into corn at V6 on June 22, 2010. Photo 10/12/2010, Andover, SD. (Photo, Cheryl Reese, SDSU)

Opportunities for planting fall cover crops exist in rotations where a short-season crop like wheat is harvested in July or if corn is harvested as silage in August (Figure 5.5). In this application, the cover crop should be seeded as soon as possible after harvest. Seeding before September 1 improves the ability of the cover crop to be established before a killing frost. Cover crops can provide fall and winter grazing, reduce compaction, and increase nutrient cycling. A cocktail that includes cereals such as rye or oats, broadleaves like radishes or turnips, and legumes are desirable and can provide excellent livestock forage (Fig. 5.5).

Figure 5.5. Cereal rye planted as a cover crop into silage stubble. (Photo courtesy Dan Forgey)

Figure 5.6. Cattle grazing on radishes in November. (Photo courtesy Dan Forgey)

In the soybean, wheat, and corn rotation, a cover crop after the wheat harvest has been used to increase the yield in the following corn crop. In South Dakota wheat is typically harvested in July or early August which provides the best opportunity to establish fall cover crops. Generally there is an ample opportunity to seed the cover crop cocktail and have a longer time for establishment and growth. Care must be taken to choose herbicides with short residuals or to provide ample time between application and seeding to optimize growth and development (see Table 5.8).

Cover crop planting dates

To optimize fall growth of cover crops, the earlier the crop is seeded, the more biomass will be produced (Fig. 5.7). In Figure 5.7, regardless of the cover crop mixtures, either brassicas or broadleaf mixture, dry biomass averaged approximately 3,800 lbs/acre when planted on August 1 and decreased to about 200 lbs/acre when cover crops were planted on August 31. Similar results have been observed in South Dakota demonstration studies where dry biomass production was 1091 and 237 lbs biomass/acre when seeded on 8/17/2010 and 9/19/2009, respectively.

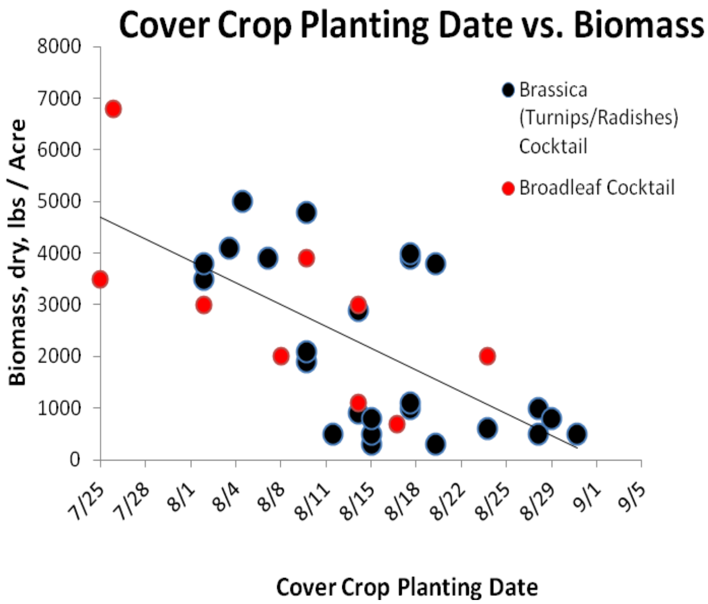

Figure 5.7. Cover crop dry biomass by planting date. Adapted from South Dakota NRCS Cover Crop Survey 2008-2010.

Cover crops composition: warm-season vs. cool-season

Selecting an appropriate seeding mixture is critical. Cover crop composition could be warm- or cool-season plants or a mixture depending on when the cover crop is seeded. Cool-season plants grow best in cool temperatures. Cool-season species start growth when air and soil temperatures are cool and will continue to grow during the spring and fall but go dormant or quickly die off when temperatures are warm (>80 F). Cool-season broadleaves can be typically divided into (1) brassicas like canola, radishes, or turnips or (2) legumes including clovers, peas, and vetch. Cool-season grasses include barley, oats, winter wheat, and rye. In a South Dakota fall, cool-season cover crops often blend broadleaf and grass species to provide the most biomass and potentially survive light frosts.

Warm-season plants grow best with warm temperatures. Warm-season species typically start growth in late spring when soil and temperatures are warm. These plants thrive during the warm summer weather. Examples of warm-season plants are big blue stem, corn, and sorghum. Warm-season species typically do not tolerate frost and will die out quickly as fall temperatures fall at or below freezing. In South Dakota, cool-season species are used for cover crops in most cases.

Cover crop categories and uses

In compacted soils, cover crop cocktails that include brassicas (grazing radish) can be used to reduce soil compaction (bulk density). These plants produce a tap root that penetrates soils up to 2 feet (Fig. 5.8). These plants can rapidly decompose leaving large pores in the soil. In Figure 5.9, a knife is inserted in a root channel of a decomposing tillage radish.

Figure 5.8. Diakon radishes and purple top turnips root size. (Photo, Cheryl Reese, SDSU)

Figure 5.9. Knife inserted into macro channel created by decomposing radish root. May, 2012. (Photo, Cheryl Reese, SDSU)

Cover crop impacts on soil health

Cover crops mixtures can help increase the diversity of the soil biota which can help increase aggregate stability (Fig. 5.10, Ketterings et al., 1996) and N mineralization (Fig. 5.11). Plants with high C to N ratios, such as wheat straw or corn stover, generally mineralize slowly, whereas plants with low C to N ratios, brassicas or turnips, peas or soybean residue, generally mineralize fast. The mineralization rate influences how much of the N contained in residue will be available to the following crop early in the growing season (Fig. 5.11)

Figure 5.10. Earthworms associated with a decomposing radish root. May, 2011.

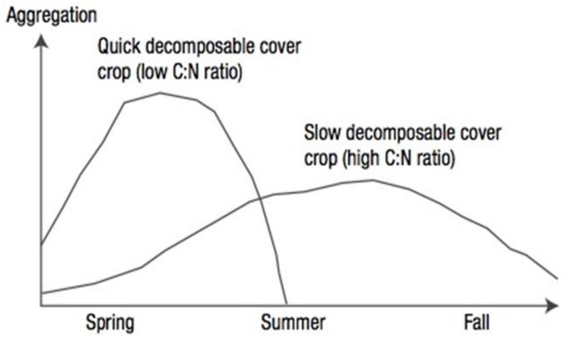

Figure 5.11. Crop residue decomposition based cover crop C:N ratios.
(Source: http://www.weblife.org/humanure/chapter3_7.html)

When determining a cover crop blend, consideration should be made for the current soil residue cover. If the desired outcome is crop residue retention, cover crops with high C:N ratios should be considered. However, if the goal is to improve soil nutrient recycling from one crop to the next, then crops with a low C to N ratio should be seeded.
http://soils.usda.gov/sqi/management/files/C_N_ratios_cropping_systems.pdf

Cover crops can be used to help manage high salt soils. Cover crops can be useful in salt management by increasing water loss through transpiration vs. evaporation, and reducing capillary movement of water and salts into surface soil. For cover crops to be effective they must germinate and reduce evaporative water loss. In South Dakota, barley, sugarbeets, rape, rye, canola, and western wheat grass can be seeded into salty soil zones (Chapter 53). Challenges using this cover crop seeding include (1) a good method to plant the cover crop into the growing corn and (2) seed germination.

Developing a cover crop cocktail

Determining the blend is accomplished by establishing the cover crop goals, evaluating seeding season characteristics of the plants (warm- vs. cool-season), and considering soil variability. Tables 5.3 to 5.7 summarize cover crop blends that provide options for various cover crop management objectives. *An important note here is that after producers have some experience with cover crops, they often will modify seed mixtures to fit their needs.* Cool-season grazing blends will often consist of turnips, radishes, and grasses whereas cowpeas, millet, and sudangrass can be used for warm-season grazing.

Table 5.3. Cover crop blends for grazing. (Revised from Jason Miller, NRCS, Pierre, SD).

Grazing Blends			Option 1		Option 2		Warm-season grazing		Grazing / Compaction	
		Full Seeding Rate Pounds	Percent	Rate in Mixture	Percent	Rate in Mixture	Percent	Rate in Mixture	Percent	Rate in Mixture
Species	Type	lbs A^{-1}	%	lbs A^{-1}	%	lbs A^{-1}	%	lbs A^{-1}	%	lbs A^{-1}
Lentils	Cool Broad	30	30	9	40	12				
Turnip	Cool Broad	4	30	1.2	30	1.2			20	0.8
Radish	Cool Broad	8	10	0.8					20	1.6
Rapeseed	Cool Broad	5			30	1.5				
Oat	Cool Grass	70	30	21						
Cowpea	Warm Broad	30					40	12	30	9
Millet	Warm Grass	25					60	15	20	5
Sudangrass	Warm Grass	25							20	5

Table 5.4. Cover crops that may aid in reducing compaction. (Revised from Jason Miller, NRCS, Pierre, SD)

Compaction Blends			Compaction		Grazing / Compaction		Residue Cycling / Compaction	
		Full Seeding Rate Pounds	Percent	Rate in Mixture	Percent	Rate in Mixture	Percent	Rate in Mixture
Species	Type	lbs A^{-1}	%	lbs A^{-1}	%	lbs A^{-1}	%	lbs A^{-1}
Lentils	Cool Broad	30	30	9	40	12		
Radish	Cool Broad	8	60	4.8				
Canola	Cool Broad	5	10	0.5			50	2.5
Cowpea	Warm Broad	30					40	12
Millet	Warm Grass	25					60	15
Sudangrass	Warm Grass	25						
Turnip	Cool Broad	4	30	1.2	30	1.2		

Table 5.5. Cover crops that may enhance residue cycling compaction. (Revised from Jason Miller, NRCS, Pierre, SD)

Residue Cycling Blends			Residue Cycling		Residue Cycling / Compaction	
		Full Seeding Rate Pounds	Percent	Rate in Mixture	Percent	Rate in Mixture
Species	Type	lbs A^{-1}	%	lbs A^{-1}	%	lbs A^{-1}
Lentils	Cool Broad	30	50	15	30	9
Canola	Cool Broad	5	50	2.5	40	2
Radish	Cool Broad	8			30	2.4

Table 5.6. Cover crops that may potentially germinate under saline conditions. (Revised from Jason Miller, NRCS, Pierre, SD)

Salinity Blends			Option 1		Option 2		Option 3	
		Full Seeding Rate Pounds	Percent	Rate in Mixture	Percent	Rate in Mixture	Percent	Rate in Mixture
Species	Type	lbs A^{-1}	%	lbs A^{-1}	%	lbs A^{-1}	%	lbs A^{-1}
Sugarbeets	Cool Broad	4	50	2	60	2.4	30	1.2
Barley	Cool Broad	50	50	25			40	20
Canola	Cool Broad	5	5		40	2	30	1.5

Table 5.7. Cover crops that may reduce soil moisture and enhance nitrogen cycling. (Revised from Jason Miller, NRCS, Pierre, SD)

Spring Moisture or N Cycling Blends			Spring Moisture / N Cycling 1		Spring Moisture / N Cycling 2		Spring Moisture	
		Full Seeding Rate Pounds	Percent	Rate in Mixture	Percent	Rate in Mixture	Percent	Rate in Mixture
Species	Type	lbs A^{-1}	%	lbs A^{-1}	%	lbs A^{-1}	%	lbs A^{-1}
Hairy Vetch	Cool Broad	15	50	7.5	50	7.5		
Canola	Cool Broad	5					50	2.5
Rye	Cool Grass	100	50	50			50	50
Triticale	Cool Grass	60			50	30		

Other considerations

The cover crop should be matched to the drainage characteristics of the soil. For example, annual rye is a cool-season grass and has a weight of 26 lbs per bushel. Annual rye will grow under wet soil conditions and tends to grow better on both poor, rocky soils and heavy clay soils than cereal rye, although cereal rye can grow under dry to excessive moisture conditions if the soils are more loamy.

Both cereal and annual rye will overwinter like winter wheat. The major problem with cereal rye is excessive spring growth that is not controlled. Under these circumstances, soil moisture is depleted and the producer is left with reside that can be up to 6 feet tall. The mat of residue can be difficult to manage in the spring and cause soils to dry out and warm up slowly.

Annual rye is typically burned down with an herbicide in the spring when its growth is between 8 to 16 inches. Annual rye has been reported to be difficult to control by many producers during cool weather when glyphosate does not translocate well in the plant. Annual ryegrass can go to seed in the spring and become a weed in future crops if not closely monitored.

Cover crops may reduce available moisture for the row crop; however, they also increase water infiltration and snow catch. Our research suggests that they can reduce as well as increase available moisture for the row crop.

Cover crops increase plant diversity which can increase soil biological diversity. It has been hypothesized that cover crops increase soil mycorrhizae. These organisms can help the row crop utilize nutrients and water (Fig. 5.10).

Figure 5.12. Fungi (not mycorrhizae) decomposing a corn root.

Many herbicides have activity for a relative long period of time. For example, Roundup (glyphosate) has no residual soil activity and there are no restrictions to planting any crop after application. In comparison, Maverick (sulfosulfuron) has a long residual activity (22 months) and planting to anything but small grain crops is not labeled (Table 5.8). Matching the herbicide rotation to the desired cover crop is critical for the cover crop success (Table 5.8).

Cost share programs may be available for cover crop seeding from county USDA-NRCS offices. EQIP and CSP are programs that typically allow some cost share benefits for cover crops. The best way to take advantage of the programs is to check early with your county NRCS office for applications and deadlines.

Table 5.8. Approximate months required between wheat herbicide applications and cover crop seeding.
Carryover risk high (black); moderate (gray); and low (white). Revised from Jason Miller, NRCS, Pierre, SD**.**

Approximate months required between wheat herbicide applications and cover crop seeding	Application Timing	Forage Legumes (Alfalfa, clover, vetch)	Pulse crops (peas, dry beans, lentils)	Seed Mustards (canola, rape)	Root Mustards (turnips, radish)	Small Grains (rye, wheat, triticale, millet)	Other grasses (sorghum, sudan)	Oilseeds (sunflower, safflower)	Other broadleaf (flax, buckwheat)
Maverick (sulfosulfuron)	Fall	**22**	**22**	**22**	**22**	**3**	**22**	**22**	**22**
Olympus (propoxycarbazone	Fall	**24**	**12-24**	**12**	**12-24**	**4**	**12**	**12**	**24**
Rimfire (propoxycarbazone + mesosulfuron)	Spring	**10**	**10**	**10**	**10**	**0-4**	**12**	**10**	**10**
Power (pyroxsulam)	Fall	**9**	**9**	**9**	**9**	**1**	**9**	**9**	**9**
GoldSky (pyroxsulum + florasulam + fluroxypyr)	Spring	**9**	**9**	**9**	**9**	**1**	**9**	**9**	**9**
Everest (flucarbazone)	Spring	**24**	**9-24**	**9-24**	**9-24**	**4-11**	**11-24**	**9**	**11-24**
Beyond (imazamox)	Spring	**3**	**3**	**18-26**	**9-18**	**4-9**	**9**	**9**	**9-18**

Approximate months required between wheat herbicide applications and cover crop seeding	Application Timing	Forage Legumes (Alfalfa, clover, vetch)	Pulse crops (peas, dry beans, lentils)	Seed Mustards (canola, rape)	Root Mustards (turnips, radish)	Small Grains (rye, wheat, triticale, millet)	Other grasses (sorghum, sudan)	Oilseeds (sunflower, safflower)	Other broadleaf (flax, buckwheat)
Ally (metsulfuron)	Spring	**22**	**22**	**22**	**22**	**1-10**	**12**	**22**	**22**
Harmony (thifensulfuron)	Spring	**1-2**	**1-2**	**2**	**2**	**0**	**1-2**	**1-2**	**1-2**
Express (tribenuron)	Spring	**1-2**	**1-2**	**2**	**2**	**0**	**1**	**1-2**	**1-2**
Buctril (bromoxynil)	Spring	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Huskie (pyrasulfotole + bromoxynil)	Spring	**9**	**9**	**9**	**9**	**0-4**	**4**	**9**	**9**
WideMatch (clopyralid + fluroxypyr)	Spring	**10.5**	**18**	**4**	**4**	**0**	**10.5**	**18**	**4**
Starane (fluroxypyr)	Spring	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**

Potential cover crop seed suppliers in South Dakota
Spink County Fertilizer & Chemical
Dylan Troske
10 Main St
Northville, SD 57465
Phone: 605-887-3422
Email: dylan.troske@uap.com

Prairie States Seed
Brad Young
Wausa, NE
Phone: 866-373-2514
Email: prairie@gpcom.net

Millborn Seeds Inc.
Matt Fenske
1335 Western Avenue
Brookings, SD 57006
Phone: 888-498-7333
Email: mattf@millbornseeds.com
Web: www.millbornseeds.com

Hansmeier Seed Inc.
Floyd & Keith Hansmeier
Bristol, SD
Phone: 605-492-3611
Email: hansson1@midconetwork.com

Howe Seeds, Inc.
Charles Howe
Box 496
McLaughlin, SD 57642
Phone: 605-823-4892
Cell: 605-845-5892
Email: charleshowe@westriv.com

Cronin Farms
Dan Forgey
30431 167th St
Gettysburg, SD 57442
Phone: 605-765-9287
Email: dcforgey@venturecomm.net

Henry Roghair
PO Box 16
Okaton, SD 57562
Phone: 605-669-2819
Email: hgrseeds@gwtc.net
Pulse USA

Brad Meckle
1900 Commerce Drive
Bismarck, ND 58501
Phone: 1-888-530-0734
Email: brad@pulseusa.com

Mark Stiegelmeier
13402 306th Avenue
Selby, SD 57472
Phone: 605-649-7009
Email: mstiegel@sbtc.net

Sunbird Inc.
Lee Klocke
PO Box 942
702 3rd St SW
Huron, SD 57350
Phone: 605-353-1321 Ext 212
Email: lklocke@sunbird-inc.com
Web: http://www.sunbird-inc.com

Jerome Webb
32050 201st ST
Harrold, SD 57536
Phone: 605-875-3558
Sioux Nation of Fort Pierre
Steve Magdanz
504 Deadwood Ave
Fort Pierre, SD 57532
Phone: 605-223-2427 (seed house)
Email: Sioux.nation2@plantpioneer.com

Winner Seed, Gene Brondsema
E. HWY 44, 27763 317th Ave
Winner, SD 57580
Phone: 605-842-0481
Cell: 605-680-9886

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South Dakota Natural Resources Conservation Service. Available at http://www.sd.nrcs.usda.gov/technical/CoverCrops.html

USDA Cover Crop Chart. Available at http://www.ars.usda.gov/Services/docs.htm?docid=20323

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Chapter 4: Mid-Season Establishment of Cover Crops in Corn

Alex D. Bich, Cheryl L. Reese, Sharon A. Clay, and David E. Clay

A cover crop is a noncash crop grown with or after a cash crop that provide soil cover. The goals of incorporating a cover crop into cropping systems are diverse and include:

- improving soil health
- preventing erosion
- suppressing weeds
- recycling nutrients
- increasing soil organic matter
- increasing water infiltration
- forage for livestock and wildlife
- improving water quality

Figure 1. Legumes (crimson clover and lentil) and a grass (winter wheat) cover crop. (Photo, Alex Bich, SDSU)

Several types of plant species are used for cover crops (Table 1) and can be grown individually or as a mixture. **Legumes** obtain and/or fix atmospheric nitrogen (N)

	Species	Life Cycle[1]	Total N	DRL[2] Seeding Rate	BRD[3] Seeding Rate	Seeding Depth
			(lb/A)	(lb/A)	(lb/A)	(in)
LEGUMES	Crimson clover	WA/SA	70 – 130	15 - 20	22 - 30	0.25 - 0.5
	Field peas	WA	90 – 150	50 - 80	90 - 100	1.5 - 3
	Lentil	CSA	30 – 130	20 - 40	100 - 160	1 - 1.5
	Hairy vetch	WA/CSA	90 – 200	15 - 20	25 - 40	0.5 - 1.5
	Medics	SP/SA	50 – 120	8 - 22	12 - 26	0.25 - 0.5
	Red clover	SP/B	70 – 150	8 - 10	10 - 12	0.25 - 0.5
	Sweetclover	B/SA	90 – 170	6 - 10	10 - 20	0.25 - 1
GRASSES	Oats	CSA	NA	80 - 110	110 - 140	0.5 - 1.5
	Barley	WA	NA	50 - 100	80 - 125	0.75 - 2
	Rye	CSA	NA	60 - 120	90 - 160	0.75 - 2
	Wheat	WA	NA	60 - 120	60 - 150	0.5 - 1.5
	Sorghum-sudan	SA	NA	35	40 - 50	0.5 - 1.5
BRASSICAS	Mustards	WA/CSA	30 – 120	5 - 12	10 - 15	0.25 - 0.75
	Radish	CSA	50 – 200	8 - 13	10 - 20	0.25 - 0.5
	Rapeseed	WA/CSA	40 – 160	5 - 10	8 - 14	0.25 - 0.75
	Turnips	CSA	40 – 160	1 - 3	1.2 - 3.6	0.25 - 0.5

Table 1. [1]**Life Cycle –** SA=Summer annual; WA=Winter annual; CSA=Cool season annual; SP=Short-lived perennial; B=Bienial. [2]**DRL Seeding Rate** = Drill. [3]**BRD Seeding Rate** = Broadcast. (Data Obtained from SARE, 2007)

into a form that is useable by plants and microorganisms if soil N is low (MCC, 2012) (Fig 1). **Grasses** scavenge and recycle soil nutrients remaining after cash crop harvest and build soil structure and quality (Fig 1). **Brassicas** (plants in the mustard family) scavenge soil nutrients remaining after harvest, reduce soil erosion, and increase soil quality. In addition, brassicas contain allelopathic compounds that suppress weeds and those with large tap roots (e.g. turnip and radish) help break soil compaction. Buckwheat, a broadleaf crop, also can be used and provides a dense canopy that helps suppress weed growth.

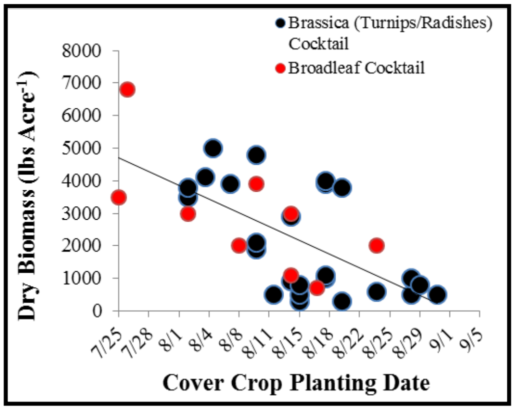

Figure 2. Cover crop dry biomass accumulation with regards to planting date. Adapted from South Dakota NRCS Cover Crop Survey 2008-2010.

The benefits provided by cover crops are dependent on several factors with establishment and density as the key components for success. Cover crop species selected, time of cover crop sowing (Fig 2), and seeding rate, affect the total biomass of the cover crop (Vos, 1999; Teasdale and Mohler, 2000; Teasdale and Daughtry, 1991; Swanton and Weise, 1991). When selecting cover crops to incorporate into a cropping system, essential factors to take into consideration include:

- environmental conditions
- length of growing season
- crop rotation
- cover crop role (e.g. weed suppression vs. nutrient scavenging)
- previous herbicide applications

Cover Crop in South Dakota Corn Production Systems

In South Dakota (SD), implementing a cover crop into corn production systems after fall harvest is challenging due to the short establishment time because of cold fall temperatures that slow growth or freeze seedlings and limit moisture. Therefore, interseeding cover crops into standing corn has been tried to provide better and longer times for establishment (Fig 3). For instance, Smeltekop et al. (2002) reported that annual snail medic broadcasted immediately after corn planting, produced about 537 lbs biomass

Figure 3. Cover crop drill interseeded into corn at the V3 corn growth stage. (Photo, Alex Bich, SDSU)

acre^{-1} with no added N, and approximately 811 lbs biomass acre^{-1} when 119 lbs N acre^{-1} was applied. Caution needs to be taken, because if sown too early; cover crops can act as weeds and, can result in yield losses (Smeltekop et al., 2002). Schaller and Larson (1955) also reported that a cover crop mixture of rye, alfalfa, red clover, and timothy interseeded into corn at planting reduced yield by 65%, however the same mixture sown following the third cultivation practice, resulted in no yield loss. The results of studies that examined the establishment and biomass production of a cover crop mixture interseeded into at two northern and one eastern South Dakota sites are reported here.

Research Locations and Descriptions

Field studies were conducted from 2010 through 2012 near Andover, Trail City, and Aurora, SD (Fig 4). Andover and Trail City had a no-till farming system with corn following spring wheat. Aurora had a conventional tillage (less than 15% soil surface residue in the spring after tillage) farming system with corn following soybean. The field research plots were established in early-May followed by a pre-corn planting and/or pre-corn emergence herbicide application of glyphosate.

Figure 4. Field research locations. (Photo obtained from South Dakota Land Title Association)

Cover Crop Interseeding

A cover crop mixture of crimson clover, winter wheat, and lentil was broadcast (BRD) and drill (DRL) into standing corn at the V3 (Aurora only,

Figure 5. Broadcast (left) and drill (right) interseeded legumes (crimson clover and lentil) and grass (winter wheat). Photos taken in July about 15 days after planting (June 28, 2011). (Photo, Cheryl Reese, SDSU)

early-June) and V5 (mid-June) corn growth stages (Fig 5). The individual cover crop seeding rates in the mixture were: 6 lbs/A (crimson clover), 10 lbs/A (winter wheat), and 11 lbs/A (lentil). **Crimson clover**, a legume, was selected due to its shade tolerance, rapid stand establishment, vigorous growth habits, and N fixing characteristics. **Winter wheat**, a grass, was chosen due to its ability to grow in cool soils (beneficial for fall growth after harvest) and erosion control. **Lentil**, a legume, was selected based on its tolerance to low soil moisture conditions and N fixing ability.

Mid-Season Field Observations

In mid-July, cover crop establishment and growth were visually evaluated (Fig 6). The DRL method of seeding was superior to the BRD method based on several observations: 1) all three cover crop species emerged, however, in the DRL treatments, the cover crops emerged within 7 to 14 d after sowing due to good seed-soil contact. 2) Dry surface soil conditions in 2012, had few established plants in most BRD treatments. 3) BRD cover crop seeds were carried to lower sections (e.g. holes) of the field with runoff after rainfall events and often sprouted with roots on the soil surface leading to no or minimal establishment when the soil surface dried (Fig 7). 4) DRL treatments provided uniform and rapid cover crop establishment (Fig 6) whereas BRD had uneven establishment (Fig 7).

Figure 6. DRL cover crop mixture at the V5 corn growth stage. Photo taken 20 days after cover crop interseeding (07/12/2011). (Photo, Cheryl Reese, SDSU)

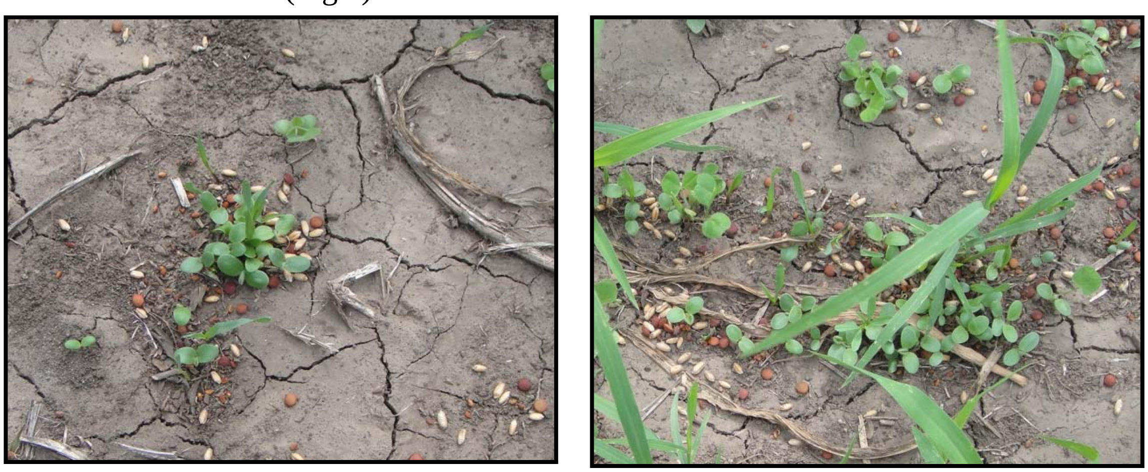

Figure 7. BRD cover crop mixture at V5 corn growth stage. Photos were taken after a 2 in. rainfall event in 2012. BRD seed was carried to lower portions of the field and often sprouted and died due to no root penetration. (Photo, Alex Bich, SDSU)

Cover Crop Biomass

Live green cover crop biomass was harvested prior-to corn grain harvest (late-August to mid-September) (Fig 8). Crimson clover and winter wheat were present. Lentils, while tolerant to low soil water conditions, does not compete well with other

Figure 8. Crimson clover and winter wheat in the BRD (left) and DRL (right) interseeding treatments prior to cover crop biomass harvest. Photos taken 100 days (09/30/2010) after cover crops were interseeded into standing corn at the V5 stage. (Photo, Cheryl Reese, SDSU)

plants and did not survive. Biomass in DRL areas generally had more biomass than any of the BRD treatments (Table 2). More biomass was present when drilled at the V5 compared with V3. As these species are annuals, the lower biomass may be due to natural senescence of the earlier planted cover crop.

Table 2. Total cover crop biomass in the broadcast (BRD) and drill (DRL) treatments at Andover, Trail City, and Aurora from 2010 to 2012. ([a]) = If letters are different within a column, treatments were significantly different at α=0.10.

Interseeding Treatment	Andover			Trail City	Aurora	
	2010	2011	2012	2011	2011	2012
		lbs/A		**lbs/A**	**lbs/A**	
BRD V5	67.7[a]	9.1[a]	0[a]	53.4[a]	1.2[b]	0[b]
DRL V5	84.2[a]	158.8[b]	48.8[b]	162.5[b]	44.4[a]	60.2[a]
BRD V3	na	na	na	na	4[b]	0[b]
DRLV3	na	na	na	na	0.9[b]	49.9[a]

Corn Grain Yield

Corn grain was harvested in mid- to late-October (Table 3). The BRD and DRL interseeded cover crops at V5 had no impact on corn grain yield. When cover crops were drilled into corn at the V3 stage of growth, corn yield was reduced. The early cover crop establishment may have suppressed corn growth through competition during the critical weed-free period. The early BRD treatment did no impact corn yield due to poor establishment. These data suggest that cover crops can be successfully interseeded into standing corn at V5 corn growth stages, without detrimentally impacting the overall corn grain yield.

Table 3. Total corn grain yield in the broadcast (BRD), drill (DRL), and control (no cover crops) at Andover, Trail City, and Aurora from 2010 to 2012. ([a]) = If letters are different within a column, treatments were significantly different at α=0.10

	Andover			Trail City	Aurora	
Treatment	**2010**	**2011**	**2012**	**2011**	**2011**	**2012**
	(bu/A)			**(bu/A)**	**(bu/A)**	
BRD V5	215.6[a]	168.2[a]	121.3[a]	123.6[a]	142.9[a]	149.2[ab]
DRL V5	205.5[a]	173.2[a]	127[a]	120.8[a]	142.1[a]	152[ab]
BRD V3	na	na	na	na	146.8[a]	163.2[a]
DRL V3	na	na	na	na	140.1[a]	144.3[b]
Control	213[a]	179.3[a]	119.9[a]	112.1[a]	148.4[a]	157.2[ab]

Post-Corn Harvest (Fall) Observations

In mid-October to early-November (post-corn grain harvest and stover baling), visual observations indicated that: 1) regrowth of winter wheat had occurred in the DRL interseeding treatments (Fig. 9) at Andover and Aurora; and 2) estimated row cover was about 50-70%, at Andover and 25-35% at Aurora. The benefits of regrowth include: additional forage for grazing cattle; some surface cover to reduce soil erosion; scavenging of remaining nitrogen in the soil; and increasing soil organic matter (Fig. 9).

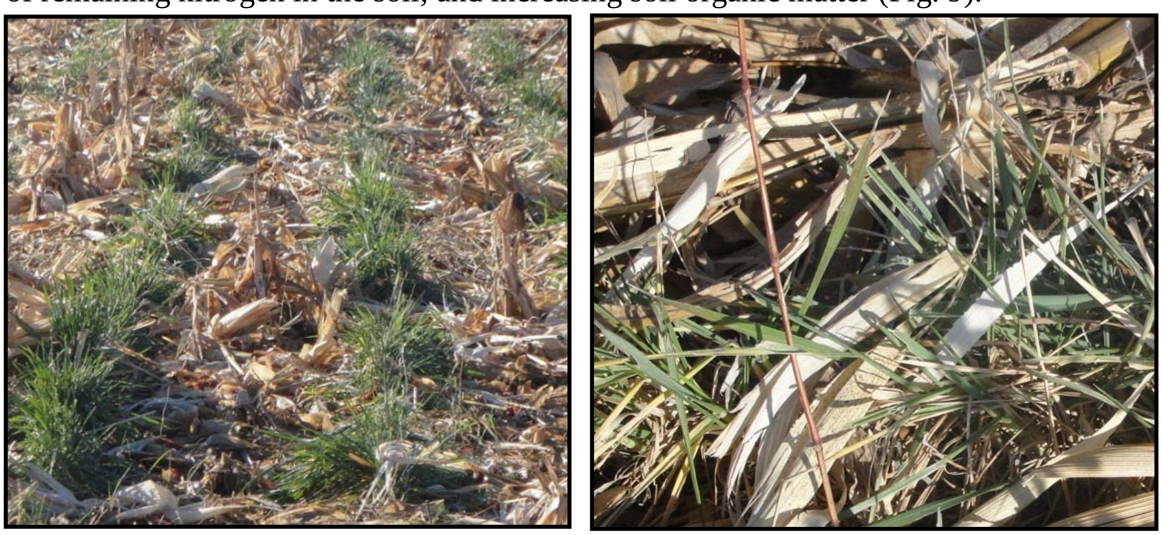

Figure 9. Winter wheat regrowth in the DRL interseeded treatments at Andover (left) observed on 10/27/2011 and at Aurora (right) on 11/08/2011. (Photo, Alex Bich, SDSU)

Summary

Cover crops:

1. were successfully established into standing corn by DRL interseeding method at the corn V3 and V5 growth stages;
2. BRD treatments did not provide uniform establishment and if left on a dry soil surface, stands were poor;

3. BRD seed washed into lower areas of fields after heavy rainfall leading to even more irregular establishment;
4. DRL interseeding had a faster, more rapid emergence, high stand uniformity, and provided 93% more above-ground cover crop biomass when compared with BRD interseeding. The superiority of the DRL interseeding method to the BRD interseeding method is directly related to the higher seed-soil-moisture contact obtained by DRL interseeding the cover crop mixture;
5. In-season cover crop did not reduce corn yields if seeded after V5.

These results indicate that cover crops can be incorporated into standing corn to provide some late-fall benefits including surface cover, forage, nutrient recycling, and soil organic matter without reducing corn productivity. The cost of seed and planting should be balanced with these benefits. It is imperative that herbicides (both pre- and post-emergence types) are carefully chosen, as some herbicides will limit both cover crop establishment and growth.

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Chapter 5: Case study on the determining cover crop N credits.

(this chapter will be published in a revision to the corn BMP manual)

David Clay, Cheryl Reese, Gregg Carlson, Sharon Clay, and Alex Birch.

Summary

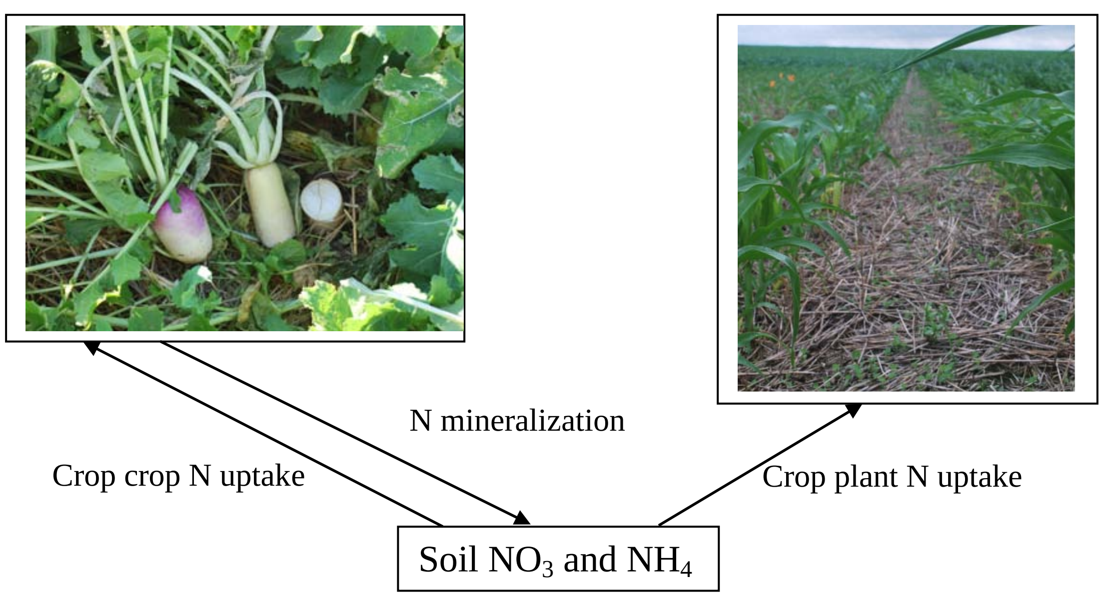
Cover crops can alter the N cycling in soil systems. Not accounting for the cover crop induced changes in N cycling can result in the over application of fertilizer which ultimately can be lost to ground water (nitrate leaching) or the atmosphere (denitrification). There are several different approaches that can be e used to estimate N fertilizer credits. Cover crop N credits are a function of many factors including, the cover crop density, livestock feeding, cover crop species, soil type, management, and calculation approach. The credits are based on the cover crop utilizing residual nutrients which are subsequently made available to the crop. This case study was designed to provide guidance on the calculation of locally based cover crop N credits.

Introduction

One of the benefits from cover crop is that sequester N that otherwise would be lost. For example, nitrate (NO_3 –N) remaining in the soil in the fall could either be leached below the root zone or denitrified. Whatever the method, the N is lost for the future crop. At a cost of between$ 0.50 to 1.00/lb of N, this lost reduces profitability.

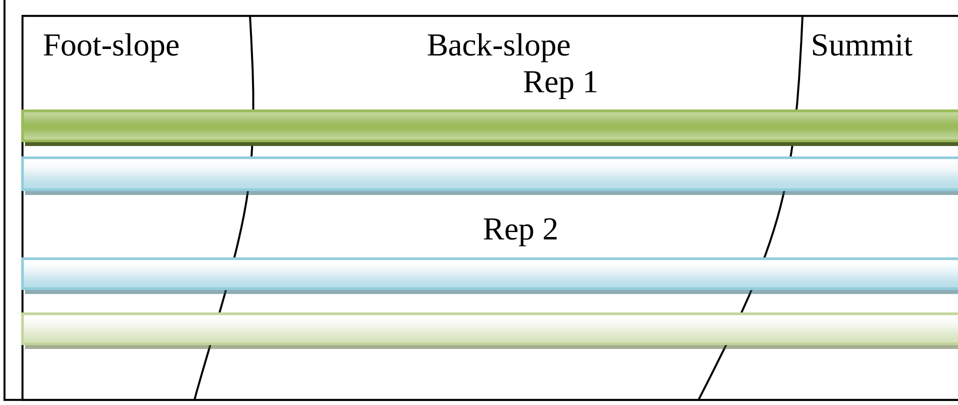
Nitrogen taken up by cover crops in fall can be mineralized by the soil microbial community during the following growing season (Fig. 1). The difference in the N mineralization rate (organic N → inorganic N) represents the cover crop N credit. This N credit is important because based on current N recommendations, the actual N recommendation may be higher in the cover crop than non-cover crop treatment.

Figure 1. Cover crop impact on N cycling and crop plant N uptake. Cover crop reductions in soil NO_3 reduces the risk of nitrate leaching to ground water or denitrification.



Locally-based N credits can be determined by conducting a cover crop N strip trial study (Fig. 2). Additional information for conducting on-farm research is available in Carlson (2013). In an on-farm cover crop study, the cover crop would be seeded in strips and non-cover crops would be placed in adjacent strips. The experiment would contain multiple replications. Crop yields and changes in soil nutrients in the two areas would be monitored. In some locations, landscape position may impact N credits and therefore, samples from the different landscape positions may be needed. Corn yields can be measured with a combine equipped with a yield monitor and changes in soil inorganic N levels can be determined by collecting "good" soil samples from each zone, followed by the analysis for nitrate and ammonia. Soil sampling protocols are available in Clay (2013). To determine the cover crop N credit, no-N fertilizer should be applied to these zones. Soil samples should be collected in the spring prior to planting and in the fall following planting. Soil samples should be analyzed for both ammonia and nitrate. To convert the gravimetric values to volumetric values, soil bulk density should be measured. To calculate cover crop N credits simplifying assumption can be made. These assumptions and ramification of these assumptions are discussed below.

Figure 2. The placement of 2 cover crop treatments across a landscape. Where possible cover crops strips should be perpendicular to the slope.



Methods

A fall cover crop experiment was conducted at Andover South Dakota in 2009-2010. The experiment was conducted at two landscape positions (summit and footslope) and contained 4 N rate (0, 30, 60, and 120 kg N/ha) and two cover crop treatments (cover crops and no-cover crops). The cover crops cocktails were seeded after wheat in the fall of 2009 and corn was seeded in the spring of 2010. Plant biomass (from cover crops and volunteer crops) was measured in October 2009. Subsamples were analyzed for total N. In the summit landscape position, plant biomass ranged from 165 to 319 kg biomass/ha in the cover crop treatments and 32 to 128 kg biomass/ha in the non-cover crop treatments. In the footslope position, plant biomass was higher and ranged from 194 to 566 in the cover crop treatments and from 63 to 388 in the non-biomass treatments. Due to high biomass in the non-cover crop treatments in the footslope area, only data from the summit landscape position is discussed below.

The gravimetric soil inorganic N concentrations (this is what most laboratories measure) were converted to an area basis using the equation below. In these calculations, the bulk density (g/cm^3) was estimated to be 1.25 g/cm^3. This value was based on field measured values and it assumes that the soil N represents the average concentration in the surface 60 cm.

$$\frac{\text{kg N}}{\text{ha}} = \frac{u g\text{N}}{gsoil} \times \frac{1.25g}{cm^3} \times 60cm \times \frac{kg}{1{,}000{,}000{,}000ug} \times \frac{10{,}000cm^2}{m^2} \times \frac{10{,}000m^2}{ha}$$

The average N percentage of the biomass harvested from the plots in October was 4.89%, which resulted in the above ground plant N containing 2 to 6 kg N/ha in the no-cover crop/summit treatments and 9 to 15 kg N/ha in the cover crop/summit treatments.

Corn was seeded the following spring. Corn yields were measured and subsamples were collected for total N analysis. Composite soil samples were collected in the spring and fall of 2010. Each soil sample was analyzed for ammonia and nitrate. Data from this experiment is provided in Table 1.

Results and Calculations

Table 1. Data from a Andover cover crop experiment conducted in 2009 and 2010.

Andover 2010							Soil	inorgan. N		Soil N
Treatment	N	Landscape			N	Prior to	planting	After	harvest	Mineral.
Cover crop	rate	position	Yield	Stover	removal	NO_3-N	NH_4-N	NO_3-N	NH_4-N	
	kg N/ha		kg/ha	kg/ha	kg/ha	Kg N/ha	Kg N/ha	Kg N/ha	Kg N/ha	Kg N/ha
yes	0	Summit	14,729	9,608	255	36.1	26.1	101	18.8	245
	30		14,659	11,153	271			82.3	20.2	
	60		13,211	8,499	243			105.3	14.7	
	120		13,203	8,597	241			135	17.3	
No	0		12,988	7,405	221	48.3	25.9	83.7	18.1	199
	30		12,887	9,816	226			64.8	20.5	
	60		14,283	10,238	262			119	18.2	
	120		13,013	9,003	239			93.4	17.1	

This experiment showed several key factors. First, in the spring following the cover crop, the nitrate-N amounts were lower. These results were expected and resulted from the cover crop utilizing the residual N contained in the soil. Second, in the unfertilized control treatment, nitrate N amounts were lower in the non-cover crop treatment than the cover crop treatment. The amount of ammonia remaining in the soil after harvest was not influenced by the cover crop. These results indicate that N mineralization was 46 kg N/ha (245-199 kg N/ha) or 23% higher in the cover crop than the non-cover crop treatment. Higher mineralization rates may be related to changes in the microbial community structure. For example in the spring of 2011, following the cover crop at Andover, the relative importance of gram negative, aerobic, and anaerobic bacteria was higher (p=0.10) in the fall cover crop than the non-cover crop treatment. These results indicate that both the cover crop and non-cover crop treatment mineralized a large amount of N, which resulted in the N fertilizer not increasing the corn yields.

Calculation based on calculated N mineralization

There are at least four fundamentally different approaches that can be used to estimate the cover crop N credit. The first approach estimates the credit based on historical values and the second approach measures the values based on yield and the amount of inorganic N contained in the soil. The second approach is discussed above. In this approach, corn grain and stover samples are analyzed for total N. This basic approach is outlines below.

$$\text{Total N uptake} = (\text{grain yield})\left(\frac{\text{N\%}}{100}\right) + (\text{Stover yeild})\left(\frac{\text{N\%}}{100}\right)$$

Calculate this for both the cover crop and non-cover crop treatments. This requires the measurement of both the grain and stover yields as well as the determination of the N contents of these materials. The total N uptake is used to calculate the N mineralization and cover crop N credit as shown below.

$$\text{N mineralization} = \text{total N utake} + \text{fall inorganic N} - \text{spring inorganic N}$$

$$\text{N credit} + \text{N min.}_{\text{cover crop}} - \text{N mineralization}_{\text{no cover crop}}$$

In the data shown in Table 1, N mineralization in the cover crop and non-cover crop treatments are 245 and 199 kg N/ha, which results in a cover crop credit of 46 kg N/ha or 41 lbs N/acre. **Using this approach the N recommendation would be 161 lbs N/acre (240-32-41).** The problem with this calculation is that it provides an end of the season recommendation.

Calculation based on estimated N mineralization

However in many on-farm studies, stover yields and the N content of the grain and stover are not measured. In addition, ammonia is typically not measured. This problem can be reduced by: 1) assuming that the harvest index is 55% [gain/(grain + stover)]; 2) the N content of grain and stover is 16.1 and 8 kg/1000 kg (1.61 and 0.8%) (Clay et al., 2012); and 3) assuming that soil ammonia is minimal (zero). Based on these assumptions, the stover yield is determined using the equation,

$$\text{Stover yield} = \frac{0.45}{0.55}\left(\text{grain yield}_{\text{dry weight}}\right)$$

Note, for these calculations, the grain yields must be converted from 15.5% moisture to dry weight. The dry weight is calculated using the equation,

$$\text{Grain yield}_{\text{dry weight}} = (1-0.155)(\text{grain yield}_{\text{15.5\% moisture,}})$$

Treatment	Grain yield 15.5% moist.	Grain yield dry weight	Estimated stover	Estimated N grain	Estimated N Stover	Plant N Grain	Plant N Stover	Plant N Total N	Soil NO3-N Pre	Soil NO3-N Post	Min N	Credit
	kg/ha	kg/ha	kg/ha	g N/g	g N/g	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha
cover	14,729	12,446	10,183	0.0161	0.0080	200	81	282	36	101	347	
												62
no-cover	12,988	10,975	8,979	0.0161	0.0080	177	72	249	48	84	285	

Based on these estimated values, the cover crop credit is calculated using the equations above. The resulting N credit is 62 kg N/ha or 55.6 lbs/acre. **For a field with a yield goal of 200 bu/acre, using this approach would result in a N recommendation of 152 lbs N/acre (240-32-56)**. It is important to point out that the resulting credit is slightly higher than the measured value. Both approaches showed that there is an N credit. It should be pointed out that these measurements should be conducted in a field that is not fertilized with N and that the credit is associated with a full season crop such as corn. Wheat would likely have a slightly lower N credit. Nitrogen uptake values can be made for crops other than corn and values for N, P, K, Mg, and S contents are available in Clay et al. (2012). The problem with this solution is that it provides a cover crop N credit after the season has been completed.

Calculation based on changes in soil nitrate-N

In South Dakota the N recommendation is based on the yield goal, soil nitrate N, and N credits [N recommendation = 1.2 ×yield goal – soil nitrate (lbsN/a) – cover crop credit]. If the field contains a non-cover crop strip, then the changes in the soil NO_3-N amount can be directly measured. In this case, nitrate N in the cover crop and non-cover crop areas were 36.1 and 48.3 kg N/ha.

$$\text{N recommendation no N credit (corn yeild goal 200 bu/acre)}$$

$$\text{N rec.} = \frac{200\text{ bu}}{\text{a}} \times \frac{1.2 lbsN}{bu} - \frac{36.1 kgN}{ha} \times \frac{1 ha}{2.47 acre} \times \frac{2.205 lbs}{1 kg} = \frac{208 lbsN}{acre}$$

$$\text{N recommendation N credit based on nitrate in no} - \text{covercrop area}$$

$$\text{N rec,} = \frac{200\text{ bu}}{\text{a}} \times \frac{1.2 lbsN}{bu} - \frac{48.3 kgN}{ha} \times \frac{1 ha}{2.47 acre} \times \frac{2.205 lbs}{1 kg} = \frac{197 lbsN}{acre}$$

In this example the N credit should be 11 lbs N/acre. **Using this approach the N rate for the cover crop field would be 197 lbs N/acre (240-32-11) and the N rate for the non-cover crop field would be 197 lbs N/acre (240-43)**. The disadvantage with this approach is that it would require a non-cover crop area.

Calculation based on N contained in the cover crop biomass

Research suggests that the cover crop biomass is rapidly mineralized. By estimating the cover crop above ground yield and N content of the biomass it should be possible to estimate the credit. If the assumption is that the biomass contains 5% N, then the credit for a dry cover crop yield of 600 kg/ha is 27 lbs/acre. **Using this approach the N recommendation would be 181 lbs N/a (240-32-27)**. The advantages with this approach are that it is based on the amount of biomass contained at the site and preseason recommendations can be calculated.

$$\text{Cover crop credit} = \frac{\text{kg biomass}}{\text{ha}} \times \frac{\text{kgN}}{1\,\text{kg biomass}} \times \frac{2.205\text{lbs}}{1\,\text{kg}} \times \frac{1\text{ha}}{2.47\,\text{acre}}$$

$$\text{Cover crop credit} = \frac{600\,\text{kg}}{\text{ha}} \times \frac{0.05\,\text{kg N}}{1\,\text{kg biomass}} \times \frac{2.205\,\text{lbs}}{1\text{kg}} \times \frac{1\text{ha}}{2.47\,\text{acre}} = \frac{26.8\,\text{lbs N}}{\text{acre}}$$

Acknowledgements

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Chapter 6: Cover crops and soil salinity
(To be published in the new Corn BMP manual)

C. Gregg Carlson (Gregg.Carlson@sdstate.edu)
David E. Clay (David.Clay@sdstate.edu)
Kurt Reitsma (Kurt.Reitsma@sdstate.edu

The purpose of this chapter is to discuss the hazards associated with salt-affected soils and to present guidelines for reducing the impacts of salts on crop production. South Dakota has many soils that are impacted by either high sodium (sodic) or high salts (saline), or by *both* high sodium and salts.

Salt problems are often discovered in low elevation areas. In the spring as the soil dries these zones may appear white. For sodic soils, extreme care must be used. High sodium has the added problem in that it can greatly reduce water infiltration. If a sodium problem is suspected, a soil sample should be collected and a water extract from that soil analyzed for Na, Ca, and Mg. Based on this value, the sodium adsorption ration (SAR) should be calculated. If the SAR is greater than **5**, the long-term goal should be to prevent further degradation.

Correct identification of the problem is critical for improving profitability and long-term sustainability. Selected guidelines are provided in Table 1

Table 1. Rules of thumb about saline and sodic soils.

Saline soils have high salts.
High levels of salts can reduce seed germination and yields

Sodic soils have high sodium.
High concentrations of sodium can result in soil dispersion.
Drainage of saline/sodic soils without the addition of Ca can make the problem worse. In South Dakota an exchangeable sodium percentage above 5% is a cause for concern.

- Different testing laboratories analyze salt-affected soils differently.
  Many soil testing laboratories use a 1:1 water to soil extract ratio, while NRCS and the United States Salinity Laboratory (where calibration of the response was initially conducted) uses the saturated paste method. Using a 1 to 1 extraction method typically results in a lower EC value than the saturated paste method. A 1:1 to saturated paste EC conversion table is shown in Table 48.2.
- Different plants have different salt tolerances.
- Saline problems can be minimized by drainage, planting deep rooted plants, using cover crops in upland position, and monitoring inputs and outputs.
- Deep rooted cover crops can reduce salt problems,
- Not all soils have the same risks. Soils that are coarse and soils that overlie shallow aquifers (less than 15 feet to the aquifer) have significantly less risk.

Salt problems, natural or man-made

Saline soils are those that contain high concentrations of soluble cations and anions (Ca^{+2}, Mg^{+2}, Na^{+1}, K^{+1}, SO_4^{-2}, NO_3^{-1}, Cl^{-1}), while sodic (Na^{+1}) soils are those that contain high concentrations of sodium. High salt concentrations can result from weathering of soil minerals or an unintended byproduct of agricultural management. Minerals that may contribute to high salt concentrations include table salt (NaCl), baking soda ($NaHCO_3$), gypsum ($CaSO_3$), and calcite ($CaCO_3$). In saline soils, seed germination or plant growth can be reduced, while in sodic soils water infiltration can be reduced and emergence of seedlings can be impaired. Saline (high salts) and sodic soils require different management practices. Salt accumulation in South Dakota soils can result from interactions among management practices that impact local hydrologic cycles and natural processes.

Soils with salt problems can result from the weathering of soil and geologic parent materials, management, or a combination of both. A generalized saline risk map is provided in Figure 1. However, salt problems are not limited to high risk areas on the map. Within a field, salt has the potential to accumulate in some areas and not others. Generally poorly drained areas have a higher potential to have higher salts than well drained areas. The lack of subsoil drainage and periods of above normal precipitation (or management that conserves water, such as summer fallowing and no tilling) often contribute to rising water tables.

When water tables rise to within several feet of the surface, ground water, through capillary rise, may be transported to the soil surface where it evaporates or is transpired. When this happens, pure water is evaporated and/or transpired leaving the salts behind. These conditions will result in elevated salt concentrations. High salt concentrations can reduce seed germination and yields. In many South Dakota fields, salt accumulation is not a problem. This is especially true if irrigation water is not applied and/or if the water table is deeper than six feet.

Saline (salts) and sodic problems can also result from irrigating with low quality (high salt content) irrigation water. When irrigation water is applied to soils, the water is used by the plants leaving the salts behind. Over a period of time these salts accumulate. These salts can reduce seed germination, plant growth, and yields. Before developing a remediation program it is important to determine if the problem is the result of high salts (saline) or high sodium (sodic soil).

Using a saline remediation program on a saline soil or vise versa produces adverse consequences:

> *In saline soils (high salts)* salts can be removed from the soil by: 1) installing tile drainage; 2) using irrigation water in excess of the plant requirement, to leach salts from the soil surface; and 3) using deep rooted cover crops to increase evaporation
>
> *In a sodium soil*, a remediation program might consist of: 1) installing tile drainage, 2) applying gypsum to the soil surface, and 3) using high quality water (low salts and sodium) to leach Na from the soil surface.

Figure 1. A map of the Northern Great Plains soils with a high risk potential for excessive soil salinity. Soils with EC> 4 dS/m constitute the high risk areas.
(Source: http://www.soilsci.ndsu.nodak.edu/DeSutter/TomDeSutter.html)

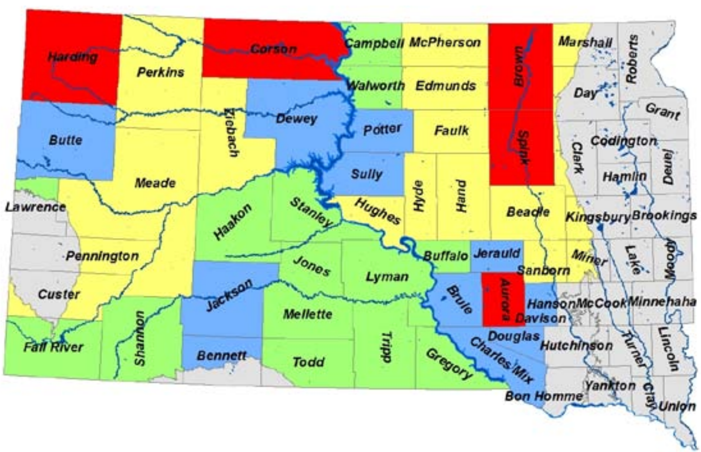

Figure 2. The percentage of sodic soils in South Dakota. In this map yellow is 10-20%, blue is 5-10%, green is 1-5%, and red is 20-30% sodium-affected soils. (Modified from Millar, 2003, http://www.sdnotill.com/Newsletters/2003_Salt_Soils.pdf)

Measurement

Many different approaches are used to measure salinity (salts). Salinity can be measured in the field with an EM meter (Geonics) or with a Veris Soil EC Mapping System. Both of the systems measure apparent EC (EC_a). Because both systems measure EC in the field, their measurements are influenced by soil water and bulk density. As the soil dries, EC_a decreases. In addition, soils with very high bulk densities or compacted layers can have very high EC_a values.

In the laboratory, EC is typically measured on water using a saturated paste extraction or a 1:1 soil/water solution. Most saline soil remediation protocols, including South Dakota, are based on saturated paste values, while most soil testing laboratories conduct a 1:1 soil/water test. A saturated paste is made by adding water to soil until it glistens and flows slightly when jarred. After allowing the mixture to equilibrate, the soil water solution is extracted by suction filtration. The electrical conductivity (dS/m) of the water is then measured.

Using a 1:1 test on saturated pasted recommendations can result in serious errors. For example, the EC of a soil sample determined by a local soil testing laboratory is 2 dS/m. Based on this value, you determine that raspberries (sensitive plant, Table 48.3) will have a minimal yield reduction. Based on this assessment you recommend that the producer plants 10 acres of pick-your-own raspberries. Two years later the producer comments to you that the raspberries died and that he (or she) planted the field with organic wheat, which did well.

The error in this assessment was that 1:1 soil test value was not converted to a saturated paste value. When converted, the 2 dS/m is converted to value ranging from 5 to 6 dS/m (Table 2). This example shows that prior to making recommendations, 1:1 EC values must be converted to saturated paste values (Table 2). According to Franzen (2007), the equations relating EC using a 1:1 soil to water extraction ratio are different for coarse (sands), medium (loams), and fine (clay) textured soils.

The equations for these soils are:

Coarse soil: $EC_{saturated\ paste} = 3.01 \times EC_{1:1} - 0.06$

Medium: $EC_{saturated\ paste} = 3.01 \times EC_{1:1} - 0.77$

Fine: $EC_{saturated\ paste} = 2.96 \times EC_{1:1} - 0.95$

Table 48.2. The relationship between EC measured using the 1:1 and saturated paste techniques. (Modified from Franzen, 2007)

	Saturated Paste EC		
EC 1:1	**Coarse (sand)**	**Medium (silt loam)**	**Fine (clay)**
dS/m		**dS/m**	
1	3	2.2	2
2	6	5.3	5
3	9	8.3	7.9
4	12	11.3	9.4
5	15	14.3	13.9

Impact on plants

Different plants have different tolerances to saline conditions (Fig. 48.3). A detailed list of plant salt tolerances is available at http://www.fao.org/DOCREP/005/Y4263E/y4263e0e.htm. A shortened list is provided in Table 48.3. Soybean is considered a moderately tolerant plant and has an EC saturated paste threshold value of 5.0 dS/m (Fig. 3; Maas, 1984). For moderately tolerant plants such as soybeans, each 1 dS/m increase above 5 dS/m results in a 20% yield loss. In addition to restricting plant growth, saline soils can restrict seed germination. Many plants have different tolerances for seed germination than for growth. For example, alfalfa has a low tolerance for seed emergence and moderate tolerance for plant growth.

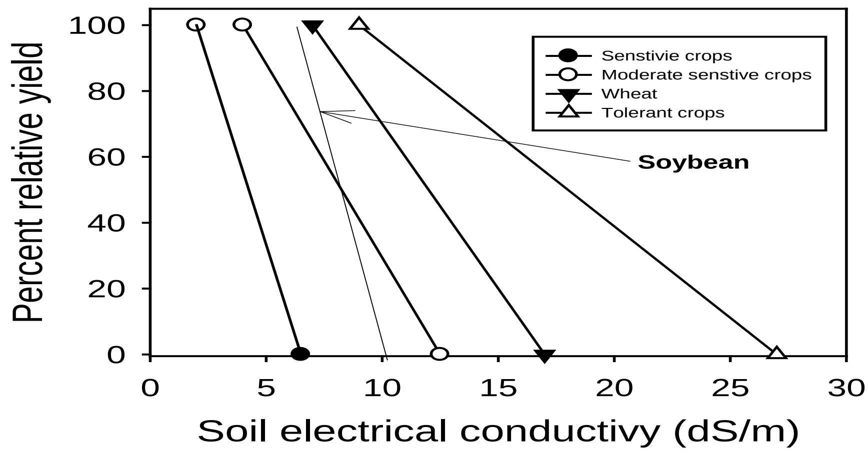

Figure 3. Relative crop yield potential as a function of soil salinity. (Developed from Data by E. V. Mass, 1984)

Table 3. A list of salt tolerances of selected plants. (Modified from Franzen, 2007)

Salt Tolerance	**Plants**			
Sensitive	Beans	Carrot	Strawberry	Onion
	Raspberry			
Moderately sensitive	Alfalfa	Corn	Flax	Cucumber
	Tomato	Lettuce	Pea	Pepper
Moderately tolerant	Oats	Sorghum	Soybean	Sunflower
	wheat	Squash		
Tolerant	Barley	Canola	Sugar beets	Durum wheat

Mapping soil salinity within a field

Several approaches can be used to assess the extent of salt problem. The first approach is targeted soils sampling. Areas that appear white as they dry often have high salt concentrations. An alternative approach is to map a field with either a Veris Technologies EC cart (http://www.veristech.com/products/soilec.aspx) or a Geonomics EM 38 (http://www.geonics.com/html/em38.html) meter. These systems measure apparent EC because the readings are sensitive to many factors including salt concentration, bulk density, and soil water content.

Salinity management: Drainage

High salinity is often a symptom of a high water table. Drainage can be used to reduce salinity risks. On average, the soil EC value will decrease 0.5 dS/m for every six inches of water that percolates through the soil.

For tile drainage to be effective, a suitable outlet for the drainage water must be available. There are many places in South Dakota where surface drainage outlets are not available. In addition, there are drainage laws that require producers to work with local authorities and USDA-NRCS. Details about tile drainage are provided in Chapter 47.

Salinity management: Cover and deep-rooted plants

In some situations, perennial deep-rooted crops, such as alfalfa, can also be used to lower the water table and reduce salinity problems. Alfalfa may not germinate in the saline area, but seeding in strips several hundred feet wide in non-saline areas just above the saline spot may be effective in reducing the water table. Seeding a salt-tolerant crop such as Tall Wheat grass or barley within a salinity pocket may also be effective in lowering the water table. Cover crops seeded in the fall may be used to reduce the water table. Lowering the water table reduces capillary rise and provides the opportunity for salts to leach.

Tillage in saline areas

In South Dakota there is a significant opportunity for salt leaching from fall, winter, and spring precipitation, assuming the water table is not close to the soil surface. Deep tillage or ripping should be used with caution because it has produced inconsistent impacts on salt concentrations. Spring tillage has the potential to reduce seed germination by moving salts leached during the fall and spring to the soil surface. For many fields with adequate natural and tile drainage, techniques that reduce surface soil evaporation, such as no-till and minimum till, have been used successfully.

Soil amendments for saline areas

A saline soil has a high concentration of total salt. The application of materials such as gypsum (calcium sulfate) **will not** resolve the salt issue. In fact, gypsum is a salt and therefore its addition may make the problem worse.

Figure 4. A sodium-affected surface soil. (Photo by Gregg Carlson)

Sodium-affected soil

Sodium (Na) is a salt that requires special attention (Figs. 2 and 4). High concentrations of sodium on the soil exchange complex when combined with low salt concentrations in the soil water solution can destroy the soil structure. Soils with high Na concentrations will be cloddy with poor infiltration. Drainage of high Na soils without adding an appropriate surface treatment ($CaCl_2$, $CaSO_4$, or elemental S) is very risking. Many tile-drained fields fall into this category. If drainage through tile lines appears to be slowing with time, you may be at risk. It is important to point out that an analysis of the tile-drained water does not provide an accurate assessment of the Na risk in the surface soil.

The sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) are two calculations used to estimate Na risk. Both calculations provide estimates of the relative amount of Na contained in the soil. Due to cost, most recommendations are based on the SAR value. If a Na problem is suspected, a soils specialist should be contacted for advice. **In dryland agriculture, the drainage of soils with sodium adsorption ratios greater than 5, without the addition of Ca or lowering the pH, can result in soil dispersion.** Sample calculations to determine the soils SAR are shown in Problem 1.

Problem 1. Sample calculations for determining SAR values.

A soil sample is sent off to a laboratory for analysis. In this analysis a saturated paste (approximately 100 g soil + 60 ml water) is made and equilibrated for 24 hours. The water is extracted by vacuum and the Na, Ca, and Mg determined. The water analysis of a soil/water saturated paste is 2136 ppm Na, 2181 ppm Mg, and 3198 ppm Ca. SAR is calculated below.

A list of laboratories that could conduct the analysis is provided in Chapter 18.

Answer to Problem 1.

Note: When doing this calculation, it is important to know that Na has a valance of +1, Ca has a valance of +2, and Mg has a valance of +2. The valances are used to convert mmol to $mmol_c$.

Step 1. Convert ppm to $mmol_c$/L. For this conversion 1ppm = 1mg/L

$$\frac{\text{Na mmol}_c}{\text{L}} = \frac{\text{2136 mg Na}}{L} \times \frac{\text{mmol Na}}{\text{23 mg Na}} \times \frac{\text{1 mmol}_c\text{ Na}}{\text{1mmol Na}} = \frac{\text{92.9 mmol}_c}{\text{L}}$$

$$\frac{\text{Mg mmol}_c}{\text{L}} = \frac{\text{2180g Mg}}{L} \times \frac{\text{mmol Mg}}{\text{24.3 mg Na}} \times \frac{\text{2 mmol}_c\text{Na}}{\text{1mmol Na}} = \frac{\text{179.3 mmol}_c}{\text{L}}$$

$$\frac{\text{Ca mmol}_c}{\text{L}} = \frac{\text{3198g Na}}{L} \times \times \frac{\text{mmol Na}}{\text{40 mg Na}} \times \frac{\text{2 mmol}_c\text{ Na}}{\text{1mmol Na}} = \frac{\text{159.9 mmol}_c}{L}$$

Step 2. Calculate SAR

$$SAR = \frac{\frac{mmol_c Na}{L}}{\left(\frac{(mmol_c Ca/L + mmol_c Mg)}{2}\right)^{0.5}} = \frac{92.9}{\left(\frac{(179+160)}{2}\right)^{0.5}} = 7.1$$

Reclamation of sodium-affected soils

As a rule of thumb, South Dakota soils should not exceed a sodium adsorption ratio (SAR) (~exchangeable sodium percent, ESP) values of 5. The reclamation of sodium soil is slow because it can take a long time to rebuild the structure. One relatively inexpensive approach to improve the soil structure is to apply low Na containing manure or to apply crop residues to these areas. The organic matter in these materials can help stabilize and improve soil structure. It must be pointed out that not all manures have low Na concentrations.

Manure from animals that have high concentrations of NaCl in their rations may not be desirable. For example, 1) distillers grains from ethanol plants may be treated with sodium chloride; and 2) swine, poultry, and beef have diets that are often supplemented with NaCl. Many animals have diets supplemented with NaCl because the plant materials do not provide enough Cl or Na to meet the animals' nutritional requirement.

A second approach is to replace the Na on the soil exchange site with calcium. For this treatment, $CaCl_2$ is often the most effective materials. However it also is very expensive. A less expensive Ca source is gypsum ($CaSO_4 \bullet 2H_2O$). **For a typical South Dakota soil with a cation exchange capacity (CEC) of 25 $cmol_c$/kg and a SAR value of 12, a one-ton application of gypsum per acre would be needed to lower the SAR value of the surface 6 inches to 8.** To lower the SAR value to 4, about 2 ton/acre of gypsum are needed. For this calculation, the CEC can be estimated from the organic matter and clay contents of the soil (Fig. 48.6). Sample calculations are below:

Figure 6. A soil contains 3% organic matter and 20% smectite clay. What is its estimated cation exchange capacity (Clay et al., 2011)?

Soil component	CEC
Organic matter	$\frac{200\ cmol_c}{kg\ soil}$
Smectite clay	$\frac{100\ cmol_c}{kg\ soil}$

$$\text{Cation Exchange Capacity} = \frac{\%\ clay}{100} \times CEC_{clay} + \frac{\%\ \text{Organic matter}}{100} \times CEC_{\text{organic matter}}$$

$$\text{Cation Exchange Capacity} = \frac{20\%}{100\%} \times \frac{100 cmol_c}{kg} + \frac{3\%}{100\%} \times \frac{200 cmol_c}{kg} = 26 cmol_c/kg = 26 mmol_c/100g$$

Calcium can also be released by lowering the pH. The soil pH can be lowered by adding elemental sulfur. To increase the effectiveness of elemental S it should be mixed into the soil. The amount of S that needs to be applied can be calculated from data provided in Table 4. To displace the Na from the soil exchange site, good quality water must be added.

Table 4. Relative amount of different soil amendments needed to reduce Na on the exchange site. Rates for alternative substances determined by taking recommended amount of Gypsum times base amount of alternate substance.

Recommended Amount of Gypsum tons/acre	Amount of $CaCl_2$ tons/acre instead of Gypsum	Amount of Elemental S tons/acre instead of Gypsum	Amount of Aluminum sulfate tons/acre instead of Gypsum
1.00	0.85 (base)	0.19 (base)	1.29 (base)
1.5	1.28	0.29	1.94
2.0	1.7	0.38	2.58

Summary

Saline (high total salts) and sodic (high sodium) must be managed differently. In managing saline and sodic soils care must be used to prevent further degradation.

In saline soils, recommended practices include:

- Collect soil and water samples to identify the scope and magnitude of the problem.
- Analyze the soil samples for both EC and SAR.
- Convert 1:1 EC values to saturated paste values (Table 48.2).
- Track changes in EC and SAR over time.
- Seed salt tolerant plants.
- Use cover crops.
- Treat soil with crop residues to increase water infiltration.
- Eliminate sources of new salt.
- Use practices that reduce surface evaporation.
- Provide subsurface drainage.

In sodic soils, recommended practices include:

- Collect soil and water samples to identify the scope and magnitude of the problem.
- Analyze the soil samples for EC and SAR.
- Track changes in EC and SAR over time.
- Seed full season, deep-rooted plants, and cover crops where feasible,
- Eliminate sources of new Na.
- Use practices that reduce surface evaporation.
- Minimize the use of tillage which brings Na to the soil surface and reduces residue cover.
- Eliminate fallow.
- Apply crop residues to increase infiltration.

- Provide subsurface drainage and treat with a Ca source such as gypsum.

Salt problems are often discovered in low elevation areas. In the spring as the soil dries, these zones may appear white. The transport of salt and water to low elevation areas can be reduced by using fall cover crops in upland areas. As the water evaporates at the soil surface it is replaced by more water from the water table. The net result is an accumulation of salts. This net gain of salts can be reduced by installing tile drainage; planting full season, deep-rooted plants; using cover crops, and eliminate fallow. The most important management consideration for these areas is to maximize transpiration and minimize evaporation (Franzen, 2007).

For sodic soils, extreme care must be used. High sodium has the added problem in that it can greatly reduce water infiltration. If a sodium problem is suspected, a soil sample should be collected and a water extract from that soil analyzed for Na, Ca, and Mg. Based on this value, the SAR should be calculated. If sodium is a problem, the SAR is greater than 5-8, then a long-term goal should be to prevent further degradation. This can be accomplished by tracking changes in the EC and SAR values of the soil, installing tile drainage, adding low Na manure or gypsum, or lowering the pH (if the soil pH is high) with elemental S. If drainage and soil amendments are not possible, consider placing the field into pasture and planting it with salt-tolerant grasses.

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Chapter 7: SD and ND Demonstration studies

South Dakota Sites, 2009-2012

Table 1. Research sites proposed and work completed.

In proposal				Work completed.	
Sites / Experiments	Cycle Year			South Dakota	North Dakota
Year 1	2009-2010	3 new sites		5 sites	2 sites
Year 2	2010-2011	3 new sites		5 sites	2 sites
Year 3 (not required by grant)	2011-2012	3 new sites		4 sites	1 site

In South Dakota, cover crop treatments were placed in the field at Andover, Gettysburg, and Ideal in fall 2009; Andover and Trail City, 2010 and 2011. In South Dakota the plots were located in MLRA 55B (Andover, SD, 2009-2012); MLRA 54 (Trail City, SD, 2010-2012); MLRA 63B (Ideal, SD 2009-2010); and MLRA 53C (Gettysburg, SD 2009-2010), while in North Dakota cover crop demonstration studies were established in North Dakota at Pingree (MLRA 55B) and McKenzie (MLRA 53B) in 2009-2011; at Mandan (Morton County, MLRA 54) and Jamestown (MLRA 55B) in 2010-2011; and at Pingree in 2011-2012 (Table 2, Figure 1 & 2).

Table 2. Geographic locations for South Dakota study sites Gettysburg, Ideal, Andover, Trail City, and Aurora, SD.

Geographical Location	Research Period	Field Location
Gettysburg	2009-2010	44°59'13"N, 100°06'14"W
Ideal	2009-2010	43°32'26"N, 99°54'15"W
Andover	2009-2010	44°22'29"N, 97°58'46"W
	2010-2011	45°27'41"N, 97°57'49"W
	2011-2012	45°22'47"N, 97°57'49"W
Trail City	2010-2011	45°33'19"N, 100°49'42"W
	2011-2012	45°33'19"N, 100°50'25"W
Aurora	2010-2011	44°18'20"N, 96°40'12"W
	2011-2012	44°18'18"N, 96°40'24"W

Table 3. Geographic locations for North Dakota study sites Pingree, McKenzie, Morton County, and Jamestown, ND.

Geographical Location	Research Period	Field Location
Pingree	2009-2010	47°07'49"N, 98°52'06"W
McKenzie		46°47'21"N, 100°21'13"W
Mandan Site	2010-2011	47°39'59"N, 100°44'45"W
Jamestown		47°47'32"N, 98°47'16"W
Pingree		47°07'49"N, 98°52'06"W

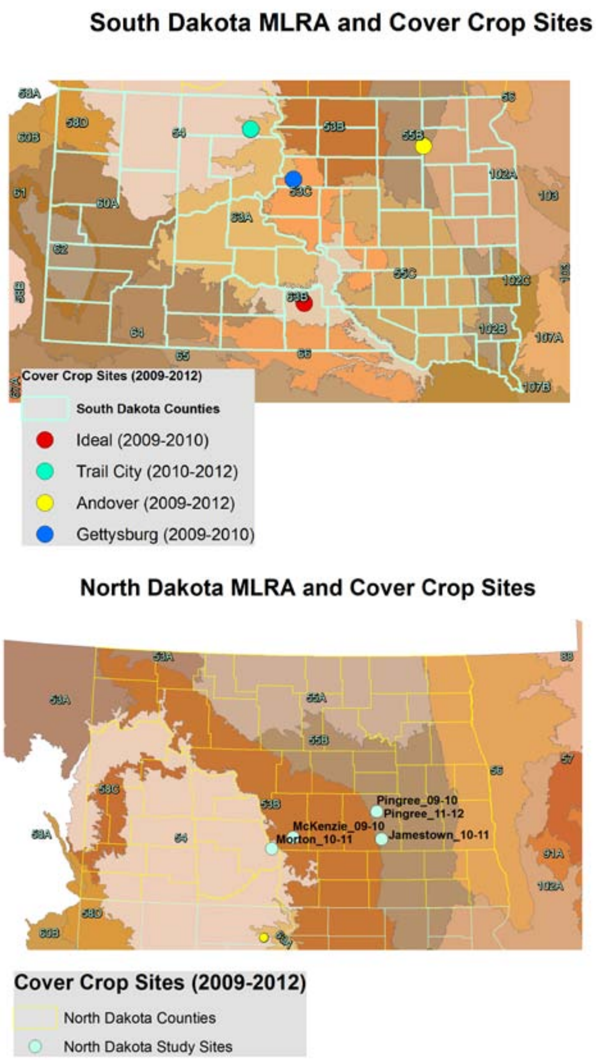


Figure 1. Cover crop sites in South Dakota and North Dakota.

In South Dakota, demonstration studies were established at summit and footslope areas (Figure 2). Saline plots were established at the Andover site in 2009-2010 and 2010-2011. Exact geographic locations for South Dakota sites are provided in Table 3. In 2009, wheat was harvested exceptionally late and cover crops were not planted until September. These cover crops germinated very late at the Gettysburg and Ideal sites. In 2010, Ideal and Gettysburg sites were very dry and the in-season cover crop planted germinated but died during the growing season. Demonstration studies in 2010 were concentrated at the Andover and Trail City sites.

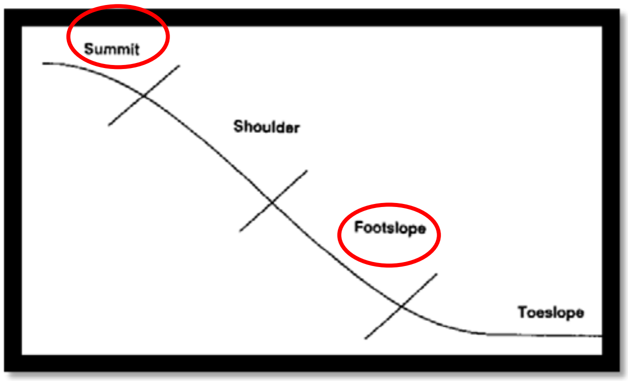


Figure 2. Demonstration studies located at summit and footslope or toeslope positions in South Dakota farmer fields.

SD Plot Design and Treatments.

At the South Dakota Andover, Trail City, Gettysburg, and Ideal sites a randomized split-plot design was used with cover crop as the main treatment and N-rates randomized within each plot. The cover crop treatments were planted at two times; either in the fall; the following summer; or both the fall and following summer (Table 4 & 5). Nitrogen rates were applied in May at 0, 30, 60, and 120 lbs-N A^{-1} (0, 34, 67, and 134 kg-N ha^{-1}). Fall cover crop cover crop species seeding rates by locations and year are provided in Table 5, September 2009; Table 6, August 2010; and Table 7, August 2011. Related information from these sites are provided in Table 4 – 9.

Table 4. Cover crop treatments at the South Dakota Andover, Trail City, Gettysburg, and Ideal sites. In some treatments, cover crops were planted twice; once in the fall and then again the following summer (June).

		Cover Crop Seeding Time	
Cover Crop Treatments	Number of Cover Crop Seeding Times	Fall, Seeded into Wheat Stubble	Following June, Seeded into Corn at V6
No Cover Crop	0		
Fall cover crop	1	X	
In-season cover crop (V5-6 drill)	1		X
Fall CC and V5-6 (Drilled)	2	X	X
V5-6 Broadcast	1		X
FallCC and V5-6 (Broadcast seeded)	2	X	X

Table 5. South Dakota fall 2009 cover crop seeding rates and locations.

	Plant Date	Radish	Chickling Vetch	Winter Canola	Sugarbeets	Lentils	Oats	Cowpeas	Turnips	Grain Millet	Hairy Vetch
		Fall 2009 Cover Crop Rates (lbs/ A)									
Andover Summit	9/9/09	3	20	2							
Andover Footslope	9/9/09	3	20	2							
Andover Saline	9/2/09			4	3						
Gettysburg	8/27/09					15	35				
Ideal	8/24/09	1						5	1	3	1

Table 6. South Dakota fall 2010 cover crop seeding rates and locations. Fall cover crop rates.

	Plant Date	Daikon Radish	Winter Canola	Purple Top Turnip	Sugar Beets	Barley	Sunflower	Indian Head Lentils	Peas	Millet (proso and golden german)	Volunteer Wheat
		Fall 2010 Cover Crop Rates (lbs/A)									
Andover, SD Summit and Footslope	8/17/2010	2	3	2							x
Andover, SD Saline	8/18/2010				2	30	2				x
Trail City, SD Summit and Footslope	8/16/2010	1.75		1.75				8	8	2.5	x

Table 7. South Dakota fall 2011 cover crop seeding rates and locations.

	Plant Date	Daikon Radish	Purple Top Turnip	Dwarf Essex Rape	Indian Head Lentils	Peas	Millet (proso and golden german)	Volunteer Wheat
		Fall 2011 Cover Crop Rates (lbs/A)						
Andover, SD Summit and Footslope	8/20/2011	4						x
Trail City, SD Summit and Footslope	8/9/2011	2	1	1	8	9	3	x

South Dakota cover crops seeded into corn at V6 corn growth stage:

Cover crop species and seeding rates for cover crops either drilled or broadcast into corn at the corn growth stage V5-V6 are provided in Table 8. A mixture of lentils, winter wheat, and crimson clover was seeded. Lentils and crimson clover were used as legume N sources. Winter wheat has a high C:N ratio and was intended to balance the low C:N ratio of the legumes. Due to crimson clovers shade tolerance, it was used for in-season cover crops. Sugar beets and barley were planted in saline areas in Andover 2010 and 2011. The in-season cover crops did germinate in 2010 but did not germinate in 2011.

Table 8. Soil type at the different South Dakota sites.

Research Site Location	Year	Soil Description
Andover	2010	Forman-Aastad Loams, 1 to 6 percent slopes (fine-loamy, mixed, frigid, Udic Argiborolls)
	2011	Forman-Buse-Aastad loams, 1 to 6 percent slopes (fine-loamy, mixed, frigid Udic Argiborolls)
Trail City	2012	Kranzburg-Brookings silt loams, 0 to 2 percent slopes (fine-silty, mixed, frigid Udic Haploborolls)
	2011 and 2012	Reeder loam, 2 to 6 percent slopes (fine-loamy, mixed, frigid Typic Argiborolls)
Aurora	2011 and 2012	Brandt silty clay loam, 0 to 2 percent slopes (fine-silty, mixed, frigid Udic Haploborrols)

Table 9. Data collected Andover, Trail City, and Aurora sites.

Activity	Fall 1	Spring 2	Summer 2 (120 N rate)	Fall 2
Soil moisture	X	X		X
Soil NO3-N and NH4-N	X	X		X
Water infiltration		X		
Cover crop biomass	X		X	X
Microbial community analysis		X		X
Weed biomass				X
Yield Grain				X
Stover Biomass				X
Corn RNA sequencing			X	

Table 10. In-season cover crop (lbs A-1) treatments in South Dakota.

Cover Crops Inter-seeded in Corn at V5-V6					
	Lentils	Winter Wheat	Crimson Clover	Sugar Beets	Barley
	lbs/ A				
Summit and Footslope areas at Andover, Trail City, Gettysburg, & Ideal. Aurora V3 and V5 seeding.	11	10	6		
Saline (Andover June 2010 and 2011)				4	30

At Aurora South Dakota, targeted research was conducted. This work assessed in-season cover crop planting date. The results of the in-season study are summarized in Bich (2013). Conclusions from this research were: 1) establishment of cover crops into standing corn was successful at the V3 and V5 growth stages; 2) crimson clover and winter wheat were the most prolific species and winter wheat had poor germination; 3) cover crops seeded using a drill produced more biomass than the cover crops broadcast on the soil surface; 4) inter-seeded cover crops were shown to reduce grass weeds, but had no impact on broadleaf weeds; and 5) interseeded cover crops did not reduce corn yields at the V5 corn growth stage, but did reduce yields when drilled into corn at V3.

Water Infiltration Studies South Dakota

Cornell sprinkle infiltrometer data was collected from Andover, June 2011 and May 2012 (Figures 13 and 14; Tables 20 and 21. The Andover site was selected to collect rainfall infiltration data. This unit can be used to collect time-to-runoff, sorptivity, and field saturated infiltrablity (Figures 3 and 4). In spring 2011 and 2012 Fall cover crop and no-cover crop treatments were compared.

Figure 3. Cornell sprinkle infiltrometer field set up.

Figure 4. Rainfall pattern from a Cornell sprinkle infiltrometer.

Water runoff rate, infiltration, and sorptivity were not affected by cover crop treatment in June 2011 (Table 11). These parameters were also similar between landscape position, summit and footslope. The fall of 2010 and the winter of 2010-2011 received above average rainfall in South Dakota. For example, at the Andover site from September 1st to November 17th, 2010, the 30 year average rainfall for this site is 3.5 inches. During this time, 5 inches of rainfall occurred which was 42% above normal. The above average rainfall may explain why no differences were observed in water runoff or infiltration rates at the significance level of alpha (α) = 0.05. However, the p value was 0.30 (summit) and 0.26 (footslope) for runoff rate. The runoff rate at the summit was 6.2 inches hr^{-1} where no cover crop was planted in the fall as compared to 4.6 inches hr^{-1} when a fall cover crop was planted (Table 20). This would suggest that at 70% of the time, in this study that water runoff was reduced and water infiltration rate increased in the spring when cover crops were planted the previous fall.

Fall 2011, winter 2012, and spring 2012 was dry in South Dakota. When infiltration and runoff rates were tested at Andover in May 2012, the infiltration rate (6.7 inches $hr^{-1)}$ was significantly higher when a fall cover crop was planted in 2011 as compared to no fall 2011 cover crop, 2.8 inches hr^{-1} at the summit position (Table 12).

Table 11. Rainfall rate, runoff rate, infiltration rate, and sorptivity collected in June 2011 at Andover for cover crops planted in fall 2010.

Landscape Position	June 2011 Cornell Sprinkle Infiltrometer			
Summit	rainfall rate	runoff rate	infiltration rate	Sorptivity
Cover Crop Treatment	Inch water $hour^{-1}$			Inch of water
No CC	11.6	6.2	4.0	0.55
Fall CC	11.4	4.6	4.6	0.68
P value	0.87	0.30	0.55	0.15
Footslope				
No CC	9.5	6.1	3.4	0.60
Fall CC	9.2	5.0	4.1	0.61
P Value	0.70	0.26	0.31	0.94

Table 12. Rainfall rate, runoff rate, infiltration rate, and sorptivity collected in May 2012 at Andover for cover crops planted in fall 2011.

Landscape Position	May 2012 Cornell Sprinkle Infiltrometer			
Summit	rainfall rate	runoff rate	infiltration rate	Sorptivity
Cover Crop Treatment	Inch water $hour^{-1}$			Inch of water
No CC	8.1	5.3	2.8	0.57
Fall CC	7.9	1.2	6.7	0.82
P value	0.93	0.14	0.02	0.20
Footslope				
No CC	4.7	3.6	1.1	0.29
Fall CC	4.3	2.7	1.5	0.32
P Value	0.44	0.45	0.60	0.50

South Dakota soil community structure.

Phospholipid-derived fatty acid analysis (PLFA) examines the basic composition of phospholipids of organisms (Fig. 5). Taxa of organisms have different signatures of lipids that compose cell membranes. PLFA analysis has become a 'biomarker' tool to characterize soil microbial ecology based on the differentiation that occurs between taxa and lipid cell membrane composition. Cell membrane phospholipids can be divided into different categories including saturated, unsaturated, or mixed. A saturated lipid has a single bond between all CH_2 groups in the fatty acid (x-CH_2-CH_2-etc). An unsaturated lipid has at least one (monounsaturated) or more (polyunsaturated) bonds between the CH_2 groups (CH2-CH=CH-CH_2).

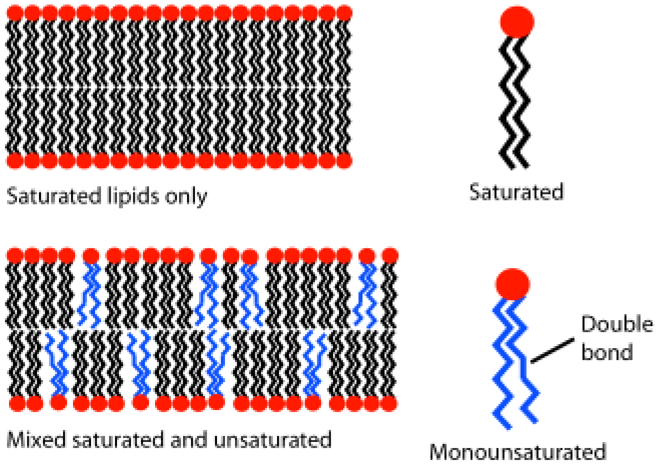


Figure 5. Saturated vs. unsaturated phospholipids (from http://en.wikipedia.org/wiki/Lipid_bilayer).

In soils, the Phospholipid fatty acids biomarkers can be used to characterize microbial community into : (1) saturated fatty acids (gram-positive bacteria and actinomycetes); (2) monounsaturated fatty acids(gram-negative bacteria and arbuscular mycorrhizal fungi); (3) polyunsaturated fatty acids (protozoa and ectomycorrhizal fungi); (4) cyclopropane fatty acids (gram-negative bacteria); and (5) dimethyl acetal marker (anaerobic bacteria) (Table 13).

Table 13. PLFA biomarker summary and associated soil microbial communities.

	Biomarkers, PLFA					
	Bacteria				Fungi	
	Gram-positive bacteria	Gram-negative bacteria	Actino-mycetes	Anaerobic bacteria	Arbuscular mycorrhizal fungi	Ecto-mycorrhizal fungi
Saturated fatty acids	x		x			
Monounsaturated fatty acids		x			x	
Polyunsaturated fatty acids						x
Cyclopropane fatty acids (?)		x				
Dimethyl acetal (?)				x		

Gram-positive bacteria in the soil include actinomycetes and some species of some nitrogen fixing bacteria (*Frankia*). These bacteria are often associated with the Rhizosphere. Gram-negative bacteria are also associated with the rhizosphere. These bacteria may improve plant growth by increasing soil phosphate solubility and increasing iron uptake.

Actinomycetes are common in soils and active in organic matter decomposition and humus formation. When soils are freshly tilled in the spring, these bacteria are responsible for the ‘earthy’ smell of soils. Some species of these bacteria form filamentous structures that mimic fungi hyphae structure.   Bacteria that form these structures may assist plants with soil nutrient uptake. Anaerobic bacteria thrive under soils that have excessive moisture and ‘waterlogged’ characteristics. These bacteria can also be found at deeper soil depths under low soil atmospheric oxygen conditions. Arbuscular mycorrhizal fungi (AMF) penetrate the root cortical cell walls and typically form a symbiotic relationship (Fig. 6), whereas ectomycorrhizal fungi do not penetrate the root cell walls. Ectomycorrhizal fungi grow on the surface of roots and are commonly associated with trees. These fungi are important for nutrient absorption by trees and some grapes. The fungus forms a sheath that penetrates between the plant cells but does not invade the root.

The fungi form hyphae structures adjacent to plant cell membranes. The symbiotic relationship exchanges phosphorus, nitrogen, and minerals (fungus to plant) to photosynthetic derived sugars (plant to fungus). These are obligate symbiotic fungi meaning that they are not free-living in the soil

Figure 6. Mycorrhizae associated with plant roots. (From http://www.annualreviews.org/doi/pdf/10.1146/annurev.micro.091208.073504, need to get permission to use in formal publication)

Soil samples analyzed using the PLFA procedure in this report was collected from the Andover and Trail City sites. The PLFA analyses of spring Trail City soils   suggest that the anaerobic bacteria mole percentages were greater at the footslope as compared to the summit. The fall cover crop was not observed to impact the PLFA mole percentages (Table 14).

Table 14. PLFA analysis results from the spring (5.11/2011) soil samples at Trail City South Dakota.

Landscape Position		Trail City, SD Site, Soil sample collected on 5/11/2011										
		Biomass	Total Bacteria	Total Fungi	Bacteria to Fungi Ratio	Gram-negative Bacteria	Gram-positive Bacteria	Aerobic Bacteria	Anaerobic Bacteria	Mycorrhizae	Saturated to Monounsaturated Ratio	Monounsaturated
Elevation		$mg\ C\ g^{-1}$	Mole %		--			Mole %			--	Mole %
Footslope		402	0.385	0.060	6.9	0.214	0.171	0.385	0.213	0.060	25.8	0.436
Summit		281	0.355	0.057	7.1	0.189	0.166	0.355	0.181	0.052	36.0	0.520
P value		0.07	0.11	0.83	0.88	0.10	0.66	0.11	0.05	0.38	0.36	0.04
Cover Crop												
No CC		312	0.363	0.060	6.64	0.195	0.168	0.363	0.191	0.060	32.7	0.485
FallCC		371	0.377	0.056	7.32	0.208	0.169	0.377	0.203	0.051	29.1	0.472
P Value		0.35	0.44	0.71	0.56	0.38	0.95	0.44	0.45	0.29	0.74	0.74
Elevation x	Cover Crop											
Footslope	No CC	342	0.373	0.066	6.24	0.204	0.170	0.373	0.203	0.066	31.0	0.453
	FallCC	461	0.397	0.054	7.56	0.224	0.172	0.397	0.223	0.054	20.6	0.420
Summit	No CC	282	0.353	0.055	7.05	0.186	0.167	0.353	0.180	0.055	34.4	0.517
	FallCC	280	0.357	0.059	7.09	0.192	0.166	0.357	0.183	0.048	37.6	0.524
P Value		0.34	0.59	0.48	0.58	0.63	0.85	0.59	0.59	0.79	0.54	0.60
Trail City May 11th, 2011												

Table 15. PLFA analysis results of fall (11/11/2012) soil at Trail City South Dakota.

Landscape Position		Trail City, SD Site, Soil sample collected on 11/11/2011										
		Biomass	Total Bacteria	Total Fungi	Bacteria to Fungi Ratio	Gram-negative Bacteria	Gram-positive Bacteria	Aerobic Bacteria	Anaerobic Bacteria	Mycorrhizae	Saturated to Monounsaturated Ratio	Monounsaturated
Elevation		$mg\ C\ g^{-1}$	Mole %		--			Mole %			--	Mole %
Footslope		161	0.274	0.029	10.3	0.198	0.076	0.274	0.198	0.027	25.4	0.770
Summit		184	0.305	0.044	7.4	0.203	0.102	0.305	0.203	0.044	70.7	0.705
P value		0.37	0.06	0.02	0.01	0.65	0.02	0.06	0.65	0.00	0.03	0.21
Cover Crop												
No CC		178	0.319	0.038	8.72	0.218	0.101	0.319	0.218	0.038	69.3	0.699
FallCC		188	0.281	0.040	8.25	0.190	0.092	0.281	0.190	0.037	39.6	0.729
CCV5-6		152	0.274	0.034	9.33	0.197	0.077	0.274	0.197	0.034	42.9	0.777
P Value		0.47	0.08	0.69	0.56	0.12	0.20	0.08	0.12	0.81	0.42	0.47
Elevation x	Cover Crop											
Footslope	No CC	192	0.321	0.033	9.90	0.221	0.101	0.321	0.221	0.033	71.0	0.679
	FallCC	164	0.267	0.033	9.39	0.192	0.075	0.267	0.192	0.028	10.4	0.772
	CCV5-6	127	0.235	0.020	11.92	0.184	0.050	0.235	0.184	0.020	0.0	0.859
Summit	No CC	168	0.317	0.041	7.85	0.216	0.101	0.317	0.216	0.041	68.1	0.715
	FallCC	213	0.295	0.046	7.10	0.187	0.108	0.295	0.187	0.046	68.9	0.687
	CCV5-6	172	0.304	0.045	7.39	0.207	0.097	0.304	0.207	0.045	75.1	0.715
P Value		0.44	0.22	0.52	0.54	0.52	0.23	0.22	0.52	0.42	0.23	0.37
Trail City Nov. 11th, 2011												

Laboratory analysis of Trail City soil collected in November, 11th, 2011 (Table 15) showed that elevation and cover crop treatments impacted PLFA mole percentages. However, no differences observed in anaerobic bacteria between summit and footslope. This is expected since it stopped raining in July 2011 this year. Mycorrhizae fungi mole percentages were also higher in the summit than footslope soils. This was also true at Andover site in the fall. The mole percentages of bacteria were higher in no-cover than the 2011 fall cover crop .

In 2011 at Andover differences were noted in landscape positions (Table 16). Bacteria and anaerobic bacteria signatures are greater at the footslope. Mycorrhizae mole percentages are higher at summit. Treatments with a fall 2011 cover crop in fall 2011 had higher mole percentage of bacteria than treatments without the cover crop. At Andover in 2011, landscape differences in PLFA microbial signatures were observed (Table 17). The bacteria to fungi ratio were higher in the footslope than the summit, while the saturated to mono-saturated ratio was lower in the summit than the footslope position.

Table 16. PLFA analysis results from the spring (5/01/2011) soils at Andover South Dakota.

Landscape Position		Andover, SD Site, Soil sample collected on 5/1/2011										
		Biomass	Total Bacteria	Total Fungi	Bacteria to Fungi Ratio	Gram-negative Bacteria	Gram-positive Bacteria	Aerobic Bacteria	Anaerobic Bacteria	Mycorrhizae	Saturated to Monounsaturated Ratio	Monounsaturated
Elevation		mg C g^{-1}	Mole %		--			Mole %			--	Mole %
Footslope		378	0.291	0.070	4.8	0.174	0.117	0.291	0.174	0.053	35.7	0.498
Summit		213	0.190	0.108	1.8	0.076	0.114	0.190	0.076	0.077	32.9	0.633
P value		0.14	0.00	0.00	0.01	0.00	0.83	0.00	0.00	0.01	0.71	0.08
Cover Crop												
No CC		339	0.210	0.091	2.54	0.100	0.110	0.210	0.100	0.068	31.8	0.542
FallCC		252	0.271	0.086	4.07	0.150	0.121	0.271	0.150	0.062	36.7	0.589
P Value		0.31	0.09	0.91	0.26	0.09	0.35	0.09	0.09	0.81	0.56	0.35
Elevation x	Cover Crop											
Footslope	No CC	506	0.258	0.078	3.58	0.144	0.115	0.258	0.144	0.061	25.0	0.449
	FallCC	281	0.315	0.063	5.68	0.197	0.119	0.315	0.197	0.046	43.7	0.534
Summit	No CC	214	0.174	0.100	1.75	0.067	0.107	0.174	0.067	0.073	36.9	0.611
	FallCC	213	0.212	0.117	1.92	0.087	0.125	0.212	0.087	0.083	27.5	0.662
P Value		0.31	0.71	0.14	0.33	0.40	0.54	0.71	0.40	0.16	0.09	0.81

Andover, May 1st 2011

Table 17. PLFA analysis results from the fall (11/07/2011) soil samples at Andover.

Landscape Position		Andover, SD Site, Soil sample collected on 11/7/2011										
		Biomass	Total Bacteria	Total Fungi	Bacteria to Fungi Ratio	Gram-negative Bacteria	Gram-positive Bacteria	Aerobic Bacteria	Anaerobic Bacteria	Mycorrhizae	Saturated to Monounsaturated Ratio	Monounsaturated
Elevation		mg C g^{-1}	Mole %		--			Mole %			--	Mole %
Footslope		215	0.238	0.034	9.0	0.118	0.121	0.238	0.116	0.034	49.0	0.640
Summit		372	0.223	0.101	2.6	0.083	0.139	0.222	0.079	0.097	21.1	0.494
P value		0.01	0.48	0.00	0.00	0.01	0.20	0.45	0.01	0.00	0.01	0.02
Cover Crop												
No CC		319	0.225	0.067	5.65	0.087	0.138	0.224	0.084	0.064	36.2	0.533
FallCC		323	0.224	0.069	5.75	0.106	0.117	0.223	0.103	0.069	34.1	0.528
CCV5-6		235	0.244	0.067	5.94	0.109	0.135	0.244	0.107	0.064	34.6	0.644
P Value		0.23	0.73	0.93	0.95	0.26	0.37	0.70	0.23	0.97	0.95	0.28
Elevation x	Cover Crop											
Footslope	No CC	234	0.214	0.037	8.77	0.097	0.118	0.214	0.094	0.037	57.0	0.610
	FallCC	240	0.242	0.028	9.66	0.119	0.123	0.242	0.119	0.028	42.5	0.590
	CCV5-6	178	0.260	0.035	8.70	0.137	0.123	0.260	0.135	0.035	45.8	0.708
Summit	No CC	404	0.237	0.097	2.54	0.078	0.157	0.235	0.074	0.092	15.4	0.457
	FallCC	386	0.211	0.099	2.83	0.097	0.112	0.209	0.092	0.099	27.8	0.482
	CCV5-6	311	0.223	0.109	2.26	0.071	0.152	0.223	0.069	0.103	19.8	0.559
P Value		0.91	0.44	0.93	0.99	0.21	0.34	0.45	0.25	0.91	0.54	0.94

Andover Nov. 7, 2011

North Dakota Sites, 2009-2012: Site Background and Plot Design

Cover crop treatments were established at Pingree, ND on August 6th, 2009. Two treatments, fall cover crop or no cover crop were established. The fall cover crop seeded were blue lupine, lentils, grazer corn, sorghum sudan grass, turnips, and faba bean (Table 17 and 18). Corn was not harvested at the Pingree, because the landowner accidently chopped the site for silage. Two treatments were established at McKenzie ND in fall 2009, fall cover crop or no fall cover crop. The fall cover crop seeded on September 10th, 2009. The cover crop mixture was composed of winter peas, lentils, turnips, radish, sunflower, red clover, rapeseed, and ryegrass. Corn yields in the following year were measured (Table 19).

Table 17. Cover crops seeded at Pingree, ND in fall 2009.

Pingree	lb/ac
Blue Lupin	40
Lentil	55
Grazer Corn	20
Sorghum Sudan Grass	20
Turnips	4
Faba Bean	180
Planted 8-6-09	

Table 18. Cover crops seeded at McKenzie, ND in fall 2009.

McKenzie	lb/ac
Winter Pea	32.5
Rosetown Lentil	10
Turnip	1
Radish	2
Sunflower	2
Red Clover	1
Rapeseed	1
Ryegrass	3
Planted 9-10-09	

Table 19. Corn yield at McKenzie, ND harvested on 10/13/10.

	Corn Yield		
Cover Crop Treatments	bu A^{-1}	kg ha^{-1}	Mg ha^{-1}
Fall Cover Crop	73	4581	4.6
No Cover Crop	77	4832	4.8
P Value	NS	NS	NS
Field Position			
Summit	70	4393	4.4
Toeslope	80	5020	5.0
P Value	NS	NS	NS

North Dakota 2010 – 2011 Sites

Due to heavy precipitation, the 2010 – 2011 growing season in North Dakota was very difficult. The Morton site was seeded late (October 4, 2010) to a field previously seeded to flax. At this site, the cover crop mixture was Austrian winter peas and 'Bobcat' winter triticale was seed on 10-4-2010. The plants were slow to grow because due to cold October temperatures. The Mandan site was seeded both fall 2010 and in-season 2011. In the fall of 2010, no fall cover crop biomass was collected due o late planting and blizzard on October 30th. In June 2011, black lentils, radish, and turnips were inter-seeded into the corn at corn growth stage V5. However, a summer hail torm destroyed the corn crop at Mandan. The Jamestown site in 2010-2011was established in the corner of a wheat field that had been no-tilled for 9 years. Treatments were either (1) fall cover crop or (2) no cover crop. The fall cover crop mixture consisted of Austrian Winter Peas and Bobcat winter triticale that was planted on 8-17-10 (Table 20). Biomass samples were harvested on 10-15-10 (Table 21). Cover crop biomass decreased from summit to toeslope positions (Table 22). However, due to record snow fall and spring rains this site was not planted in May 2011 (Fig. 7)

Table 20. Cover crop planting at Mandan, ND site, fall 2010.

Mandan (Morton County), ND	Lbs A^{-1}
Austrian Winter Peas	40
Bobcat Winter Triticale	53
Planted 10-4-2010	

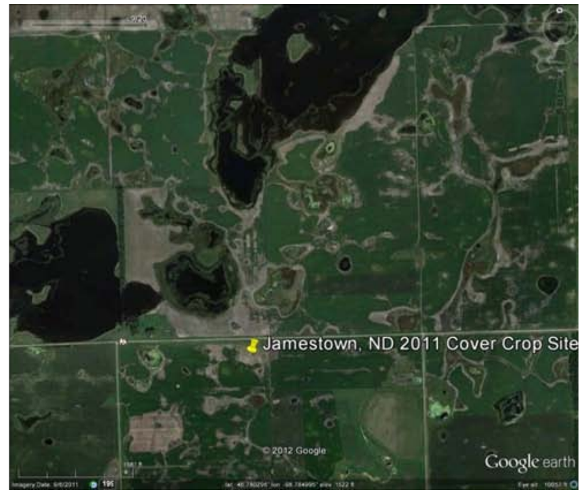
Table 21. Cover crop planted at Jamestown in August 2010.

Jamestown, ND	Lbs A^{-1}
Austrian Winter Peas	40
Bobcat Winter Triticale	53
Planted 8-17-10	

Table 22. Biomass at Jamestown, ND site collected on 10/15/2010.

Cover Crop Biomass (kg ha^{-1})			
	Summit	Midslope	Toeslope
Sample 1	1189	900	467
Sample 2	1633	800	278
Sample 3	1367	344	211

(A)



(B)

Figure 7A and B. Cover crop research site in North Dakota, June 2009 (A) and September 2011 (B). Note size increase in wetland / small lake area north of the study site from 2009 to 2011.

North Dakota 2011 – 2012 and 2012-2013 Sites

A study was established in spring 2012 near Pingree, ND. The field had a cover crop in the fall of 2012. However, germination was poor. In-season cover crops were seeded on May 10th 2012. The four in-season treatments were (1) check; (2) clover alone; (3) fertilizer N, and (4) fertilizer N and clover. The experimental design was a randomized block with 4 replications. However the plot area was mowed prior to harvest.

In 2012-2013 the experiment was repeated at Pingree. The treatments were: 1) ingree were: 1) full season cover crop (2012) followed by no-till corn with fertilizer (2013); 2) full season cover crop (2012) followed by no-till corn without fertilizer (2013); 3) no-till Wheat no-cover crop (2012) followed by no-till corn with fertilizer (2013); and 4) no-till Wheat no-cover crop (2012) followed by no-till corn without fertilizer.
The experimental design was a randomized complete block with either 3 or 4 blocks. Data collected from the plots include T plant population, height, yield, and test weight.

Trail City SD 2010-2011 Case Study Data

Fall cover crop biomass was greater at the footslope position as compared to the summit position at Trail City, fall 2010 (Table 23). Soil moisture was greater at toeslope position as compared to summit (Table 24). Fall cover crop did not affect soil moisture at Trail City in November 2010. Soil nitrate was lower where fall cover crops were located at summit position (Table 25). Spring soil ammonium was greater when fall cover crops were seeded the previous year.

Table 23. Cover crop biomass collected on November, 2010, at Trail City, SD.

Treatments	Broadleaf		Volunteer Wheat		Total Biomass	
Field Position	**kg ha^{-1}**	**lb A^{-1}**	**kg ha^{-1}**	**lb A^{-1}**	**kg ha^{-1}**	**lb A^{-1}**
Summit	91[a]	82[a]	29[b]	26[b]	120[b]	107[b]
Toeslope	194[b]	173[b]	100[a]	89[a]	248[a]	262[a]
P value	<0.001		<0.001		<0.001	
Cover Crop						
No Fall Cover Crop	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
Fall Cover Crop	285[a]	254[a]	129[a]	115[a]	414[a]	368[a]
P Value	<0.001		<0.001		<0.001	

Table 24. Soil moisture collected on November, 2010, at Trail City, SD.

Treatments	November 2010 Soil Moisture (%)			
Field Position	**0-6 in. (0-15 cm)**	**6-12 in. (15-30 cm)**	**12-18 in. (30-45 cm)**	**12-24 in. (45-60 cm)**
Summit	19.6[b]	19.5[b]	15.9[b]	18.5[b]
Toeslope	23.7[a]	22.5[a]	20.1[a]	24.1[a]
P value	<0.001	<0.001	<0.001	<0.001
Cover Crop				
No Fall Cover Crop	20.8	19.4	18.3	16.4
Fall Cover Crop	20.0	20.5	18.0	16.9
P Value	NS	NS	NS	NS

Table 25. Effect of cover crop at either summit or footslope field landscape positions on soil nitrate, ammonium, and total nitrogen. Samples collected in May 2011 at Trail City.

Landscape Position	NO_3-N		NH_4-N		Total N	
Summit	**lbs A^{-1}**	**kg ha^{-1}**	**lbs A^{-1}**	**kg ha^{-1}**	**lbs A^{-1}**	**kg ha^{-1}**
No CC	21	24	27	30	47	53
Fall CC	16	18	28	31	45	50
P value	**0.005**		0.149		**0.093**	
Footslope						
No CC	23	26	26	29	52	58
Fall CC	24	27	30	34	56	63
	0.938		0.026		0.33	

Corn yields at the summit and toeslope positions were not influenced by cover crops in 2011 (Table 26). As nitrogen rate increased, yield increased at both summit and toeslope positions at Trail City, fall 2011 (Table 27). Soil ammonium nitrate (0-3 in. depth) was greatest at the summit position when a fall cover crop was planted (Table 30). As fertilizer N rate increased, soil nitrate and ammonium increased. Cover crop and N treatment did not interact to effect yield. Total soil nitrate was greatest when fall cover crops or cover crops were drilled in-season at the footslope position (Table 28). Total soil ammonium was greatest when cover crops were drilled in-season into corn. Soil nitrate and ammonium increased as fertilizer N increased.

Table 26. Cover crop treatment effect on corn grain yield (bu A^{-1} or kg ha^{-1}). Grain collected in October 2011 at Trail City, SD.

Cover Crop Treatments	Summit Area		Toeslope Area	
Field Position	Yield			
CC = Cover Crop	bu A^{-1}	kg ha^{-1}	bu A^{-1}	kg ha^{-1}
No CC	72	4501	144	9032
Fall CC	83	5231	162	10140
CC V6 Only, Drilled	73	4561	158	9936
Fall CC and V6 CC, Drilled	78	4867	153	9581
CC V6 Only, Broadcast	79	4976	160	10020
Fall CC and V6 CC, Broadcast	80	5039	153	9612
P Value	0.13		0.20	

Table 27. Nitrogen fertilizer effect on corn grain yield (bu A^{-1} or kg ha^{-1}). Grain collected in October 2011 at Trail City, SD.

Nitrogen Treatments	Summit Area		Toeslope Area	
lbs N $acre^{-1}$ and (kg N ha^{-1})	Yield			
	bu A^{-1}	kg ha^{-1}	bu A^{-1}	kg ha^{-1}
0	56	3533	122	7656
30 (34)	75	4720	145	9103
60 (67)	86	5390	169	10627
120 (134)	93	5808	183	11474
P Value	<0.0001		<0.0001	

Table 28. Effect of cover crop and nitrogen rate on soil nitrate, ammonium, and total nitrogen. Samples collected in November 2011 at Trail City at the summit position.

Treatments	November 2011 Soil N							
	NO_3-N				NH_4-N			
Cover Crop (CC)Treatment; Br = Broadcast; Dr = Drilled	0-3 in. (0-7.6 cm)	3-6 in. (7.6-15 cm)	6-12 in. (15-30 cm)	Total lbs NO_3-N $acre^{-1}$	0-3 in. (0-7.6 cm)	3-6 in. (7.6-15 cm)	6-12 in. (15-30 cm)	Total lbs NH_4-N $acre^{-1}$
	µg NO_3-N g-$soil^{-1}$				µg NH_4-N g-$soil^{-1}$			
No CC	11.2	1.8	3.5	16.5	7.1	4.2	6.1	12.4
Fall CC	11.7	2.3	2.8	16.8	8.1	4.3	7.6	13.2
V6 CC Dr	9.9	1.8	2.8	14.5	5.7	3.7	5.7	10.3
Fall CC + V6 CC Dr	11.2	2.2	2.7	16.1	5.7	5.0	7.8	10.6
V6 CC Br	10.2	2.0	3.6	15.8	8.5	5.3	9.0	14.1
Fall CC + V6 CC Br	11.6	1.7	2.5	15.8	6.6	4.6	6.0	10.8
P value	0.87	0.28	0.58	0.94	0.04	0.27	0.13	0.11
LSD @ α =0.05					2.1			
N Rate (lbs-N A^{-1})								
0	6.7	1.5	1.8	10.0	5.9	4.3	6.4	9.2
30	8.1	1.6	2.2	11.9	6.2	4.4	7.1	10.0
60	10.4	1.9	3.1	15.4	6.8	4.8	7.2	11.8
120	18.7	2.8	4.8	26.3	9.0	4.5	7.3	16.6
P Value	<0.0001	<0.0001	<0.0001	<0.0001	0.003	0.862	0.865	<0.0001
LSD @ α =0.05	2.8	0.5	1.2	3.7	1.8			2.6
CC x N Rate								
P Value	0.36	0.78	0.95	0.55	0.37	0.89	0.80	0.50

Table 29. Effect of cover crop and nitrogen rate on soil nitrate, ammonium, and total nitrogen. Samples collected in November 2011 at Trail City at the footslope position.

Treatments	November 2011 Soil N							
	NO_3-N				NH_4-N			
Cover Crop (CC)Treatment; Br = Broadcast; Dr = Drilled	0-3 in. (0-7.6 cm)	3-6 in. (7.6-15 cm)	6-12 in. (15-30 cm)	Total lbs NO_3-N $acre^{-1}$	0-3 in. (0-7.6 cm)	3-6 in. (7.6-15 cm)	6-12 in. (15-30 cm)	Total lbs NH_4-N $acre^{-1}$
	µg NO_3-N g-$soil^{-1}$				µg NH_4-N g-$soil^{-1}$			
No CC	12.1	3.5	2.2	20.0	8.7	7.1	6.3	23.0
Fall CC	15.5	5.5	2.6	26.2	6.2	3.6	2.7	20.5
V6 CC Dr	16.9	4.3	3.3	27.7	11.7	6.6	6.9	30.8
Fall CC + V6 CC Dr	16.2	3.8	2.9	25.9	7.6	3.9	4.6	22.0
V6 CC Br	14.1	4.3	2.4	23.1	7.7	4.7	3.9	22.0
Fall CC + V6 CC Br	13.1	2.6	2.8	21.4	8.6	3.5	4.1	22.6
P value	0.07	0.03	0.58	0.01	0.00	0.00	0.00	0.00
LSD @ α =0.05	3.6	1.6		4.7	2.4	2.1	2.1	5.2
N Rate (lbs-N A^{-1})								
0	11.5	2.9	1.8	18.0	8.2	4.5	4.2	21.2
30	14.1	3.5	1.9	21.5	8.1	5.9	5.2	21.7
60	15.1	4.1	2.3	23.7	8.2	4.7	5.6	22.8
120	18.0	5.4	4.8	33.0	9.0	4.5	4.1	28.3
P Value	0.000	0.004	<0.0001	<0.0001	0.761	0.294	0.209	0.004
LSD @ α =0.05	2.9	1.3	1.0	3.8				4.2
CC x N Rate								
P Value	0.67	0.07	0.85	0.20	1.00	0.86	0.93	0.97

Trail City South Dakota 2011-2012 yields

In 2011 the cover crop was limited by poor rainfall. Yields ranged from 40 – 50 bushels at either summit or footslope positions. The site was not able to soil sampled in fall 2012 due to the lack of rain.

Andover 2009-2010 Case Study Data

Winter canola was planted at Andover as part of a fall cover crop in fall 2009. The no cover crop plots were sprayed with glyphosate in September to create the 'no cover crop' treatment. Some winter canola was not completely killed when sampled on October 8th. (Table 30). Cover crop broadleaf species were more prevalent at the summit position. Volunteer wheat was greater at the footslope position.

Cover crops had a larger difference on nitrate concentrations than ammonia concentration. Although not significant, spring nitrate amounts were generally lower in the fall cover crop than the no-cover crop treatment. Yield was not affected by cover crops at either summit or toeslope position if the $P = 0.05$; no treatment differences. However if the p value was changed to 0.11 for summit, then where fall cover crops were planted, yields were greater. At the summit, this would mean that 100 - 11 or 87% of time in this study, yield was greater when a fall cover crop was planted in fall 2009 (Table 31). At the summit position, as nitrogen fertilizer decreased, yield increased, P value =0.11. These results are consistent with N increasing water use, which in turn reduces water availability. Nitrogen fertilizer did not affect yield at the footslope position (Table 32). The cover crop treatment by N fertilizer interaction did not affect yield. Soil nitrate and soil total N were greatest when an in-season cover crop was drilled into the corn crop (Table 33). Crimson clover is a legume that stores N and is shade tolerant. The crimson clover in the drilled plots germinated and biomass from this cover crop was harvested in October (Fig. 8). Cover crop treatment, N fertilizer, or the interaction between treatments did not affect grain yield at Andover footslope position in fall 2010 (Table 34).

Table 30. Cover crop biomass, volunteer wheat, and total biomass collected at Andover on October 8th, 2009.

Treatments	Broadleaves		Volunteer Wheat		Total Biomass	
Field Position	kg ha^{-1}	lb A^{-1}	kg ha^{-1}	lb A^{-1}	kg ha^{-1}	lb A^{-1}
Summit	24	22	123	110	147	131
Footslope	17	15	231	206	248	221
P-value	0.06		0.00		0.01	
LSD	7		70		68	
Cover Crop						
No Fall CC	13	12	119	106	132	118
Fall CC	28	25	235	210	263	235
P-value	0.05		0.00		0.00	
LSD	7		70		68	
Cover Crop x Landscape (p value)	0.06		0.79		0.81	

Table 31. Effect of cover crop and landscape position on soil nitrate, ammonium, and total nitrogen. Samples collected in May 2010 at Andover. Soil nitrate, ammonium, and total N presented to from 0 to 24 inches depth.

Treatments	NO3-N		NH4-N		Total N	
Field Position	lbs A^{-1}	kg ha^{-1}	lbs A^{-1}	kg ha^{-1}	lbs A^{-1}	kg ha^{-1}
Summit	40	45	25	28	65	73
Footslope	60	67	23	26	83	93
P-value	0.12		0.31		0.20	
LSD						
Cover Crop Treatment						
No Fall CC	56	63	23	26	79	89
Fall CC	44	49	24	27	68	77
P-value	0.34		0.62		0.42	
LSD						
Cover Crop x Field Position						
P-value	0.98		0.62		0.96	
LSD						

Table 32. Cover crop treatment effect on corn grain yield (bu A^{-1} or kg ha^{-1}). Grain collected in October 2010 at Andover, SD.

Field Position	Summit Area		Toeslope Area	
	Yield			
Cover Crop Treatments	bu A^{-1}	kg ha^{-1}	bu A^{-1}	kg ha^{-1}
No Cover Crop	198	12426	205	12865
Fall Cover Crop	216	13555	200	12551
Cover Crop V6 Drilled	204	12802	222	13932
Fall CC & Drilled V6 CC	181	11359	205	12865
Cover Crop V6 Broadcast	216	13555	216	13555
FallCC & Broadcast V6 CC	189	11861	221	13869
P Value	0.11		0.54	

Table 33. Nitrogen fertilizer effect on corn grain yield (bu A^{-1} or kg ha^{-1}). Grain collected in October 2010 at Andover, SD.

N Rate	Summit		Footslope	
lbs N $acre^{-1}$	Yield			
	bu A^{-1}	kg ha^{-1}	bu A^{-1}	kg ha^{-1}
0	215	13492	217	11132
30	206	12928	210	11296
60	193	12112	207	12963
120	188	11798	213	13472
P Value	0.11		0.85	

Table 34. Cover Crop x N Rate Effect on Yield

Cover Crop x N Rate	Summit		Footslope	
lbs N $acre^{-1}$	Yield			
	bu A^{-1}	kg ha^{-1}	bu A^{-1}	kg ha^{-1}
P Value	0.42		0.45	

Table 35. Effect of cover crop and nitrogen rate on soil nitrate, ammonium, and total nitrogen. Samples collected in October 2010 at Andover, summit position. Total nitrate, ammonium, and total N from 0 to 24 inches.

Summit	NO_3-N		NH_4-N		Total N	
Cover Crop Treatment	lbs A^{-1}	kg ha^{-1}	lbs A^{-1}	kg ha^{-1}	lbs A^{-1}	kg ha^{-1}
No CC	74	83	16	18	90	100
Fall CC	78	88	15	17	93	104
CC V6Drill	134	150	16	18	150	168
Fall CC + CC V6 Drill	75	84	18	21	93	104
CC V6 Broadcast	82	91	16	18	98	109
Fall CC + CC V6 Broadcast	95	106	18	21	113	126
P value	0.009		0.085		0.009	
LSD @ α = 0.05	36		3		36	
N Rate (lbs N A^{-1})						
0	82	91	17	18	98	110
30	69	78	19	21	88	99
60	83	93	16	18	99	111

120	124	139	15	16	138	155
P Value	**0.002**		**0.003**		**0.005**	
LSD @ α = 0.05	**29**		**2**		**29**	
Cover Crop Treatment x N Rate						
P Value	**0.777**		**0.820**		**0.795**	

Figure 8. Crimson clover growing in corn in October 2010, Andover, SD.

Table 36. Effect of cover crop and nitrogen rate on soil nitrate, ammonium, and total nitrogen. Samples collected in October 2010 at Andover, footslope position. Total nitrate, ammonium, and total N from 0 to 24 inches.

Footslope	**NO_3-N**		**NH_4-N**		**Total N**	
Cover Crop Treatment	**lbs A^{-1}**	**kg ha^{-1}**	**lbs A^{-1}**	**kg ha^{-1}**	**lbs A^{-1}**	**kg ha^{-1}**
No CC	116	130	19	21	135	151
Fall CC	80	89	19	21	99	111
CC V6Drill	94	105	15	17	109	122
Fall CC + CC V6 Drill	94	105	16	18	110	123
CC V6 Broadcast	115	129	14	16	129	144
Fall CC + CC V6 Broadcast	97	109	16	18	113	127
P value	**0.47**		**0.12**		**0.53**	
N Rate (lbs N A^{-1})						
0	108	121	18	21	127	142
30	88	99	16	18	104	117
60	95	106	16	18	111	124
120	105	118	16	18	121	136
P Value	**0.61**		**0.32**		**0.54**	
Cover Crop Treatment x N Rate						
P Value	**0.96**		**0.99**		**0.97**	

Andover South Dakota 2010-2011 Case Study Data

Broadleaf cover crop biomass was greater at footslope position whereas volunteer wheat was greater at summit positions (Table 37). Soil moisture was least the summit position for all depths and least for 6-12 inches when a fall cover crop was planted (Table 38). The majority of the cover crop roots were in the 6-12 inch zone (Fig. 9)

Table 37. Cover crop biomass, volunteer wheat, and total biomass collected at Andover on October 8th, 2010.

Treatments	Broadleaf		Volunteer Wheat		Total Biomass	
Field Position	**kg ha^{-1}**	**lb A^{-1}**	**kg ha^{-1}**	**lb A^{-1}**	**kg ha^{-1}**	**lb A^{-1}**
Summit	319	285	968	864	1286	1148
Footslope	653	583	506	452	1159	1034
P value	<0.001		<0.001		NS	
LSD (0.05)	199	178	156	139	208	186
Cover Crop						
No Fall Cover Crop	0	0	0	0	0	0
Fall Cover Crop	971	866	1476	1317	2445	2182
P Value	<0.001		<0.001		<0.001	
LSD (0.05)	199	178	156	139	208	186

Table 38. Soil moisture collected on November, 2011, at Andover, SD.

Treatments	Soil Moisture (%)		
Field Position	**0-6 in. (0-15 cm)**	**6-12 in. (15-30 cm)**	**12-24 in. (30-60 cm)**
Summit	19.6	19.5	20.7
Footslope	29.3	27.7	24.1
P value	<0.001	<0.001	<0.01
LSD (0.05)	1.8	1.8	2
Cover Crop			
No Fall Cover Crop	29.7	29.3	24.6
Fall Cover Crop	29.0	26.0	23.6
P Value	NS	<0.05	NS
LSD (0.05)		2.6	

Figure 9. Cover crops from Andover collected in November 2011. Root depth of many radishes was 6-12 inches or greater.

In May 2011, the field was scouted for cover crops that may have survived the winter. When decaying turnips and radishes were observed in the field, many decomposing structures had insects eating (Fig. 10, 11, 12). Many turnips had earthworms associated with the root structure (Figure 20). The number of mites and arthropods was greater when a cover crop was present (Table 41). This indicates increased biodiversity. Soil nitrate and total soil N was lower when a fall cover crop (2010) was planted when soil was tested the following spring (May 2011). This suggests that nitrogen was sequestered in the organic material of the cover crops (Table 42). Summer of 2011 became very dry. The rains stopped about July 1st and the summer was very hot. At p-values 0.20, grain yield from the fall cover crop treatments were least (Table 43). As nitrogen fertilizer rate increased, yield increased at both summit and footslope positions (Table 44). Treatment interactions were not significant. Soil nitrogen was not affected by cover crop treatment (Table 43 and 44). Yield did increase as fertilizer N increased at summit position (Table 45). Interaction was not significant. No interactions were observed between cover crop and nitrogen treatments.

Table 39. Mites and arthropods numbers at footslope or summit positions with either no fall cover crop or a fall cover crop. Fall cover crop planted in 2010. Field sampled in May 2011.

	Values	
Row Labels	Average of # mites	Average of # other arthropods
No Cover Crop	**323**	**62**
Footslope	421	89
Summit	226	35
Cover crop	**401**	**246**
Footslope	581	430
Summit	221	62
Grand Total	**362**	**154**

Figure 10. Isopods inhabiting a decaying purple top turnip.

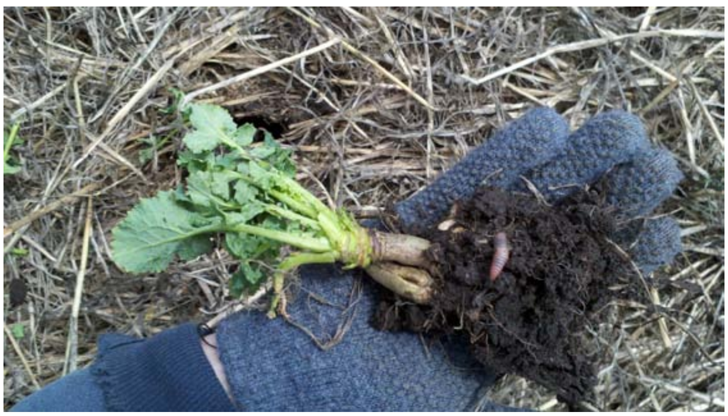


Figure 11. Earthworms associated with a turnip root.

Table 40. Effect of cover crop and landscape position on soil nitrate, ammonium, and total nitrogen. Samples collected in May 2011 at Andover. Soil nitrate, ammonium, and total N presented to from 0 to 24 inches depth.

Landscape Position	NO_3-N		NH_4-N		Total N	
Summit	lbs A^{-1}	kg ha^{-1}	lbs A^{-1}	kg ha^{-1}	lbs A^{-1}	kg ha^{-1}
No CC	32	36	20	22	52	58
Fall CC	15	17	19	21	34	38
P value	**0.003**		0.411		**0.006**	
Footslope						
No CC	37	41	26	29	63	71
Fall CC	27	30	27	30	54	61
P Value	0.013		**0.170**		0.016	

Table 41. Corn grain yield (bu A^{-1} or kg ha^{-1}) as impacted by cover crop yields. Grain collected in October 2011 at Andover, SD.

Cover Crop Treatments	Summit		Footslope	
Field Position	Yield			
CC = Cover Crop	bu A^{-1}	kg ha^{-1}	bu A^{-1}	kg ha^{-1}
No CC	175	11010	199	12488
Fall CC	139	8739	182	11395
CC V6 Drilled	158	9910	201	12603
Fall CC and V6 CC, Drilled	171	10700	185	11630
CC V6 Broadcast	154	9685	191	12007
Fall CC and V6 CC Broadcast	144	9052	210	13194
P Value	0.17		0.20	

Table 42. Nitrogen fertilizer effect on corn grain yield (bu A^{-1} or kg ha^{-1}). Grain collected in October 2011 at Andover, SD.

N Rate	Summit		Footslope	
lbs N $acre^{-1}$	Yield			
	bu A^{-1}	kg ha^{-1}	bu A^{-1}	kg ha^{-1}
0	125	7813	177	11132
30	141	8866	180	11296
60	170	10696	207	12963
120	192	12021	215	13472
P Value	<0.0001		0.0005	

Cover Crop x N Rate	Summit		Footslope	
lbs N $acre^{-1}$	Yield			
	bu A^{-1}	kg ha^{-1}	bu A^{-1}	kg ha^{-1}
P Value	0.71		0.38	

Table 43. Effect of cover crop and nitrogen rate on soil nitrate, ammonium, and total nitrogen. Samples collected in October 2011 at Andover, summit position. Total nitrate, ammonium, and total N from 0 to 12 inches.

Summit	NO_3-N		NH_4-N		Total N	
Cover Crop Treatment	lbs A^{-1}	kg ha^{-1}	lbs A^{-1}	kg ha^{-1}	lbs A^{-1}	kg ha^{-1}
No CC	18	20	23	26	41	46
Fall CC	15	17	26	29	40	45
CC V6Drill	16	18	25	28	41	46
Fall CC + CC V6 Drill	16	18	25	28	40	45
CC V6 Broadcast	19	21	22	25	41	46
Fall CC + CC V6 Broadcast	16	18	24	27	40	45
P value	**0.67**		**0.79**		**1.00**	
LSD @ α = 0.05						
N Rate (lbs N A^{-1})						
0	14	16	24	27		38
30	14	16	22	25		36
60	18	20	26	29		44
120	20	23	24	27		44
P Value	**0.01**		**0.46**		**0.04**	
LSD @ α = 0.05	**4**				**7**	
Cover Crop Treatment x N Rate						
P Value	**0.26**		**0.93**		**0.65**	

Table 44. Effect of cover crop and nitrogen rate on soil nitrate, ammonium, and total nitrogen. Samples collected in October 2011 at Andover, footslope position. Total nitrate, ammonium, and total N from 0 to 12 inches.

Footslope	NO_3-N		NH_4-N		Total N	
Cover Crop Treatment	lbs A^{-1}	kg ha^{-1}	lbs A^{-1}	kg ha^{-1}	lbs A^{-1}	kg ha^{-1}
No CC	116	130	19	21	135	151
Fall CC	80	89	19	21	99	111
CC V6Drill	94	105	15	17	109	122
Fall CC + CC V6 Drill	94	105	16	18	110	123
CC V6 Broadcast	115	129	14	16	129	144

Fall CC + CC V6 Broadcast	97	109	16	18	113	127
P value	**0.47**		**0.12**		**0.53**	
LSD @ α = 0.05						
N Rate (lbs N A^{-1})						
0	108	121	18	21	127	142
30	88	99	16	18	104	117
60	95	106	16	18	111	124
120	105	118	16	18	121	136
P Value	**0.61**		**0.32**		**0.54**	
LSD @ α = 0.05						
Cover Crop Treatment x N Rate						
P Value	**0.96**	**0.99**	**0.97**			

Andover 2011-2012 Case Study Data

Soil moisture was not affected by field position or fall cover crop treatments (Table 45). Soil moisture was greater at toeslope positions in May 2012 (Table 46). No broadcast cover crops germinated in June 2012 due to drought. Cover crop or N treatments did not affect yield at Andover in fall 2012 (Table 47 and 48). The interaction was not significant. Cover crop treatments or N rates did not affect soil moisture (Table 49). Soil moisture was greatest when a fall cover crop was planted the previous year at the footslope position (Table 50).

Table 45. Soil moisture collected at Andover in October 2011.

Treatments	**October 2011 Soil Moisture (%)**	
Field Position	**0-6 in. (0-15 cm)**	**6-12 in. (15-30 cm)**
Summit	24.9	29.4
Toeslope	25.1	28.6
P value	0.85	0.64
Cover Crop		
No Fall Cover Crop	25.0	29.3
Fall Cover Crop	25.1	28.6
P Value	0.95	0.65

Table 46. Soil moisture collected at Andover in May 2012.
Spring May 2012 Soil Moisture:

Treatments	May 2012 Soil Moisture (%)			
Field Position	**0-3 in. (0-7.5 cm)**	**3-6 in. (7.5-15 cm)**	**6-12 in. (15-30 cm)**	**12-24 in. (30-60 cm)**
Summit	25.0	26.8	27.1	27.1
Toeslope	31.0	31.1	31.2	31.2
P value	<0.0001	0.02	0.03	0.00
Cover Crop				
No Fall Cover Crop	28.1	29.2	28.3	30.3
Fall Cover Crop	28.0	28.8	30.1	27.1
P Value	0.91	0.82	0.32	0.19

Table 47. Grain yield at summit and toeslope positions at Andover, fall 2012. Cover crop treatments affects are presented.

	Summit		**Toeslope**	
	Yield			
Cover Crop Treatments	**bu A^{-1}**	**kg ha^{-1}**	**bu A^{-1}**	**kg ha^{-1}**
No CC	139	8723	100	6291
Fall CC	136	8535	97	6113
Drilled CC V6	134	8409	100	6291
Fall CC and Drilled V6 CC	131	8221	113	7086
P Value	0.73		0.30	

Table 48. Nitrogen treatment affects on yield, Andover, fall 2012.

N Rate	**Summit**		**Toeslope**	
lbs N $acre^{-1}$	**Yield**			
	bu A^{-1}	**kg ha^{-1}**	**bu A^{-1}**	**kg ha^{-1}**
0	128	8033	102	6391
30	139	8723	99	6213
60	134	8409	109	6870
120	139	8723	102	6396
P Value	0.30		0.66	

Table 49. The influence of cover crop treatment on soil water content in October 2012 at Andover South Dakota.

Treatments	October 2012 Soil Moisture (%)		
Cover Crop	0-3 in. (0-7.5 cm)	3-6 in. (7.5-15 cm)	6-12 in. (15-30 cm)
No Fall Cover Crop	25.27	27.78	25.21
Fall Cover Crop	24.50	24.58	25.60
Drilled CC V6	26.10	25.72	26.26
Fall CC and Drilled V6 CC	23.81	24.76	28.41
P value at α =0.05	0.41	0.63	0.80
N Rate (lbs-N A^{-1})			
0	25.29	25.94	26.09
120	24.55	25.48	26.65
P Value	0.46	0.81	0.82
CC x N Rate			
P Value	0.93	0.79	0.95

Table 50. Andover 2012 Soil moisture to 12 inches, footslope position.

Treatments	November 2012 Soil Moisture (%)		
Cover Crop	0-3 in. (0-7.5 cm)	3-6 in. (7.5-15 cm)	6-12 in. (15-30 cm)
No Fall Cover Crop	28.74	28.03	31.48
Fall Cover Crop	29.40	25.41	33.73
Drilled CC V6	28.29	24.96	31.77
Fall CC and Drilled V6 CC	26.79	26.77	31.66
P value	0.05	0.85	0.17
LSD @ α =0.05	1.84		
N Rate (lbs-N A^{-1})			
0	28.64	26.78	32.35
120	27.97	25.81	31.97
P Value	0.30	0.72	0.63
CC x N Rate			
P Value	0.40	0.41	0.65

Chapter 8: Gene expression in corn under differing cover crop treatments.

Determining what physiological and metabolic effects cover crops have on corn is important in understanding why and when the use of cover crops is beneficial or not beneficial to the producer. Cover crop application timing, landscape effects, soil moisture, and weather can impact the yield gains or losses incurred by incorporating cover crops. In this project, we determined the impact of cover crops and landscape position on genes expression in corn. The candidate genes were selected based on the results of previous experiments in South Dakota and Nebraska. Cover crop treatments were fall cover crops following wheat and before corn and summer cover crop in corn.

Methods

This research was conducted in two locations (Andover and Trail City, SD), over a period of three years. Cover crop cocktails were seeded in the fall following wheat or in the summer at corn V6 growth stage. The treatments were: 1) no cover crops; 2) fall cover crop only; and 3) summer cover crops only. Each treatment was replicated 4 times and the experimental design was a randomized block. The summit, footslope, and saline areas were sampled in Andover in 2010 and 2011. However, in 2012, only the summit and footslope areas were sampled. At Trail City, summit and footslope areas were sampled in 2011 and 2012. At V12 (plants with about 12 leaf collars), samples were collected from the newest leaf on corn plants. Five leaf tips, 8 cm long, from the most recently emerged leaves were collected and immediately placed in liquid N. The samples were stored at –80°C until ribonucleic acid (RNA) transcriptome analysis.

Total RNA was extracted using Trizol reagent and Superscript First Strand Synthesis System (Invitrogen, Life Technologies, Inc., Carlsbad, CA) and purified using Qiagen RNeasy MinElute cleanup kit (Qiagen, Valencia, CA) following the manufacturer's protocol. First-strand complementary DNA (cDNA) synthesis was performed using 1,900 ng total RNA. Real-time quantitative polymerase chain reaction (RT-qPCR) assay and analyses were performed on selected genes (Table 1) (Moriles et al., 2012 and Hansen et al., 2013).

The ubiquitin conjugating enzyme was included as the endogenous control. This gene was chosen because it showed minimal differential expression in all treatments based on hybridization in the microarray experiments. Manufacturer's protocols were followed, using supplied Oligo (dT) primers and 5 μg total sample RNA for each 25 μL reaction. Primers were designed for select genes using Primer Express software (Applied Biosystems, 2004). Quantitative polymerase chain reaction (qPCR) using Go Taq Promega Master Mix Kit (Promega Corp.) was performed on high throughput ABI 7900 PCR system (Applied Biosystems) following manufacturer's protocols (established protocols are found in the GoTaq qPCR Master Mix Technical Manual #TM318 [Promega Corporation, 2011]). Threshold values were determined with SDS2.4 software (Applied Biosystems, 2010). Samples were run in four biological replicates except for Trail City 2011 (three replicates) and averaged for data analysis.

Table 1. List of genes and their function used in analysis.

Gene ID	Annotation	Function/s
MZ00017722	Iron transport protein 2	metal transporter in plants(i e.iron and zinc)
MZ00041134	Ferredoxin	Electron transfer during Photosynthesis
MZ00043643	Putative anion transporter	Plant nutrition and compartmentalization of metabolites
MZ00048663	Putative high affinity potassium transporter	Na uptake & reduce K requirements, reduce Na accumulation in leaves
MZ00041292	Photosynthesis	Photosynthesis
MZ00019894	acid phosphatase	P metabolism, plant metabolic regulation
MZ00023951	inorganic diphosphatase	Oxidative phosphorylation
MZ00042137	phosphate-induced protein 1-like protein	Mineral nutrition
Ubiq	Ubiquitin	

The resulting cycle threshold (Ct) values were normalized to the average of an ubiquitin gene and relative quantification was conducted when PCR efficiency calculated by slope of the standard curve of the targert gene/slope of the reference gene × 100 was between 95 and 105% or had an R2 close to 0.99 (Livak and Schmittgen, 2001), an indication that the efficiency of the target and reference genes were comparable. The ΔΔCt method in which target gene Δcycle threshold (Ct) – control gene ΔCt, in which ΔCt = target gene Ct – reference gene Ct was used to compare differential gene expression among treatments (Livak and Schmittgen, 2001).

Fall cover crop

Landscape position and location influenced the impact of the fall cover crops on corn yields and gene expression the following year. In the summit landscape position at Andover, yields were either increased or not impacted by cover crop, while in the footslope, yields were not impacted by cover crops.

At Andover, genes measured at the summit position were mostly up-regulated or unchanged compared to controls, with the putative anion transporter gene unaffected all three years. A trend towards up-regulation was present in Andover in 2010 and 2012, but had no effect on yield. In the footslope position, the fall cover crop had a minimal impact on gene expression. Ferredoxin and the putative anion transporter genes were unaffected all three years (Table 2). The lack of differences may be responsible for the cover crop not inducing a yield increase in the footslope area.

In the saline area, the cover crop resulted in the up-regulation in genes associated with nutrient uptake (Putative high affinity potassium transporter, acid phosphatase, inorganic diphosphatase, phosphate-induced protein 1-like protein). However, increased gene expression did not result in higher yields.

At the Trail City location, gene expression differed greatly between landscape positions. Summit and footslope positions in 2011 demonstrated almost completely opposite gene expressions, with only two of the eight genes demonstrating the same up or down regulation (ferredoxin and photosynthesis genes) (Table 3). In 2012, three of the eight genes were similarly expressed between the summit and footslope (photosynthesis, acid phosphatase, and inorganic disphosphatase). Differences between the landscape positions and sites may be related to differences in the relative amount of cover crops at the sites as well as soil and climatic differences.

Table 2. Gene expression at Andover summit and footslope positions with Fall cover crops when compared to control plots. *NC=no change from control, "-"= downregulated from control, "+" = upregulated from control.

	ANDOVER 2010			ANDOVER 2011			ANDOVER 2012	
Landscape position	Summit	Footslope	Saline	Summit	Footslope	Saline	Summit	Footslope
Gene Description	Fall CC	Fall CC	Fall CC	Fall CC	Fall CC	Fall CC	Fall CC	Fall CC
Iron transport protein 2	+	NC	NC	NC	-	-	NC	+
Ferredoxin	+	NC	NC	-	NC	NC	+	NC
Putative anion transporter	NC	NC	NC	NC	NC	+	NC	NC
Putative high affinity potassium transporter	+	+	+	-	-	-	+	-
Photosynthesis	+	-	NC	NC	+	NC	+	NC
acid phosphatase	+	NC	+	+	-	+	NC	+
inorganic diphosphatase	+	NC	+	NC	NC	NC	NC	+
phosphate-induced protein 1-like protein	-	+	+	-	-	-	NC	+

Table 3. Gene expression at Trail City summit and footslope positions with Fall cover crops when compared to control plots. . *NC=no change from control, "-"= downregulated from control, "+" = upregulated from control.

	Trail City 2011		Trail City 2012	
Landscape position	Summit	Footslope	Summit	Footslope
Gene Description	Fall CC	Fall CC	Fall CC	Fall CC
Iron transport protein 2	NC	-	-	NC
Ferredoxin	-	-	+	NC
Putative anion transporter	NC	-	NC	-
Putative high affinity potassium transporter	+	NC	+	NC
Photosynthesis	-	-	NC	NC
acid phosphatase	+	-	+	+
inorganic diphosphatase	+	-	NC	NC
phosphate-induced protein 1-like protein	+	-	-	+

Summer cover crops

When cover crops were seeded into corn at V5, there was very little impact on corn yield at any location during any year. Landscape position had minimal effect on gene expression at Andover in 2010 and 2011, but in 2012 gene expression differed between summit and footslope in three out of eight measured genes (Table 4). This was probably due to environmental pressures and development, or lack of development, of cover crops. Acid phosphatase had similar expression among all three landscape positions in 2011 and 2012, although they were up-regulated in 2010, but down-regulated in 2011. Growing environments differed greatly between 2010 and 2011 at Andover. It is interesting to note the gene expression at all three locations in Andover in 2011 was almost identical.

Cover crops interseeded at V5 at Trail City had a greater effect on gene expression at both landscape locations than was observed at Andover. Up-regulation was observed in every measured gene in the 2011 Trail City summit location, while down regulation in half of the analyzed genes was observed at the footslope location. In 2012, only three genes were similarly expressed between footslope and summit (Ferredoxin, putative high affinity potassium transporter, and acid phosphatase).

Table 4. Gene expression at Andover summit, footslope, and saline positions with Summer cover crops when compared to control plots. *NC=no change from control, "-"= downregulated from control, "+" = upregulated from control.

	ANDOVER 2010			ANDOVER 2011			ANDOVER 2012	
Landscape position	Summit	Footslope	Saline	Summit	Footslope	Saline	Summit	Footslope
Gene Description	Drill V5	Drill V5	Drill V5	Drill V5	Drill V5	Drill V5	Drill V5	Drill V5
Iron transport protein 2	+	NC	-	NC	NC	NC	NC	+
Ferredoxin	NC	NC	NC	NC	NC	NC	NC	-
Putative anion transporter	NC	NC	NC	NC	NC	NC	NC	NC
Putative high affinity potassium transporter	NC	NC	-	-	-	-	NC	NC
Photosynthesis	NC	NC	NC	NC	+	+	NC	NC
acid phosphatase	+	+	+	-	-	-	NC	-
inorganic diphosphatase	NC	+	NC	NC	NC	NC	NC	NC
phosphate-induced protein 1-like protein	+	NC	-	-	-	-	-	-

Table 5. Gene expression at Trail City summit and footslope positions with Summer cover crops when compared to control plots. *NC=no change from control, "-"= downregulated from control, "+" = upregulated from control.

	Trail City 2011		Trail City 2012	
Landscape position	Summit	Footslope	Summit	Footslope
Gene Description	Drill V5	Drill V5	Drill V5	Drill V5
Iron transport protein 2	+	-	-	NC
Ferredoxin	+	NC	+	+

Putative anion transporter	+	-	NC	-
Putative high affinity potassium transporter	+	NC	+	+
Photosynthesis	+	NC	+	NC
acid phosphatase	+	-	+	+
inorganic diphosphatase	+	-	NC	+
phosphate-induced protein 1-like protein	+	NC	NC	+

Relative gene expression

The individual genes varied in the amount of change in expression. The least effected gene was the putative anion transporter, which was affected only 25% of the time. The gene that appeared the most affected by cover crop presence was acid phosphatase, which was affected 88% of the time. Acid phosphatase appears to demonstrate the most similar expression trend regardless of landscape position, but is affected by year/weather. This gene was upregulated in both summit and footslope postions at Trail City in 2012 in both Fall and Summer cover crop treatments.

References

Livak, KJ and T.D. Schmittgen. Analysis of relative gene expression data using real time quantitative PCR and the 2-ddCt method. Methods 25, 402-408. 2001.

Chapter 9: Landscape position and winter cover crops impact northern Great Plains corn (*Zea mays*) yield and N and water cycling.

Cheryl Reese, David Clay, Sharon Clay, Alex Bich, Ann Kennedy, Stephanie Hansen, Morteza Mamaghani

Abstract

In semi-arid Great Plains soils, fallow was used to save water required for the cash crop. The need for fallow was decreased by the adoption of no-tillage. The objective of this paper was to determine the impacts of winter cover crop cocktails that contain plants from the mustard family (Brassicaceae) on corn yields, corn yield losses due to water and N stress, soil bacterial to fungi ratio, and corn gene regulation in responses in 8 selected genes. The research was conducted at two landscape positions (summit and footslope) at three northern Great Plains sites in 2011 and 2012. These sites were characterized as low, moderate, and high water stress environments. No-tillage was used at all sites and the fall cover crops plot were split by 4 N rates (0, 34, 67, and 134 kg ammonium nitrate-N ha^{-1}). Soil was analyzed for bacteria/fungi ratios, soil moisture, and inorganic N. Leaf samples, collected at V12 were analyzed for gene regulation and grain samples were analyzed for yield loss due to water (YLWS) and N stress (YLNS) using the ^{13}C stable isotopic technique. In the moderate water stress environment, the cover crops reduced ($p=0.09$) the corn yield. These results are attributed to the cover crop using water that could have been used by the crop. Findings also showed that winter cover crops contributed to a higher bacterium to fungi ratio, reduced nitrate-N in the spring soil samples, increased or did not impact water infiltration, and had a mixed impact on gene regulation. The cover crop impact on gene regulation was attributed to the cover crop impact on water stress. In the moderate yield environment, cover crops increased YLWS. Associated with increased water stress was down regulation in 2 of the 3 genes associated with mineral nutrition and one of the two genes associated with photosynthesis. Findings from this study suggest that cover crops can reduce yields through increased water stress. This risk is increased by planting the cover crops early.

Abbreviations: SOC, Soil organic C; YLNS, yield loss due to N stress; YLWS, yield loss due to water stress

Introduction

The impact of cover crop species and planting date has been extensively tested in soils with an udic soil moisture and mesic soil temperature regimes (annual temperature between 8^o and 15^o C). The benefits of cover crops in soils with a ustic soil moisture and frigid soil (annual temperature < 8^o C) temperature regimes are not well defined.

In the 1700's the importance of replacing fallow with cover crops in England was promoted by Viscount Charles "Turnip" Townshend. He encouraged farmers to replace the fallow with a cover crop of turnips (*Brassica rapa*) and ryegrass (*Lolium multiflorum*) or clover (*Trifolium)*. The power of this rotation was that it provided forages (turnips, clover and ryegrass) for grazing by livestock. This change improved nutrient budgets, increased the amount of land devoted to food production by 33%, and increased yields. The net result was that from 1750 to 1860 wheat and pulse yields increased 68 and 44%, respectively. In addition, stocking densities for milk cows, sheep, and swine increased 46, 25, and 43%, respectively (Broadberry et al., 2010). This rotational change: 1) powered the Industrial Revolution, 2) provided resources that grew the English population from 5.7 million in 1750 to 16.6 million people in 1850, and 3) provided the theoretical basis for the organic agricultural industry today.

Today, many non-organic farmers are rediscovering the importance of cover crops. Of the many choices, spring, summer, and fall seeding techniques have been tested in the United States Northern Great Plains. Developing Best Management Practices for semi-arid frigid soils is complicated by a short growing season and limited availability of water. In areas with an adequate water supply (udic) and moderate temperature (mesic) regime, the benefits from cover crops include improved soil health, reduced erosion, reduced nutrient losses, increased yields, and increased plant diversity (Angus et al., 1994; Bending and Lincoln, 1999; Mazzola, 2002; Snapp et al., 2005), while disadvantages include lower yields resulting from reduced nutrient availability (Ruffo et al., 2004; Miquey and Ballero, 2006; Monteserrat et al., 2010; Blanco-Canqui et al., 2012).

Findings from these studies cannot be directly transferred to the water limited (ustic) and northern (frigid) environments observed in the northern Great Plains. In addition, crops grown in northern semi-arid locations are challenged by high climate variability. In northern Great Plains three cover crop options have been explored. In the first approach, cover crop and cash crop are often seeded at approximately the same time in the spring. This approach contains a number of risks because seeding the cover crop and the cash crop at the same time can reduce the cash crops yield through a number of mechanisms (Smeltekop et al., 2002; Horvath et al., 2006, Clay et al., 2009). For example, cash crop yields can be reduced through direct competition for N (Smeltekop et al., 2002) or through changes in light quality (Green-Tracewicz et al., 2011). If the cover crop is present in the field during the weed free period it can reduce yield by changing the plants plant growth characteristics (Green-Tracewicz et al., 2011). These changes can be detected at the molecular level and different plants have different shade avoidance mechanisms (Moriles et al., 2012). For example, soybeans become etiolated, while corn down regulates genes involved with photosynthesis (Horvath et al., 2006; Clay et al., 2009; Moriles et al., 2012). Corn's response to competition is almost completely opposite to velvet leaf (*Abutilon theophrasti*), which up regulates photosynthesis and becomes etiolated (Horvath et al., 2006, 2007). Corn also has other unexpected responses to stress. For example, in response to water stress it up-regulates genes associated with cold tolerance, salt tolerance, and water stress, and down regulates genes associated with nutrient uptake and pest management (Hansen et al., 2013). Corn's differential response to stress can produce conditions where cover crops increase, decrease, and do not impact corn yield. For example, there is a general perception that by increasing plant diversity the disease risks are reduced. However, in semi-arid landscapes reduction in these risks need to be balanced with reduction in plant available water.

The second general approach is seeding a cover crop during the summer after the weed free period. In corn, this may involve seeding the cover crop after V6 while in soybean this may involve seeding the after V4 (Bich, 2013). The summer cover crop approach can also suppress weeds and provide ground cover following harvest. Generally, shade tolerant cover crops are needed for this approach. The success of the summer cover crop approach depends on placing the seeds at a location containing moisture. In a semi-arid environment, germination can often be enhanced by drilling the seed (Bich, 2013).

In the winter cover approach, a cover crop cocktail is seeded between two cash crops, such as wheat and corn. In the northern Great Plains, cocktails include plants from the mustard family (Brassicaceae), which helps speed up the decomposition of the previous crops residue (Hoffbeck et al., 2008). Winter cover crops can increase, decrease, or not impact the following crops yields. The direction of impact depends on water and nutrient resources available, the microbial community structure, the types of cover crops planted, and the cash plants ability to respond to stress. For winter cover crops, Clark et al. (2007) reported that corn grain yields were greater following a pure stand of vetch (*Vicia villosa)* than any other cover crop treatment, and that hairy vetch replaced 80 kg N ha^{-1}, while a vetch mixture replaced 15 kg N ha^{-1}.

The ability to mechanistically define the impacts of cover crops on yields has been limited by our ability to clearly define responses between crops, soils, and management. These complex interactions can be defined by using new techniques for characterizing the microbial community structure and quantifying the impact of stress on gene regulation and the yield limiting factors (Horvath et al., 2007). The purpose of this paper is to determine the impact of winter cover crop cocktails that contain plants from the mustard family on corn yields, corn yield losses due to water and N stress, soil bacterial to fungi ratio, and corn gene regulation in response to cover-crop induced stress.

Methods

The research was conducted at Andover in 2009-2010, 2010-2011, and at Trail City in 2010-2011. The locations of Andover 2010, Andover 2011, and Trail City were 44° 22'29" N, 97° 58'46" W, 45° 27'41" N, 97° 57'49" W, and 45° 33'19" N, 100° 49'42" W, respectively.

At each location, two landscape positions were tested (summit and footslope). The May to October rainfall for Andover 2010, Andover 2011, and Trail City 2011 were 48.5, 49.2, and 46.2 cm, while the growing degree days (10^{o} C base) were 1,577, 1,630, and 1,555, respectively. Soils at Andover and Trail City were a Forman-Aastad loam and a Reeder loam, respectively. All soils were characterized as fine-loamy, mixed, frigid Typic Argiboroll. The Forman-Aastad loam contains approximately 350 g sand kg^{-1}, 370 g silt kg^{-1}, and 26.9 g organic matter kg^{-1}, while the Reeder loam contains approximately 370 g sand kg^{-1}, 280 g silt kg^{-1}, and 22.9 g organic matter kg^{-1}. The soil pH values across the landscapes ranged from 6 to 7 in summit areas to 7 to 8 in footslope areas.

The experimental design was a split-plot randomized block. Andover 2010 and Trail City contained 4 blocks while Andover 2011 contained 3 blocks. In each experiment, the 2 cover crop plots (fall cover crop or no fall cover crop) were split by 4 N-rates. The plot sizes were 4.6 by 27.4 m and the corn row width was 0.76 m at all sites. The winter cover crop cocktails were planted following wheat harvest in the fall. Based on prior herbicides and soil characteristics, each site had slightly different cocktail mixtures (Table 1). All cover crop cocktails contained plants from the mustard family. The fall cover crop treatment was terminated in the spring using an appropriate herbicide. The N rates were 0, 34, 67, and 134 kg ammonium nitrate-N ha^{-1}, which was surface applied prior to corn seedling emergence. At Andover 2010, Andover 2011, and

Trail City 2011 Mycogen 2J463 (Mycogen, Indianapolis, Indiana, USA), Stine 9204 (Stine Seed Company, Adel, IA), and REA 3V375 (REA Hybrids, Aberdeen, SD USA) was directly seeded into wheat stubble on 21 April 2010, 11 May 2011, and 16 May 2011, respectively. The seeding density was 74,100, 76,570, and 61,750 seeds ha^{-1} at Andover 2010, Andover 2011, and Trail City 2011, respectively.

The fall winter cover crop biomass was measured in November by randomly placing a PVC square (0.1 m^2) in the plot. The plant biomass within the sampling areas was clipped at the soil surface. Samples were weighed and dried at 30^{o} C. Selected biomass samples were dried, weighed, ground, and analyzed for total N, total C, $\delta^{15}N$, and $\delta^{13}C$ on a ratio mass spectrometer. Corn grain and stover was measured on 28 September 2010, 13 October 2011, and 5 October 2011 at Andover 2010, Andover 2011, and Trail City 2011, respectively. Corn grain was picked from 36.3 m of row and each sample was weighed, sub-sampled, dried, shelled, weighed, ground, and analyzed for total N, total C, $\delta^{15}N$, and $\delta^{13}C$ on a ratio mass spectrometer. Based on measured yields and associated $\delta^{13}C$ values, yield loss due to N stress (YLNS) and yield loss due to water stress (YLWS) were determined (Clay et al., 2005).

^{13}C isotopic approach to define yield losses due to N and water stress

The ^{13}C approach for defining water and N stress provides and indirect measure of the plants' physiological response to stress. This approach is based on mathematically separating the combined impacts of water and N stress on ^{13}C isotopic fractionation. Isotopic ^{13}C fractionation results from: 1) stomatal closure during water stress; 2) the equilibrium relationships between $^{13}CO_2 + H_2O \rightarrow H_2{}^{13}CO_3$ and $^{12}CO_2 + H_2O \rightarrow H_2{}^{12}CO_3$; and 3) the impact of N stress on the plants photosynthesis capacity (Clay et al., 2005). Based on these relationships, YLNS and YLWS is determined (Clay et al., 2005). In this analysis, the maximum yield was defined as 16,000 kg grain ha^{-1} and yield was reported at 15.5% moisture.

Soil analysis for inorganic N and microbial community structure

Soil samples (0-15, 15-30, and 30-60 cm depths) were collected following wheat harvest in September or November, prior to applying fertilizers in the spring, and following corn harvest. Each soil sample consisted of at least 10 cores that were weighed, analyzed for soil moisture, air dried, ground, sieved, and analyzed for ammonia and nitrate-N (Clay et al., 2005). Apparent N mineralization in the unfertilized controls was determined with the equation, N mineralization = plant N uptake + soil inorganic N fall – soil inorganic N spring (Kharel et al., 2011).

Surface soil samples collected in May and November were also analyzed for Phospholipid-derived fatty acid (PLFA) (Carpenter-Boggs et al., 1998; Peterson et al., 2002). This analysis evaluates the basic phospholipids of soil organisms, and it is based on different soil microbial organisms having different lipid signatures. For example, a saturated lipid has a single bond between all CH_2 groups in the fatty acid (x-CH_2-CH_2-etc), while an unsaturated lipid has at least one (monounsaturated) or more (polyunsaturated) bonds between the CH_2 groups (CH2-CH=CH-CH_2). Phospholipid fatty acid signatures are used to characterize microbial communities into: (1) saturated fatty acids (gram-positive bacteria and actinomycetes); (2) monounsaturated fatty acids(gram-negative bacteria and arbuscular mycorrhizal fungi); (3) polyunsaturated fatty acids (protozoa and ectomycorrhizal fungi); (4) cyclopropane fatty acids (gram-negative bacteria); and (5) dimethyl acetal marker (anaerobic bacteria). Based on these signatures the soil bacteria to fungi ratio were determined.

Gene regulation at corns V12 growth stage

Corn leaf tip samples from the newest leaves on 5 plants growing in summit and footslope positions were collected in the 134 kg N ha^{-1} treatments at V12. Each leaf sample was 8 cm long, and after collection they were immediately placed in liquid N and stored at –80°C until analysis. Total RNA was extracted using Trizol reagent and purified using Qiagen RNeasy MinElute cleanup kit (Qiagen, Valencia, CA) following the manufacturer's protocol. First-strand complementary DNA (cDNA) synthesis was performed using 1,900 ng total RNA. Real-time quantitative polymerase chain reaction (RT-qPCR) assay and analyses were performed on genes identified in a previous analysis (Table 2) (Moriles et al., 2012; Hansen et al., 2013). The ubiquitin conjugating enzyme was included as the endogenous control. In this analysis the cover crop treatment was compared to the no-cover crop treatment.

Manufacturer's protocols were followed, using supplied Oligo (dT) primers and 5 µg total sample RNA for each 25 µL reaction. Primers were designed for select genes using Primer Express software (Applied Biosystems, 2004). Quantitative polymerase chain reaction (qPCR) using Go Taq Promega Master Mix Kit (Promega Corp.) was performed on a high throughput ABI 7900 PCR system following manufacturer's protocols (Applied Biosystems, 2010). Threshold values were determined with SDS2.4 software (Applied Biosystems, 2010). Samples were run in four biological replicates except for Trail City 2011 which had three replicates. The resulting cycle threshold (Ct) values were normalized to the average of an ubiquitin gene and relative quantification was conducted when PCR efficiency calculated by slope of the standard curve of the target gene/slope of the reference gene × 100 was between 95 and 105% or had an R^2 close to 0.99 (Livak and Schmittgen, 2001), an indication that the efficiency of the target and reference genes were comparable. In the ΔΔCt method, differential expression is determined by comparing the target gene in the control treatment with the same gene in the cover crop treatment (Livak and Schmittgen, 2001).

Statistical analysis

The experimental design was a randomized split plot design that was repeated at 3 locations and 2 landscape positions. Due to lack of homogeneity of variance, analysis was conducted for each site. The landscape positions were treated as additional locations. In this analysis, which used a mixed model, locations were treated as random, while the cover crops and N rates were considered fixed (SAS Institute, 2008). A Fisher protected, $p < 0.05$, LSD was used to compare means (Milliken and Johnson, 1992). Soil bacterial/fungi ratios, gene regulation, and the change in soil nutrients in cover crop and non-cover crop values from the same block were compared. A soil bacterial/fungi value greater than one indicates that the cover crop increased the relative importance of bacteria. A relative nitrate-N (nitrate-N_{cc}/(ammonia$_{cc}$ + nitrate$_{cc}$-N)/nitrate-N_{ncc}/(ammonia$_{cc}$ + nitrate$_{cc}$-N) value greater than one indicates that the cover crop increased the relative nitrate concentration, while a gene regulation value greater than one indicates that the cover crop resulted in an up-regulation of that specific gene. A 95% confidence intervals were calculated for the soil bacteria/fungi, relative nitrate, and gene regulation ratios.

Table 1. South Dakota fall 2011 cover crop seeding rates and locations.

Site	Planting date	Year	Radish	Winter canola	Purple top Turnip	Lentils	Peas	Millet	Rape
Scientific name			*Raphanus sativus*	*Brassica napus*	*Brassica campestris*	*Lens culinaris*	Pisum sativum	Pennisetum glaucum	Brassica napus
Andover (kg/ha)	9 Sep	2009	3.4	2.2	0.0	0.0	0.0	0.0	0.0
Andover (kg/ha)	17 Aug	2010	2.2	3.4	2.2	0.0	0.0	0.0	0.0
Trail City (kg/ha)	16 Aug	2010	2.0	0.0	2.0	8.9	8.9	2.8	0.0

Table 2. List of genes and their function used in analysis.

Gene ID	Annotation	Function/s
17722	Iron transport protein 2	Metal transporter in plants(i e.iron and zinc)
19894	Acid phosphatase	P metabolism, plant metabolic regulation
23951	Inorganic diphosphatase	Oxidative phosphorylation
41134	Ferredoxin	Electron transfer during Photosynthesis
41292	Photosynthesis	Photosynthesis
42137	Phosphate-induced protein 1-like protein	Mineral nutrition
43643	Putative anion transporter	Plant nutrition and compartmentalization of metabolites
48663	Putative high affinity potassium transporter	Na uptake & reduce K requirements, reduce Na accumulation in leaves
Ubiq	Ubiquitin	

Results and Discussion

Based on the measured yields and calculated yield loss due to water stress Andover 2010 was characterized as a low water stress environment, Andover 2011 was characterized as a moderate water stress environment, and Trail City 2011 was characterized as a high water stress environment.

Low yield loss due to water stress environment

In the low water stress (Andover 2011) the cover crop did not impact yield, the source of the N in the plant ($\delta\ ^{15}N$), YLNS, YLWS, or the amount of water in the soil at the end of the growing season (Table 3). In addition, corn grown at this site was not responsive to N fertilizer. The lack of response to N was attributed to high apparent N mineralization which was 293 kg N ha^{-1} in the summit position and 320 kg N ha in the footslope position. The high apparent N mineralization rates were attributed to: 1) high N rates applied to the previous wheat crop, 2) adverse climate conditions in previous years which increased the N mineralization potential, and 3) climatic conditions during 2011 that were optimum for N mineralization. It is not uncommon for high organic matter semi-arid soils to have high N mineralization spatial and temporal variability. For example, Kharel et al. (2011) reported that in central SD the apparent N mineralization was 192 and 99 Kg N ha^{-1} in 2007 and 2008, respectively. This variability is attributed to climate variability which results in low mineralization rates in drought years that can be followed by very high mineralization rates in the following years. The relatively high

Table 3. The influence of N rate, landscape position, and locations on corn yield, $\delta^{13}C$, $\delta^{15}N$, N uptake, yield loss due to N stress (YLNS), yield loss due to water stress (YLWS), and the amount of inorganic N contained in the soil at the end of the growing season at the low water site (Andover 2011).

Cover										0-60 cm
crop	N rate	Landscape	Site	year	yield (15.5%)	%N	dN15	YLNS	YLWS	kg/ha
	kg/ha				Kg/ha	%	‰	kg/ha	kg/ha	
None	0	Summit	Andover	2010	12,988	1.43	6.82	1405	1607	102.0
	30	Summit	Andover	2010	12,713	1.5	4.49	1826	1460	85.0
	60	Summit	Andover	2010	14,086	1.41	6.54	1258	655	137.0
	120	Summit	Andover	2010	13,272	1.47	4.25	1570	1158	110.0
Fall	0	Summit	Andover	2010	14,239	1.43	3.51	565	706	120.0
	30	Summit	Andover	2010	14,730	1.44	3.76	727	806	102.0
	60	Summit	Andover	2010	13,211	1.43	3.47	1093	1696	120.0
	120	Summit	Andover	2010	13,703	1.42	3.16	1291	1506	153.0
None	0	Footslope	Andover	2010	14,441	1.48	0.71	651	908	164.0
	30	Footslope	Andover	2010	13,665	1.5	0.76	1272	1275	137.0
	60	Footslope	Andover	2010	13,949	1.5	0.5	1287	763	214.0
	120	Footslope	Andover	2010	13,289	1.57	0.57	1254	1681	193.0
Fall	0	Footslope	Andover	2010	13,062	1.47	4.07	1426	1512	106.0
	30	Footslope	Andover	2010	11,867	1.48	4.51	1519	2614	99.0
	60	Footslope	Andover	2010	12,739	1.53	2.89	836	2425	131.0
	120	Footslope	Andover	2010	10,680	1.52	2.75	2167	3152	149.0
p					0.30	0.90	0.59	0.44	0.56	0.86
	0				13,695	1.46	3.77	1,028	1,258	133
	30				13,226	1.50	2.63	1,549	1,368	111
	60				13,331	1.46	3.52	1,273	709	176
	120				12,555	1.52	2.41	1,412	1,420	152
p					0.22	0.48	0.20	0.48	0.34	0.01
None					13,385	1.48	3.08	1,315	1,188	142.75
Fall					13,020	1.47	3.52	1,203	1,802	122.50
p					0.57	0.57	0.96	0.70	0.24	0.53
		Summit			13,609	1.44	4.50	1,217	1,199	116
		Footslope			12,796	1.51	2.10	1,302	1,791	149
					0.02	0.001	0.03	0.68	0.06	0.28

grain $\delta^{15}N$ values, which ranged from 3 to 7 ‰ in the summit area suggests that most of the N in the plant was derived from the soil.

At Andover in 2010 high corn yields were generally associated with low yield losses to N and water stress while low yields were associated with high yield losses due to N and water stress. In some blocks, yields were increased by N, while in other blocks yields were reduced by N. These results were attributed to high inorganic N and mineralization variability. For example, in the no-cover crop treatments the spring surface 60 cm inorganic N ranged from 56 to 118 kg N ha^{-1}, while in the cover crop treatments the inorganic N amounts ranged from 32 to 93 kg N ha^{-1}. In the cover crop treatment, 55% of the inorganic N was in the nitrate form, while in the no cover crop treatments, 74% of the inorganic N was in the nitrate form.

Table 4. The influence of N rate, landscape position, and locations on corn yield, $\delta^{13}C$, $\delta^{15}N$, N uptake, yield loss due to N stress (YLNS), yield loss due to water stress (YLWS), and the amount of inorganic N contained in the soil at the end of the growing season at the moderate water site (Andover 2012).

cover										0-60 cm
crop	N rate	Landscape	Site	year	yield (15.5%)	%N	dN15	YLNS	YLWS	kg/ha
	kg/ha				Kg/ha	%	‰	kg/ha	kg/ha	Oct 26 2011
None	0	Summit	Andover	2011	8573	1.02	2.38	6566	861	39
	30	Summit	Andover	2011	10875	1.32	2.27	2118	3007	32
	60	Summit	Andover	2011	12018	1.33	1.87	1068	2914	55
	120	Summit	Andover	2011	12419	1.42	1.41	1395	2185	39
Fall	0	Summit	Andover	2011	6581	0.91	1.78	6345	3074	30
	30	Summit	Andover	2011	7213	1.16	1.63	2412	6374	41
	60	Summit	Andover	2011	8151	1.36	1.87	881	6968	41
	120	Summit	Andover	2011	12451	1.42	1.47	1654	1895	53
None	0	Backslope	Andover	2011	11933	1.49	8.72	3227	842	47
	30	Backslope	Andover	2011	12231	1.42	8.51	2419	1351	44
	60	Backslope	Andover	2011	12998	1.45	9.13	2228	774	44
	120	Backslope	Andover	2011	13576	1.46	9.21	841	912	46
Fall	0	Backslope	Andover	2011	10666	1.23	9.35	2851	2483	37
	30	Backslope	Andover	2011	10442	1.28	9.63	4274	1285	50
	60	Backslope	Andover	2011	11815	1.37	10.06	3350	856	49
	120	Backslope	Andover	2011	13216	1.37	10.28	2089	695	57
					0.62	0.70	0.91	0.61	0.16	0.51
	0				9438	1.16	5.56	4747	1815	38
	30				10190	1.29	5.51	2806	3004	42
	60				11245	1.38	5.73	1882	2878	47
	120				12916	1.42	5.59	1995	1422	49
					0.001	0.01	0.90	0.001	0.01	0.06
None					11828	1.36	5.44	2732	1606	43
Fall					10067	1.26	5.76	2982	2954	45
					0.09	0.02	0.06	0.49	0.05	0.48
		Summit			8785	1.24	1.81	2805	3410	41
		Backslope			1210	1.39	8.49	2909	1150	47
					0.2	0.08	0.04	0.91	0.24	0.31

Table 5. The influence of N rate, landscape position, and locations on corn yield, $\delta^{13}C$, $\delta^{15}N$, N uptake, yield loss due to N stress (YLNS), yield loss due to water stress (YLWS), and the amount of inorganic N contained in the soil at the end of the growing season at the low water stressed site (Trail City 2011).

cover crop	N rate	Landscape	Site	year	yield (15.5%)	%N	dN15	YLNS	YLWS	0-60 cm kg/ha
	kg/ha				Kg/ha	%	‰	kg/ha	kg/ha	Oct 26 2011
None	0	Summit	Trail City	2011	4,347	1.19	1.39	5457	6196	28.2
	30	Summit	Trail City	2011	5,442	1.39	0.9	4014	6543	48.4
	60	Summit	Trail City	2011	6,667	1.57	1.56	2307	7025	51.8
	120	Summit	Trail City	2011	6,541	1.72	-0.09	2714	6744	52.5
Fall	0	Summit	Trail City	2011	5,176	1.18	2.33	5457	6507	29.2
	30	Summit	Trail City	2011	6,500	1.38	0.85	4014	6664	38.5
	60	Summit	Trail City	2011	7,462	1.59	1.62	2307	6624	36.0
	120	Summit	Trail City	2011	7,334	1.83	0.255	2714	6638	51.4
None	0	Footslope	Trail City	2011	5,719	1.3	4.90	4759	5522	23.0
	30	Footslope	Trail City	2011	7,581	1.41	5.19	3206	5213	33.6
	60	Footslope	Trail City	2011	9,039	1.59	4.75	2273	4687	47.0
	120	Footslope	Trail City	2011	9,858	1.61	3.33	1433	4707	45.7
Fall	0	Footslope	Trail City	2011	6,599	1.32	4.47	4260	5140	25.1
	30	Footslope	Trail City	2011	7,951	1.39	3.86	2319	5729	32.8
	60	Footslope	Trail City	2011	9,730	1.46	4.36	1961	4308	27.6
	120	Footslope	Trail City	2011	10,491	1.63	3.15	1451	4057	36.2
					0.94	0.50	0.75	0.92	0.70	0.78
	0				5,033	1.25	3.15	5,108	5,859	25.58
	30				6,512	1.40	3.05	3,610	5,878	41.04
	60				7,853	1.58	3.16	2,290	5,856	49.42
	120				8,200	1.67	1.62	2,074	5,726	49.12
					0.001	0.001	0.001	0.001	0.26	0.001
None					6,899	1.47	2.74	3,270	5,830	41.29
Fall					7,655	1.47	2.61	3,060	5,708	34.60
					0.12	0.73	0.80	0.61	0.24	0.05
		Summit			6184	1.48	1.48	3623	6618	42
		Footslope			8371	1.45	1.45	2708	4921	33
					0.08	0.34	0.02	0.333	0.04	0.23

Moderate yield loss due to water stress environment

In the moderate water stress environment, cover crops reduced grain yield (p=0.09), reduced the N concentration in the grain, increase the plants use of soil derived N, and increased the yield loss due to water stress (Table 4). Yields were generally increased with N, and the N response [(kg $yield_{134\ N}$/ha – kg $yield_{0N}$/ha)/134 kg N ha^{-1}] was greater in the no-cover crop summit landscape position [31 kg grain (kg N)$^{-1}$] than the no-cover crop footslope position [12 kg grain (kg N)$^{-1}$]. Similar results were observed in the cover crop treatments where N responsiveness was 43 kg grain (kg N)$^{-1}$ and 19 kg grain (kg N)$^{-1}$ in the summit and footslope positions, respectively. Landscape differences were attributed to predictable differences in soil water, inorganic N, and N mineralization (Table 4). For example, in the spring, summit soil samples (0-60 cm depth) contained 7cm of soil water and 23.4 kg inorganic N ha^{-1}, while the footslope soil contained 12.6 cm of soil water and 34.6 kg of inorganic N. In addition at Andover 2011, the apparent N mineralization was 89 and 190 kg N ha in the summit and footslope landscape positions, respectively. Yield losses due to water stress were much higher in the summit than footslope position.

High water stress environment

In the high water stress environment cover crops appeared to increase yield (p=0.12), and did not impact N concentration in the grain, N source in the plant ($\delta^{15}N$), YLNS, YLWS, and reduced the amount of water in the soil at harvest (Table 5). Yields ranged from 4,347 kg grain ha^{-1} in the unfertilized no-cover crop summit landscape position to 9,730 in the 134 kg N ha^{-1}, cover crop, footslope landscape position (Table 5). Landscape differences were attributed to higher N mineralization rates and available water in the footslope than summit soils. For example, in the summit landscape position, the soil contained 14 cm of soil water on 11 May 2011 and mineralized 69 kg N ha^{-1}, while the footslope soil contained 17.8 cm of soil water on 11 May 2011 and mineralized 96 kg N ha^{-1} over the growing season. In addition, the spring summit soil samples contained 47 kg inorganic N ha^{-1} while the footslope soil contained 56 kg inorganic N ha^{-1}. Of the inorganic N contained in the soil, 44% of the inorganic N was in the nitrate form.

The impacts of N on grain yields were much higher in the footslope than the summit landscape position. These results are attributed to more available water in the footslope than summit landscape position. The source of the N in the grain changed with increasing N rate. In the unfertilized plots the plant N was derived from the soil (high $\delta^{15}N$). The relative importance of soil derived N decreased with increasing N fertilizer rates (decreasing $\delta^{15}N$).

Across sites and landscape positions

Across sites and landscape positions the mixed impact of cover crops on corn yields were attributed to the soil moisture at planting the date that he cover crop was planted (Table 6). For example, the cover crop production was much lower at Trail City 2011 (high water stress) than Andover 2011 (moderate water stress) because the surface soil (0-30 cm) at Trail City very dry (<80 g kg) on 10 September 2010. Planting the cover crop in August in the moderate water stressed environment (Andover 2011) resulted in cover crop biomass yields that were greater than 2000 kg ha^{-1}. Associated with the high cover crop biomass yields was a reduction in the following year's corn yield due to increased water stress. These results suggest that planting date and soil moisture at seeding are critical in semi-arid environments. Planting cover crops early in a dry soil can have a minimal impact on the following crop yield, while early cover crop seeding into a moist soil can increase water stress in the following crop. Others have noted the impact of planting date on cover crop yield (Reese et al., 2013).

In the low water stress environment, yields were high, and unresponsive to N fertilizer. The lack of N response was attributed to high N mineralization. In the moderate yield environment, N mineralization was lower than observed in the high yield environment and cover crops increased YLWS (P=0.09). In the high water stress environment, N fertilizer had a large impact on yield and the cover crop appeared to increase yields (p=0.12). The responsiveness of the site to N was attributed to relatively low mineralization rates. Cover crop differences in the amount of inorganic N remaining the soil were not detected. These results were attributed to high nitrate and ammonia variability. However the over crop did reduce the relative amount of nitrate-N contained in the soil samples [$NO_{3\,CC}$-N/($NO_{3\,CC}$+ $NH_{4\,CC}$)/ $NO_{3\,NCC}$/($NO_{3\,NCC}$ + $NH_{4\,NCC}$)] which was 0.813 (±0.109) across sites and landscape positions. The decrease in relative nitrate-N amounts suggests that cover crop reduced the risk of N loss through leaching and denitrification.

Table 6. The influence of location and planting date on cover crop production.

Water stress environment	Site		Seeding Date	Fall CC Ave.	95% CI
				kg/ha	
Low	Andover 10	Summit	Sept. 9	211	70.4
		Footslope		328	157
Moderate	Andover 11	Summit	August 17	2585	106
		Footslope		2135	242
High	Trail City 11	Summit	August 17	630	26.3
		Footslope		200	18.9

Table 7. Site and location impact on gene regulation. A value of 1 indicates that cover crops and non-cover crops have similar activity, while a value great than one indicates that the cover crop increased activity.

Water stress		Plant growth	Energy processing		Photosynthesis		Mineral nutrition		
environ.	Ratio	17722	19894	23951	41134	41292	42137	43643	48663
Low	CC/NCC	1.4	2.02	1.11	1.55	1.96	1.49	1.04	1.55
	95% CI	0.3	0.39	0.11	0.24	0.43	0.29	0.1	0.36
Moderate	CC/NCC	0.8	0.94	1.05	0.8	1.23	0.17	1.01	0.31
	95% CI	0.16	0.29	0.17	0.33	0.13	0.27	0.16	0.35
High	CC/NCC	0.91	1.26	1.19	0.74	0.86	0.85	0.6	1.92
	95% CI	0.45	0.62	1.01	0.5	0.59	0.3	0.37	2.3

In the moderate (Andover 2011) and high water stress (Trail City 2011) environment, increasing the N rate reduced the yield losses due to N stress. This decrease was expected and resulted from an increased amount of inorganic N contained in the soil. If water stress did not reduce yields, then decreases in YLNS should increase yield. However, in the northern Great Plains frigid soils, N fertilizer can produce mixed impacts on water use efficiency (Kim et al., 2008). When timely rains do not occur, early season growth can result in water shortages during grain filling, whereas when rains do occur, early season growth can result in a yield increase. N fertilizer can also stimulate above and below ground plant development, which can help the plant increase it resilience to water stress. The mixed impact of N and cover crops on yields was attributed to N and cover crops interacting to influence both N and water availability.

Cover crop impact on the bacteria to fungi ratio

Across sites and landscape positions the ratio between the cover crop (CC) bacteria/fungi (B/F) and the non-cover crop (NCC) ratio $[(B_{CC}/F_{CC})/(B_{NCC}/F_{NCC})]$ was 1.29 ± 0.246. This ratio suggests that cover crops increased the relative presence of soil bacteria. The bacteria to fungi ratio is sensitive to many factors including N fertilizer, tillage, pH, measurement technique, and the C/N ratio of non-harvested carbon returned to the soil. The return of non-harvested carbon with high C/N ratios tends to favor fungi while the addition of low C/N ratio materials tends to favor bacteria (Bossuyt et al., 2001). In addition, high pH values tend to favor bacteria over fungi (Bååth and Anderson, 2003). The soils used in this study were derived from calcareous till with pH values that ranged from 6.5 to 8.

The C to N ratios in the cover crop was much lower than the C to N ratios in the wheat straw and corn stover. For example, at Andover 2010 broadleaf and grass plant cover crops collected from the site in November had C/N ratio that ranged from 6.3 to 9.6, while the corn stover had C/N ratios that ranged from 38 to 68. Wheat straw can also have very high C/N ratios and can have values that range from 50 to over 100 (Kharel et al., 2011). The cover crop induced change in the bacteria to fungi ratio was attributed to relatively low C/N ratios in the cover crops. Changes in the soil microbial community could change C storage in these soils, because fungi often store more C than bacteria (Bailey et al., 2002; Six et al., 2005).

Cover crop impact on gene regulation

The cover crops had a mixed impact on gene regulation (Table 7). In the low water stress environment (high yield) cover crops resulted in the up-regulation in 2 gene associated with mineral nutrition and 2 gene associated with photosynthesis. These responses are associated with cover crops having a minimal impact on yield at Andover 2011.

In the moderate water stress environment, cover crops resulted in the down regulation in 2 genes associated with mineral nutrient and one gene associated with photosynthesis. In this environment, the cover crops reduced corn yields by increasing YLWS. These results are attributed to high cover crop yields. To understand the mixed impact of the cover crops on gene regulation it is important to review the impact of water stress on gene regulation. Hansen et al. (2013) reported that water stress in the summit positions resulted in the down regulation of 708 genes and the up-regulation of 399 genes. Findings from this study suggest that corn grown in water stressed summit areas increase their capacity to manage water stress at the expense of their ability to manage other stresses.

In the high water stress (low yield environment), cover crops appeared to increase corn yields (p=0.12). Associated with an apparent yield increase was a down regulation in one the three mineral nutrition genes. In summary, cover crops had a mixed impact on gene regulation. Differences between the sites were attributed to the cover crop impact on water stress.

Impact on soil moisture

In the northern Great Plains salts are being transported from higher elevation areas to lower elevation areas with percolating water (Clay et al., 2001). It is hoped that cover crops, by reducing hydrologic transport of water from summit/shoulder areas to footslope areas can reduce salt accumulation in footslope soils. The impact of cover crops on water cycling can be variable because they increase evaporation transpiration and reduce runoff.

Summary

In the high, moderate, and low yield environments cover crops did not influence, reduced (p=0.09), and appeared to increase yield (p=0.12), respectively. Yield reductions were attributed to increased yield loss due to water stress. Cover crops also resulted in an increase in the soil bacteria to fungi ratio. This increase was attributed to the low C/N ratios of the cover crops, relative to the high C/N ratios corn stover and wheat straw. The cover crops had a mixed impact on gene regulation. For example, in the low water stress environment cover crops resulted in the up regulation in two genes, while in the moderate water stress environment cover crops resulted in the down regulation of two genes involved in mineral nutrition (2137, 43643, and 48663). A slightly different trend was observed for genes involved in photosynthesis (41134, and 41292) where cover crops contributed to up regulation at 3 sites. The cover crop impacts on gene regulation suggest that mineral nutrition of cover crop systems may need modification. For example, one modification could be to switch from a broadcast surface application to a sub-surface band application.

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Chapter 10: Publication, articles, curricula, presentations, and case studies

Fact sheets prepared for the project

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C. Bich, A.E,., C.R. Reese, S.A. Clay, and D.E. Clay. 2014, Mid-Season Establishment of Cover Crops in Corn. Crop Management (In preparation).

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A. Clay, D.E., C.G. Carlson, J. Chang, G. Reicks, S.A. Clay, and C. Reese. 2014. Determining C Budgets and Estimating the Potential Impact of Precision Conservation on Soil Organic Carbon Maintenance. Precision Conservation (in review).

B. Clay, D.E., S.A. Clay, K. Reitsma, B. Dunn, C.G. Carlson, D. Horvath, D. W. Clay, and J. Stone. 2014. Global food security through enhanced resilience of northern Great Plains lands against extreme climatic events. Food Security (in review).

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A. David Clay, Cheryl Reese, Gregg Carlson, Sharon Clay, and Alex Birch. 2014. Case study on the determining cover crop N credits. South Dakota Corn BMP manual. (in progress).

B. Cheryl Reese, Gregg Carlson, Sharon Clay, and Alex Birch. 2014. Findings from the field demonstration studies. South Dakota Corn BMP manual. (in progress).

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A. Reese, C. L., D. E. Clay, S. A. Clay, H. Bücking, T. Schumacher, C. Neuhart, T. Kharel, F. Pati, and P. WestHoff. 2010. Progress Report: Fall and Summer Seed Cover Crop Impact on Corn Productivity and Soil Health. Research Progress Meeting. 20 August 2010. Brookings, SD.

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D. Wiederholt, R. 2012. Conservation Crop Plot Tours. 18 July 2012. Pingree, ND.

Chapter 9: Copies of programs, articles, and factsheets

1. Factsheets (Section A above): First pages of articles is presented below:

Fall 2011 Soil N:

Summit Soil N

Cover Crop (CC)Treatment; Dr = Drilled	NO_3-N 0- 12 in	NH_4-N 0-12 in	Total N 0-12 in
	lb N A^{-1} (0-12 inches)		
No CC	14 a	11 a	26 a
Fall CC	15 a	12 a	27 a
V6 CC Dr	13 a	9 a	22 a
Fall CC + V6 CC Dr	14 a	10 a	24 a
P value	0.79	0.17	0.52

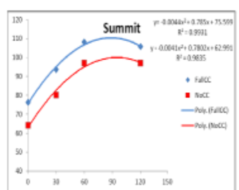
Footslope Soil N

Cover Crop (CC)Treatment; Dr = Drilled	NO_3-N 0- 12 in	NH_4-N 0-12 in	Total N 0-12 in
	lb N A^{-1} (0-12 inches)		
No CC	17 b	14 b	32 c
Fall CC	23 a	15 b	38 ab
V6 CC Dr	24 a	20 a	44 a
Fall CC + V6 CC Dr	23 a	15 b	38 ab
P value	0.01	0.03	0.02

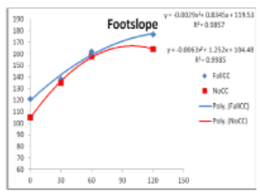
Water Infiltration (Andover, May 2012)

Landscape Position	May 2012 Cornell Sprinkle Infiltrometer			
Summit	rainfall rate	runoff rate	infiltration rate	Sorptivity
Cover Crop Treatment	Inch water $hour^{-1}$			Inch of water
No CC	8.1	5.3	2.8	0.57
Fall CC	7.9	1.2	6.7	0.82
P value	0.93	0.14	0.02	0.20
Footslope				
No CC	4.7	3.6	1.1	0.29
Fall CC	4.3	2.7	1.5	0.32
P Value	0.44	0.45	0.60	0.50

Partial Economic Analysis $$$



Corn = $7.03 / bu
Fall CC Yield = 75 bu /A
No Fall CC = 60 bu/A
••••••••
15 bu/A *$7.03 = $105/A
$105/A–$23/A = $82/A

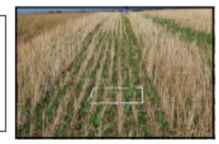


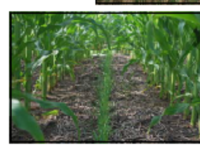
Corn = $7.03 / bu
Fall CC Yield = 163 bu /A
No Fall CC = 146 bu/A
•••••••
17 bu/A *$7.03 = $119/A
$119/A–$23/A = $96/A

Precision Cover Crops Field Tour

Tuesday
July 10th, 2012
Dewey County and SDWG Crop Tour
Rick and Ben Bieber Farm
Trail City, SD

August 2010 Seeded Cover Crop
Sept. 21st, 2010





June 2011 Seeded Cover Crop
July 13th. 2011

June 2011 Seeded Cover Crop
Sept. 15th. 2011

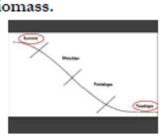
Research funded from NRCS -CIG
Grant- Agreement Number: 9-148

Experiment Design

Time Line:

1. Fall 2010:
   A. Plant cover crop into spring wheat stubble. (Est. Fall CC and NoCC Trt).
   B. Soil sample for NO3, NH4, and PO4.
2. Spring 2011:
   A. Corn is planted.
   B. Soil sample: spring NO3, NH4, and PO4.
   C. Apply ammonium nitrate fertilizer rates to each plot.
3. June 2011:
   Plant cover crop into corn at V5 -V6 (SDSU).

4. Fall 2011 (SDSU):
   A. Harvest and soil sample.
   B. Soil Analysis: Soil-- NO3, NH4, and PO4; aggregate stability, soil microbial activity and soil mycorrhizae activity.
   C. Collect weed and cover crop biomass.
5. Collect at summit and footslope position. Water and N Mineralization Differences.



Fall 2010 Cover Crops

Fall 2010 Cover Crop Seeding:

Fall 2010 Seeding Mixture, 8/16/2010

Species	Class	lbs/A	$/lb	Est. Cost
Purple Top Turnips	Cool Broad	1.75	$2.50	$4.38
Diakon Radish	Cool Broad	1.75	$3.75	$6.56
Lentils	Cool Legume	8	$0.90	$7.20
Peas	Cool Legume	8	$0.40	$3.20
Proso Millet	Warm Grass	1.5	$0.40	$0.60
German Millet	Warm Grass	1	$0.40	$0.40
Vol. Spring Wheat	Cool Grass	NA		
Total Cost				$22.34

Fall 2010 Cover Crop Biomass:

Biomass, November, 2010, Trail City

Treatments	Broadleaf	Volunteer Wheat	Total Biomass
Field Position		lb A^{-1}	
Summit	82 b	26 b	107 b
Toeslope	173 a	89 a	262 a
P value	<0.001	<0.001	<0.001
Cover Crop			
No Fall Cover Crop	0 b	0 b	0 b
Fall Cover Crop	254 a	115 a	368 a
P Value	<0.001	<0.001	<0.001

Fall 2010 Soil Moisture:

Treatments	November 2010 Soil Moisture (%)			
Field Position	0-6 in. (0-15 cm)	6-12 in. (15-30 cm)	12-18 in. (30-45 cm)	12-24 in. (45-60 cm)
Summit	19.6 b	19.5 b	15.9 b	18.5 b
Toeslope	23.7 a	22.5 a	20.1 a	24.1 a
P value	<0.001	<0.001	<0.001	<0.001
Cover Crop	No moisture difference between NoCC and FallCC			
No Fall Cover Crop	20.8	19.4	18.3	16.4
Fall Cover Crop	20.0	20.5	18.0	16.9
P Value	NS	NS	NS	NS

Spring 2011 Soil N:

Landscape Position	May 2011 Soil N, lbs / A		
Summit	NO_3	NH_4	Total N
No CC	23	30	53
Fall CC	18	31	50
P value	0.005	0.156	0.100
Footslope			
No CC	29	29	58
Fall CC	30	34	63
P Value	0.938	0.027	0.330

Yield Fall 2011

	Summit	Toeslope
Cover Crop Treatments	Yield	
Cover Crop (CC)Treatment; Dr = Drilled	bu A^{-1}	
No CC	60 c	146 c
Fall CC	75 a	163 a
V6 CC Dr	64 bc	160 bc
Fall CC + V6 CC Dr	74 ab	155 ab
P Value	0.01	0.18

Letters explain difference 95% of time (Summit) and 80% of time (Toeslope)

Ears /A Fall 2011

	Summit	Toeslope
Cover Crop (CC)Treatment	ears $Acre^{-1}$	
No CC	32637 b	32057 b
Fall CC	34255 a	39091 a
P Value	0.04	0.02

Lilleboe, Don. 2013. Caretaker of the Soil: South Dakota No-Till Producer Rick Bieber is Empathic About Good Stewardship. The Sunflower Magazine. March/April 2013. Published by the National Sunflower Association.

Areas are highlighted in yellow on the second page of the article reference the NRCS-CIG cover crop grant.

Photo: Rick Bieber

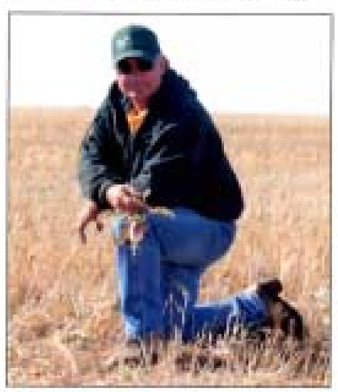
Caretaker of the Soil

South Dakota No-Till Producer Rick Bieber Is Emphatic About Good Stewardship

Every wise farmer knows the foundation of his success lies within the soil. But few if any farmers imprint that fact upon their own consciousness and methodology with more conviction than Rick Bieber.

Bieber, who along with his son, Ben, farms near the north central South Dakota community of Trail City, has become a popular national and even international speaker on the subjects of no-till crop production and soil health. He is a fervent believer in both — and crop yields on their Corson County farm confirm the validity of his approach. Yet Bieber simultaneously waves off any suggestion that he's an expert in these areas. "The hero is the crops — their roots and their ability to gather carbon so the soil biota can live in a healthy environment," he emphasizes. "And the hero becomes the soil itself. I didn't have anything to do with it other than leaving it alone; I didn't contribute anything by using a 'piece of green or red paint.' "

The core of the Bieber farm is comprised of side-by-side acreage homesteaded by his two sets of grandparents. "One of my grandfathers was very conservation minded; the other one was very much 'let's see what we can get off the land' " he relates. The locale's light soils have been prone to wind-driven erosion for generations, and the differences in the two sets of land — one that blew heavily during the '30s and '40s and one that did not — are still manifested today in their respective productivity levels, he says.



Rick Bieber

Bieber and his father farmed very conventionally during the 1970s, tilling extensively. "The county average spring wheat yield was 17 bu/ac; our proven yield was 21 bu. So we were good — or so we thought," he recounts. During the '80s, the Bieber operation was under extreme financial stress of the degree that forced numerous Upper Midwest farmers out of business. The turnaround began in the late '80s, about the time Rick started no-tilling. "Through a complete change in farming style, our farm survived and thrived in the '90s," he says. "The decade of the 2000s put our farm through some of the most extreme conditions, from the lowest rainfall ever recorded to some of the highest temperatures in several decades. And yet our soils continued to perform. This was achieved through no-till, rotations and downright stubbornness."

Long-term rainfall in the Trail City area averages less than 17 inches per year. While 2011 brought above-average precipitation, 2012 was just the opposite. Still, crop yields on the Bieber farm have, for years, been far above the county average. "It's not about how much moisture one receives; but rather, how efficiently you manage what you receive," Rick states. "We judge our management skills by 'pounds of harvestable material per inch of water fallen.' And our soil health has allowed that number to keep rising. It's about the soils taking care of themselves and taking care of the crops planted there.

"Our 'bucket' becomes larger and larger every year if we cause less soil disturbance, through increased organic matter," he adds. The typical tilled field in Bieber's area has around 2% organic matter. His own longtime no-till fields run around 5%. "So if my soils would typically hold three or four inches of water with 2% OM, now they hold six inches of moisture at the root zone."

Rotation & Cover Cropping

The Bieber crop rotation has evolved a long way since the straight wheat-fallow days of the '60s, '70s and early '80s. "We start off with a four- or five-year rotation that includes cool-season grasses (wheat and oats); then go to a warm-season grass (corn, millet, forages). From there, we go to a broadleaf (sunflower, flax, peas, alfalfa) and anything else that we feel may improve our soils and reduce our inputs in the following wheat crops," Rick observes. He admits to occasionally deviating from his planned rotation because of the temptation to "chase a market," but feels doing so extracts a definite price from the next year's crop.

Bieber's intense interest in improving his fields' soil health led him into seeding cover crops the past several years. He has experimented with various types: warm-season, cool-season, broadleaves and grasses. In some instances, the cover crop has thrived; in others, it has not. In 2012, for instance, the extreme drought resulted in poor germination and minimal growth. Overall, however, Bieber says cover cropping has definitely benefited yield in the succeeding cash crop. Cover crops also provide forage for their expanding cattle numbers — and, of course, contribute to improved soil structure.

South Dakota State University agronomist Cheryl Reese has been testing cover crops on the Bieber farm the past three years as part of a multi-site research project partially funded through the USDA Natural Resources Conservation Service (NRCS). Her focus has been on the impact that cover crops have on soil quality, corn yield and soil nitrogen.

In this NRCS study, cover crops were seeded in August 2010 into wheat stubble. To compare the fall cover crop effect, control plots were established in August 2010 where a fall cover crop was not planted. The following spring, 2011, Bieber planted corn into the test plot area. A third cover crop treatment was added in June of that year when cover crops were drilled into the growing corn.

(The August 2010-seeded cover was a mixture of purple top turnips, diakon radish, lentils, peas, proso millet, german millet and volunteer spring wheat. The June 2011 mixture consisted of crimson clover, winter wheat and lentils.)

In 2012, Bieber planted sunflower across Reese's cover crop plots on the Bieber farm. In the fall, Reese sampled sunflower from the cover crop plots seeded in August 2010; those seeded in June 2011; and from the plots that did not have cover crops. In this single-year, single-site study, sunflower yield was greater in the plots where cover crops were planted in August 2010 as compared to the other two treatments. "Basically, what we saw at Rick's farm was that an in-season cover crop did not benefit sunflower production the following year, but a fall cover crop did," Reese says. "The 'fall cover crop 2010 plots' sunflower yields were statistically significantly greater than those of the sunflower planted into the cover crops planted into corn in June 2011, or where there were no cover crops."

Why did those cover crop trials produce those results? "While I am still working on the data to support my idea, it goes along with Rick's," Reese says by way of explanation. "When wheat is harvested in mid-July or around August 1, the living root mass is gone. That leaves August, September, October and maybe even some of November with soil that does not have a living root mass.

Photo: Cheryl Reese

Cover crop grows in wheat stubble in an SDSU research plot on the Bieber farm.

"If we think about soils at Trail City, these soils supported mid to short native prairie grasses where a living root provided carbon, as well as other nutrient sources for the soil microorganisms, from April to November. By adding this fall cover crop following a short-season crop such as wheat, we assist maintaining a healthy population of soil biota.

"In 2011, corn yield was better where we had a fall cover crop as well. We are reaping the rewards in corn yield (2011) and sunflower yield (2012) of maintaining a living soil for those three to four months after spring wheat was harvested."

What Sunflower Brings

Ironically, both Rick Bieber and son Ben are allergic to sunflower. During the crop's bloom period, "I look like I've been run through a washing machine — red and rashy all over," he quips. But he's also allergic to cattle . . . cats . . . kochia . . . and tomatoes, among other things. So that in-season allergy is not about to stop him from growing this crop — especially when yields on the Bieber farm averaged in the neighborhood of 2,400 to 2,600 lbs/ac in 2010 (with one field hitting nearly 3,500 lbs). During the very dry 2012 season, yields varied from 1,500 to 2,500 lbs/ac across their 2,000 acres of oil-type sunflower.

The Biebers actually didn't start growing sunflower until 2002. "We needed a broadleaf in our rotation," Rick recalls. "A lot of broadleaves just don't sustain under high temperatures and low moisture; but sunflower will.

"We manage intensely for high-quality, high-yield wheat. We fertilize with the

Photo: Rick Bieber

drill, we top dress — and we'll even fertilize the wheat a third time, because we're going for high-quality spring wheat."

Corn typically follows wheat on the Bieber farm, "and we manage the corn for some high yields also." Then comes sunflower the following year, planted between the standing corn stalks. Because it's the deepest-rooting crop in the rotation, "we do fertilize — but we fertilize extremely early, because we want the nitrogen to go down deep," Bieber says. "We don't want a lot of vegetative growth on that sunflower plant.

"When it hits the nitrogen, the sunflower has some 'age' on it already. We want it to be taking full advantage of that nitrogen during seed fill. We wind up with tremendous oil — and that oil gives you tremendous weight at the elevator."

Weed control has proven very manageable in the Bieber sunflower fields. "Our weed control is close to maximum in all the other crops, so there's not much of a weed seed bank there when the sunflower goes in," Rick observes. "We do put down Spartan; but it's more of a preventative measure." He also counts on the sunflower plant canopy to aid with suppression of any late-emerging weeds.

Another benefit to sunflower's deep taproot, Bieber says, comes a year or two after a field of 'flowers has been harvested.

"If you recognize the wealth that God has given you in the soil, and you look at it as a resource you must protect, the soils respond unbelievably."

"When the sunflower plant decomposes, you have that channel that is now devoid of the old root," he points out. "If you never go through there with a seeding apparatus or tillage tool that closes the channel, it then becomes a capillary to let moisture migrate back and forth. The moisture percolates down quickly if we get a big rain event; but [the channel] also lets deeper soil moisture move upward in a dry spell."

Bieber says one downside with sunflower to date has been "we have a hard time keeping the sunflower residue stable after [seeding spring wheat] and prior to the wheat's emergence." That's especially true if early spring brings high winds — which is not at all uncommon. He is experimenting with flying on a cover crop in the sunflower at about the V5-V6 stage (as he did on 100% of this past season's corn acreage); "but 2012 wasn't a good year to experiment with that, because we got virtually no rain during July and August."

Again, It's the Soil!

When you have the Risk Management Agency auditing you because they have a hard time believing how high your yields were, you must have been doing something right. But again, Rick Bieber shines the spotlight on his soils.

"It's come to where our soils are so willing to give back and produce on so little moisture," he reiterates. "If you pay attention to your soils, they just come alive! If you recognize the wealth that God has given you in the soil, and you look at it as a resource that you must protect — rather than just protecting your bank account — the soils respond unbelievably, including in very adverse weather years.

"Take care of your soil, and it will take care of you." — **Don Lilleboe** ■

2. Workshops (Section D above):

   a. Precision Fall and Summer Seeded Cover Crop Impact on Corn Productivity and Soil Health in No-Till Production Systems of the Northern Great Plains. Precision Cover Crops **Workshop**. 06 July 2011. Bristol, SD.

LOCATION:

HOT SPOT RESTAURANT
42295 US HWY 12
BRISTOL, SD 57219

DIRECTIONS:
INTERSECTION OF HIGHWAY 12 AND COUNTY ROAD 33,
SW CORNER OF HIGHWAY INTERSECTION BY DALE'S SERVICE

THANK YOU TO WORKSHOP SPONSORS!!!!

SOUTH DAKOTA WHEAT GROWERS

DAY COUNTY CONSERVATION DISTRICT

NATURAL RESOURCE CONSERVATION SERVICE

SOUTH DAKOTA STATE UNIVERSITY

NORTH CENTRAL SUSTAINABLE AGRICULTURE, RESEARCH, AND EDUCATION

PLEASE MAKE PLANS TO ATTEND THIS WORKSHOP!!!

THIS EVENT IS ORGANIZED TO ALLOW TIME FOR:

1. PRESENTERS TO DISCUSS THEIR EXPERIENCES GROWING COVER CROPS

AND

2. TIME FOR DISCUSSIONS AND QUESTIONS AT THE END OF EACH PRESENTATION

REMEMBER TO PRE-REGISTRATION FOR FREE LUNCH

PRE-REGISTRATION DUE BY JUNE 28TH, 2011

TO PRE-REGISTER, CONTACT:
Anita Wells
Phone: 605-688-4600
Email: Anita.Wells@sdstate.edu
Or
Cheryl Reese
Phone: 605-688-6309
Email: Cheryl.Reese@sdstate.edu

CERTIFIED CROP ADVISOR CEU CREDITS WILL AVAILABLE AT THIS WORKSHOP

PRECISION COVER CROPS FIELD TOUR AND WORKSHOP

WEDNESDAY JULY 6TH, 2011

HOT SPOT RESTAURANT
42295 US HWY 12
BRISTOL, SD 57219

8:45 AM TO 3:30 PM

CONFERENCE SPONSORS:

SOUTH DAKOTA STATE UNIVERSITY

USDA-NRCS

WHEAT GROWERS (PROVIDING LUNCH FOR REGISTERED ATTENDEES)

DAY COUNTY CONSERVATION DISTRICT

NORTH CENTRAL SUSTAINABLE AGRICULTURE, RESEARCH, AND EDUCATION

LUNCH PROVIDED IF PRE-REGISTERED

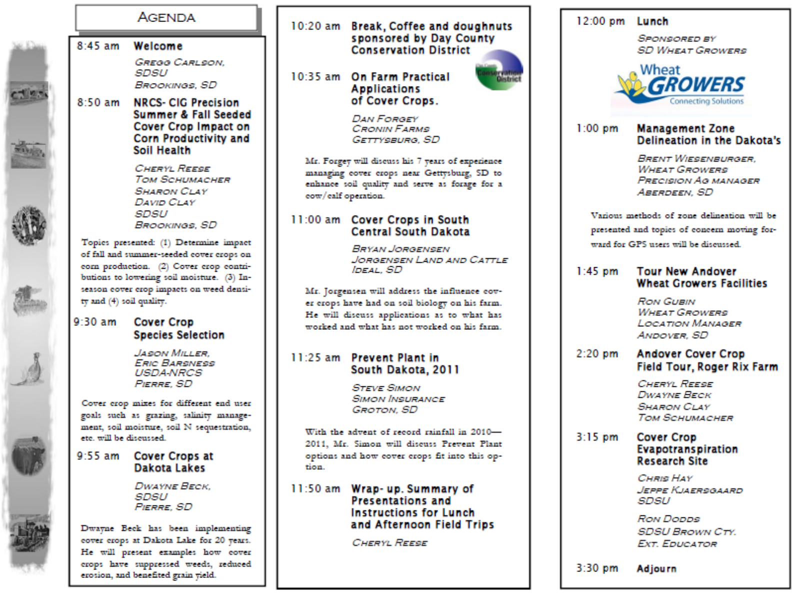
OTHERWISE

$10.00 AT THE DOOR

TO PRE-REGISTER, BY JUNE 28TH, CONTACT
Anita Wells
Phone: 605-688-4600
Email: Anita.Wells@sdstate.edu
Or
Cheryl Reese
Phone: 605-688-6309
Email: Cheryl.Reese@sdstate.edu

For Questions About The Meeting,
Please Contact Cheryl Reese

Figure 21A. Agenda from cover crop meeting on July 6th, 2011, Bristol, SD.



AGENDA

8:45 am Welcome

*Gregg Carlson, SDSU
Brookings, SD*

8:50 am NRCS- CIG Precision Summer & Fall Seeded Cover Crop Impact on Corn Productivity and Soil Health

*Cheryl Reese
Tom Schumacher
Sharon Clay
David Clay
SDSU
Brookings, SD*

Topics presented: (1) Determine impact of fall and summer-seeded cover crops on corn production. (2) Cover crop contributions to lowering soil moisture. (3) In-season cover crop impacts on weed density and (4) soil quality.

9:30 am Cover Crop Species Selection

*Jason Miller,
Eric Barsness
USDA-NRCS
Pierre, SD*

Cover crop mixes for different end user goals such as grazing, salinity management, soil moisture, soil N sequestration, etc. will be discussed.

9:55 am Cover Crops at Dakota Lakes

*Dwayne Beck,
SDSU
Pierre, SD*

Dwayne Beck has been implementing cover crops at Dakota Lake for 20 years. He will present examples how cover crops have suppressed weeds, reduced erosion, and benefited grain yield.

10:20 am Break, Coffee and doughnuts sponsored by Day County Conservation District

10:35 am On Farm Practical Applications of Cover Crops.

*Dan Forgey
Cronin Farms
Gettysburg, SD*

Mr. Forgey will discuss his 7 years of experience managing cover crops near Gettysburg, SD to enhance soil quality and serve as forage for a cow/calf operation.

11:00 am Cover Crops in South Central South Dakota

*Bryan Jorgensen
Jorgensen Land and Cattle
Ideal, SD*

Mr. Jorgensen will address the influence cover crops have had on soil biology on his farm. He will discuss applications as to what has worked and what has not worked on his farm.

11:25 am Prevent Plant in South Dakota, 2011

*Steve Simon
Simon Insurance
Groton, SD*

With the advent of record rainfall in 2010—2011, Mr. Simon will discuss Prevent Plant options and how cover crops fit into this option.

11:50 am Wrap- up. Summary of Presentations and Instructions for Lunch and Afternoon Field Trips

Cheryl Reese

12:00 pm Lunch

*Sponsored by
SD Wheat Growers*

1:00 pm Management Zone Delineation in the Dakota's

*Brent Wiesenburger,
Wheat Growers
Precision Ag manager
Aberdeen, SD*

Various methods of zone delineation will be presented and topics of concern moving forward for GPS users will be discussed.

1:45 pm Tour New Andover Wheat Growers Facilities

*Ron Gubin
Wheat Growers
Location Manager
Andover, SD*

2:20 pm Andover Cover Crop Field Tour, Roger Rix Farm

*Cheryl Reese
Dwayne Beck
Sharon Clay
Tom Schumacher*

3:15 pm Cover Crop Evapotranspiration Research Site

*Chris Hay
Jeppe Kjaersgaard
SDSU*

*Ron Dodds
SDSU Brown Cty.
Ext. Educator*

3:30 pm Adjourn

b. Cover crops and soybeans. Soy100: Growing 100-Bushel Soybeans. Cover Crop Breakout Session. 05 March 2013.

c. Bismarck, ND. March 28th, 2012. Cover Crops: The Science Behind the Numbers Workshop. 28 March 2012. Bismarck, ND. Results of a survey conducted at this meeting are available upon request.

Cover Crops: The Science Behind the Numbers

March 28th, Burleigh County Extension Office, Bismarck, ND

9:45 AM CDST to 4:30 PM CDST

Agenda:

9:45 Welcome and Introductions

10:00 Beef production and annual forages: calves, cows, and yearlings. *Doug Landblom, NDSU DREC*

10:30 The Agronomic and Economic Value of Cover Crops for Late-Season Grazing in the central and eastern Dakotas – synopsis of a 5 year study. *Kevin Sedivec, NDSU*

11:00 Breaking New Ground. *Justin Zahradka, Park River*

11:30 Crop Response After Cover Crops *Ken Miller, Burleigh County*

Noon: Lunch Provided On Site

1:00 Soil Fertility and Cover Crops. *Dave Franzen, NDSU Soil Science*

1:30 Southwest North Dakota Soil Health Demonstration Project Report. *Jon Stika, ND NRCS*

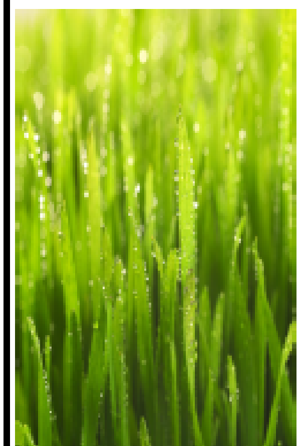
2:00 Challenges of Growing Cover Crops in Dryland Farming Systems in Southwestern ND. *Pat Carr, NDSU DREC*

2:30 Cover Crop Impact on Corn Productivity and Soil Health in No-Till Production. *Cheryl Reese, SDSU Agron.*

3:00 Are there advantages of interseeding cover crops into corn? *Sharon Clay, SDSU Weed Science*

3:30 Bio Strip till at the Conservation Cropping Systems Project, one hit, one miss. *Kelly Cooper, SCD CCSP*

4:00 Update on NW ND Cover Crops *Chet Hill, Williston REC*



Registration is free but please contact Linda at the Carrington REC (701)652-2951 or Linda.Schuster@ndsu.edu to register.

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NDSU Extension
Pulse USA
Agassiz Seed

NDSU EXTENSION SERVICE

Individuals with disabilities are invited to request reasonable accommodations to participate in NDSU-sponsored programs and events. To request an accommodation(s), please contact the Burleigh County Extension office (701.221.6865) by March 20th to make arrangements.

d. Northeast Cover Crops Demonstration Project. 14 September 2011. Park River, ND.

NORTHEAST COVER CROPS DEMONSTRATION PROJECT
September 14, 2011
101 County Rd 12B
Park River, North Dakota

8:30 Registration

9:00 Selection of Cover Crops
Brad Brummond and Theresa Jeske, NDSU Extension Agents Walsh County

9:40 Soil Quality Factors and Cover Crops
Hal Weiser, NRCS Agronomist/Soil Salinity Specialist

10:30 Break

10:45 Grazing Cover Crops
Dr. Kevin Sedivec, NDSU Extension Range Management Specialist

11:30 Status of Cover Crops in North Dakota
Ron Wiederholt, NDSU Extension Nutrient Management Specialist

12:10 Lunch

1:00 Cover Crops on CRP
Brad Brummond, Rita Sveen (NRCS), Hal Weiser, Kevin Sedivec and Cooperator

2:30 Cover Crops on Harvested Grain Crops
Brad Brummond, Rita Sveen, Hal Weiser, Kevin Sedivec and Cooperator

4:00 Cover Crops and Salinity
Hal Weiser and Rita Sveen

5:00 Close

There will be a half hour of travel time figured between the start of each segment of the tour

Field Days (Section E above):

a. Dewey County and SDWG Crop Tour. 07 July 2012. Trail City, SD.

b. Dewey County Crop Tour. 13 July 2011. Dewey County, SD.

News Release

07/05/2011

Contact: Mike Huber, SD Wheat Growers Agronomist

605 823-4441

AREA CROP TOURS

The South Dakota Wheat Growers, SDSU & NDSU Extension Services and area Crop Improvement Associations will be conducting their annual Crop Tours in the next few weeks. Most crops are off to a good start; however the cool spring and wet weather have also caused some challenges. We should have a lot of things to look at and discuss during this year's tours.

These Crop Tours are an excellent way to discuss the issues that are showing up and work on managing them in the future. The tours are also an excellent opportunity for producers to view new crop varieties that are being released for our area. It is also a great time to visit with friends and neighbors.

Some of the staff that will be taking part in the tours during July include: John Rickertsen-SDSU Extension Agronomist, Eric Eriksmoen-NDSU Extension Agronomist, Cheryl Reese-SDSU Research Associate and Mike Huber-SD Wheat Growers Agronomist.

Here are the dates for the upcoming tours:

July 13th	**Dewey County Crop Tour**	**3:00 PM MT**	**Rick & Ben Bieber Farm, Trail City (Spring & Winter Wheat Varieties, & Cover Crop Discussion)**
		5:00 PM MT	**Faron Schweitzer Farm, Glencross (Cool Season Forages)**
		6:30 PM MT	**Alan & Jiggs Biegler Farm, Timber Lake (Spring & Winter Wheat Varieties) (Supper sponsored by Dewey Co. CIA)**

Precision Fall and Summer Seeded Cover Crop Impact on Corn Productivity and Soil Health in No-Till Production Systems of the Northern Great Plains. Precision Cover Crops **Field Tour**. 06 July 2011. Bristol, SD.

c. Wiederholt, R. 2012. Conservation Crop Plot Tours. 18 July 2012. Pingree, ND.

Crop Tour

Conservation Crop Plots
Wednesday July 18, 2012

Meet at 9:00 AM
at the CRP Conversion Plots
3 miles north of Buchanan, ND
West of Highway 281 N

Featuring Representatives:

☆ **Emmett Lampert**
Regional Agronomist ND/SD, Winfield Solutions

☆ **Hal Weiser**
State Soil Health Specialist, NRCS

☆ **Allen St. Michel**
Seed and Agronomy Advisor, Winfield Solutions

☆ **Daron Lacina**
Sales Agronomist, Farmers Union Oil

☆ **Ryan Odenbach**
319 Watershed Coordinator, Stutsman Co. SCD

☆ **Ron Wiederholt**
Nutrient Management Specialist
NDSU Carrington Research Extension Center

Persons requiring special accommodations or materials in an alternative format or language should contact Codie Lacina DC, 701-252-2521 ext. 3, prior to July 18th.

The USDA is an equal opportunity provider and employer.

Stutsman County NRCS/SCD
701-252-2521 ext. 3
1301 Business Loop East
Jamestown, ND 58401

Topics Covered:

- Double Cropping in Stutsman County with Soybeans
- Nutrient Availability & Supply with Cover Crops
- Corn Stages and Management
- Soybean Genetics
- Wheat, Corn and Soybean Trials