

WICST Twelfth Report

THE WISCONSIN INTEGRATED CROPPING SYSTEMS TRIAL Twelfth Report - 2007 & 2008

Compiled by Janet Hedtcke and Josh Posner

<http://wicst.wisc.edu>

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PROLOGUE

This is the twelfth technical report of the Wisconsin Integrated Cropping Systems Trial (WICST). In earlier reports, we discussed the objectives of the project, the results of the uniformity year (1989), and the first seventeen production years (1990 – 2006). In this report, we discuss the results of the 2007 & 2008 growing seasons. This is the sixteenth time all the phases of the six rotations have run concurrently, permitting us to again compare all the systems. By the end of the growing season in 2008, all the treatments of the Cropping Systems had completed at least four full cycles of their respective rotations. Also included in this report are research results of satellite trials conducted both on-farm and adjacent to the WICST core trials.

Funding for the project continues to come primarily from the USDA-ARS's national program on food and animal production entitled 'Improving Dairy Forage and Manure Management to Reduce Environmental Risk'. Other grants important to the success of the project come from the Wisconsin Fertilizer Research Council, USDA-National Research Initiative, USDA-Sustainable Agriculture Research and Education Fund, as well as Hatch funds managed by the College of Agricultural and Life Sciences.

Summer 2007 & 2008 Collaborators

Janet Hedtcke, UW-Madison, Agronomy Dept. jlrieste@wisc.edu

Joshua Posner, UW-Madison, Agronomy Dept. jlposner@wisc.edu

John Hall, Michael Fields Agricultural Institute, jhall@michaelfieldsagainst.org

Randall Jackson, UW-Madison, Agronomy Dept. rdjackson@wisc.edu

Phillip Barak, UW-Madison, Soil Sci. Dept. pwbarak@wisc.edu

Dave Stoltenberg, UW-Madison, Agronomy Dept. destolte@wisc.edu

Jon Baldock, AgStat, Verona, agstat@tds.net

Bill Jokela, USDA Institute for Environmentally Integrated Dairy Management,
Bill.Jokela@ars.usda.gov

Rick Walgenbach, USDA Dairy Forage Research Center, rwalgenb@wisc.edu

Ed Luschei, UW-Madison, Agronomy Dept. ecluschei@wisc.edu

Dave Hogg, UW-Madison, Entomology Dept. dhogg@cals.wisc.edu

Teri Balser, UW-Madison, Soil Sci. Dept. tcbalser@wisc.edu

Gregg Hadley, UW-Extension, River Falls

Gregg Sanford, graduate student, UW-Madison, Agronomy Dept. gsanford@wisc.edu

Gary Oates, post doc, UW-Madison, Agronomy Dept. oates@wisc.edu

Emily Bernstein, graduate student, UW-Madison, Agronomy Dept.

Dustin Sawyer, graduate student, UW-Madison, Soil Sci. Dept. dsawyer@wisc.edu

Rachel Mallinger, graduate student, UW-Madison, Entomology Dept.

Herika Kummel, graduate student, UW-Madison, Agronomy Dept.

Laura Lipps, graduate student, UW-Madison, Soil Sci. Dept.

Nick Goeser, graduate student, UW-Madison, Agronomy Dept.

Laura Smith, graduate student, UW-Madison, Agronomy Dept.

Craig Maier, graduate student, UW-Madison, Agronomy Dept.

Nicole Budd, undergraduate, UW-Madison, Environmental Studies

Rachael Cox, graduate student, UW-Madison, Agronomy Dept.

Carrie Laboski, UW-Madison, Soil Sci. Dept.

Todd Andraski, UW-Madison, Soil Sci. Dept.

We also acknowledge with many thanks, the contributions of those who assisted at the Arlington, Marshfield, and Prairie du Sac research stations and at Michael Fields Ag Institute in managing the crops and animals related to this project. Specifically, Darwin Frye and Paul Bergum and the crew at Arlington; Dave Combs and Mike Peters and the staff at Blaine Dairy; Rick Walgenbach and Wayne Coblentz at USDA Dairy Forage Research Center in Sauk Co. Likewise, we are grateful to the Farmer Steering Committee who provided invaluable, experienced advice to the project with input on their various cropping system management: Tim Zander (organic grain farmer), Tom Miller (organic dairy farmer), and Ron Schoepp (custom heifer grower/grazier and crop enterprise).

INTRODUCTION

In the fall of 1988, a group consisting of faculty from the College of Agricultural Life Sciences, agents from the Wisconsin Extension Service, agronomists from the Michael Fields Agricultural Institute, and farmers came together to design the Wisconsin Integrated Cropping Systems Trial (WICST). The overall objective of the trial was to compare alternative production strategies with the performance criteria of productivity, profitability, and environmental impact. Concomitant with this technical objective was the decision to develop the trial in a “Learning Center” environment, where all the members of the community could learn about agroecology and production agriculture.

From these discussions evolved a plan to work at two locations in southern Wisconsin. The Lakeland Agricultural Complex (LAC) is situated on the Walworth County Farm about 45 minutes west of Milwaukee was used until 2002. The other site is still active at the Arlington Research Station (ARS), a University of Wisconsin agricultural research farm about 30 minutes north of Madison (see Figure 1a). At both sites a 60-acre area was set aside and in 1989 a uniformity trial was held in order to facilitate the subsequent blocking of the core rotation experiment. The year 1990 was the first production year of the project. Most of the chapters and data in this current report are from the Arlington Station site.

The selection of cropping systems provoked a great deal of discussion within the group. Ultimately, a factorial array of rotations was selected. It was observed that within southern Wisconsin there were two principal types of farm enterprises: cash-grain and forage-based systems, each with its own production requirements. At the level of production strategy, our hypothesis stated that as systems became more complex, they would require less and less external inputs to remain productive. As a result, production strategies with a high, medium, and low level of complexity were designed. Put in an inverse fashion, systems that required a high, medium, and low level of purchased inputs were put into practice. The six rotations are schematically represented in Figure 1b. Some of the anticipated differences between the rotations are outlined in Table i.

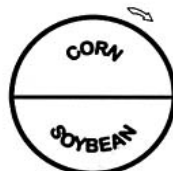


Figure 1a. Outline of major Land Resource Area 95B and the two sites of the Wisconsin Integrated Cropping Systems Trial.

Cash-Grain Cropping Systems:



CS1
Continuous corn



CS2
No-till



CS3
Organic Grain Rotation

Forage-based Cropping Systems:



CS4
"Green Gold"



CS5
Organic Dairy Rotation



CS6
Rotational Grazing

Figure 1b. Schematic diagram of the cropping systems of the WICST experiment.

Table i. Productivity, Economic, and Environmental Comparisons between Rotations on WICST 1990.

Rotation	Predicted Yield/acre	Mean above ground productivity ¹ Lb/a/yr	Mean energy input ² Mcal/a/yr	Energy output/input ³ ratio	Variable costs ⁴ \$/a/yr	Chemical inputs			Erosion ⁵ t/a/yr
						N Fertilizer on corn lb/a	Herbicide AI/a	Insecticide AI/a	
R₁ Continuous Corn	150 bu	15,780	2369	6.0	140	150	Atrazine 2 lb Alachlor 2 lb	Counter 1.4 lb	4.1
R₂ Drilled Soybean Corn	55 bu 160 bu	12,510	1788	6.9	104	110	Bladex 2.5 lb Alachlor 2.5 lb Sencor 0.5 lb Treflan 1.5 lb	0	4.0
R₃ Row soybean Wheat Corn	40 bu 60 bu/2t straw 120 bu	10,010	763	12.6	50	0	0	0	2.9
R₄ Seeding alfalfa Hay I Hay II Corn	3t dm 5t dm 5t dm 160 bu	10,710	1188	13.7	110	10	Eptam 2.9 lb Bladex 2.0 lb Alachlor 2.5 lb	Lorsban 1.0 lb	1.9
R₅ Oats/alfalfa Hay I Corn	60 bu/2t dm 4t dm 120 bu	9,440	811	18.2	45	10	0	0	1.6
R₆ Rotational Grazing	4t dm	8,000	129	104.3	16	na	0	0	0.5

¹ Mean above ground productivity: dry matter biomass production per acre per year. Calculated based on the following harvest indices: Corn .45; soybean .35; wheat .42; oat .45.

² Mean energy input includes only seed, fertilizer, lime, pesticides, and fuel. Based on Pimentel, D. 1980 Handbook of Energy Utilization in Agriculture, CRS Press Inc.

³ Ratio of energy value of agricultural output to energy consumption

⁴ Variable costs include seed, fertilizer, pesticides, drying, fuel, and labor. Costs based on 1988 Wisconsin Crop Budgets. R. Klemme and L. Gillespie.

⁵ Erosion estimates were made using the USLE for a 4% slope, 200 feet long with a silt loam soil and contour planting

¹ 3-plot average. Severe ground squirrel damage in plot 206 corn and intensive/expensive hand weeding in 411 beans led to their omission.

² Due to poor stand and late replanting date, corn did not make blacklayer before end of season and was harvested as snaplage (cob+husk+ear) yielding 1.07 and 1.36 ton DM/a for CS3 and CS5, respectively.

³ Soybeans replanted 6/15 due to severe herbicide damage to soybeans and poor weed control.

CROPPING SYSTEMS TRIAL DATA

WICST Annual Crop Yields

Table 1. Yields on WICST at the Arlington Research Station 1993-2008

System	Corn	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
		-----bu/acre-----															
CS ₁	Continuous corn	123.7	178.1	143.1	131.5	128.6	196.2	170.4	161.6	193.6	192.2	175.0	193.9	197.3	192.7	204.0	141.7
CS ₂	After sb (No Till)	129.8	190.2	167.7	140.0	157.4	212.6	162.9	162.9	207.7	159.2 ¹	176.5	189.0	210.2	190.6 ¹	189.2	175.3
CS ₃	Organic 3-crop	87.1	188.4	155.6	83.4	147.6	197.8	155.6	132.8	155.5	157.8	110.0	53.0 ²	102.2	144.8	161.8	173.5
Chemlite	Low input 3-crop	-	-	146.5	150.9	158.8	199.8	156.2	155.4	190.5	173.8	155.2	223.8	201.5	199.8	196.8	179.7
CS ₄	After 3-yr alf	165.1	196.5	167.5	151.2	159.1	226.8	189.7	179.4	227.8	186.6	190.6	212.7	231.4	217.7	215.5	208.6
CS ₅	After 2-yr alf (org)	119.1	198.8	157.1	153.6	155.3	205.1	181.9	135.2	181.2	174.1	149.7	66.1 ²	128.3	189.0	174.0	205.7
LSD (0.05)		7.3	9.1	9.4	16.5	10.2	9.6	15.1	25.1	18.4	18.5	17.9	5.6	21.6	4.4	8.6	18.1
	Soybeans	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
		-----bu/acre-----															
CS ₂	Drilled – No till	52.8	42.7 ³	58.1	53.7	51.9	63.6	59.2	56.3	51.6	54.5	35.6	49.8	59.0	63.8	57.3	45.8
CS ₃	Organic 3-crop	53.3	44.4	63.3	60.2	48.8	51.9	31.0	40.9	35.4	50.9 ¹	32.5	33.6	24.6	58.7	62.2	63.0
Chemlite	Low input 3-crop	-	-	66.6	60.2	46.1	62.5	48.7	52.0	39.7	60.8	22.6 ³	47.5	54.5	54.2	59.5	58.2
LSD (0.05)		NS	NS	2.6	4.0	NS	13.3	3.4	3.8	11.1	4.8	2.6	7.0	5.2	7.6	5.1	5.1
	Wheat grain	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
		-----bu/acre-----															
CS ₃	Organic 3-crop	28.6	60.9	69.3	46.9	55.3	58.2	57.6	42.6	55.5	70.5	53.6	34.9	49.8	66.6	84.2	63.8
Chemlite	Low input 3-crop	-	-	76.9	45.8	51.9	61.3	59.8	52.9	54.9	78.3	67.1	38.5	79.3	109.7	97.4	83.6
LSD (0.05)				NS	1.3	NS	1.2	NS	1.0	NS	NS	NS	NS	21.5	0.14	8.8	15.5
	Wheat straw	-----tons DM/acre-----															
CS ₃	Organic 3-crop	1.44	1.44	1.22	1.55	0.97	0.58	0.63	0.83	0.71	1.43	0.33	0.54	0.65	1.04	0.87	0.62
Chemlite	Low input 3-crop	-	-	1.50	1.68	0.99	0.73	0.66	0.75	0.66	1.79	0.39	0.48	1.17	1.13	0.92	0.86
LSD (0.05)				0.10	0.11	NS	NS	NS	NS	NS	NS	0.01	NS	0.23	0.01	0.09	0.29
	Seeding yr. Forage	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
		-----tons DM/acre-----															
CS ₄	Direct seeded	3.27	3.21	3.19	1.57	3.56	2.63	2.27	2.59	3.21	2.96	2.91	1.85	1.71	2.81	3.40	2.55
CS ₅	Oats/peas/alf	NA	3.37	3.21	2.68	4.66	5.67	4.69	4.14	4.53	3.56	2.30	4.35	3.02	4.62	3.31	2.88
LSD (0.05)		0.51	NS	NS	0.90	NS	0.67	0.34	0.24	1.27	NS	NS	1.06	0.19	0.43	0.25	0.34
	Estab'd Forage	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
		-----tons DM/acre-----															
CS ₄	Hay I	3.93	4.56	4.02	4.16	5.08	4.30	4.49	5.44	5.89	5.18	4.83	5.09	4.63	4.53	4.64	5.86
CS ₅	Hay I	4.65	5.30	4.89	4.43	4.99	4.45	5.49	5.86	5.29	5.10	5.94	4.88	3.88	4.39	4.03	5.36
CS ₄	Hay II	3.25	3.68	2.24	3.78	4.50	4.13	4.06	5.31	5.53	4.50	3.37	5.15	3.11	3.85	3.87	5.33
CS ₆	Pasture	-	-	-	-	-	-	-	-	-	-	-	5.48	2.61	5.80	3.37	3.23
LSD (0.05)		0.95	0.34	0.47	0.64	0.42	NS	0.32	0.29	0.43	0.46	0.71	NS	0.50	0.51	0.49	0.48

¹ 3-plot average. Severe ground squirrel damage in plot 206 corn and intensive/expensive hand weeding in 411 beans led to their omission.

² Due to poor stand and late replanting date, corn did not make blacklayer before end of season and was harvested as snaplage (cob+husk+ear) yielding 1.07 and 1.36 ton DM/a for CS3 and CS5, respectively then converted to grain.

³ Herbicide damage to soybeans; soybeans were replanted in 1994 on June 15; not replanted in 2003.

Heavy rains in 2008 likely leached the fertilizer N on the CS1 and CS2 corn resulting in relatively poor yields

Arlington Agricultural Research Station – 2007 Report

Janet Hedtcke and Josh Posner

Weather

The 2007 season started out warm and dry with every day in May above 60°F and 19 days above 70°F. Throughout the season, accumulated heat units were above the long-term average (Fig. 1). Warm temperatures coupled with below normal rainfall (38% of norm) in May (Fig. 2) allowed for very timely field operations and quick crop emergence. In fact, most months of the season were below average for rainfall except August when frequent and heavy rainfall events (>11" total) resulted in the need to reseed one "sacrifice" pasture (plot 302) where the heifers had seriously damaged the sod.

Changes

This spring, for the first time, we modified the no-till corn-soybean system to a reduced-till system by using a strip-till unit in the soybean stubble in preparation for corn planting. In the future however, strip tilling would occur in the fall to allow the soil to 'mellow' over winter. Researchers at Pioneer International (DeFelice et al 2006) reported that in the upper Midwest, corn yields were often reduced in no-till systems because of cool and wet soils. Strip till offers benefits of tillage by creating an 8" zone that warms and dries faster where the seed is planted while it maintains the residue on over 70% of the field.

Weed Quantification

To quantify weed pressure, weed biomass was collected from the plot centers of the corn and soybean phases across the systems in August. In the corn phase, the organic grain (CS3) plots had significantly higher grass and broadleaf weed pressure than the conventional systems (Table 1). This higher grass weed pressure in the organic grain plots is likely contributing to lower yields in that system. Due to the sod phase in the organic forage system (CS5), the annual grass weed biomass in the corn phase was not statistically different than in the conventional systems. However, in the soybean phase, the organic grain plots did not have higher grass weed pressure than the conventional beans but tended to be higher in broadleaf weeds (Table 2).

Plot edges (manured and non-manured) in CS1, CS2, and CS3 corn were also sampled. The analysis showed a strong system x manure interaction ($p < 0.0003$) in that grasses were significantly higher on the manured strip in CS2, the no-till system, but lower in the manured strip on the other two frequently-tilled systems. It appears that the grass weeds responded to the fall slurry application (10,000 gal/a) more so in the no-till system than in the tillage-based weed control systems. Interestingly, there was no effect of manure on broadleaf weed pressure in any system.

Finally, samples from the non-manured edge were compared to the plot centers. The analysis showed the edges tended to be 2-3x more weedy than the centers for both grass and broadleaf weeds (data not shown; $p < 0.16$ and 0.06). In order to deal with this problem of additional weed pressure along the plot borders, more effort into keeping the alleyways between plots tilled throughout the season is essential. Likewise, in the organic soybean plots, the outer 6 rows will be hand weeded.

Manure

Using the manure from the 'East Pit' at Blaine dairy, rates were determined from previous analyses to result in nutrient drawdown in the forage systems, causing us to reduce rates in front of the corn phase and increase the rates in front of the legume seeding. The CS4 (c-a-a-a) corn plots received 12,000 gals/a in the fall after corn harvest and 4,000 gal/acre in the fall on the plowdown alfalfa while the CS5 (c-o/a-a) corn and plowdown alfalfa received 8,000 and 4,000 gal/a respectively. When pro-rated across the entire system, these rates equaled 4,000 gal/a/yr in both systems. For the on-going Linking Farms Project, manure was added to the eastern 15' of the CS2 and CS3 grain system that were going into corn in 2008 at a rate of 12,000 gal/acre. In order to prevent P & K build-up, the continuous corn plots were not manured this fall since they received manure in the fall of 2006.

Corn Phase

This was an excellent year for corn production due to the warm spring and timely rains in August. Conventional corn yields averaged 203 bu/a with the strip-till corn ranking the lowest (<http://wicst.wisc.edu/technical-reports-peer-reviewed-journal-articles/11th-technical-report/wicst-yield-summary-1993-2007-at-arlington/>). Although starter fertilizer (100 lb/a of 5-14-42) was the same in all three systems, we noted that the strip-till corn showed nutrient deficiency early in the season. The continuous corn ranked 2nd in yield behind the 'Green-gold' corn in the nutrient-rich alfalfa system. The organic corn yields continue to increase with improved corn stands (32,350 to 36,150 pl/a) and weed control (average of 168 bu/a). This season, the CS5 corn yields were somewhat lower than expected due to an early time weeding which buried the already-emerged corn for several days. Soil was hand raked off this corn to rescue the crop shortly after Memorial Day. There is still a large yield differential between the grain (CS3) and forage-based system (CS5), suggesting that weed control and nitrogen availability still limit organic corn yields.

Soybean Phase

The weed control was excellent in the organic soybean plots and visually, there were more weeds, particularly lambsquarter, in the no-till plots (Table 2). This was likely due to ineffective herbicide control from heavy dew at time of application. Ultimately, the organic beans outyielded the no-till beans by 5 bu/a. The Chemlite bean yields were in between the organic and no-till beans at 60 bu/a.

Wheat/Red Clover Phase

Organic wheat in CS3 yielded very well this year (84 bu/a). The Chemlite plots approached 100 bu/a, benefiting from a spring application of 50 lb N/a. High wheat yields were attributed to excellent stands and low disease pressure, probably due to the dry May and June weather. After wheat harvest, a cover crop of oats and berseem clover was planted on the CS3 plots (Aug. 13) with excellent results due to good soil moisture and frequent rains. The red clover cover crop in the Chemlite plots had unusually high foxtail load so forage was clipped and removed in August to prevent weed seed shed.

Forage Phases

Average seeding year yields (CS4 & CS5) were excellent (3.3 tons DM/a) due to the good start they got in May. The established alfalfa plots yields were similar among systems and average

just over 4 tons DM/a. Because it was predominantly a dry summer, yield from the pasture exclosures were only 3.4 tons DM/a.

Native Systems

This season we decided to plant switchgrass in place of corn in the prairie blocks. The first seeding of switchgrass in late June failed due to poor seed quality. A no-till reseeding took place mid-August and looked promising going into winter.

Citations

DeFelice, M.S., P.R. Carter, and S.B. Mitchell. 2006. Influence of tillage on corn and soybean yield in the United States and Canada. Crop Management. Plant Management Network. Online. <http://www.plantmanagementnetwork.org/pub/cm/research/2006/tillage/>

Fig. 1. Seasonal heat unit accumulation in 2007 vs. 30-yr norm (1971-2000)

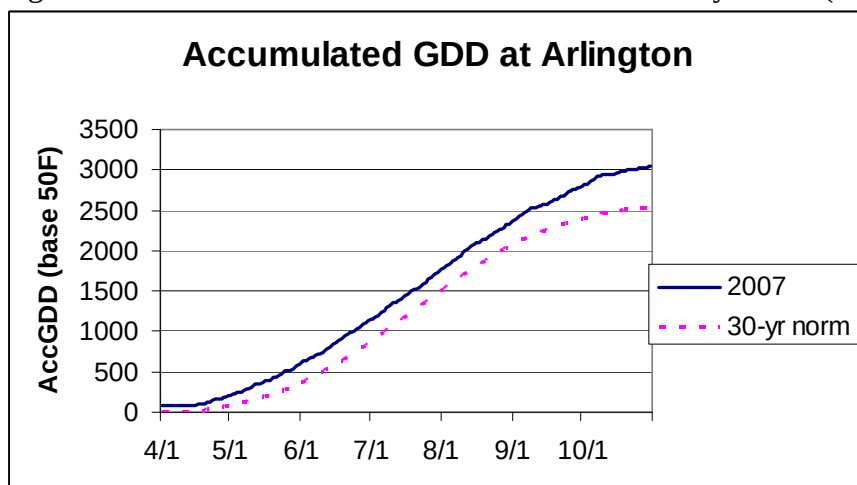


Fig. 2. Seasonal precipitation in 2007 vs. 30-yr norm (1971-2000)

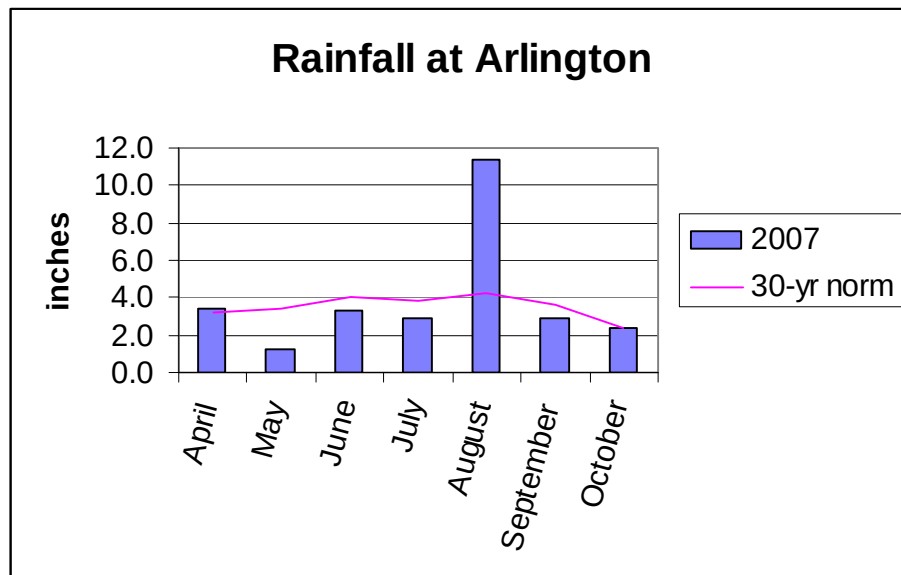


Table 1. Weed pressure in corn across systems from middle of plot in 2007.

	Grass	Broadleaf
	Dry biomass (grams/m ²)	
CS1 (conventional)	0.22b	0.13c
CS2 (conventional)	0.09b	2.03bc
CS3 (organic)	56.03a	6.72a
CS4 (conventional)	0.09b	0.04c
CS5 (organic)	4.18b	3.53b
<i>Overall p-value</i>	<i>0.0001</i>	<i>0.0005</i>

Table 2. Weed pressure in soybeans across systems from middle of plot in 2007.

	Grass	Broadleaf
	Dry biomass (grams/m ²)	
CS2 (conventional)	0.18	8.28
CS3 (organic)	0.23	0.56
<i>Overall p-value</i>	<i>0.7946</i>	<i>0.0742</i>

Table 3. Weed pressure in manured vs. not manured corn in 2007.

	Manured	Not Manured
System	Dry grass weed biomass (g m ⁻²)	
CS1 (conventional)	0.19	0.68
CS2 (conventional)	1.42	0.10
CS3 (organic)	47.84	80.60
Sys*trt p-value	0.0003	
main effects of manure (p<0.0044) and system (p<0.0001)		
	Manured	Not Manured
	Dry broadleaf weed biomass (g m ⁻²)	
CS1 (conventional)	0.19	1.43
CS2 (conventional)	1.29	0.42
CS3 (organic)	14.53	15.78
Sys*trt p-value	0.8302	
No main effects of manure; sys main effect p<0.0001		

Arlington Agricultural Research Station – 2008 Report

Janet Hedtcke, Gregg Sanford, and Josh Posner

Weather

The 2008 season was very extreme in terms of weather events and for the first time the organic corn and soybeans out-yielded that of the conventional systems. The winter of '07-08 had record snowfall with over 100" in many areas of southern Wisconsin. Even with the season-long snow cover, there was some winterkill because a layer of ice beneath the snow smothered the plants. Amazingly, by late April, all the snow had melted and spring field work proceeded in a timely fashion. The month of May started out dry but by early June, unprecedented rainfall led to severe flooding across the upper Midwest. On the WICST plots, most of Rep 2 was flooded for nearly 6 weeks and several perennial plots had to be partially reseeded. Flooded areas of the annual plots were kept fallow with tillage or mowing. In addition to all the rain in June, the heat units were below average with just one day above 90°F. This resulted in high corn grain moisture at harvest.

Changes

2008 also marks the year of transitioning the 'Chemlite' plots on the east end of the trial to 'Flexitill'. This took the emphasis off reducing inputs (i.e. N and herbicide) and placed the emphasis on expanded rotations. Inherent to an expanded rotation is reduced chemical inputs across the system. The beans were drilled instead of being planted in wide rows to reduce soil erosion potential and tillage will be reduced; mostly in preparation for corn planting.

Weed Quantification

Weed biomass was collected in the corn and soybean phases across the systems in August from the plot centers. Weed control was surprisingly good this season in spite of the wet conditions in June. Grass weed biomass in 2008 corn was much less than in previous years (i.e. 2006=32, 2007=56, 2008=11 g/m² in CS3). Still the organic corn plots had significantly higher weeds than the conventional plots; of the conventional plots, the CS2 corn (no-till corn-soy system) had the most weeds (Table 1). In the soybean phase, the organic plots also had higher grass and broadleaf pressure than the conventional beans (Table 2) but again, weed biomass was lower than in the past few years. Plot edges (manured vs. non-manured) in the corn phase of the three grain systems were also sampled to test the effect of manure additions. It was interesting to see that CS1 and CS2 had higher grass weeds in the manured strip but CS3 had lower grass weeds in the manure strip (Table 3). Broadleaf weed pressure was similar between manured and non-manured plots. The analysis also showed the edges tended to be 2-3x higher in weed pressure than the centers for both grass (0.1533) and broadleaf weeds ($p < 0.2356$; data not shown).

Manure

In the summer of 2008, the new dairy expansion project was finished and all the livestock was consolidated into the 'Blaine Dairy Complex'. Just before the cattle moved into their new quarters, the manure pit filled up with rain water from heavy storms. Furthermore, the barn was understocked so the manure was very, very, dilute during fall application (total nutrients were N: 9.5, P₂O₅: 2.5, K₂O: 11.2 lbs/1000 gal with 1.3% solids). On November 4+5th, manure was broadcast onto the WICST plots with tractor-pulled tankers. Because of the extremely low nutrient value of the watery manure, we tried to maximize application rates at 16,000

gallons/acre. Because of the high volume of water, the plots were wet for several days, delaying tillage until the following week. The CS4 (c-a-a-a) corn and plowdown alfalfa plots each received 16,000 gal/acre while the CS5 (c-o/a-a) corn and plowdown alfalfa received 16,000 and 8,000 gal/a respectively. When prorated across the entire system, these rates equaled 8,000 gal/a/yr in both systems. These rates were 2x higher than in 2007 due to lack of nutrients in the slurry. In addition to the usual manure application in the dairy systems, we continued to apply slurry in front of the corn in the 3 grain systems as part of the Linking Farms Project. Unfortunately due to the dilute manure, even at a 16,000 gal/a rate, we'll need to top off the plots with commercial N next spring to meet the corn requirement.

Corn Phase

Corn was planted on May 6th in the conventional systems and on May 16th in the organic systems. This year, the ground squirrels were kept under control with baiting and natural predators (raptors, foxes, cats). It was evident from the PPNT that there was absolutely no residual N carried over from last fall. Nitrogen (urea) was applied about a week after planting. However, after the heavy rains, it would have been prudent to reapply N fertilizer but by the time things dried out, the corn was already canopying. Any N in the profile likely leached from the 12+ inches of rain in June which was probably the main reason the conventional corn yielded less than usual. On average, all the conventional corn yielded 176 bu/a compared to 190 bu/a in the organic corn systems.

Soybean Phase

Organic soybean yields were impressive for the 3rd consecutive year, averaging 63 vs. 46 bu/a for the no-till and 58 bu/a for the Flextill drilled beans. Emergence was quicker and more uniform for the wide row beans than the drilled beans. Timely and frequent mechanical weed control this spring was crucial. The addition of the tine weeder has given us a tool to use during the period between the last rotary hoeing and before the plants are large enough to withstand row cultivation. There was no hand weeding done other than on the border rows.

Wheat/Red Clover Phase

Winter wheat had some winterkill in low areas where ice sat on the crowns. We tried tine weeding the organic wheat since there was no underseeding of clover but the ground was very hard and the tines did not penetrate that well. Nonetheless, yields were on track at 64 and 84 bu/a for organic and Flextill plots, respectively. Obviously, the Flextill wheat benefited from the split application of N (total=80 lb/a). Summer tillage after wheat harvest in CS3 was continued this summer. The disk and field cultivator were used to prepare the seedbed for berseem clover companion seeded with oats. Frost-seeded (drilled) red clover was kept in the Flextill wheat plots since weed control is not a problem there. Due to a very dry August, the summer seeding of oats and berseem cover crop did not establish well although there was a lot of volunteer and diseased winter wheat. Biomass estimates from the berseem/oats mix were much less than the spring established red clover and only provided a nitrogen credit of 54 lb vs. 177 N/a.

Forage Phases

Because of the uneven distribution of rainfall, the pasture yielded less than the established alfalfa systems (3.23 vs. 5.55 tons DM/a), even with N additions. Heifers had their best performance in years (2.3 lb/d; 743 lbs/a) with modest grain supplementation. This is similar to what

Lehmkuhler and Albrecht found on their steers grazing grass-clover plots at Arlington (CIAS Research Brief #76; Sept 2008). Most of the forage plots are in 'maintenance' management for potassium fertilization as soil test levels have dropped into the yield response range. Leaf hoppers were controlled with pesticide in the seeding of CS4 but the established alfalfa plots were managed by cutting. Two cuts were taken on the seeding year plots while four cuts were taken on all the established plots.

Native Systems

The prairie plots were burned on April 17 and Canada thistles were rouged from the plots after a saturating rain. With the establishment of switchgrass last season, we now have a continuum of diversity in our native systems ranging from no diversity (100% switchgrass) to low diversity prairie (6 species; 33% grass) to high diversity prairie (25 species; 12% grass). In collaboration with Randy Jackson, the native plots were divided into quarters for 2 concurrent studies: the southern $\frac{1}{4}$ will be harvested for biomass (GLBRC project) while the northern $\frac{3}{4}$ will be used for establishing native legumes via grazing, mowing or doing nothing (SARE project). This season we installed 3-strand high-tensile electric wire and water lines around the native systems for the grazing study in 2009. We intend to use the heifers on the CS6 cool-season pastures to graze the prairie for a short time in spring and summer as part of their overall ration. This will give the CS6 pastures a longer rest/recovery window that is surely needed while providing an opportunity for research in harvesting the biomass for biofuels for the SARE project.

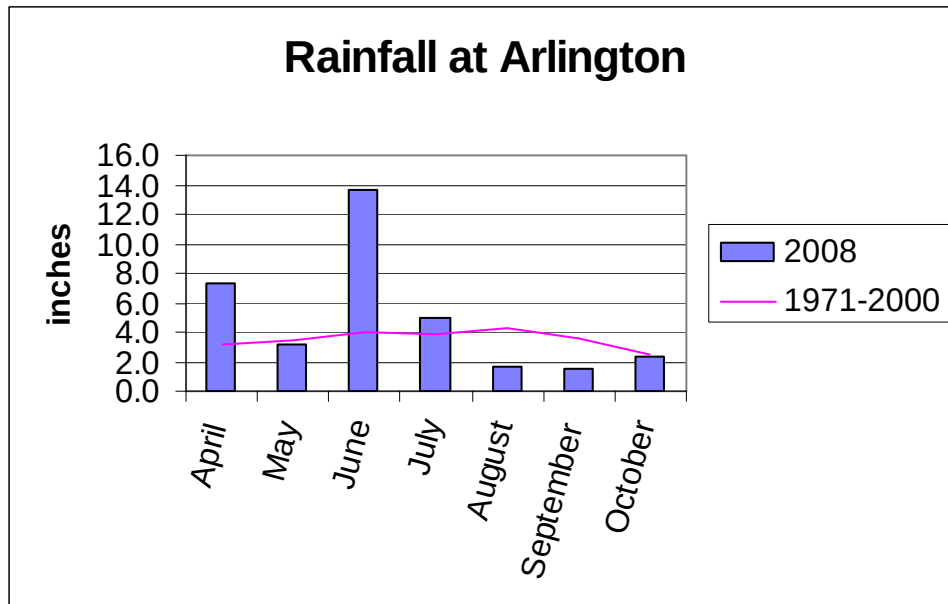
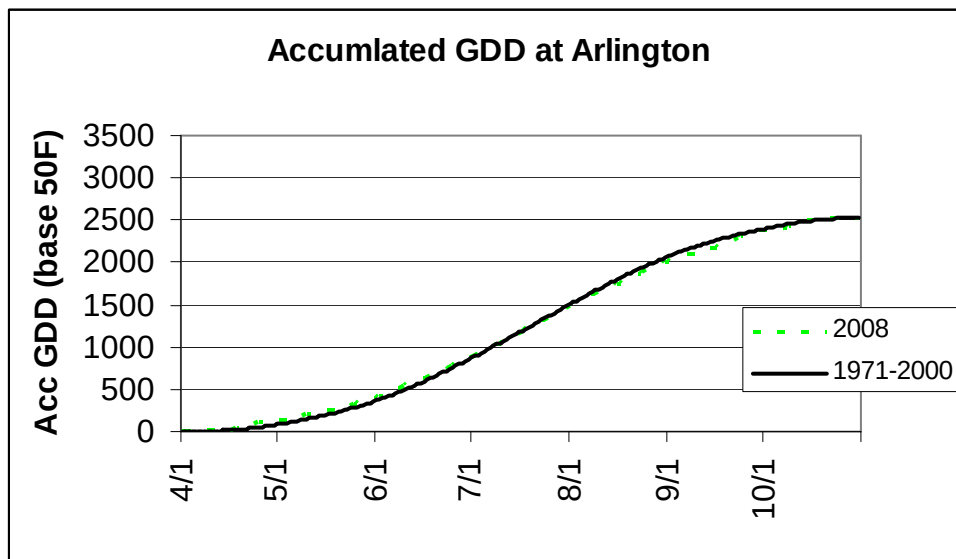


Table 1. Weed pressure in corn across systems from middle of plot in 2008.

	Grass	Broadleaf
	Dry biomass (g m ⁻²)	
CS1 (conventional)	0.09b	0.17c
CS2 (conventional)	2.45b	7.49a
CS3 (organic)	10.76a	5.94ab
CS4 (conventional)	0.09b	0.13c
CS5 (organic)	9.73a	4.39b
<i>Overall p-value</i>	<i>0.0018</i>	<i>0.0006</i>

Table 2. Weed pressure in soybeans across systems from middle of plot in 2008.

	Grass	Broadleaf
	Dry biomass (g m ⁻²)	
CS2 (conventional)	0.04	0.39
CS3 (organic)	21.10	3.36
<i>Overall p-value</i>	<i>0.0105</i>	<i>0.0138</i>

Table 3. Weed pressure in manured vs. not manured corn in 2008.

	Manured	Not Manured
System	Dry grass weed biomass (g m ⁻²)	
CS1 (conventional)	9.7	3.6
CS2 (conventional)	19.7	6.9
CS3 (organic)	7.2	14.5
Sys*trt <i>p-value</i>	0.0897	
No main effects of manure or system		
	Manured	Not Manured
	Dry broadleaf weed biomass (g m ⁻²)	
CS1 (conventional)	64.0	68.8
CS2 (conventional)	20.8	6.9
CS3 (organic)	6.8	10.6
Sys*trt <i>p-value</i>	0.9119	
No main effects of manure; sys main effect <i>p</i> <0.0386		

OUTREACH ACTIVITY ON THE WICST PLOTS 2007-2008

WICST continues to serve as an ‘outdoor laboratory’ for learning about issues of sustainable agriculture such as crop rotation, environmental stewardship, economic sustainability, and biodiversity. In addition to field days for the public and farm tours for schools and tech colleges, we have disseminated WICST results at regional events (Organic Farming Conference), as well as scientific meetings. Table 1 summarizes the outreach and educational activities for WICST 2007 and 2008.

Table 1. Outreach activities involving the WICST project in 2007 and 2008.

	EVENT	LOCATION	DATE	ATTENDANCE
2007	WICST Winter Meeting	Madison	February 14	30
	Upper Midwest Organic Farming Conf (posters)	Lacrosse	February 22-24	1800
	Cover Crop Council	Indianapolis	March 10-12	40
	Linking Farms Road Show	Delavan	March 21	8
	Linking Farms Road Show	Arlington	March 28	18
	Linking Farms Road Show	Fitchburg	April 13	15
	Local Grade School Tours	Arlington	April/May	200
	Quinney Farm Field Day	Delavan	July 10	30
	UW Organic Field Day	Arlington	August 30	125
2008	Sustainable Agriculture 101 Workshop	UW-Riverfalls	January 22-23	30
	WICST Winter Meeting	Madison	February 15	30
	Upper Midwest Organic Farming Conf	Lacrosse	February 21-23	2400
	Local Grade School Tours	Arlington	Throughout May	100
	UW Soils of Wisconsin Class tour	Arlington	May 27	15
	Wisconsin Christmas Tree Assn. Field day	Arlington	August 8	10
	UW Plant Breeding Club field day	Arlington	August 19	15
	UW Organic Field Day	Arlington	September 4	100
	Wisconsin Technical College System	Arlington	October 8	20

Oral Extension–

Arlington Organic Field Day August 30, 2007:

- Bernstein, E. No-tillage organic soybean production in winter rye
- Goeser, N. Assessing organic seed treatments for enhanced corn establishment
- Hedtcke. Long term (1992-2006) yield results from organic rotations on WICST

Hedtcke, J., J. Posner, and J. Hall. 2008. Production, Environmental and Economic Analysis of WICST: Farming System Comparisons. Sustainable Ag 101 Workshop. UW-River Falls, River Falls, WI. Jan 22-23, 2008.

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TRANSITION FROM CONVENTIONAL AGRICULTURE TO BEST MANAGEMENT PRACTICES AT WICST

Dustin Sawyer¹, Phillip Barak², Janet Hedtcke³, Joshua Posner⁴

INTRODUCTION

The Wisconsin Integrated Cropping Systems Trial exists as a living laboratory for the major cropping systems present in Wisconsin, as well as some organic practices that were still emerging at WICST's inception in 1989. Even as a long-term experiment, in which much the same rotations and the same inputs are employed throughout, the system has not reached true steady state in nutrient inputs and outputs. The decision to engage in fertility management based on UW-EX recommendations has led to conservative fertilizer applications that have in turn led to net nutrient extraction, particularly of phosphorus and potassium, to levels that are no longer supra-optimal or excessive but trending toward optimal. WICST therefore may be regarded as a yet-unfinished experiment in converting these fields from the earlier conventional agricultural practices to current best management practices. Such best management practices today involve keeping soil test P in the top soil layer sufficiently low to reduce the Phosphorus Index associated with erosion of that surface soil, but more generally do not 'bank' nutrients in soil where they can be leached, fixed, or eroded. This report describes the start of our investigation of this transition.

METHODS

Soil surface nutrient (NPK) balances for the six cropping systems were constructed plot-wise based on 20 years of data from 1989 to 2008. The strongly linear nature of the cumulative NPK inputs, offtakes, and net is clearly apparent (Fig. 1). Regression analysis was used to determine the annual NPK soil surface balances for each plot and results for each cropping system are reported in Table 1.

RESULTS

Nitrogen. Continuous corn, CS1, shows (Table 1) a 20-yr average offtake in grain N, 117.8 lb/ac/yr, which is 88.6% of the average N input, 132.9 lb/ac/yr. The difference between the input and offtake, the net of 19.9 lb N/ac/yr, could be interpreted either as N accumulating in the soil profile or N lost by leaching or denitrification. Avila (PhD dissertation, 2004), however, found that C/N/S concentrations of this system neither increased nor decreased over a 12-yr period, making it reasonable to assign the 19.9 lb N/ac/yr to N losses.

The WICST cropping systems other than CS1 contain legumes that biologically fixing nitrogen and a simple surface balance is therefore more complicated. The 'net' nitrogen is therefore an approximation of the minimum amount of N entering the rotation other than through fertilizer and manure, i.e., biological nitrogen fixation. For CS2, corn/soybean, the net N balance is -84.9 lb N/ac/yr when on average half of the rotation is in soybean. This means that a minimum of 169.8 lb N/ac/yr must be biologically fixed by the soybean phase of the rotation to maintain both

¹ MSc candidate, Dept of Soil Science, UW-Madison

² PhD, Professor, Dept of Soil Science, UW-Madison

³ Research specialist, Dept of Agronomy, UW-Madison

⁴ PhD, Professor, Dept of Agronomy, UW-Madison

N offtake (of soybean and corn) and soil organic-N levels. This value is higher than the typical book value (100 lb N/a/yr; Havlin et al., Soil Fertility and Fertilizers, 7th ed, Table 4-7), but not outside of the range (40-260 lb N/a/yr) for temperate climates. In the 3-yr 'organic' corn/soybean/wheat/red clover rotation, CS3, the offtake of -98.4 lb N/ac/yr when 2/3 of the rotation is in legume implies that the legumes together average 147.6 lb N/ac/yr. By the same measure, three years of alfalfa in a 4-yr rotation, CS4, fixes an average (direct seeded, 1st and 2nd production years) of 177.6 lb N/ac/yr.

Phosphorus. Offtake of phosphorus exceeded input in all six cropping systems, ranging from net removal of 10 to 16 lb P /ac/yr (Table 1). The greatest rate of P removal was CS2, corn/soybean, 16.3, followed by CS3 and CS1, 14.7 and 14.0, respectively.

Potassium. Offtake of potassium exceeded input in all six cropping systems, ranging from net removal of 11 to 77 lb P /ac/yr (Table 1). Greatest removal rates were those in which leafy forage was harvested, as in CS5 (corn/oats/alfalfa, 77.5), CS6 (pasture, 73.4), and CS4 (corn/alfalfa/alfalfa/alfalfa, 65.2). Removal of grain-only systems was associated with lesser K removal, as in CS3 (corn/soybean/wheat, 33.3), CS2 (corn/soybean, 32.0), and CS1 (continuous corn, 10.9).

Soil Test P and K. In a simple world, these relatively systematic extractions of P and K from the soil surface would be reflected in a monotonic and proportional decrease in soil test P and K. In fact, in the real world with considerable soil heterogeneity and sampling error, the reality is more complex and the scatter in surface soil test values is more difficult to interpret (Fig. 2). To further complicate the issue, plants have available to them nutrients in deeper soil horizons. Further, some of those nutrients derived from deeper horizons may be deposited on the soil surface, and thus the surface layer, by plant residue from the previous season, in a process of phytocycling. Soil test P and K, though both mildly acidic and intended to extract relatively insoluble P and K that may be available to plants, may be imperfect tools for nutrient drawdown experiments such as this and may not fully assess the availability of fixed mineral phosphorus and interlayer potassium that may be present in high-nutrient soils. Research is continuing on these open questions.

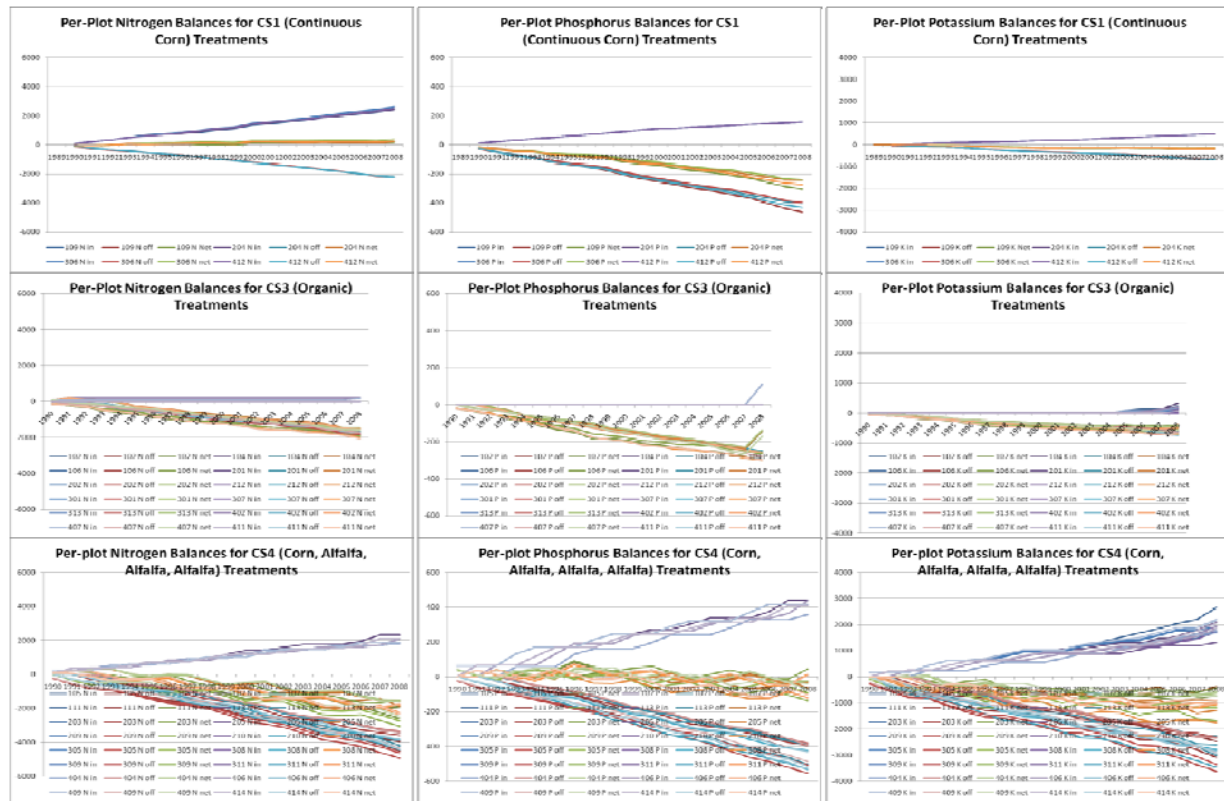


Figure 1. Plot-wise cumulative soil surface nutrient (NPK) balances for CS1 (continuous corn), CS3 (corn/soybean/wheat), and CS4 (corn/alfalfa/alfalfa/alfalfa). In all nine graphs, the upper group of 4 lines is nutrient input as fertilizer (CS1) or manure (CS4); the bottom group of 4 lines is nutrient offtake as harvested grain or hay; and the middle group of 4 lines is the net of input minus offtake. Where inputs are small or nil, the plots for offtake and net are coincident and indistinguishable. For CS3 and CS4, both legume-containing rotations, the net negative balances likely provide long-term minimum biological nitrogen fixation estimates (see text).

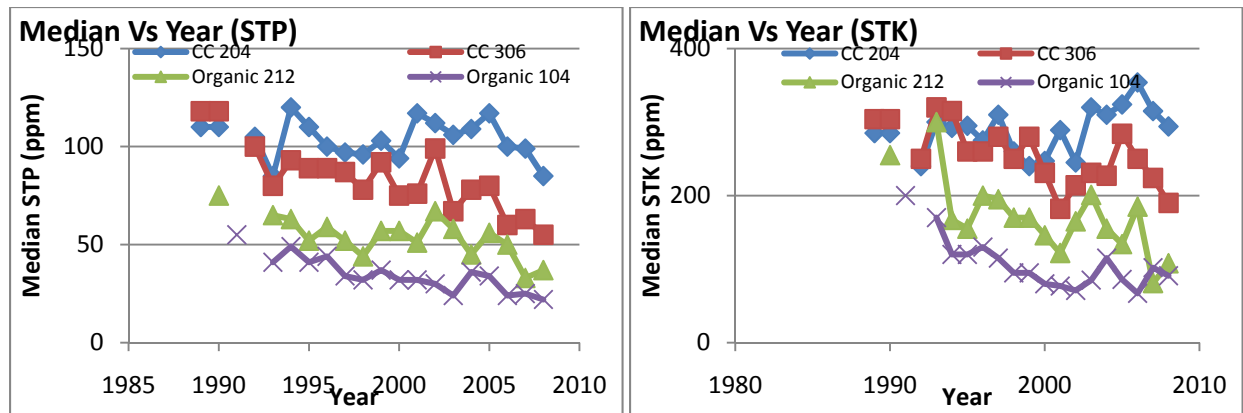


Figure 2. Soil test P and K for two plots each of CS1 and CS3, where the points represent the median value of three composite samples from each plot. Alternative measures of central tendency, including arithmetic and geometric means, present approximately similar scatter.

Table 1. Soil surface nutrient balance of WICST cropping systems at Arlington, WI. Twenty-year average (1989 - 2008) nutrient input as fertilizer and manure, nutrient offtake as harvested crop, and net nutrient input.

ID	Crop Rotation	Nitrogen (lb N /ac/yr)			Phosphorus (lb P /ac/yr)			Potassium (lb K /ac/yr)		
		Input	Offtake	Net	Input	Offtake	Net	Input	Offtake	Net
CS1	continuous corn	132.9	-117.8	19.9	8.3	-22.0	-14.0	26.4	-35.4	-10.9
	(n = 4)*	(5.2)**	1.1	3.9	0.0	1.3	1.4	0.0	0.8	0.9
CS2	corn/soybean	62.8	-145.6	-84.9	3.8	-20.0	-16.3	18.8	-45.5	-32.0
	(n = 8)	(7.0)	5.1	5.3	0.5	1.6	1.1	7.4	1.4	2.7
CS3	corn/soybean/wheat	3.1	-98.8	-98.4	4.1	-14.9	-14.7	11.7	-35.7	-33.3
	(n = 12)	(4.6)	7.0	7.6	6.1	0.8	0.9	7.0	3.1	4.2
CS4	corn/alfalfa/alfalfa/alfalfa	104.6	-230.4	-133.2	21.7	-26.3	-10.0	100.2	-148.2	-65.2
	(n = 16)	(6.4)	12.1	11.6	0.7	2.1	1.9	13.5	13.2	15.2
CS5	corn/oats/alfalfa	103.4	-207.4	-108.2	19.9	-28.0	-10.2	91.2	-158.4	-77.5
	(n = 12)	(5.8)	6.4	8.1	1.7	1.3	1.7	5.4	10.9	11.5
CS6	pasture	32.3	-92.9	-79.4	7.5	-11.8	-11.8	27.6	-85.2	-73.4
	(n = 4)	(0.8)	4.6	3.4	0.0	0.8	0.8	1.0	10.3	11.7

* n, the number of replicate fields used to calculate averages and standard deviations.

** (), standard deviation of the n replicates.

COMPARING THE GREENHOUSE GAS EMISSIONS OF DIFFERENT MIDWESTERN CROP PRODUCTION SYSTEMS USING LIFE CYCLE ASSESSMET, CROP MODELING, AND IN-FIELD EMISSION MEASUREMENTS

Rachael Cox, Josh Posner, Janet Hedtcke, and Gregg Sanford,

INTRODUCTION & BACKGROUND:

Globally, it is estimated that agriculture contributes 10% of total anthropogenic greenhouse gas (GHG) emissions (IPCC 2007), and is the largest emitter of N₂O and the second greatest contributor of CH₄ (EIA 2007). Greenhouse gases of particular interest due to their impact on the environment are CO₂ (Carbon dioxide), N₂O (Nitrous oxide), and CH₄ (Methane). Despite being a large contributor to GHG emissions, agricultural systems also have the potential to sequester carbon in the soil, decreasing their net impact on climate change (Lal 2004 and Lal 2007). Emerging alternative production methods within agriculture are offering the potential to decrease GHG emissions (Dyer and Desjardins 2005 and Flessa et al. 2002) and to sequester carbon (Fornara and Tilman 2008 and Lehmann et al. 2006) at higher rates.

In order to compare alternative crop production systems on the basis of their potential to reduce GHG emissions and other environmental impacts, it is necessary to be able to account more fully for the impacts of each system. Life Cycle Assessment, which was originally developed for industrial production processes, is a standardized method to account for the majority of imbedded and in-process environmental impacts of a given production process (ISO 2001). Recently, LCA has been adapted to assess agricultural production. However, most studies have been conducted in Europe and are based on farm averages, not in-field measurements (Thomassen et al. 2008, Charles et al. 2006, and Gasol et al. 2007). LCA of agriculture focuses on the imbedded environmental impacts of the inputs required for production (i.e. fertilizers, pesticides, fuel) as well as the in-field environmental impacts (i.e. emissions due to tillage, application of fertilizer or manure). The environmental impacts—specifically the GHG emissions—resulting from food production in the Midwestern United States are still largely unknown.

RESEARCH PLAN:

I. LCA of Long-term research study

The research I propose to conduct will occur in three stages. First, a LCA will be conducted on a twenty year cropping system trial in Wisconsin (Posner et al. 2008), which includes six cropping systems¹ that represent the gradients of plant diversity and perennality commonly encountered on the Midwest agricultural landscape. This study was conducted at two locations with different soil types, both which will be analyzed using LCA². Also, in recent years, native

¹ (1) Continuous corn, (2) Corn and Soybean, (3) Organic Corn, Soybean, Winter Wheat, and Red Clover, (4) Alfalfa (3 years) and Corn, (5) Organic Corn, Oats, and Alfalfa (2 years), and (6) Rotationally grazed mixed-grass pasture.

² Columbia county location has been studied for twenty years and is ongoing, whereas Walworth county location was discontinued in 2000.

prairie and Switchgrass has been added to the trial, which will also be analyzed. With exact values of inputs from twenty years of data collection, we will be able to precisely account for the variance in upstream (or imbedded) GHG emissions among the six systems. The GHG emissions associated with each of these inputs will be estimated using one of several LCA modeling programs (GABI and SimaPro).

II. In-field measurements and modeling of environmental impacts

The second stage of the research will be modeling in-field environmental impacts and validating modeled results with in-field measurements of GHG emissions. I plan to use EPIC (EPIC 2009), a model which simulates GHG emissions, carbon sequestration, soil erosion, and nutrient losses in agricultural fields based on soil data, climatic conditions, farm practices and yields. To validate the modeled data, greenhouse gases will be monitored in all phases of the cropping systems at the long-term research trial. Fluxes will be measured twice a month from April through October, but more frequently during periods where fluxes are expected to spike, including after manure application, tillage, and grazing. During these time periods, N₂O emissions are likely to be higher than background fluxes (Livesley et al. 2008 and Rochette et al. 2008). To monitor GHG emissions, vented chambers will be mounted on PVC rings installed in the plots and gas samples will be collected at 0, 15, 30 and 45 minutes following chamber deployment (Robertson 1999). GHG concentrations will be analyzed on a Shimadzu 14B gas chromatograph and fluxes will be calculated as the rate of change in the chamber headspace over 45 minutes.

The results of imbedded GHG emissions and net in-field GHG emissions will be totaled and compared among cropping systems. Systems may be compared on a unit land area basis, unit of biomass production, and a unit basis of net profit. The study design provides temporal (20 years of replication) and spatial (4 replications of each phase of each rotation) replication for statistical comparisons. Using ANOVA I will be able to determine if the GHG emissions for each cropping system are statistically different. Two years of in-field measurements will also be compared for statistical differences among systems and compared to model estimates.

III. On-farm environmental impact assessment

The third stage of the research will involve the development of a tool to evaluate the environmental impacts of agricultural systems across a wider landscape and a diversity of production systems. The tool will be developed based on a sensitivity analysis of the LCA of the twenty-year study, to identify the most important data sets which affect the net GHG emissions for each system. It will serve two purposes, first to quantify the environmental impacts of a wider range of farming systems and compare them with research station results, and second, to use as a tool for engaging farmers of a wide range of production systems in discussions about the potential for reducing GHG emissions. Our goal by conducting on-farm research is to actively engage the agricultural community in the discussion about GHG emissions and climate change.

HYPOTHESES:

- 1) Increased crop rotation plant diversity will result in lower total GHG emissions.
- 2) Increased inclusion of perennial plants will result in lower total GHG emissions.

- 3) Low external input production systems (i.e. organic systems) will have lower imbedded and total GHG emissions than conventional production systems.
- 4) An increase in tillage within a system will correlate to an increase in measured and modeled in-field GHG emissions.

OUTCOMES:

- 1) Understand the environmental impacts of WICST crop systems in the context of there agronomic performance and economic viability.
- 2) Understand the role cropping systems in Wisconsin play in the mitigation of and contribution to climate change.
- 3) Create conversations with producers of all types on the Wisconsin landscape about issues of greenhouse gas emissions, carbon sequestration, and climate change.

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LONG-TERM CROPPING SYSTEM EFFECTS ON SOIL PROPERTIES AND ON A SOIL QUALITY INDEX

Bill Jokela¹, Josh Posner², and Janet Hedtcke²

INTRODUCTION

Intensive row-crop production can lead to soil degradation over time if insufficient biomass return, intensive tillage, or excessive erosion lead to depletion of soil organic C. Soil quality may be improved by incorporating forage crops or grazing into the rotation, adding manure or other organic sources, and shifting to minimum tillage. We evaluated a range of physical, chemical, and microbial soil properties from six cropping systems in the Wisconsin Integrated Cropping Systems Trial (WICST) after 18 years of continuous treatments.

METHODS

The Wisconsin Integrated Cropping Systems Trial was established in 1989 at the University of Wisconsin Agricultural Research Station in Arlington, WI, to compare six different cropping systems that varied in the specific grain and perennial forage crops in the rotation, the type of nutrient and pest control inputs (organic or synthetic), and soil and crop management practices (Posner et al., 2008). This field study offered an opportunity to evaluate the long-term effects of the cropping systems on various soil properties that can be indicators of soil quality.

We selected eight individual crop phases from the six cropping systems, including five following the corn year of rotation, two following alfalfa, and one in rotationally grazed grass-legume pasture (Table 1). Soils were hand-sampled Oct 29-31 2008 after 18 continuous years of cropping system treatments. We chose the fall, post-harvest time before any fall tillage because we expected it would be a fairly stable time (cool temperatures, no recent manure or fresh biomass additions, and no recent tillage) for assessing long-term effects. We took 16 cores (38-mm in diameter) in a zig-zag pattern from the center 9- by 52-m section of each 18-m by 155-m plot. In corn plots we distributed sampling in different positions relative to the row and avoided visible wheel tracks. Cores were separated into depth increments of 0 to 5 and 5 to 20 cm. We determined penetration resistance using a constant rate recording cone penetrometer with a cone base of 129 mm² and a penetration rate of 8 mm s⁻¹ (Lowery, 1986). We made four measurements per plot (every fourth core) with readings every 1-cm to a depth of 40-cm.

The field-moist soil cores from each plot were combined and weighed before further processing. After hand-mixing, a subsample (100 g) was removed and immediately freeze-dried for subsequent lipid analysis to assess microbial populations. The remainder of the field-moist soil sample was passed through an 8-mm screen. Gravimetric soil water content was determined on a 200-g subsample by drying at 105°C. Bulk density (BD) was calculated from the dry weight and the volume of the 38-mm-diam. cores from each depth, an approach that has been used in other soil quality assessment studies (Clark et al., 2004; Karlen et al., 2006). Laboratory methods were similar to those reported by Jokela et al. (2009) and are described briefly below. Water-stable macroaggregation (WSA) was determined on 100-g air-dried subsamples using a wet-sieve method (Cambardella and Elliott, 1993) with five sieves that separated stable aggregates into the following macroaggregate size classes: 4 to 8, 2 to 4, 1 to 2, 0.5 to 1, and 0.25 to 0.50 mm. We combined individual size classes to create three size categories of water-stable macroaggregates:

All (0.25–8 mm), Small (0.25–2 mm), and Large (2–8 mm), each expressed on the basis of the total soil mass (%). To characterize stable aggregate size distribution, we calculated mean weight diameter (MWD), a single-number index equal to the sum of the fraction of total soil mass in each aggregate size class (including < 0.25 mm), weighted by the mean diameter of each size class (Vansteenberg et al., 1991). Samples were dried at 50°C, passed through a 2-mm screen, and analyzed for water pH, extractable P and K (Bray P1), and soil organic matter (weight loss on ignition) (Peters, 2007). Biologically active soil C was estimated using a method described by Weil et al. (2003), in which readily oxidizable (active) forms of soil C react with dilute KMnO_4 resulting in a reduction in color intensity that is measured colorimetrically. Potentially mineralizable N (PMN) was estimated from the mineral N ($\text{NO}_3\text{-N} + \text{NH}_4\text{-N}$) released during a 28-day incubation using a modification of the method described in Drinkwater et al. (1996; C. Cambardella, personal communication).

Microbial biomass and microbial community composition were determined by measurement of phospholipid fatty acids (Peacock et al., 2001; Vestal and White, 1989) in the Balser Lab in the Soil Science Department, UW-Madison. Briefly, phospholipid fatty acids were extracted, purified, and identified from microbial cell membranes in soil samples using a hybrid lipid extraction based on a modified Bligh and Dyer (1959) technique (Kao-Kniffin and Balser, 2007). The total nmol lipid g^{-1} soil was used as an index of microbial abundance (Balser and Firestone, 2005; Hill et al., 1993; White et al., 1979; Zelles et al., 1992).

The Soil Management Assessment Framework (SMAF) is a soil quality index (SQI), a tool for assessing the impact of management practices on soil functions associated with management goals of crop productivity, waste recycling, or environmental protection (Andrews et al., 2004). Specific soil properties, or indicators, are transformed via scoring algorithms into unitless scores (0 to 1) that reflect the level of function of that indicator, with 1 representing the highest potential. We used seven indicators representing physical, chemical, and biological properties, -- water-stable macroaggregation (WSA), bulk density (BD), water-filled pore space (WFPS), total organic C (TOC), potentially mineralizable N (PMN), pH, and soil test P. Water-filled pore space was calculated from BD and soil water content (Weinhold et al., 2009). We calculated SMAF scores for each parameter using scoring algorithms in a 2009 version of an Excel spreadsheet developed by Susan Andrews (Douglas Karlen, personal communication) and combined the scores to obtain an overall SMAF soil quality index (0 to 100 scale) for each treatment. The SMAF scores and the SQI were calculated for the 0- to 5- and 5- to 20-cm depths and summed (depth-weighted) to obtain a SQI estimate for the 0-20-cm surface, or plow, layer of soil.

Two-factor, repeated measures, randomized complete block ANOVAs were performed using PROC MIXED in SAS to detect treatment and depth main effects and interactions for each dependent soil variable (SAS Institute, 2006). Single-factor ANOVAs were then performed using PROC GLM in SAS to examine treatment differences at each depth. If a significant F test ($P < 0.10$) was obtained from an ANOVA, Duncan's New Multiple Range test was used for determining treatment differences at $P = 0.10$.

RESULTS AND DISCUSSION

Physical Properties

There were significant main effects and interactions for most of the physical parameters –WSA, aggregate mean weight diameter (MWD), and bulk density (Table 2). Treatment effects were significant for all parameters in the surface 5-cm (though only at $P=0.08$ for All aggregates) but not for BD and All WSA in the 5-20-cm depth. The rotationally grazed treatment (CS6) had more large WSA than all other others in both depth increments (Fig. 1), and was numerically highest in all WSA in the 0-5-cm depth (but significantly higher than only two others). Large WSA in 0-5 cm depth were lowest in the corn phase of the two organic rotations (CS3-C and CS5-C). This most likely was due to the intensive mechanical weeding in the corn phase of the organic treatments. In 2008 these plots received a total of five passes with the rotary hoe, tine weeder, or cultivator. Differences in WSA-All were nonsignificant in the lower depth, but the continuous corn treatment was numerically the lowest. In some cases (e.g. CS6-Gr, CS5-C) more large sized aggregates was accompanied by fewer small sized ones and vice versa, with the total aggregates remaining relatively constant. Aggregate MWD, another measure of water stable aggregation, showed more consistent effects, with the grazing treatment significantly larger than others in both depths. The lowest MWD was in the Organic Dairy-Corn (CS5-C) in the 0-5-cm depth, again likely due to multiple tillage operations, and in the Green Gold (CS4-A) in the 5-20-cm depth (Fig. 2; Table 2), in both cases consistent with results of large WSA (Fig. 1).

Bulk density was lower in the upper soil layer, as would be expected, and treatment effects were significant only in that layer (Fig. 3; Table 2). The two alfalfa treatments (CS4-A and CS5-A) and the corn year following three years of alfalfa (CS4-C) had the highest BD. This was likely the result of multiple trips with harvesting equipment and no tillage to alleviate the compaction. Penetrometer resistance showed similar trends except that the grazing treatment had the highest resistance in the lower depths (Fig. 4).

Carbon and Nitrogen

Total organic carbon (TOC) and total N followed similar patterns with significant treatment effects in the 0-5-cm depth but nonsignificance in the 5-20-cm depth, resulting in significant treatment by depth interactions (Fig. 5; Table 3). Total organic C and TN were higher in the surface layer for most treatments (significant depth main effect), in particular for the pasture treatment, which was significantly higher than all other treatments (Fig. 5; Table 3). The organic grain-corn (CS3-C) treatment was the lowest in both C and N, significantly lower than most, reflecting multiple cultivations and only a single year of green manure in the rotation (Table 1). The other organic rotation, CS5, was intermediate in TOC and TN, presumably because it involved less tillage and more C and N additions (from alfalfa and manure) than CS3. The similarity in C and N treatment response is further supported by C-N linear regressions with high R^2 (0.95 and 0.83 for 0-5 and 5-20-cm depths (data not shown) and by similar C:N ratios across treatments.

Active soil C, an estimate of biologically active C, was significantly greater in the pasture treatment (CS6-Gr) than in all other treatments in the surface depth but lower than most in the lower depth (Fig. 6; Table 3). This is the only system with continuous, non-tilled perennial grass-legume forage, which typically results in a high density of fine roots, providing a source of

readily decomposable organic C. Surface deposits of manure and hoof action were probably other factors. The highest active C levels in the lower depth were from the corn and alfalfa phases of the organic dairy system (CS5), likely reflecting the greater additions of organic C from forages and manure in this system. Active C levels were similar in both soil depths, presumably a result of regular chisel plowing, in contrast to most other systems, in which levels in the 0-5-cm depth were greater (significant main effect of depth, Table 3). Treatment effects on active C showed a similar pattern to that of TOC (Fig. 5) and linear relationships between active and total C were strong in the surface depth (though primarily driven by the high values for CS6-Gr), but not in the lower depth ($R^2=0.86$; data not shown).

Potentially mineralizable N (PMN) showed similar patterns of treatment effects as active C with the pasture treatment (CS6-Gr) much greater than all other systems in the surface layer (Fig.6). Continuous corn (CS1-C) was numerically the lowest though not significantly lower than most other treatments. As with active C, the organic dairy system (CS5) had the highest levels in the lower soil depth, significantly higher in several, and showed a good linear relationship with total N (data not shown).

pH, P, and K

Average pH values ranged from 6.2 to 6.9, with the lowest values in the continuous corn (CS1-C) and pasture (CS6-Gr) systems (data not shown). This presumably reflects acidification from regular application of N fertilizers (CS1) or lack of liming (CS6). The main effect of soil depth was nonsignificant (Table 3). Soil test P and K were significantly affected by treatment, and levels in the 0-5-cm depth were consistently and significantly higher than those in the 5-20-cm depth (Table 3; Fig. 7). Soil test P was highest in the alfalfa phase of the Green Gold rotation (CS4-A), followed by other treatments with alfalfa in the rotation (CS4-C and CS5). These results are consistent with estimates by Sawyer et al. (2009) that the CS4 and CS5 cropping systems had the highest annual P input and the lowest net negative P balance. (P offtake exceeded input in all systems.) . All soil P levels were above optimum for crop production (Laboski et al., 2006). Soil test K in the 0-5 cm depth was much higher in continuous corn (CS1-C) and Green Gold-alfalfa (CS4-A) than in all others, while in the lower depth continuous corn alone was highest (Fig. 7). Both treatments received regular applications of K fertilizer (Posner et al., 2008), but in the continuous corn it was applied sub-surface as a starter fertilizer and chisel plowed, resulting in mixing into the 5-20 cm depth; whereas in the alfalfa system, K fertilizer was surface-applied. Soil test K levels were above optimum in the surface layer of all treatments, but optimum or below optimum for the CS4, CS5, and CS6 treatments in the 5-20 cm depth.

Microbial biomass

Microbial biomass, as determined by measurement of phospholipid fatty acids, was higher in the grazing system than in all others, twice as high in the 0-5 cm layer (Fig. 8). This is consistent with the results for active soil C and PMN (Fig. 6), which are indicators of biologically active C and N that support growth of the microbial population. Lipid types indicative of various microbial population groups were also measured, but results are preliminary and are not reported here.

Soil Quality Index

The SMAF soil quality index for the 0-20-cm depth showed a range of 78 to 87, reflecting relatively small differences (Fig. 9). Scores for some soil quality indicators (pH, WSA, and soil test P) were optimum (1 or almost 1) for all cropping system treatments. As a result, Soil Quality Index values were driven primarily by differences in TOC, BD, WFPS, and PMN. SQI values were higher in the 0-5-cm depth but showed greater differences in the 5-20-cm depth (data not shown). There was a trend for highest values for the pasture (CS6-G) and specific phases of the Green Gold (CS4-Alfalfa) and organic dairy (CS5-Corn) cropping systems (no statistical analysis). These cropping systems are rotations with perennial forages and/or manure additions, but it is not clear why other phases of the Green Gold and Organic Dairy systems are lower.

SUMMARY/CONCLUSION

Cropping system treatments had significant effects on all soil properties measured in the surface 0-5-cm soil layer and on most properties in the 5-20-cm layer. The pasture system had the highest proportion of water-stable aggregates, as indicated by aggregate MWD and large WSA. The surface layer of that treatment, in particular, was also highest in C and N content (both total and active/mineralizable forms) and in microbial biomass. All of these properties likely reflect the continuous grass-legume forage and manure deposition in the pasture system. Some of the other rotations with perennial forages also had trends toward higher C and N, especially the active forms. Pasture and rotations with alfalfa also tended to have the highest penetrometer resistance and bulk density, reflecting wheel traffic and lack of tillage. Relative differences in individual scores from the SMAF soil quality index varied greatly, but there was a trend for higher overall SQI in the pasture and most rotations with alfalfa.

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Table 1. WICST cropping systems and the treatment rotation-years selected for soil quality assessment.

Crop System	Name	Rotation
CS1	Cont. Corn	C-C-C-C
CS2	Corn-SB No-Till	C-SB
CS3	Organic Grain	C-SB(W. Wht)-RedClover
CS4	Green Gold	C-Alf-Alf-Alf
CS5	Organic Dairy Rotational	C-Oats/Pea/Alf-Alf
CS6	Grazing	Grass/Legume
Crop System Phase		
CS1-C	Cont. Corn	C-C-C- <u>C</u>
CS2-C	Corn-SB No-Till	<u>C</u> -SB
CS3-C	Organic Grain	<u>C</u> -SB(W. Wht)-RedClover
CS4-A	Green Gold	C-Alf-Alf- <u>Alf</u>
CS4-C	Green Gold	<u>C</u> -Alf-Alf-Alf
CS5-C	Organic Dairy	<u>C</u> -Oats/Pea/Alf-Alf
CS5-A	Organic Dairy Rotational	C-Oats/Pea/Alf- <u>Alf</u>
CS6-Gr	Grazing/Pasture	<u>Grass/Legume</u>

Bold/Underline indicates year of rotation (2008) sampled for given treatment.

C = corn, SB = soybean, Alf = alfalfa, Gr = grass/legume

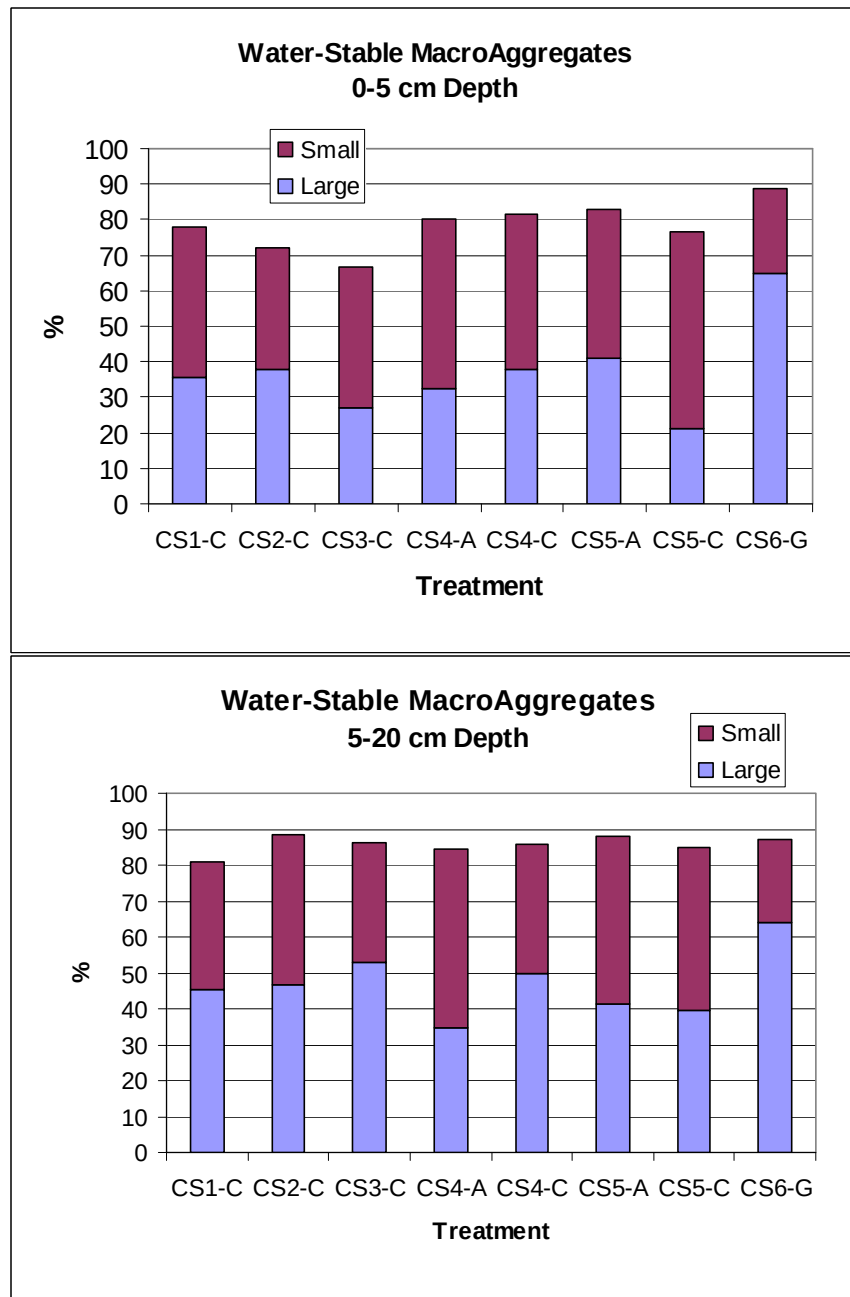


Figure 1. Water-stable aggregates in the 0-5-cm (top) and 5-20-cm (bottom) depth as affected by cropping system treatment.

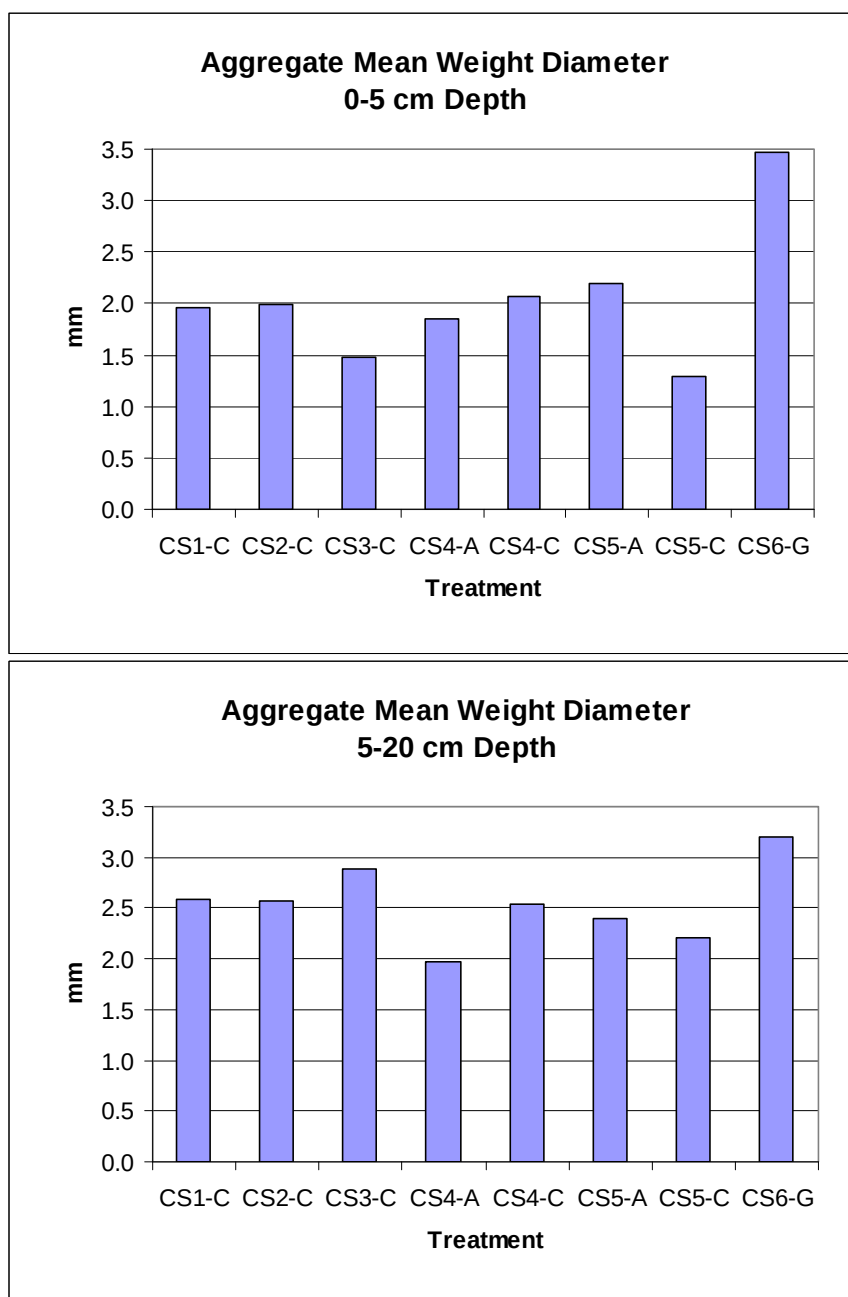


Figure 2. Water-stable aggregate mean weight diameter in the 0-5-cm (top) and 5-20-cm (bottom) depth as affected by cropping system treatment.

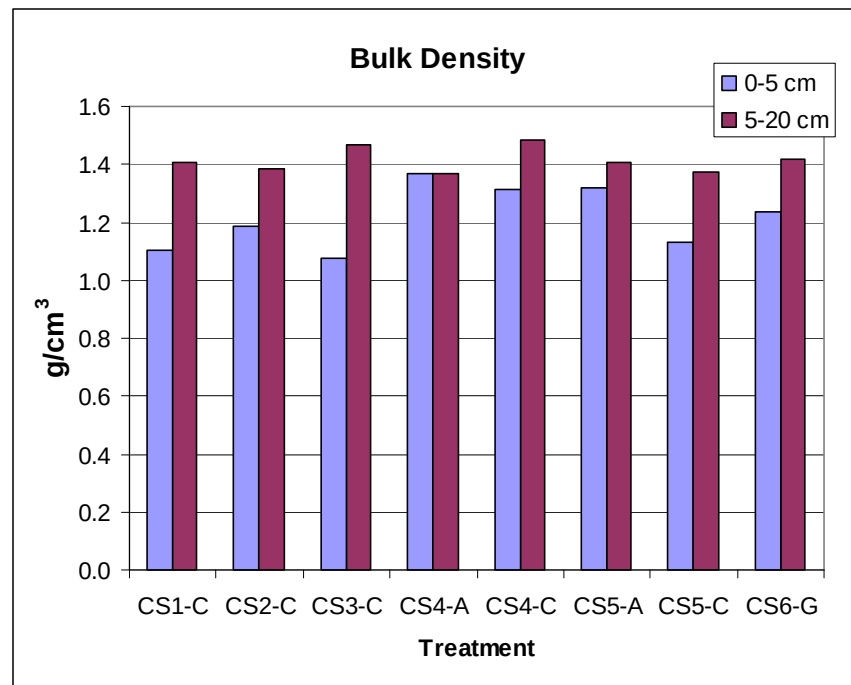


Figure 3. Bulk density in the 0-5-cm (top) and 5-20-cm (bottom) depth as affected by cropping system treatment.

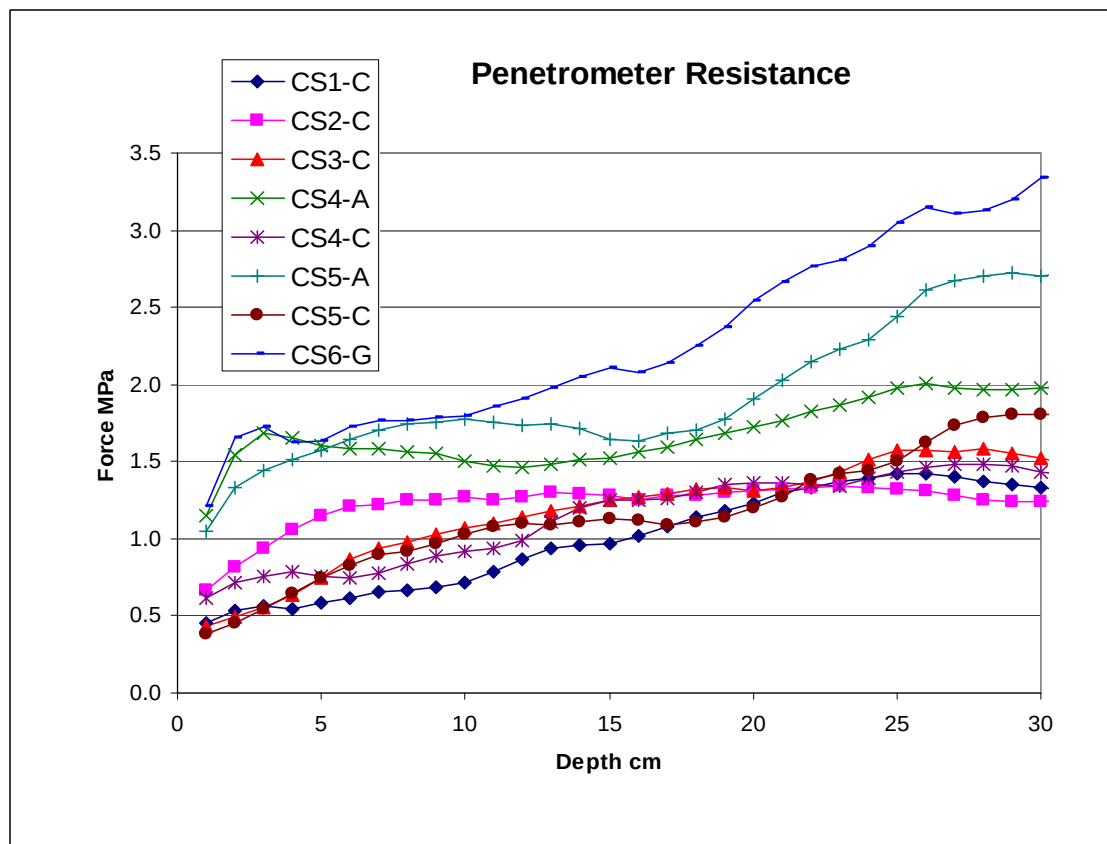


Figure 4. Penetrometer resistance by depth as affected by cropping system treatment.

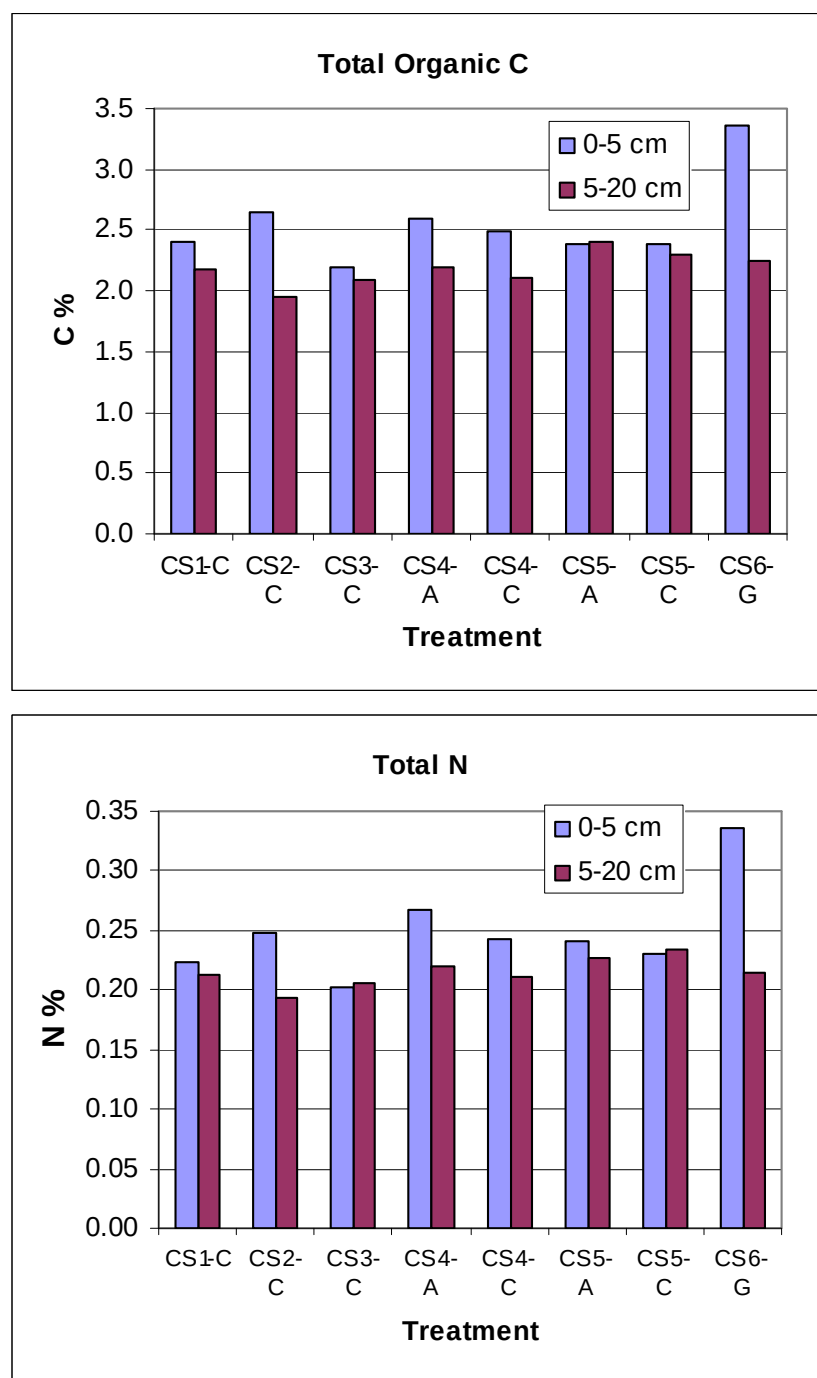


Figure 5. Total organic C (top) and total soil N (bottom) as affected by cropping system.

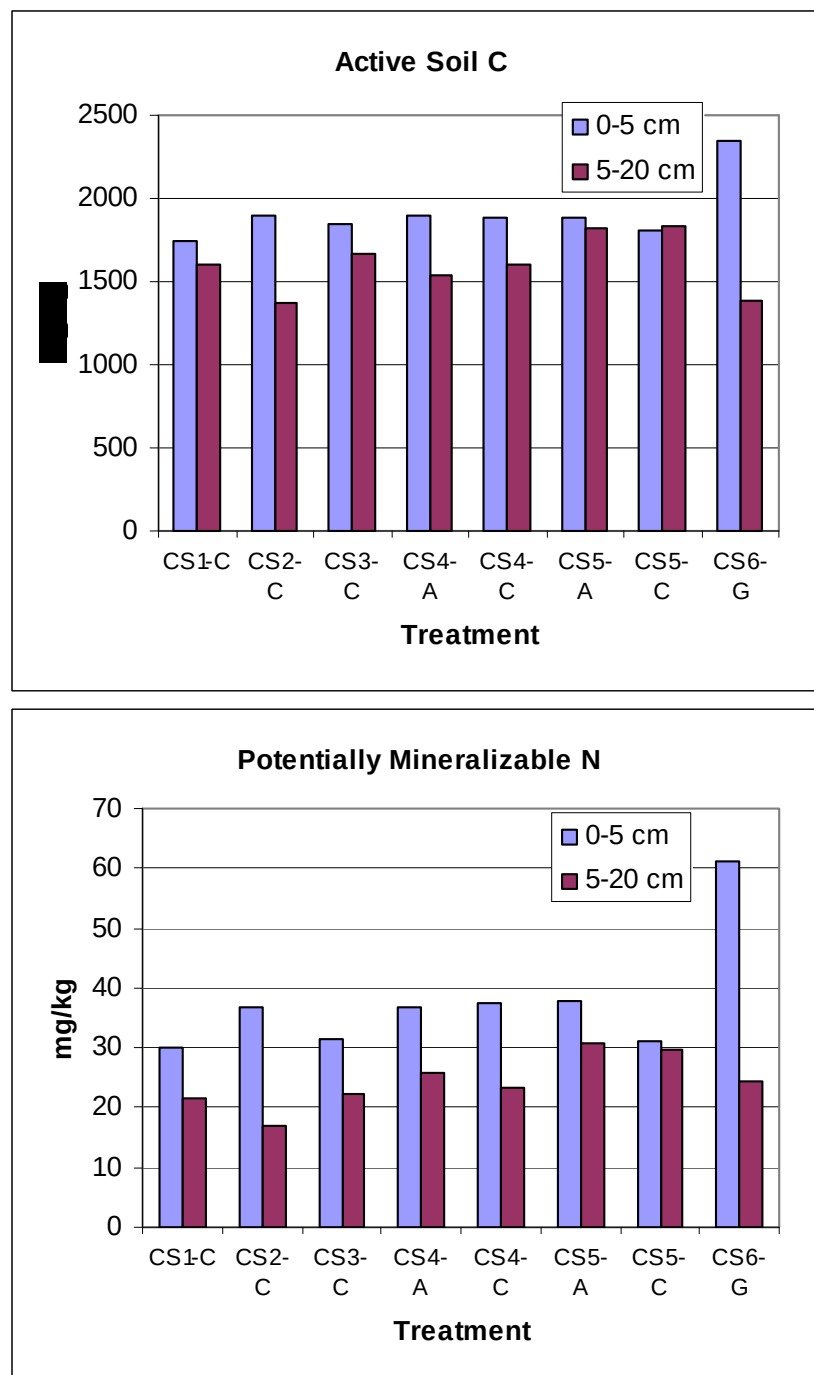


Figure 6. Active soil C (top) and potentially mineralizable N (bottom) as affected by cropping system.

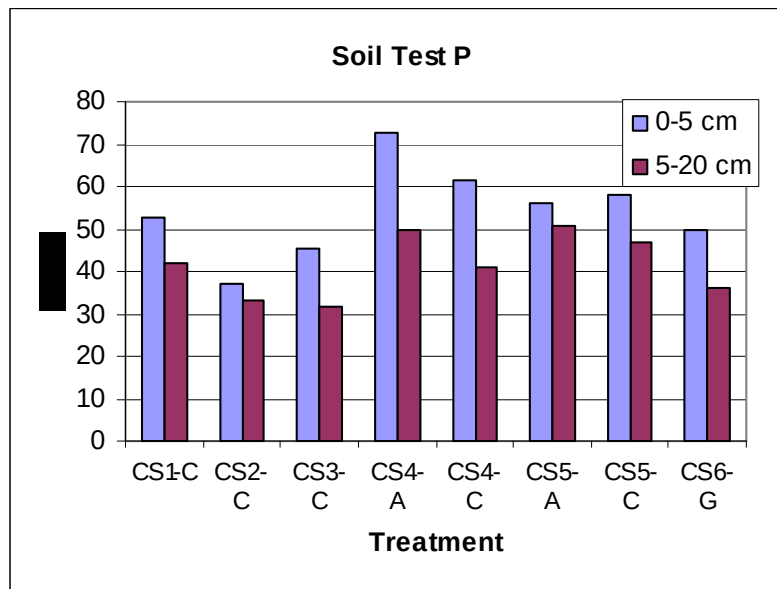
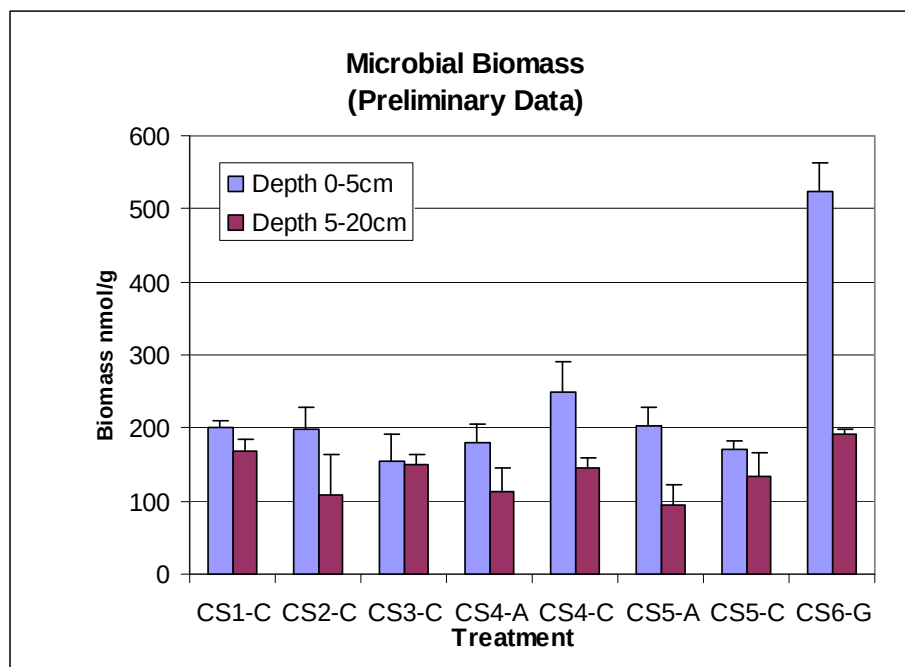


Figure 7. Soil test P (top) and soil test K (bottom) as affected by cropping system.

Figure 8. Microbial biomass as affected by cropping system.

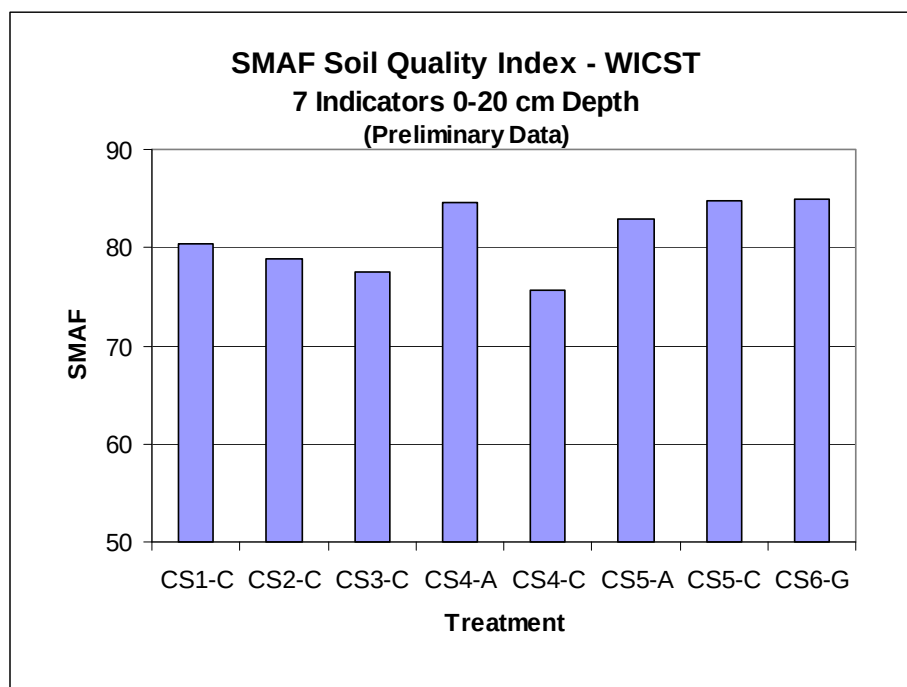


Figure 9. SMAF soil quality index (0-20-cm depth) as affected by cropping system.



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Endogeic and anecic earthworm abundance in six Midwestern cropping systems

Jonathan Simonsen^a, Joshua Posner^{b,*}, Martha Rosemeyer^c, Jon Baldock^d^a Wisconsin Department of Natural Resources, 107 Stutliff Ave, Rhinelander, WI 54501, United States^b Agronomy Department, University of Wisconsin, 1575 Linden Drive, Madison, WI 53706, United States^c Evergreen State College, 2700 Evergreen Parkway, Olympia, WA 98505, United States^d AgStat Consulting Service, 6394 Grandview Road, Verona, WI 53593, United States

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ABSTRACT

Endogeic and juvenile anecic earthworm abundance was measured in soil samples and anecic populations were studied by counting midden numbers at the sites of two long-term cropping systems trials in South-central Wisconsin. The three grain and three forage systems at each site were designed to reflect a range of Midwestern USA production strategies. The primary objectives of this work were to determine if the abundance of endogeic or anecic earthworms varied among cropping systems or crop phases within a cropping system and were there specific management practices that impacted endogeic or anecic earthworm numbers. The earthworms present in the surface soil were: *Aporrectodea tuberculata* (Eisen), *A. caliginosa* (Savigny), *A. trapezoides* (Dugés); and juvenile *Lumbricus terrestris* (L.). True endogeic abundance was greatest in rotationally grazed pasture [188 m⁻² at Arlington (ARL) and 299 m⁻² at Elkhorn (ELK)], and smallest in conventional continuous corn (27 m⁻² at ARL and 32 m⁻² at ELK). The only type of anecic earthworm found was *L. terrestris* L. There was an average of 1.2 middens per adult anecic earthworm and the population of anecics was greatest in the no-till cash grain system (28 middens m⁻² at ARL, 18 m⁻² at ELK) and smallest in the conventional continuous corn system (3 middens m⁻² at ARL, 1 m⁻² at ELK). Earthworm numbers in individual crop phases within a cropping system were too variable from year-to-year to recommend using a single phase to characterize a whole cropping system. Indices for five management factors (tillage, manure inputs, solid stand, pesticide use, and crop diversity) were examined, and manure use and tillage were the most important impacting earthworm numbers across the range of cropping systems. Manure use was the most important management factor affecting endogeic earthworm numbers; but no-tillage was the most important for the juvenile and adult anecic groups and had a significantly positive influence on endogeic earthworm counts as well. The pesticides used, which were among the most commonly applied pesticides in the Midwestern USA, and increasing crop diversity did not have a significant effect on either the endogeic or anecic earthworm groups in this study. Consequently, designing cropping systems that reduce tillage and include manure with less regard to omitting pesticides or increasing crop diversity should enhance earthworm populations and probably improve sustainability.

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1. Introduction

Elevated earthworm populations are often recognized by farmers as an indication of a healthy soil (Romig et al., 1996). Indeed, research has confirmed that earthworms have a large impact on the physical, chemical, and biological properties of the soil (Lee, 1985; Edwards and Bohlen, 1996), to the point that some researchers have echoed the farmers claims, and discussed the use of these organisms as biological indicators of soil health (Doran and Safley, 1997; Yeates et al., 1998). In light of their importance to organic matter dynamics and soil structure, ecologists such as

Hendrix et al. (1992), Edwards et al. (1995), and Ernst (1995) argue that the long-term sustainability of agricultural soils could be improved by employing cropping systems that promote earthworm numbers.

The species of earthworms present in agricultural fields of the Midwest are primarily peregrine lumbricids that can be broadly classified into two ecological groups: endogeics, or topsoil-dwelling earthworms, and anecics, or deep burrowing, often subsoil-dwelling earthworms (Bouche, 1977). The topsoil-dwelling earthworms are noted for their extensive burrowing activity in the top 25 cm of the soil; for example, Cook and Linden (1996) estimated that the endogeic species, *Aporrectodea tuberculata* (Eisen), produced approximately 1058 km ha⁻¹ of new burrows each week. On the other hand, anecic earthworms create one or two burrows that may extend three or more meters into the soil

* Corresponding author. Tel.: +1 608 262 0876; fax: +1 608 262 5217.

E-mail address: JLPosner@wisc.edu (J. Posner).

profile. Above their burrows these species create structures known as middens, which consist of plant residues pulled partially into their burrows and cemented with cast material. It has been estimated that 0.5 cm of soil (or 2–5 kg soil m⁻²) is brought to the surface each year by the casting activity of these earthworms (Darwin, 1881).

Agricultural management practices; such as, tillage, crop cover, manuring, and pesticide use; are known to influence both endogeic and anecic abundance (Edwards and Bohlen, 1996). Tillage generally affects both endogeic (Clapperton et al., 1997; Hubbard et al., 1999; Hutcheon et al., 2001) and anecic (Nuutinen, 1992; Wyss and Glasstetter, 1992; Bostrom, 1995; Peigne et al., 2009) earthworm numbers negatively compared to no-tillage. Tillage, however, does not always result in lower abundance of endogeic (Bostrom, 1995; Kladvik et al., 1997; Butt et al., 1999) or anecic earthworms (Edwards and Lofly, 1982; Lofs-Holmin, 1983; Whalen et al., 1998). One reason for this inconsistency is that tillage often occurs in conjunction with the incorporation of crop residues or manure, which are food sources for earthworms. Thus, depending on the quality and quantity of the residues incorporated versus that left on the surface, tillage may inhibit or enhance endogeic or anecic earthworm populations (Siegrist et al., 1998; Carpenter-Boggs et al., 2000; Chan, 2001; Zaller and Kopke, 2004).

Because of the tillage–food-supply interaction it is difficult to draw broad conclusions about how earthworms will respond to a complex set of management practices (such as tillage, fertilizers, pesticides, and crop rotation) that make up a cropping system. A few studies have undertaken this difficult task and examined earthworm responses to component changes within a cropping system. Lofs-Holmin (1983) and Fonte et al. (2009) studied endogeic numbers as a function of crop residue management, finding that the presence of mulch increased abundance. In the same manner, a number of authors have studied a common rotation under organic, conventional, or biodynamic management (Siegrist et al., 1998; Zaller and Kopke, 2004) or a common rotation with different tillage regimes (Werner and Dindal, 1989; Tomlin et al., 1995; Hubbard et al., 1999; Ernst and Emmerling, 2009). Similarly, with anecics most work has been limited to comparing alternative agronomic techniques on a constant crop rotation, or were conducted on a narrow range of rotations (Werner and Dindal, 1989; Pfiffner and Mader, 1998; Blakemore, 2000).

Recently, a number of authors have investigated the effect on earthworms of adding forage or pasture ley phases to annual crop rotations (Katsvairo et al., 2007; Eekeren et al., 2008; Riley et al., 2008; Nelson et al., 2009). Nelson et al. (2009) found in organic potato rotations in Canada, that although earthworm numbers dropped drastically in the potato and grain phases, it only took 2 years of forage production to return to initial abundance levels. Similarly, Eekeren et al. (2008) studied a 3-year grain and 3-year ley system and found that after 1 year of annual crops, earthworm numbers had dropped and it was not until the third year of temporary grassland that numbers and biomass of endogeics had returned to permanent grassland levels. Anecics, however, did not recover as rapidly. In a comparison of several 4-year rotations with 1–3 years of grass ley in Norway, Riley et al. (2008) concluded that 50% ley in the rotation appeared desirable for maintenance of satisfactory soil structure and earthworm activity. And, in Southeast USA researchers added a single bahiagrass (*Paspalum notatum* Fluegge) phase to a cotton/peanut rotation and with just that year of sod, earthworm abundance and water infiltrations rates increased significantly (Katsvairo et al., 2007).

The Wisconsin Integrated Cropping Systems Trial (WICST) is a long-term study that began in 1990 to examine six cropping systems with production strategies ranging from monocropped corn managed with high inputs, to rotational grazing and organic production with few additional inputs (Posner et al., 1995).

Approximately 20 million hectares of crop land in Minnesota, Wisconsin, and Iowa are planted to corn for grain, soybean and alfalfa forage in systems similar to the ones under review in these trials (National Agricultural Statistics Service, 2009). Thus, it provided an excellent opportunity to examine the effect of a range of practical cropping systems that incorporated several management practices known to affect earthworm abundance. Three research questions were examined: (1) did the abundance of endogeic or anecic earthworms vary among cropping systems, (2) did the abundance of endogeic or anecic earthworms vary among crop phases within a cropping system and, if not, could a single phase be sampled to characterize earthworm numbers of the entire cropping system, and (3) were there specific management practices that impacted endogeic or anecic earthworm numbers and, if so, what was the relative importance of these practices?

2. Materials and methods

2.1. WICST study sites

The WICST began in 1990 at two study sites, the Arlington Research Station (43°20'N, 89°21'W) near Arlington (ARL) in south central Wisconsin, and the Lakeland Agricultural Complex (42°40'N, 88°32'W) near Elkhorn (ELK) in southeast Wisconsin, USA. The soil at ARL is a deep and well-drained silt loam, a Typic Argiudoll (USDA soil taxonomy), with an average organic matter content of 4.5% and a pH of 6.6. The soil at the ELK site is a somewhat poorly drained silt loam classified as an Aquic Argiudoll with average organic matter content of 5.4% and average pH of 6.9. Both sites are relatively flat, with a few undulations of less than 2% grade (Posner et al., 1995).

2.2. Cropping systems design

The six cropping systems represent a range of production strategies as seen in Table 1A and the common pesticides used in the conventional production systems are listed in Table 1B. The three cash grain production systems include: (1) a chisel-plowed continuous corn system (*Zea mays* L.) with a high level of external inputs (CS1) including fertilizer, herbicide and a corn rootworm (*Diabrotica virgifera*) insecticidal treatment; (2) a no-till corn and soybean [*Glycine max* (L.) Merr.] system with a moderate level of external inputs (common practice in the Midwestern United States) (CS2); and, an organic corn/soybean/wheat system (*Triticum aestivum* L.) seeded with a red clover (*Trifolium pretense* L.) green manure crop (CS3). Three additional systems apply primarily to the dairy industry and consist of: (1) a high input (herbicides, insecticides) alfalfa [*Medicago sativa* (L.)]/corn rotation (CS4) with manuring; (2) an organic forage rotation system with three crops (CS5) plus manuring; and (3) a rotationally grazed pasture system (CS6) with Holstein heifers (*Bos Taurus*) on timothy, (*Phleum pratense* L.), brome grass (*Bromus inermis* L.), orchard grass (*Dactylis glomerata* L.), and red clover. The trial was designed so that all crop phases of the six cropping systems were present each year and there were four blocks (one replication of the 14 phases in each block) at each site. Conventional farm machinery was used to manage the plots that were approximately 0.3 ha each. Additional agronomic details about the WICST have been previously published (Posner et al., 1995; Posner et al., 2008).

2.3. Earthworm sampling and identification

2.3.1. Endogeics

Soil samples were collected to determine topsoil earthworm abundance. In the spring of 1999, two cores per plot were taken

Table 1

Selected agronomic practices of the six cropping systems of the Wisconsin Integrated Cropping Systems Trials.

Cropping system	Management summary			
Crop rotation	Tillage intensity	Nitrogen source	Pesticide use ^a	Crop diversity
(A) <i>Cropping systems management</i>				
Cash grain systems				
CS1, corn	Fall chisel plow, spring seed bed preparation ^b	Anhydrous ammonia	High pre-plant incorporated; herbicide; rootworm insecticide	Low
CS2, corn/soybean	None	Soybean residue and anhydrous ammonia	Medium pre- and post-emerge herbicide	Medium
CS3, corn/soy/wheat + red clover	Fall chisel plow, spring seed bed preparation and rotary hoeing plus cultivations during corn and soybean phases	Red clover plowdown and soybean residue	None	High
Forage-based systems				
CS4 corn/alfalfa/alfalfa/alfalfa	Fall chisel plow and spring seed bed preparation (prior to both corn and alfalfa)	Solid manure and alfalfa residue	High pre-plant incorporated herbicide early years; post-emerge foliar herbicide and insecticide later years	Low
CS5 corn/oats + alfalfa/alfalfa	Fall chisel plow and spring seed bed preparation (prior to both corn and alfalfa)	Solid manure and alfalfa residue	None	Medium
CS6 pasture	None	Manure	None	High
Type of pesticide	Crop	Active ingredient	Class	
(B) <i>Pesticide use</i>				
Insecticide	Alfalfa	Lambda-cyhalothrin	Synthetic pyrethroid	
	Corn	Permethrin	Synthetic pyrethroid	
		Dimethoate	Organo-phosphate	
Tefluthrin		Synthetic pyrethroid		
Terbufos		Organo-phosphate		
Tebupirimophos + cyfluthrin		Organo-phosphate + pyrethroid		
Mode of action				
Herbicide	Alfalfa	Imazethapyr	ALS inhibitor	
	Corn	Imazamox	ALS inhibitor	
		S-Metolachlor	Mitosis inhibitor	
		Bromoxynil	Photosystem II inhibitor	
		Dicamba	Synthetic auxin	
		Glyphosate	EPSP synthase inhibitor	
	Nicosulfuron	ALS inhibitor		
Soybean	Glyphosate	EPSP synthase inhibitor		

ALS inhibitor: inhibition of acetolactate synthase enzyme.

EPSP inhibitor: inhibition of EPSP synthase enzyme in shikimic acid pathway.

^a Includes herbicides and insecticides.^b Field cultivator or soil finisher to prepare smooth, residue-free seedbed.

with a small cylindrical corer (10.6 cm diameter, 25 cm deep). For the following 2 years sample volume was increased to 25 cm × 25 cm × 25 cm, which has been demonstrated to be a more effective sample size for endogeic earthworms (Springett, 1981; Callahan and Hendrix, 1997). Three of these larger samples were taken per plot in 2000 and (due to labor constraints) only two samples per plot in 2001. Soil sampling for earthworms was conducted once the soil temperature (at 10 cm) was between 8 and 15 °C each year. Sampling was done at ARL in mid April prior to planting, and at ELK, the more poorly drained site, in early June shortly after planting in all 3 years. The soil cores were stored in plastic grain bags in a cold room at 10 °C for up to 2 weeks, then each sample was hand-searched for earthworms by passing the soil through a 6.3 mm sieve and the number of endogeic and juvenile anecic earthworms was recorded. Three different species of endogeic earthworms were identified. Identifications were based on the taxonomic keys by Schwert (1990) and Reynolds (1997). Considering that only *Aporrectodea* spp. and *Lumbricus terrestris* L. were present on the two sites, it was possible to determine the genera and ecological group of the juvenile earthworms by noting the presence or absence of dorsal pigmentation and characteristics of the prostomium (Sam James, personal communication). The counts were converted to abun-

dance values (number m⁻²) based on the area of the sampling probe.

2.3.2. Midden counting

To estimate the populations of adult anecic earthworms, the number of middens was counted in 1 m² quadrats. Unlike the April/May sampling for endogeic earthworms, sampling for anecic middens was done at ARL in early July and mid-July at the ELK site, in all 3 years. In 1999, 20 randomly placed quadrats were counted in each plot, while in the two subsequent years 15 quadrats were used. When fifteen 1 m² quadrats were sampled in each plot it took two people approximately 4 h to completely sample one replication (13 plots). CS6 (rotational grazing system) was not sampled because of the difficulty of identifying middens in the thick sod layer.

Although this sampling technique is not used as frequently as soil coring or chemical extraction, there is growing evidence that it is a reliable method to estimate anecic abundance in agricultural soils (Dickey, 1990; Nuutinen, 1992; Gallagher, 1994; Schmidt, 1997). Previous research at the ARL demonstrated that there are approximately 1.2 middens per adult (Gallagher and Wollenhaupt, 1997) and similar results have also been found in corn and soybean fields in Indiana (Schmidt, 1997). To determine if the same

relationship of adults per midden held on the WICST, chemical extractions were done at ARL using a diluted mustard (0.9% by weight) extraction method following the recommendations outlined by Gunn (1992). Chemical extraction was done in one replication of each cropping system phase and two samples (7 l of mustard solution added to each 0.6 m × 0.6 m quadrat) were taken in each plot. To further validate the midden technique on the trial, middens in a specific area were counted every 2 weeks throughout the growing season to determine how quickly they recovered from cultivation and compaction, the latter being especially associated with repeated hay harvest in CS4 and CS5.

2.4. Statistical analyses

The research plots were arranged in a randomized complete block design with four replications at each location. Due to changes in two cropping systems, CS4 and CS5, at ELK in 1999 and a preliminary analysis showing a significant location × cropping system variance interaction, the analyses were done separately for each site. However, the cropping system × year interaction was not significant, which indicated the results were consistent across years. Thus, analyses combined across years were reported for each site. The sources of variation for these combined analyses included: year, block, cropping system, and phase within cropping system, plus all interactions and experimental error and sampling error for a total of nine sources. Blocks, years, and their interactions were considered random factors while cropping systems and crop phase within each cropping system were considered fixed factors. To simplify the presentation of the results while using the most appropriate standard errors (SE) (Littell et al., 2006), the ANOVAs were conducted in SAS Proc GLM, but when means were given the SE were from SAS Proc Mixed (SAS Institute, 2002a). All tests of significance were made at $\alpha < 0.10$ to decrease the probability of a type II error, and the residuals were examined in SAS and JMP 5.1 (SAS Institute, 2002b). Although the distributions of the residuals were skewed and the sampling variances were somewhat heterogeneous, we felt there were no transformations or nonparametric statistics that adequately corrected these problems and fit the experimental design. Considering the robustness of the classical parametric tests (Stonehouse and Forrester, 1998), we considered them the best statistical procedures for this study. To permit further analysis of the results, cropping systems indices related to earthworm habitat were developed for each rotation. The subsequent correlations between the abundance data and these crop management indices were calculated with Statistix 8.0 (Anon., 2003).

3. Results

3.1. Soil sampling

At ARL only one species of endogeic earthworm was identified from the soil cores, *A. tuberculata*, but at ELK three were found. At ELK approximately 50% of the adults were *A. caliginosa* (Savigny), 41% were *A. trapezoides* (Dugés), and 9% were *A. tuberculata* (Eisen.). We found juveniles comprised 79% of the endogeic earthworms at ELK, while at ARL they made up 91% of the total. Juvenile *L. terrestris* was 25 and 10% as abundant as the endogeics at ARL and ELK, respectively.

Due to the modest abundance of endogeics under several systems, the presence of only one species at ARL, and the predominance of juveniles that we could only identify to the genus level, we decided to treat all the species together to obtain the total endogeic abundance data (*Aporrectodea* spp.). In addition, biomass was measured and analyzed on all the samples, but due to the similarity of results of the statistical analysis, only abundance data is reported here. Because soil sampling took place early in the growing season, the number of endogeic earthworms observed primarily reflected the legacy of the previous crop and crop management. In the corn–soybean rotation for example, the early spring earthworm abundance in the corn year primarily reflected the influence of the previous soybean phase.

The chemical extractions for the anecic earthworms revealed that there was a single type of anecic earthworm (*L. terrestris*) and an average of 1.2 middens (SEM 0.41) per adult, which agreed with previous work (Gallagher and Wollenhaupt, 1997). An exception occurred in the frequently cultivated corn phase of CS3, 4, and 5. In these plots there were 1–5 anecics m⁻², but in some cases no middens were recorded. A potential source of variability was avoided by waiting at least 2 weeks after hay harvest before counting middens. Monitoring of the permanent quadrats had shown that following hay harvest, midden numbers took approximately 2 weeks to recover to the levels observed before the traffic disturbance at the soil surface. Due to the mid-summer counting of middens, these counts were assigned to the current crop phase.

3.2. Does cropping system affect earthworm abundance?

Cropping systems significantly impacted the abundance of both the endogeic and anecic earthworms at the two sites (Table 2). The mean counts per system for the endogeic group ranged from 27 to 299 m⁻² (8.7–117.2 g m⁻²) while the anecic midden counts ranged

Table 2
Analysis of variance for endogeic earthworm and anecic midden abundance at Arlington and Elkhorn, Wisconsin for 1999 through 2001.

Source	Endogeic earthworm counts				Anecic midden counts			
	Arlington		Elkhorn		Arlington		Elkhorn	
	df	MS	df	MS	df	MS	df	MS
Year, Y	2	102,080 [*]	2	18,439 ns	2	45,866 ^{***}	2	1202 ns
Block, B	3	36,612 ns	3	16,264 ns	3	297 ns	3	197 ns
B × Y	6	15,979	6	10,568	6	725	6	201
System, S ^a	5	148,751 ^{***}	3	460,213 ^{***}	4	32,210 ^{***}	2	34,274 ^{***}
Phase (S), P(S) ^a	8	14,256 ns	3	2163 ns	8	48,071 ^{***}	3	1150 [*]
Y × S	10	8983 ns	6	7029 ns	8	1853 ns	4	442 ns
Y × P(S)	16	42,969 ^{**}	6	3564 ns	16	6779 ^{***}	6	201 ns
Experimental error	117	5686	54	10,234	108	380	45	200
Sampling error	224	4659	112	5318	2443	49	1126	17

ns = not significant at the 10% level.

^a Year and block were random factors so in a balanced design the error to test S would be Y × S and to test P(S) it would Y × P(S). However, due to the small imbalance in sample numbers, a small portion (<2%) was composed of other error terms.

^{*} $p < 0.05$.

^{**} $p < 0.01$.

^{***} $p < 0.001$.

Table 3

Three-year (1999 through 2001) mean endogeic earthworm and anecic midden abundance by phase and cropping system at Arlington and Elkhorn, Wisconsin.

Cropping system	Phase	Endogeic earthworm counts ^a		Anecic midden counts ^b	
		Phase mean (SE) ^c	System mean (SE)	Phase mean (SE)	System mean (SE)
Arlington (number m ⁻²)					
CS1	Corn	27 (34.6)	27 (34.6)	3 (6.8)	3 (6.8)
CS2	Corn	125 (36.0)	123 (27.7)	28 (6.8)	28 (5.8)
	Soybean	120 ((37.2)		28 (6.8)	
CS3	Corn	51 (35.4)	64(23.7)	3 (6.8)	10 (5.4)
	Soybean	57 (36.0)		0 (6.8)	
	Wheat	85 (35.9)		26 (6.8)	
CS4	Corn	127 (35.0)	149(21.9)	2 (6.8)	20 (5.2)
	Alfalfa A ₀	195 (39.3)		9 (6.8)	
	Alfalfa A ₁	155 (35.3)		38 (7.0)	
	Alfalfa A ₂	119 (35.6)		31 (6.8)	
CS5	Corn	141 (38.6)	143(23.9)	1 (6.8)	21 (5.4)
	Oats/alfalfa A ₀	147 (34.0)		24 (6.8)	
	Alfalfa A ₁	139 (36.0)		37 (6.8)	
CS6	Pasture	188 (43.7)	188 (43.7)	n.a. ^d	n.a.
Elkhorn ^e					
CS1	Corn	32 (10.2)	32 (10.2)	1 (1.4)	1 (1.4)
CS2	Corn	80 (10.5)	79 (11.2)	16 (1.5)	18 (1.3)
	Soybean	78 (17.3)		19 (1.5)	
CS3	Corn	50 (12.9)	53 (8.8)	0 (1.4)	2 (1.2)
	Soybean	44 (9.8)		0 (1.4)	
	Wheat	65 (12.7)		5 (1.4)	
CS6	Pasture	299 (43.6)	299 (43.6)	n.a.	n.a

^a Soil cores taken the spring following the cropping system phase to 25 cm deep.^b Quadrats counted in July of the crop phase.^c SE = standard errors of the mean from SAS Proc Mixed given in parentheses.^d n.a. = not available; midden abundance data not collected from pasture at either site.^e CS4 and CS5 were changed at Elkhorn in 1999, thus omitted from this study.

from 0 to 38 m⁻² (Table 3). For the endogeic earthworms the pasture system, CS6, was the only system to average more than 150 m⁻² at both locations and the rank in abundance was the same at both locations for the four systems present at both: CS6 > CS2 > CS3 > CS1. One cropping system, CS2, also had the highest mean anecic midden count at both sites and the rank of the cropping systems was identical for both sites: CS2 > CS3 > CS1. The nonsignificant Year × System interaction terms for both earthworm groups and sites (Table 2) further demonstrated the consistency of the significant impact of cropping systems across years.

3.3. Characterizing the systems from earthworm abundance in a single phase

In contrast to cropping systems, after 9 years of cropping, the phases within systems did not have a significant effect on endogeic earthworm abundance (Table 2), suggesting that perhaps sampling a single phase could characterize the entire rotation. However, this nonsignificant effect was a result of the large year-to-year variation in the number of earthworms by phase within system, which caused the mean differences across years to be small (Table 3) and the error term, the mean squares for the Year × Phase (system), to be large (Table 2). When endogeic earthworm counts following just the corn phase were compared to counts averaged over all phases of a cropping system, essentially the same rankings were obtained for the endogeic group (data not shown). Although using a single, common crop phase for sampling may be efficacious as it was in this case and it would reduce the workload of characterizing endogeic earthworm abundance in mature cropping systems, the soundness of this approach is questionable due to the large variation in phases across years.

There was however, a significant effect of phase within cropping system at each site on anecic midden counts (Table 2) indicating that working with a single phase would be misleading. Also, in contrast to the results with the endogeic group, comparing midden numbers in the common phase (corn) was not at all useful in characterizing anecic abundance in the cropping systems. A problem with the common phase approach with these rotations was that it was chisel-plowed corn, which had low counts (<4), making it difficult to distinguish between systems—with the exception of the no-till system, CS2. Perhaps the common phase approach would do better if it was one that was more favorable for anecics.

3.4. Effect of production strategy and agricultural management practices

Two approaches were used to better ascertain what aspects of the different systems either promoted or suppressed earthworm numbers. As with most systems trials, the WICST cropping systems were designed to test the combined effects of the components making up each system (Posner et al., 1995) and not to ascribe differences to a single factor. Nevertheless, it is possible to make some constructive comparisons by using some of the dominant features of each system. One method to make such comparisons was to use linear contrasts (Table 4). At both sites, significantly higher populations of endogeic and anecic earthworms were characteristic of the forage-based systems that received manure compared to the cash grain systems (Contrast 1). Within the grain systems, the no-till system (CS2) had significantly more of both types of earthworms than the other two grain systems that included tillage at both sites (Contrast 2). However, in this study, the no-till, pasture system (CS6) did not have significantly more

Table 4

Linear contrasts of system influence on endogeic earthworm and anecic midden abundance (1999–2001).

Linear contrast		Endogeic earthworms		Anecic middens	
No.	Description	Arlington	Elkhorn	Arlington	Elkhorn
Estimated difference in number m ⁻² (SE)					
1	Forage (CS4, CS5, CS6) vs. cash grain systems (CS1, CS2, CS3)	89 (21.8)**	244 (43.3)**	7 (3.0)*	n.a. ^a
2	No-till (CS2) vs. tilled grain systems (CS1 and CS3)	77 (30.1)*	36 (10.1)**	21 (4.6)**	16 (1.3)**
3	No-till (CS6) vs. tilled forage systems (CS4 and CS5)	43 (43.3) ns	n.a.	n.a.	n.a.
4	Organic (CS3) vs. conventional grain system (CS1)	37 (36.8) ns	20 (9.5)*	7 (5.9) ns	0 (1.5) ns
5	Organic (CS5) vs. conventional forage system (CS4)	-7 (25.5) ns	n.a.	1 (3.9) ns	n.a.

ns = not significant at the 10% level.

* $p < 0.05$.** $p < 0.01$.^a n.a. = not available: CS4 and CS5 were discontinued at Elkhorn prior to earthworm observations and no measurement of middens in pasture at either site.

endogeic earthworms than the other two forage systems that included occasional tillage—at the one site where Contrast 3 could be made. Also, the organic grain system did not have greater earthworm numbers than the conventional grain systems, with the exception of endogeic abundance at ELK (Contrast 4). Similarly, there was no significant difference in both endogeic earthworm and anecic midden abundance between the conventional forage (CS4) and organic forage system (CS5) at Arlington (Contrast 5).

The second approach to determine the relative importance of management factors across systems was to develop a score for each of five factors known or hypothesized to affect earthworm abundance (tillage, manure input, solid stand or crop cover, crop diversity, and pesticide use). The scores were similar to, but not identical to the indices used in designing the cropping systems (Posner et al., 1995). The scores were averaged across phases for each cropping system in order to arrive at each index value (Table 5A). The resulting indices were not significantly correlated, hence not confounded, except for solid stand with manure inputs, because that combination only occurred together in the WICST forage rotations. The correlation coefficient of each index with endogeic abundance was computed across the 10 cropping system-site combinations (Table 5B). In the same manner, the

correlation coefficient of each index with anecic midden numbers was calculated across the eight cropping system-site combinations (Table 5B).

Manure use ($p = 0.01$), more frequent solid stands ($p = 0.01$) and no-tillage ($p = 0.07$) were all positively and significantly correlated with endogeic earthworm abundance (Table 5B). These three management factors were also positively correlated with anecic midden counts, but only the correlation with no-tillage was significant ($p = 0.01$) (Table 5B). On the other hand, with this set of common crops, pesticides (see Table 1B), and application rates; neither crop diversity nor pesticide use indices were significantly correlated with either type of earthworm counts.

3.5. Juvenile anecic abundance in the WICST cropping systems

Abundance of juvenile anecic earthworms in the WICST systems ranged from 2 to 65 m⁻² (1–22.2 g m⁻²). Similar to the endogeics, the cropping systems significantly impacted their populations and pattern of abundance (Fig. 1), and the results of the contrasts were, again, essentially the same as that for endogeic earthworm populations (data not shown). Not surprisingly, the juvenile anecic abundance on a plot-by-plot basis was significantly

Table 5

Management factor indices for the WICST cropping systems.

Indices for the six cropping systems					
Cropping system	Tillage ^a	Manure ^b	Solid stand ^c	Diversity ^d	Pesticides ^e
(A) How they were constructed (see Table 1 for details on the cropping systems)					
1. Continuous corn	−1	0	0	1	−1.5
2. No-till C−Sb	0	0	0.25 ^f	2	−0.5
3. Organic grain (C−Sb−W)	−1	0	0.33	4	0
4. Alfalfa (C−A ₀ −A ₁ −A ₂)	−0.50	.50	0.75	2	−1.0
5. Organic forage (C−O/P/A ₀ −A ₁)	−0.67	.67	0.67	3	0
6. Rotational grazing	0 ^g	1.00	1.00	4	0
Management indices	Endogeic earthworms			Adult anecic middens	
	<i>r</i>				
(B) Resulting correlation coefficients (<i>r</i>) for endogeic earthworm and adult anecic midden abundance					
1. Solid stand	0.91 ^{**}			0.58 ns	
2. Manure	0.89 ^{**}			0.46 ns	
3. No-tillage	0.60 [†]			0.84 ^{**}	
4. No pesticides	0.51 ns			0.33 ns	
5. Crop diversity	0.50 ns			0.03 ns	

ns = not significant at the 10% level.

^a The frequency of tillage over the entire rotation where each tilled phase is -1.^b The frequency of manure application, each manured phase is +1.^c The frequency of a solid stand covering the soil for most of the season, over the entire rotation.^d The number of plant species in each system.^e The frequency and type of pesticide applications where each phase that received an insecticide is -1 and each phase that received a herbicide is -0.5.^f Since the soybeans are drilled, but take some time to cover the field, that phase is given an index of 0.5. Therefore for the rotation the composite index is 0.25.^g At Arlington there was no-tillage so the index is 0. At Elkhorn, due to the renovation of the paddock prior to the trial, the index is -0.33 or one tillage in 3 years.* $p < 0.01$.[†] $p < 0.10$.

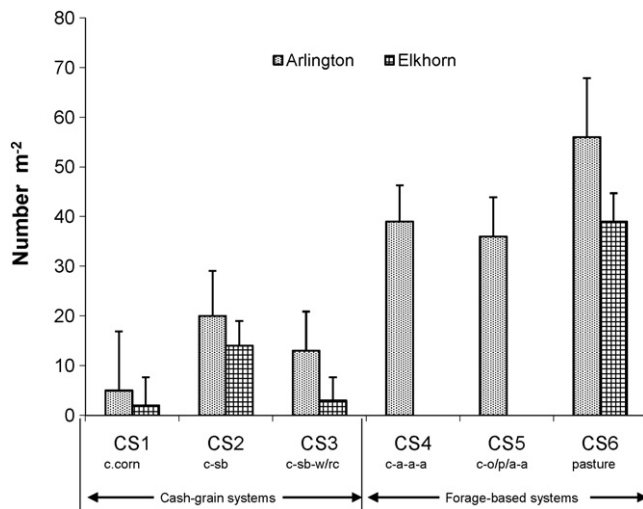


Fig. 1. Mean juvenile anecic earthworm abundance (No. m⁻²) in the six cropping systems at Arlington and Elkhorn (1999–2001). c.corn = continuous corn; c = corn; sb = soybean; w = wheat; rc = red clover, o = oats; p = peas; a = alfalfa

correlated with the endogeic abundance at ARL ($r = 0.37$, $p < 0.01$) and at ELK ($r = 0.65$, $p < 0.01$).

4. Discussion

Although only two or three soil cores were taken from the large plots in this study to estimate endogeic earthworm abundance, the results detected highly significant differences between systems. Other recent studies (Riley et al., 2008; Smith et al., 2008) have also found that relatively few samples per plot are adequate to distinguish between cropping systems. The primary reason for this statistical power is that there was sufficient replication in time as well as space. That is, in addition to two or three samples per plot, there were 3 years of measurement as well as four replications of each phase. Thus, every phase mean contained 28 observations across all 3 years. Furthermore, those cropping systems that had multiple phases had additional replication. For example, CS2, which had two phases, had 56 observations in its 3-year mean, and CS4, which had four phases, had 112 in its 3-year mean. As a consequence of this multiplier effect over space and time, two samples per plot was sufficient to find significant differences among the cropping systems in endogeic earthworm abundance. The small sample number was not a problem with the anecic midden data since there were 15–20 samples per plot; nevertheless the replication in time and space increased the power of these tests as well.

Midden counting proved to be a reliable method to estimate the populations of adult anecic earthworms. Abundance estimates in these systems were similar to what Gallagher and Wollenhaupt (1997) observed on alfalfa fields at Arlington (40 and 60 m⁻²) and Berry and Karlen (1993) reported in Iowa for no-till (20–60 anecics m⁻²) and chisel-plowed corn (5–12 anecics m⁻²).

Both the linear contrast and index approaches identified no-tillage, manure use, and solid-seeded (e.g. forage) crops as important management components to include in designing cropping systems to enhance earthworm abundance. The indices allowed for the more nuanced observations on what was affecting earthworm numbers. The relative importance of manure use and no-till was different for the endogeic earthworms than it was for the anecic midden counts. While in the case of the former, the use of manure was highly correlated with abundance and tillage less so, with the midden counts, manure use was actually not significant and tillage was the most important factor. The anecic

midden abundance was significantly different between both systems (cumulative amount of tillage) and phases within a system (annual tillage), but the endogeic earthworm counts were only different among systems. These contrasting responses to tillage can be attributed to the distinct burrowing and feeding habits of the earthworm groups.

Although this study was limited to two tillage methods, no-till and chisel plowing, it appears that the amount of disturbance and the amount of surface residues remaining versus the amount incorporated are the two factors that determine the effect of tillage. Not all researchers agree however, on the relative importance of disturbance (tillage) and distribution of food (residues, manure) for earthworm abundance. Ernst and Emmerling (2009) studied five levels of tillage and concluded that the reduction in tillage intensity modified the vertical distribution of soil organic carbon, resulting in positive effects on earthworm abundance and diversity. On the other hand, a group of Canadian researchers (Eriksen-Hamel et al., 2009) also found that reduced tillage favored earthworm numbers at two levels of residue additions, but concluded it was the reduction in physical disturbance itself, rather than food availability that did most to impact earthworm populations in their cool, humid agroecosystem.

The linear contrast and index approaches also agreed that neither the pesticides used (see Table 1B) nor the range of crop diversity in these systems (Table 1A) had a significant effect on the abundance of either earthworm group. This is perhaps not surprising. Although a number of researchers have found that, in laboratory studies, some agricultural insecticides (Edwards and Bohlen, 1992) can be very toxic to earthworms, this is not always the case with herbicides (Dalby et al., 1995). However, most researchers working with the pesticides used on the crops in this study have not been able to measure a negative effect in the field (Tarrant et al., 1997; Farehorst et al., 2003).

Also of interest was that, in general, earthworm abundance was not greater in the organic grain system than the conventional systems at either site. While a number of researchers have reported greater earthworm abundance in organic systems (Pfißner and Luka, 2007; Birkhofer et al., 2008) others have found no difference (Foissner, 1992; Pelosi et al., 2009). In this study, the organic grain system (CS3) included a plow down green manure, but it did not include additional animal manure, nor a ley phase (Table 1A and B). It is possible, that, with these modest organic matter inputs, coupled with frequent tillage and cultivation, this system did not promote earthworm development as much as those in previous reports or compared to the conventional corn system (CS1).

The finding that pasture did not have more endogeic earthworms than the two occasionally tilled forage systems (Table 4, contrast 3) is similar to the findings of Eekeren et al. (2008), Riley et al. (2008) and Nelson et al. (2009) who reported that after just a 2- or 3-year forage phase, earthworm numbers rebounded to the abundance of the untilled check plots. And perhaps it should be expected that the organic forage (CS5) and conventional forage systems (CS4) would have nearly equivalent earthworm numbers due to their similarity of including manure, a 2- or 3-year forage phase and only the occasional use of low doses of insecticide for leaf hopper (*Empoasca* spp.) (see Table 1B). Although this study did not examine every pesticide, it included a range of insecticides and herbicides commonly used in the Midwest USA. Thus, these results demonstrate that it is not true that pesticides always have a detrimental effect on earthworm abundance.

Despite important differences in the effect of crop management factors on endogeic earthworm abundance and anecic earthworm midden counts, there were also substantial similarities among the two earthworm groups. Although they did not have the same

relative importance, the same two management factors (reduced tillage and manure use) had a positive influence on these populations and on juvenile anecic earthworms. Neither the pesticides used nor range of crop diversity among these common rotations however, had a significant impact on any of the earthworm groups. These similarities were borne out by the fact that the mean counts of anecic middens and endogeic earthworm counts by cropping system and sites were positively correlated ($r = 0.88, p < 0.01$). The juvenile anecic counts fit the same pattern, but they were more closely correlated with the endogeic group ($r = 0.95, p < 0.01$), than with the anecic midden counts ($r = 0.78, p = 0.02$). Consequently, to design cropping systems for the Midwest that promote earthworm populations and thereby improve their sustainability as proposed by Hendrix et al. (1992), Edwards et al. (1995), and Ernst (1995) this study found that reducing tillage was the most important factor. It also found that manure application (and probably other organic matter additions) was very important to enhancing earthworm populations, especially for the endogeic earthworms; but that neither the pesticides used in the study nor the crop diversity examined had a significant impact on earthworms.

5. Conclusions

Although cropping systems are a complex set of management factors applied over a range of years, it was found that both endogeic earthworm numbers and anecic midden counts were highly correlated ($r = 0.88, p < 0.01$) and varied by cropping system in a consistent manner in each of 3 years and at two locations. Juvenile anecic abundance was even more closely correlated with true endogeic abundance ($r = 0.95, p < 0.01$). The most surprising finding was that on these prairie-derived soils the organic systems did not have higher earthworm numbers than their conventional counterparts. However, the differences among crop phases within specific cropping systems were much less consistent. As a result, it is not recommended to sample a single phase, nor a common target phase (in this case corn) to characterize a whole system. Of five management factors examined (tillage, manure inputs, solid stand, pesticide use, and crop diversity) manure use and tillage significantly impacted earthworm numbers across a range of cropping systems and two sites. Manure use was the most important management factor affecting endogeic earthworm numbers; but no-tillage was the most important for the juvenile and adult anecic groups and had a significantly positive influence on endogeic earthworm counts as well. Recommended pesticide use and crop diversity did not have a significant effect on any of the three earthworm groups studied. Consequently, grain farmers who want to increase earthworm numbers to improve sustainability should lower tillage options (e.g. strip-tillage, no-till) and include manure in their production systems as opposed to omitting pesticides or increasing crop diversity.

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CROPPING SYSTEM IMPACTS ON CHANGES IN SUBSOIL P AND K FERTILITY STATUS

Carrie A.M. Laboski and Todd W. Andraski
Department of Soil Science, University of Wisconsin-Madison

BACKGROUND:

In the 1950's it was recognized that the subsoil could contribute nutrients to crops and that "available phosphorus and potassium are relatively constant in the subsoils of most soil types." (Beatty & Corey, 1962). Thus, M.T. Beatty and R.B. Corey from the Department of Soil Science, University of Wisconsin in conjunction with the Wisconsin Geologic Survey and the USDA-SCS (presently USDA-NRCS) surveyed the subsoil (8 to 30 inch-depth) phosphorus (P) and potassium (K) levels of various soil types throughout the state. This survey information was used to create and map subsoil fertility groups (Figure 1). These groups were based on the relative rating (low, medium, and high) of P and K. In addition, Beatty and Corey (1962) noted that the subsoil groups shared interesting relationships to factors that influenced their soil genesis (eg. parent materials and vegetation).

Subsoil fertility groups have been used as part of the Wisconsin soil testing and fertilizer recommendation program since the program was originally developed in the early 1960s. Subsoil groups allowed better calibration of soil tests (surface soil samples) to fertilizer requirements. These subsoil groups are still being used in Wisconsin's current nutrient application guidelines (Laboski, 2006).

Although the original work by Beatty and Corey undoubtedly reflected the general subsoil P and K status of these soils approximately fifty years ago, adjusting nutrient recommendations based on these same categories today may no longer be valid. Different cultural practices and cropping patterns combined with a half century of crop removal and fertilization have likely changed the subsoil status of many of these soils. The most recent version of the Wisconsin nutrient application guidelines (Laboski, 2006) reflects this change in philosophy. The name of these subsoil fertility groups was changed to soil groups to reflect the fact that we really do not know the current subsoil fertility status of many of our state's soils.

OBJECTIVES:

The objective of this study was to determine if cropping systems can impact subsoil P and K levels.

METHODS AND MATERIALS:

Data from the WICST plots at Arlington and Lakeland Agricultural Complex (Lakeland) were used to evaluate changes in soil test P and K levels in the 0-6, 6-12, 12-24, and 24-36 inch depths CS1 (continuous corn), CS2 (corn-soybean), and CS4 (corn-alfalfa-alfalfa-alfalfa) rotations.

RESULTS AND DISCUSSION:

From 1990 through 2007 at Arlington, the net P and K addition (fertilizer or manure P or K added minus crop removal of P or K) for all cropping systems evaluated was negative. Meaning that more P and K were removed than added (Table 1). The same is true for the CS1 and CS2 rotations at Lakeland from 1990 through 2001. The CS4 rotation at Lakeland had a positive net addition of P and K.

At Arlington, there was no significant change over time in soil test P levels for the 12-24" and 24-36" depths for any rotation (Table 2). Surficial (0-6") soil test P levels decreased over time for all rotations, owing to the negative net P additions. Soil test K levels decrease significantly for all soil depths and all rotations (Table 3). The soil test K data show that when K applications are less than crop removal soil test K levels will decrease throughout the soil profile. At Lakeland, under application of P and K relative to crop removal affected soil test P and K levels over time much less than at Arlington for all soil depths and crop rotations (Tables 4 and 5).

CONCLUSIONS:

Subsoil K levels will decrease overtime in continuous corn, corn-soybean, and corn-alfalfa-alfalfa-alfalfa rotations if crop removal exceeds K applications. The data raise an important question regarding the validity and long-term implications of following current UWEX nutrient application guidelines for K. However, at this time there is not enough information to offer alternative strategies that are agronomically and economically sustainable. Further study of this topic is required to fully understand K availability and redistribution in the soil under various cropping systems and fertilization strategies.

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Table 1. Description of cropping systems, tillage, manure additions, and cumulative P and K addition, removal, and net addition since inception of the WICST at Arlington and the Lakeland Agricultural Complex, 1989 to 2007.

Location	System	Sequence †	Tillage ‡	Manure §	Period	Cumulative					
						Addition		Removal ¶		Net addition	
						P	K	P	K	P	K
						----- lb/a -----					
Arlington	CS1	Cont. C	Chisel plow	None	1990-1996	70	140	147	241	-77	-101
					1990-2001	114	250	262	393	-148	-143
					1990-2007	150	459	405	634	-255	-175
	CS2	CS	No-till	None	1990-1996	30	60	131	344	-101	-284
					1990-2001	44	105	234	556	-190	-451
					1990-2007	62	268	347	812	-285	-544
	CS4	CAAA	Chisel plow	Applied	1990-1996	170	660	172	1338	-2	-678
					1990-2001	291	1205	311	1913	-20	-708
					1990-2007	416	1936	480	2979	-64	-1043
Lakeland	CS1	Cont. C	Chisel plow	None	1990-1996	45	91	117	175	-72	-84
					1990-2001	95	216	193	275	-98	-59
	CS2	CS	No-till	None	1990-1996	27	56	120	283	-93	-227
					1990-2001	87	205	205	469	-118	-264
	CS4	CAAA	Chisel plow	Applied	1990-1996	252	973	133	981	119	-8
					1990-2001	519	1813	238	1507	281	306

† Cont. C, continuous corn; CS, annual corn – soybean rotation, CAAA, one-year corn and three years alfalfa.

‡ Chisel plowing was done annually in Cont. C sequence and before and after corn phase in the CAAA sequence.

§ Manure was applied at 20 ton/a before and after corn phase in the CAAA sequence.

¶ P and K removal values were calculated based on yield and tissue (corn grain, soybean grain, and alfalfa) analysis.

Table 2. Effect of year on soil test P levels at four soil depth increments in three cropping systems at Arlington (WICST), 1989 to 2008.

System	Treatment	Sequence †	Year	Soil depth increment, inches			
				0-6	6-12	12-24	24-36
				----- soil test P, ppm -----			
CS1	1	Cont. C	1989	105 a ‡	65 a	29	48
			1996	91 ab	43 b	29	
			2001	85 b	43 b	28	51
			2007	59 c	29 b	25	51
			<i>p</i>	<0.01	0.02	0.96	0.64
			CV, %	13	28	54	8
			Fisher's LSD	14	16	§	§
			Tukey's HSD	20	24	3.8	3.7
CS2	3	CS	1989	98 a	43 a	24	51
			1996	66 b	30 b	28	
			2001	57 b	38 a	23	53
			2007	37 c	22 c	23	46
			<i>p</i>	<0.02	<0.01	0.91	0.28
			CV, %	17	13	41	11
			Fisher's LSD	14	6	13	8
			Tukey's HSD	21	8	19	10
CS4	7	CAAA	1989	115 a	46	35	57
			1996	90 ab	47	31	
			2001	95 a	52	29	48
			2007	66 b	38	31	55
			<i>p</i>	0.04	0.68	0.90	0.64
			CV, %	21	35	38	26
			Fisher's LSD	25	21	16	19
			Tukey's HSD	34	28	21	22

† Cont. C, continuous corn; CS, annual corn – soybean rotation, CAAA, one-year corn and three years alfalfa.

‡ Values within each column for each system followed by the same letter are not significantly different at the 0.10 probability level using Fisher's LSD test.

§ Fisher's LSD cannot be determined due to unequal cell sizes.

Table 3. Effect of year on soil test K levels at four soil depth increments in three cropping systems at Arlington (WICST), 1989 to 2008.

System	Treatment	Sequence †	Year	Soil depth increment, inches			
				0-6	6-12	12-24	24-36
				----- soil test K, ppm -----			
CS1	1	Cont. C	1989	257 a ‡	143 a	125 a	135 a
			1996	257 a	100 b	74 c	
			2001	194 b	83 b	88 b	121 ab
			2007	204 b	81 b	89 b	112 b
			<i>p</i>	0.05	<0.01	<0.01	0.09
			CV, %	15	19	8	10
			Fisher's LSD	44	26	10	17
			Tukey's HSD	64	37	15	22
CS2	3	CS	1989	199 a	121 a	134 a	155 a
			1996	214 a	91 b	83 c	
			2001	126 b	90 b	99 b	118 b
			2007	121 b	75 b	92 bc	103 c
			<i>p</i>	0.05	0.02	<0.01	<0.01
			CV, %	30	17	11	8
			Fisher's LSD	63	21	14	15
			Tukey's HSD	91	30	21	19
CS4	7	CAAA	1989	277 a	123 a	126 a	131 a
			1996	180 b	81 b	80 b	
			2001	127 b	68 bc	82 b	96 b
			2007	131 b	60 c	76 b	100 b
			<i>p</i>	<0.01	<0.01	<0.01	0.03
			CV, %	22	17	18	14
			Fisher's LSD	51	19	21	21
			Tukey's HSD	72	26	31	28

† Cont. C, continuous corn; CS, annual corn – soybean rotation, CAAA, one-year corn and three years alfalfa.

‡ Values within each column for each system followed by the same letter are not significantly different at the 0.10 probability level using Fisher's LSD test.

Table 4. Effect of year on soil test P levels at four soil depth increments in three cropping systems at the Lakeland Ag. Complex in Walworth County (WICST), 1989 to 2001.

System	Treatment	Sequence †	Year	Soil depth increment, inches			
				0-6	6-12	12-24	24-36
				----- soil test P, ppm -----			
CS1	1	Cont. C	1989	66	39 a ‡	13	8
			1996	61	31 ab	15	
			2001	58	22 b	10	9
			<i>p</i>	0.17	0.10	0.60	0.74
			CV, %	9	31	53	48
			Fisher's LSD	8	13	9	6
			Tukey's HSD	10	17	12	6
CS2	3	CS	1989	59	24 a	9	6
			1996	41	14 b	7	
			2001	49	13 b	8	5
			<i>p</i>	0.26	<0.01	0.85	0.42
			CV, %	28	20	62	31
			Fisher's LSD	19	4	7	3
			Tukey's HSD	24	6	9	3
CS4	7	CAAA	1989	76	39	10	8
			1996	67	21	7	
			2001	79	18	11	11
			<i>p</i>	0.15	0.14	0.40	0.48
			CV, %	10	54	43	60
			Fisher's LSD	10	19	5	10
			Tukey's HSD	13	24	7	10

† Cont. C, continuous corn; CS, annual corn – soybean rotation, CAAA, one-year corn and three years alfalfa.

‡ Values within each column for each system followed by the same letter are not significantly different at the 0.10 probability level using Fisher's LSD test.

Table 5. Effect of year on soil test K levels at four soil depth increments in three cropping systems at the Lakeland Ag. Complex in Walworth County (WICST), 1989 to 2001.

System	Treatment	Sequence †	Year	Soil depth increment, inches			
				0-6	6-12	12-24	24-36
				----- soil test K, ppm -----			
CS1	1	Cont. C	1989	196 a ‡	134	126	124
			1996	191 a	105	114	
			2001	144 b	113	127	129
			<i>p</i>	0.03	0.22	0.64	0.75
			CV, %	13	18	18	17
			Fisher's LSD	32	29	30	36
			Tukey's HSD	41	37	39	36
CS2	3	CS	1989	178 a	118	126	115
			1996	132 b	86	103	
			2001	93 c	105	125	102
			<i>p</i>	<0.01	0.30	0.27	0.47
			CV, %	8	25	18	20
			Fisher's LSD	16	36	29	37
			Tukey's HSD	20	46	37	37
CS4	7	CAAA	1989	216 a	148 a	143 a	128
			1996	163 b	88 b	95 c	
			2001	109 c	98 b	125 ab	121
			<i>p</i>	<0.01	0.11	0.09	0.66
			CV, %	8	32	21	15
			Fisher's LSD	17	48	34	31
			Tukey's HSD	22	62	45	31

† Cont. C, continuous corn; CS, annual corn – soybean rotation, CAAA, one-year corn and three years alfalfa.

‡ Values within each column for each system followed by the same letter are not significantly different at the 0.10 probability level using Fisher's LSD test.

PRAIRIE AND BIOFUELS RESEARCH

POTENTIAL C SEQUESTRATION INCREASES WITH C4 GRASS ABUNDANCE IN RESTORED PRAIRIE OF SOUTHERN WISCONSIN

Herika Kummel and Randy Jackson

INTRODUCTION

The tallgrass prairie, which is dominated by warm-season (C4 photosynthesis) grasses has been transformed mainly into grassland/agricultural mosaics if not totally converted to annual crops (Rhemtulla et al., 2007). Interest in restoring the native prairie has increased at the same time that the potential for increasing soil organic carbon (SOC) sequestration when degraded soils and ecosystems are restored have been touted (Lal, 2003). Finding long-term C storage in terrestrial ecosystems is being promoted as a key part to climate stabilization as greenhouse gases (GHG) continue to accumulate in the atmosphere (Bruce et al., 1999; Smith, 2004). Much emphasis has been placed on the adoption of best management practices and restoration to perennial vegetation in agricultural systems (Smith et al., 2008; Johnson et al., 2005) because soil carbon increases the most after a carbon enhancing land-management change is adopted (Smith, 2004; McLauchlan et al., 2006; Matamala et al., 2008).

Working grasslands, such as sown pastures, tend to be dominated by European species that are highly productive in the spring and fall since they are mostly cool-season (C3 photosynthesis) grasses (Paine et al., 1999). These pastures sustain the profitable dairy (Taylor and Foltz, 2006) and beef industry (CIAS, 2008) in Wisconsin. Combining the challenges of food production and the need for environmental conservation on such working lands have the potential to positively impact a large part of the landscape since in the U.S. alone over 50% of US is cropped or grazed (Robertson and Swinton, 2005). The reintroduction of C4 prairie grasses into working lands offers a compromise between the complete restoration and the complete eradication of the native prairie (Woodis, 2008; Nelson and Burns, 2006) and simultaneously promotes the multifunctional use of the rural landscape (Buttel, 2003; Western, 2001; Hilderbrand et al., 2005). While much is known about C4 prairies and C3 dominated pastures ecosystems, there is a lack of information about mixed C3-C4 grasslands in the upper Midwest. Adding functional diversity to the C3 dominated pastures have the potential to increase ecosystem properties through positive interaction among functional groups by complementarity and facilitation (Spehn et al., 2000; Hooper et al., 2005). However, most of the recent studies evaluating the effects of photosynthetic pathway on ecosystem services focus on the effects of totally converting agricultural lands to prairie or to CRP (Camill et al., 2004; McLauchlan et al., 2006). Only a few studies have recognized the need to understand how ecosystems are affected by the reintroduction of C4 native grasses into C3 grassland (*sensu* Hooper et al., 2005); but even then, the comparisons are made between C4 dominated and C3 dominated communities (Mahaney et al., 2008), not mixed C3-C4 grasslands *per se*. Little is known about how the C3 dominated grasslands may change as C4 prairie grasses are reintroduced to working lands—this information will assist land managers in decision-making on issues such as: How much prairie grass is needed to boost productivity? Is the ecosystem storing carbon? How does the seasonality of production change with various ratios of C3 and C4 grasses?

To address these questions, we compared how net ecosystem production (NEP) and the major components of this metric, net primary production (NPP) and soil respiration (Rs), were influenced by the relative abundance of C3 and C4 grasses in restored tallgrass prairie of southern Wisconsin over two years. We expected that NEP would increase as C4 grass abundance increased because C3 and C4 grasses differ in important functional traits such as quantity and quality of below- and above-ground biomass that can directly and indirectly alter soil processes (Dijkster et al., 2006). We also expected that the major components of the C cycle, above- and below-ground NPP and Rs, would be influenced by the increase in C4 grasses in opposite directions (*i.e.*, NPP would increase, while Rs would decrease) because C4 grasses typically produce more below- than above-ground biomass and are more productive overall than

C3 grasses (Wedin and Tilman, 1990; Baer et al., 2002; Camill et al., 2004) and that 2) and C4 grasses tissues are more resistant to decay (Luo et al., 1996; Craine et al., 1998).

METHODOLOGY

Study Site:

This study was conducted at two Wisconsin prairie restoration sites, Bison Ridge Ranch (BR Ranch) in Marquette County (89° 27' W, 43° 44' N) and the Wisconsin Integrated Cropping Systems Trial (WICST) at the University of Wisconsin–Madison's Arlington Agricultural Research Station in Columbia County (89° 19' W, 43° 18' N). The soils of BR Ranch were classified as Gotham loamy fine sand and Metea fine sandy loam on 2 to 6 % slope (NRCS). Both series consist of very deep, well-drained soils with rapid permeability. The 4-ha pasture at BR Ranch was seeded with a diverse prairie mix in 1990 and subsequently harvested for hay annually at summer's end. The hay harvest during our study occurred on August 31, 2007 and September 1, 2008. The grass community is comprised of *Elymus repens* (L.) Gould (quackgrass), *Andropogon gerardii* Vitman (big bluestem), *Bouteloua curtipendula* (Michx.) Torr. (side oats grama), *Bromus tectorum* L. (downy brome), *Digitaria cognata* (Schult.) Pilg. (fall witchgrass), *Panicum virgatum* L. (switchgrass), *Poa pratensis* L. (Kentucky bluegrass), *Schizachyrium scoparium* (Michx.) Nash (little bluestem) and *Sorghastrum nutans* (L.) Nash (indiangrass).

Soils at WICST were classified as Plano silt loam on 0 to 2% slopes (NRCS). Annual total precipitation in 2007 and 2008 was 892 and 938 mm, respectively (AWON-WI). Historical average annual precipitation in Arlington, Wisconsin is 833 mm and average temperatures in July and January are 21 °C and -9 °C, respectively (NOAA). At WICST, our experiment was conducted on six plots, each 0.33 ha in size. In 1999 these plots were seeded with one of two mixtures (high and low diversity seed mixes); prior to that it was plowed and planted with soybeans in 1998. The low diversity prairie seed mix contained six species and the high diversity seed mix contained 25 species comprised of forbs, legumes and grasses (Simonsen, 2004). The prairie plots in WICST were burned approximately every three years since the spring of 2003, including a burn in 2007 but not 2008. Today the grass community is mainly comprised of *Elymus repens* (L.) Gould (quackgrass), *Andropogon gerardii* Vitman (big bluestem), *Bromus inermis* Leyss. (smooth brome), *Dactylis glomerata* L. (orchardgrass), *Elymus canadensis* L. (Canada wildrye), *Phleum pratense* L. (timothy), *Poa pratensis* L. (Kentucky bluegrass), and *Sorghastrum nutans* (L.) Nash. (indiangrass).

At each site, we chose thirty ~100-m² plots (15 in 2007 and 15 in 2008) for their respective C3:C4 grass ratio. At each plot, a centralized 1-m² quadrat was permanently marked to monitor soils, environmental conditions, nutrient content, and respiration over time (Figure 1). Plant species cover was estimated with the line-point method performed on permanently marked soil monitoring stations, root ingrowth core areas, and transient biomass harvest areas that were located within each 100-m² experimental unit (Figure 1). The quadrat area to be sampled was divided by 5 horizontal and vertical lines forming 25 intersections where the first intercept of a sharpened rod with any part of herbaceous vegetation at each intersection was recorded (Heady, 1959). During the months when two distinctly vertical layers of different vegetation could be observed, we recorded the first hit with the taller herbaceous vegetation and the second hit with the herbaceous vegetation in the layer below the first one totaling for 50 hits per quadrat. For each sampling event, total species cover was calculated as total species hits divided by the total possible hits for each quadrat. Plants were identified to the species level and grouped into functional groups. The classification of plants into groups can be based on different traits such as taxonomy (graminoids or forbs), ability to host bacteria nitrogen fixing (leguminous or not), the dominant photosynthetic pathway (C4, C3 or CAM), and the origin (native to the area or introduced). We mirrored the classification method used in previous prairies studies (Kindscher and Wells, 1995; Tilman et al., 1997).

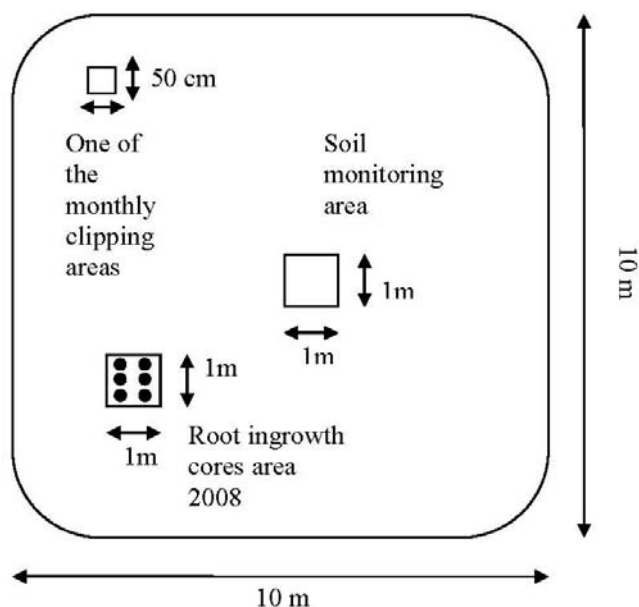


FIGURE 1. Layout of one of 60 experimental units (15 at each site for 2 years). A ~10x10-m area was delineated for it C4:C3 cover ratio. Within each area were located 1 permanent and 2 transient quadrats.

Plant cover data per species and functional groups were taken three times during the season and aggregated to calculate an annual average of cover for each experimental unit. The sampling events were mid-season (July), peak of standing biomass (end of August, beginning September) and fall (end of October, beginning November). The mid-season, peak of standing biomass, and fall cover were calculated by averaging the total cover estimated in each individual sampling event from the permanent and transient sample stations noted above. We also calculated the average and maximum number of species for each experimental unit for each year.

The annual average of C4 grass cover ranged from 0 to 74% in the first year and from 8 to 52% for the second year at BR Ranch. At WICST, the annual average C4 grass cover varied from 0 to 86 % in 2007 and 0 to 76% in 2008. The average number of species for each experimental unit was similar for both sites, averaging $6.18 \pm (0.14)^1$ species per square meter. Therefore, most plots had not only similar functional richness but also similar species richness. The two main dominant C4 grass species were the same for both sites, e.g. *Andropogon gerardii* Vitman and *Sorghastrum nutans* (L.) Nash; however, there were differences in the plant communities worth noting. For instance, BR Ranch had other species of C4 grasses present such as *Panicum virgatum* L., *Schizachyrium scoparium* (Michx.) Nash and *Bouteloua curtipendula* (Michx.) Torr. The dominant C3 grass species in both sites were also quite similar. Yet, only BR Ranch had the winter annual *Bromus tectorum* L. and only WICST had *Elymus canadensis* L. and *Phleum pratense* L. present.

Net ecosystem production

Annually, SOC storage or loss is the net balance between inputs and outputs of C (Six et al., 2002). Carbon sequestration is calculated as the difference between C inputs as NPP and C outputs as heterotrophic respiration (Rh), harvest, and fire. Net primary production is the sum of aboveground net primary production (ANPP) and belowground net primary production (BNPP). Soil respiration (Rs) is a combination of autotrophic (i.e., root respiration, Ra) and heterotrophic respiration (i.e., microbial respiration, Rh). Because separating these forms of respiration is quite difficult (Kuzyakov and Larionova, 2006), we used literature estimates of Ra and calculated Rh from Rs measurements. We estimated potential carbon sequestration in grams of carbon per unit area by measuring the major fluxes of C such as ANPP, BNPP, and Rs of each experimental unit (Chapin et al., 2002). Because our intention was to compare the potential in C sequestration of different areas along the C3:C4 gradient for each year, we did not estimate C loss from burning,

¹ mean $\pm$ (s.e.)

which occurred intermittently (i.e., every 3 years or so).

Net primary production

Within each delineated 100-m² experimental unit, we clipped available biomass within a single 50 × 50-cm randomly placed quadrat to ~3 cm residual stubble height (Figure 1). Biomass was bagged, dried to constant weight at 60°C, and weighed. Prior to each clipping event, we estimated leaf area index (LAI) on the 50 × 50-cm quadrat, which was calculated from intercepted photosynthetically active radiation readings (Accupar LP-80, Decagon, Inc., Pullman, WA) made above and below the leaf canopy at four points along each quadrat. Clipping dates at BR Ranch were: May 9, Jun 27, July 11, August 14, and August 31 in 2007; June 10, June 24, July 3, August 26 and November 14 in 2008. The clipping dates at WICST were: June 21, July 25, September 5 and October 24 in 2007; May 22, June 23, July 24, August 29, September 25, and October 30 in 2008. Biomass was never clipped after the August 31 harvest at BR Ranch in 2007.

Because the focus of our study was to capture differences along the C3:C4 grass gradient, we estimated ANPP not by simply harvesting the biomass at peak standing biomass, as is normally done to estimate ANPP in prairie, but by summing the biomass increments between clipping events throughout the season to account for the simultaneous and overlapping production and mortality of both plant functional groups (Vogt et al., 1986). In each experimental unit, annual ANPP was calculated as the sum of monthly aboveground production values for a growing season (approximately May through October). The aboveground biomass monthly production was calculated as the difference in biomass measured at one month from biomass at an earlier month. Since we did not measure the biomass production after the harvest in August 2007 at the BR Ranch, we estimated the fall biomass with an allometric equation. The allometric equation ($r^2 = 0.69$) was developed from the relationship between LAI and biomass weight measurements taken from both sites and both years. In the same way, we estimated the amount of biomass left on the pasture after harvesting events.

Belowground NPP was estimated using root ingrowth cores in each experimental unit (4 subsamples per experimental unit in 2007 and six subsamples per experimental unit in 2008). Soil cores were removed prior to the growing season (~ end of May, beginning of June) with a hammer-core and sieved to remove rocks, roots, and debris (Fahey et al., 1999). Cores were made of 2-mm plastic mesh (5 cm diameter × 15 cm long) and were filled with the sieved soil: sand (1:1). These mesh cylinders were inserted back into the original holes and two cores were harvested at each of the following time periods: in 2007, peak of standing biomass and fall and in 2008, mid-season, peak of standing biomass and fall. The root biomass of each core was bagged, refrigerated until washing, dried to constant weight at 60°C, and weighed. We did not attempt to separate live to dead roots assuming that only a very small fraction was dead (Fahey and Hughes, 1994). For each experimental unit, we averaged the two root biomass weights to estimate root biomass per unit area for each harvest. We calculated the belowground biomass production as the difference in root biomass harvested at one time from the root biomass of an earlier harvest. The root net production was calculated as the sum of positive production values. Since the root ingrowth cores do not account for the amount of roots that are produced and die during the period when the cores are deployed (i.e., fine root turnover (FRT)), we corrected the net root production using the FRT rates using equation 2 from the literature (Gill and Jackson, 2000; Fahey et al., 1999).

We also estimated the belowground root stock of C4 and C3 grasses at the end of April, August, and November of 2008 using soil coring (Fahey et al., 1999). Soil cores were 5 cm in diameter and taken to a 60-cm depth immediately above six C4, and six C3 individual grasses totaling 12 randomly chosen plants in each site. The 60-cm soil cores were divided into four 15-cm sections, sieved in 2-mm mesh, washed out of debris, rocks and soil, dried to constant weight at 60°C, and weighed. No attempt was made to separate living from dead roots. For each functional group of grasses, the six root weight values per segment were averaged to access the vertical distribution of root stock biomass. We used the percent average of biomass found in the first 15 cm of the

soil profile to later extrapolate BNPP to 60-cm depth.

Above- and below-ground production was calculated by multiplying shoot and root biomass estimates by a constant C concentration of the prairie plant tissues as 50% (studies in restored and remnant prairies found 40 to 50% C in shoot and root tissues, i.e. Brye et al., 2002 and Matamala et al., 2008).

Soil Respiration

Soil respiration was measured once monthly between 0900 to 1500 hours with a soil respiration chamber linked to an infrared gas analyzer (LiCor 6400-09, Li-Cor Biosciences, Lincoln, NE) (Norman et al., 1992). The efflux chamber was used in conjunction with polyvinyl chloride (PVC) thin-walled collars that were inserted 2 cm into the soil surface at least 30 min prior to conducting measurements. There were three collars per 1-m² quadrat, which were repositioned in a random manner within each experimental unit every month. At BR Ranch, Rs measurements were taken on May 9, Jun 12 & 20, July 12, August 14, September 19 & 26, and October 24 in 2007 and May 16, June 24, July 16, August 25, September 23 and October 12 in 2008. In the WICST, sampling dates were June 18, July 25, September 5 and October 5 of 2007 and May 13, June 17, July 15, August 21, September 25 and October 11 of 2008. We estimated Rs, the soil CO₂ efflux ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$), in each experimental unit by averaging the three measurements taken in each of the three collars. Because shoots were clipped prior to measuring Rs, the efflux of soil CO₂ measured excludes shoot respiration. Annual Rs, the mass of C per unit area respired annually was estimated for each experimental unit by summation of daily interpolations of the monthly measurements (Brye et al., 2002; Chou et al., 2008).

Soil characteristics:

To determine soil texture we used the hydrometer (Bouyucous) procedure and bulk density was calculated as oven-dried mass of dry soil per unit volume of soil. We discounted the weight and volume of pebbles that were > 2mm. Volume was calculated using volumetric displacement in water (Elliot et al., 1999).

Soils were sent to The University of Wisconsin Soil & Plant Analysis Lab to determine soil total carbon (TC) and total nitrogen (TN), potassium (K), phosphorus (P), and organic matter (OM). Percent of TC and TN were determined by dry combustion using a Leco CNS-2000 analyzer (Organic Carbon Dry Combustion method, Leco CN-2000, FP 2000, or CNS-2000). Plant available K and P were estimated using the Bray P method. Soil organic matter was estimated by the loss of weight in a sample heated at a temperature high enough to burn organic matter but not so high as to decompose carbonates (Weight Loss-on-Ignition - LOI 360o). Soil pH was measured in water using a 1:1 soil: solution ratio and in a buffer solution with a 1:1:1 of soil: water: buffer ratio.

Data analysis and calculations

First, we used linear regression to address potential relationships between NEP and vegetation cover by functional group, by plant species cover, and then by plant species richness. Cook's distance test, which measures the influence of individual observations on the regression coefficients, was assessed to identify potential outliers. Furthermore, the fit of a quadratic function was compared to a linear fit using the generalized least squares algorithm in S-plus (S-Plus 8.0, Insightful Corporation Seattle, WA). Models were compared with likelihood ratio tests. When significant differences were determined ($p < 0.05$) the model with the lowest AIC values were chosen, otherwise the simpler model was determined to be the better fit.

We built regression trees (S-Plus 8.0, Insightful Corporation Seattle, WA) to explore how groupings of potential predictor variables related to soil and cover characteristics might explain variability in NEP. The potential predictors variables of NEP used in our tree modeling were: site and year; soil properties such as soil pH, O.M %, bulk density, P, K, TC, TN, C:N; cover characteristics such as June, July, peak of the season and fall C3 and C4 grass cover (%), average of C3 and C4 grass cover (%), average and maximum species richness and individual species cover (%) including forbs cover (%). Because site differences were obvious, regression trees were also constructed for each site using the same set of potential predictors of NEP described

above plus ANPP, BNPP, and Rs.

Regression trees are nonparametric models used to explore dependencies among continuous and/or categorical variables. The predictor variable that explains the greatest amount of the deviance in the response variable is chosen. They are constructed by splitting a dataset into smaller and smaller groups, where each split depends on a single variable (Gotelli and Ellison, 2004). The splitting process continues until there is only one explanatory variable at the end of a “branch” and no further improvement in the fit of the model is obtained relative to the number of split ends, also called nodes (Gotelli and Ellison, 2004). The means of the groupings from the same split were further compared using the Welch Modified Two-Sample t-Test (S-Plus 8.0, Insightful Corporation Seattle, WA) If groupings were not significant, the tree was pruned meaning the data was not longer divided.

RESULTS

Net ecosystem production and C4 grass cover (%) were better described by a quadratic than a linear function ($p < 0.01$, Figure 2A). Net ecosystem production was not related to C3 grass cover, species richness, or cover of any of the individual species with the exception of *Andropogon gerardii*. A quadratic fit best represented the relationship between NEP and *Andropogon gerardii* cover ($p = 0.0001$, Figure 2B).

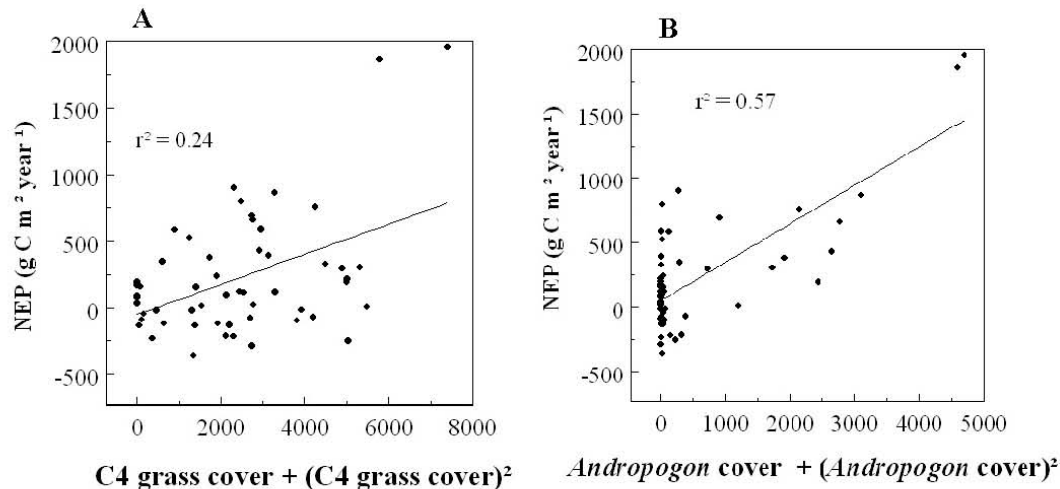


FIGURE 2. Linear relationships between NEP and A) the quadratic term for C4 grass cover and B) the quadratic term for *Andropogon* cover. The r^2 value was determined with ordinary least squares regression.

Total NPP was not significantly correlated to C4 grass cover (Figure 3A). While ANPP increased significantly with increasing C4 grass cover (Figure 3B), no relationship was found between C4 grass cover and BNPP (Figure 3C). Warm-season grass cover explained 17% of the annual variability in soil CO₂ efflux (Figure 3D).

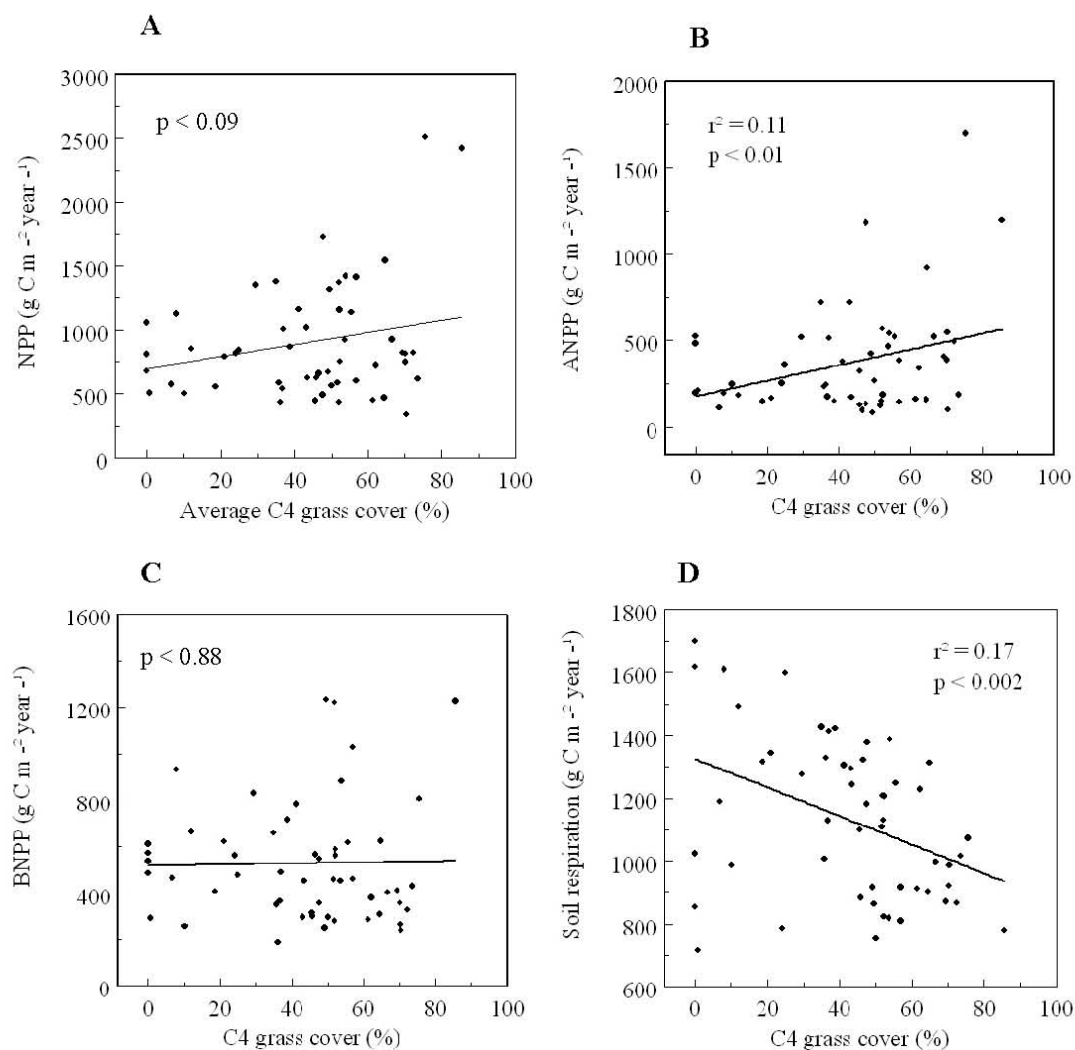


FIGURE 3. Linear relationship between A) NPP and C4 grass cover (%), B) ANPP and C4 grass cover (%), C) BNPP and C4 grass cover (%), and D) Soil respiration and C4 grass cover (%). The r^2 value was determined with ordinary least squares regression.

While we did not find a correlation between BNPP and plant cover, we did find significant differences in root stock biomass found immediately below C4 and C3 grasses at both sites (Figure 4).

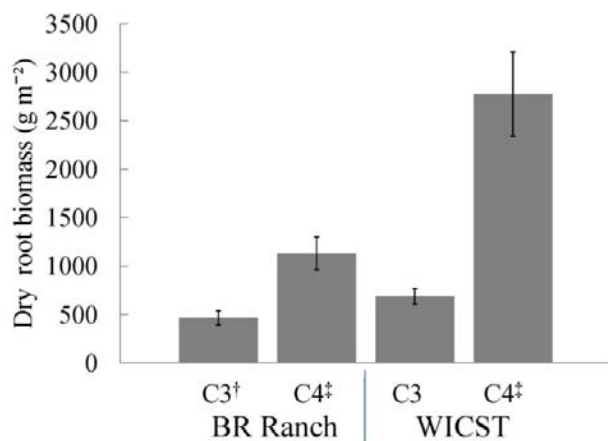


FIGURE 4. Dry root biomass (0 -15 cm) harvested at the end of April, August and November of 2008.

† Averaged values (n= 15)

‡ Averaged values (n= 16)

§ Averaged values (n= 17)

According to the regression tree results, the best predictor for NEP was *Andropogon gerardii* cover. If *Andropogon* cover was lower than 42%, soil K was the next variable used to split the data (Figure 5).

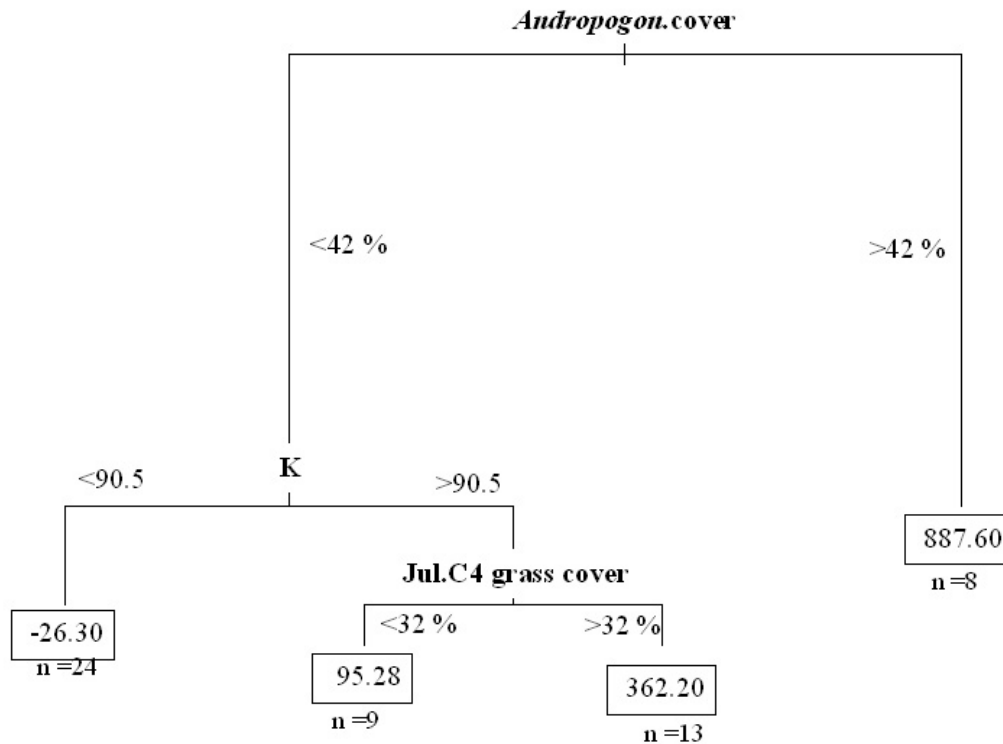


FIGURE 5. Regression tree predicting response variable (NEP). The value in each terminal node is the NEP average for the respective group and n is the number of experimental units grouped under that node. The first and best predictor of NEP is *Andropogon* cover. After that the data was separated into experimental units with higher and lower K than 90.5 ppm. Units with higher K than 90.5 ppm were further separated into units with higher and lower than 32% of C4 grass cover in July.

In plots with soil K lower than 90.5, the next predictor chosen by the model did not split the data in significantly different groups at the 5% level so the tree was pruned to four terminal nodes. In the experimental units with soil K higher than 90.5, the best predictor was C4 grass cover in July. Plots with a higher C4 grass cover than 32% were grouped into a terminal node that in average had a higher NEP than the group with lower C4 grass cover. It is important to note that the soil K splits effectively separated the dataset by site. Soils were very different at each site for all variables (Table 1), so we explored the linear relationship between NEP and the C cycle components to C4 grass cover (%) and *Andropogon gerardii* cover (%) for each site separately (Table 2).

TABLE 1. Climate and soil characteristics at Bison Ridge Ranch, Marquette County, WI and Wisconsin Integrated Cropping Systems Trial, Columbia County, WI.

Characteristic	BR Ranch mean $\pm$ s.e.	WICST mean $\pm$ s.e.
Soil Physical Properties		
Sand (%) [†]	89 $\pm$ 0.72	31.7 $\pm$ 2.21
Silt (%) [†]	5 $\pm$ 0.49	37.5 $\pm$ 2.34
Clay (%) [†]	5.7 $\pm$ 0.38	30.7 $\pm$ 0.67
Bulk density (g cm ⁻³) [†]	1.43 $\pm$ 0.01	1.17 $\pm$ 0.02
Soil Chemical Properties ‡		
Total soil C (%)	0.78 $\pm$ 0.02	2.65 $\pm$ 0.03
Total soil N (%)	0.06 $\pm$ 0.002	0.22 $\pm$ 0.005
C:N	12.45 $\pm$ 0.23	12.20 $\pm$ 0.24
pH	6.59 $\pm$ 0.07	6.74 $\pm$ 0.04
K(ppm)	64.1 $\pm$ 2.84	150.06 $\pm$ 7.90
P(ppm)	76.73 $\pm$ 6.35	53.16 $\pm$ 2.21
Organic matter (%)	1.31 $\pm$ 0.04	4.49 $\pm$ 0.08
Climate		
Annual mean maximum temperature (°C)	11.77	12.33
Annual mean minimum temperature (°C)	0.88	2.38
Annual mean temperature (°C)	6.33	7.38
Annual precipitation (mm)	803.25	833.12

TABLE 2. Kind and magnitude of the linear relationships between NEP and the C cycle components and C4 grass cover (%) and *Andropogon gerardii* cover (%) for each site. The r^2 value was determined with ordinary least squares regression.

Explanatory variable	Response variable	BR Ranch	WICST
C4 grass cover	NEP	none	Positive, $r^2 = 0.35^*$
	ANPP	none	Positive, $r^2 = 0.25^*$
	BNPP	none	none
	Rs	Negative, $r^2 = 0.33^*$	Negative, $r^2 = 0.11^\dagger$
<i>Andropogon</i> cover	NEP	none	Positive, $r^2 = 0.53^*$
	ANPP	none	Positive, $r^2 = 0.28^*$
	BNPP	none	Positive, $r^2 = 0.24^*$
	Rs	none	Negative, $r^2 = 0.14^*$

$^\dagger p < 0.1$

$^* p < 0.05$

When NEP data were analyzed separately by sites with the regression tree, we found that at WICST, the best predictor of NEP was ANPP—calculated as peak standing biomass—and that at BR Ranch, the best predictor of NEP was BNPP. At WICST, 73% of the deviance was reduced by the split of the database by ANPP estimated as peak standing biomass and at BR Ranch, 76% of the deviance was reduced when the database was split by BNPP (trees not shown). Clearly, the aboveground parameters were most important at the more productive site which was reflected in NEP, ANPP, and BNPP estimates (Table 3).

TABLE 3. Table summarizing the values of C3 and C4 grass cover (%), C cycle components and net ecosystem production (NEP) per experimental unit (EU) per year (Y). The C cycle components are the aboveground production estimated as the biomass harvested at the peak of the season period (peak biomass), and as net primary production (ANPP), the belowground net primary production (BNPP), and the soil respiration (Rs).

EU	Site	Y	S†	% C3 grass cover	% C4 grass cover	peak biomass* (g m ⁻² y ⁻¹)	ANPP mean (g dry biomass m ⁻² y ⁻¹)	BNPP mean (g dry biomass m ⁻² y ⁻¹)	Rs (g C m ⁻² y ⁻¹)	NEP 40% Ra [§] (g C m ⁻² y ⁻¹)
1	BR Ranch	07	7	64	3	310.80	316.67	619.78	901.30	-72.55
2	BR Ranch	07	7	46	23	235.84	254.45	634.90	1,100.28	-215.49
3	BR Ranch	07	5	7	79	210.22	220.91	929.67	1,188.70	-137.93
4	BR Ranch	07	8	74	10	343.98	373.89	861.65	1,016.92	7.62
5	BR Ranch	07	8	48	10	245.40	264.95	718.04	1,182.00	-217.71
6	BR Ranch	07	7	61	13	299.84	324.56	574.43	911.03	-97.12
7	BR Ranch	07	6	21	51	318.64	331.67	1,247.12	1,345.48	-17.89
8	BR Ranch	07	8	43	28	331.40	344.43	907.00	1,244.02	-120.70
9	BR Ranch	07	5	37	26	330.64	351.36	733.16	1,129.21	-135.27
10	BR Ranch	07	7	62	6	652.84	683.48	763.39	1,228.43	-13.63
11	BR Ranch	07	7	70	2	184.30	200.72	476.17	986.93	-253.71
12	BR Ranch	07	5	0	98	379.08	395.50	1,224.45	1,023.85	195.67
13	BR Ranch	07	7	70	20	1,073.64	1,092.25	529.08	986.92	218.51
14	BR Ranch	07	6	19	64	266.39	292.96	816.30	1,317.35	-235.78
15	BR Ranch	07	6	57	2	258.88	287.19	922.12	809.43	118.99
AVG	BR Ranch	07	-	-	-	363 ± 58	382 ± 58	797 ± 59	1,091 ± 41	-65 ± 39
16	WICST	07	6	0	98	392.24	392.24	975.02	854.83	170.73
17	WICST	07	5	52	43	1,135.12	1,135.12	1,179.10	822.97	663.33
18	WICST	07	7	86	12	2,386.44	2,386.44	2,456.46	779.98	1,953.46
19	WICST	07	5	72	24	985.32	985.32	658.93	867.39	301.69
20	WICST	07	7	54	44	932.24	932.24	907.98	818.75	428.86
21	WICST	07	5	50	48	531.52	531.52	597.11	752.60	112.75
22	WICST	07	4	24	72	506.92	506.92	1,126.19	786.09	344.90
23	WICST	07	6	1	93	423.40	423.40	589.70	715.86	77.04
24	WICST	07	6	57	42	703.92	771.09	2,055.86	915.25	864.33
25	WICST	07	5	69	27	815.40	815.40	824.61	871.76	296.95
26	WICST	07	5	46	50	647.12	647.12	604.67	884.15	95.40
27	WICST	07	5	70	28	773.60	773.60	718.04	919.02	194.41
28	WICST	07	5	10	84	494.12	494.12	513.36	989.03	-89.68
29	WICST	07	4	49	47	849.96	849.96	498.24	915.39	124.87
30	WICST	07	5	67	31	863.76	1,040.61	809.12	996.92	326.71
AVG	WICST	07	-	-	-	829 ± 125	846 ± 125	968 ± 147	391 ± 128	391 ± 128

EU	Site	Y	S [†]	% C3 grass cover	% C4 grass cover	peak biomass* (g m ⁻² y ⁻¹)	ANPP mean (g dry biomass m ⁻² y ⁻¹)	BNPP mean (g dry biomass m ⁻² y ⁻¹)	Rs (g C m ⁻² y ⁻¹)	NEP 40% Ra [§] (g C m ⁻² y ⁻¹)
91	BR Ranch	08	7	46	30	170.16	191.29	1,132.92	1,322.54	-131.42
93	BR Ranch	08	7	52	5	251.00	251.00	919.70	1,108.85	-79.96
94	BR Ranch	08	7	52	24	349.80	371.69	1,124.45	1,206.95	23.90
95	BR Ranch	08	7	36	31	449.52	470.67	703.98	1,007.03	-16.89
96	BR Ranch	08	6	12	75	348.84	370.52	1,331.17	1,493.08	-45.00
97	BR Ranch	08	6	8	81	375.44	389.49	1,863.73	1,609.57	160.87
98	BR Ranch	08	5	52	17	302.40	302.40	564.61	1,207.15	-290.79
101	BR Ranch	08	6	49	8	167.88	167.88	2,468.32	864.54	799.38
102	BR Ranch	08	7	39	33	250.60	300.44	1,431.85	1,421.32	13.35
103	BR Ranch	08	8	52	28	255.92	299.06	2,440.96	1,130.68	691.61
104	BR Ranch	08	8	41	44	740.00	757.69	1,563.59	1,305.75	377.19
105	BR Ranch	08	6	36	53	433.88	491.09	374.21	1,329.35	-364.96
AVG	BR Ranch	08	-	-	-	341 ± 45	364 ± 46	1,327 ± 195	1,251 ± 60	95 ± 104
106	WICST	08	5	56	32	926.80	1,040.00	1,240.12	1,247.56	391.52
108	WICST	08	6	0	94	749.24	962.74	1,145.24	1,700.07	33.95
109	WICST	08	6	0	92	1,044.80	1,044.80	1,075.55	1,618.43	89.12
111	WICST	08	6	43	43	1,320.00	1,440.00	596.81	1,295.57	241.06
112	WICST	08	6	65	28	1,838.60	1,838.60	1,249.92	1,313.58	756.11
114	WICST	08	6	76	17	3,400.00	3,400.00	1,614.46	1,072.97	1,863.45
115	WICST	08	7	37	49	1,000.00	1,026.20	982.58	1,412.32	157.00
116	WICST	08	6	25	57	720.00	720.00	957.26	1,599.76	-121.22
117	WICST	08	8	48	38	2,240.00	2,360.00	1,096.86	1,378.92	901.08
118	WICST	08	7	54	32	1,080.00	1,080.00	1,763.28	1,387.55	589.11
119	WICST	08	7	29	63	794.70	1,038.90	1,664.57	1,276.40	585.89
120	WICST	08	5	35	51	1,440.00	1,440.00	1,318.70	1,426.30	523.57
AVG	WICST	08	-	-	-	1,380 ± 226	1,449 ± 220	1,225 ± 96	1,394 ± 51	501 ± 152

† S = species richness, i.e. maximum number of species found in each experimental unit.

‡ Peak biomass harvest dates = August 30 and 31, 2007 and August 25, 26 in 2008.

§ Autotrophic respiration is assumed to be 40% of soil respiration (value reported by Kucera & Kirkham, 1971).

DISCUSSION

Net ecosystem production increased as C4 grass abundance increased, but the results indicated that species composition was more important than functional groupings for C dynamics. The relationships between the estimated major components of the C cycle (ANPP, BNPP, and Rs) to functional group and plant species cover followed the predicted directions but were modified primarily by site productivity. One of the caveats of a mensurative experiment (Hurlbert, 1984) such as this is that it is set in a natural setting where consistently representing all possible variations of species composition may be impossible. While, field experiments may improve ecosystem representativeness, it also may increase the chances of randomly picking combinations of species that are dominated by one or more highly productive species that drive the system. We found a clear dominance of *Andropogon gerardii*, which was highly productive in all the experimental units at the higher end of the C4 grass cover gradient in our study. In addition, all the plots that on average were covered with more than 55% of *A. gerardii* yielded two to three times the average of all the other plots. Simultaneously, of all the species from either functional group, only one of the C4 grasses (*A. gerardii*) was correlated positively to NEP, ANPP, and BNPP. Hence, our study indicates that increasing *A. gerardii* cover can positively affect NEP and that the composition drives changes in C dynamics more than the functional groupings. Similarly, comparing soils under three C4 grasses to soils from adjacent C3 dominated fields, Mahaney et al. (2008) found that the identity of the C4 species influenced the magnitude of the effects on soil carbon and nitrogen cycling, particularly *A. gerardii* cover. Other studies that had manipulated the functional diversity and species richness in Minnesota found that only C4 grasses and legumes significantly affected productivity and they suggest that the increase in productivity with diversity was partially caused by high yielding C4 species in high-diversity plots (Tillman and Downing, 1994). Inferences beyond those 2 sites should be carefully drawn (Hurlbert, 1984) and a more complete representation of the C3:C4 grass gradient with replicated plots can help to clarify if the observed quadratic fit suggesting that there might be a threshold of C4 grass cover above which the ecosystem responds in a non-linear fashion is general. Also, a manipulative experiment could help determine if our results were driven by coincidentally selecting very productive sites in the high end of the gradient or if compositional identity of the C4 group really drives the system.

We predicted that net primary productivity should increase with higher abundance of C4 grass cover and that soil respiration would decrease. Our study supports the prediction that soil respiration decreases with increasing C4 abundance and that ANPP increases as documented in several prairie studies (Seastedt et al., 1994; Tilman et al., 1997; Mahaney et al., 2008). However, despite differences in root stock biomass found under C4 and C3 grasses, we did not find a correlation between BNPP and plant cover. This result runs counter to our prediction and it is inconsistent with other studies that report positive changes in BNPP when community composition shifts to C4 dominance in restored prairies (Baer et al., 2002; Camill et al., 2004; Mahaney et al., 2008) and CRP lands (Kucharik et al., 2001). This result may not be surprising considering that aboveground functional cover may not translate directly into belowground functional cover. One possible explanation is that spatial variability under bunch and sod forming grasses is high enough that estimates of aboveground cover do not match well belowground composition. Another point to consider is that most of the studies mentioned above compared cool-season pastures or agricultural lands that were restored into grasslands highly dominated by C4 grasses (60-80%). An efficient and productive technique to separate roots by functional groups is necessary to access the belowground responses along a C3:C4 grass gradient. Because BNPP provides most of the carbon to the soil in grassland systems (Jobbagy and Jackson, 2000; Gill et al., 2002), we need a more precise estimate of BNPP along the C3:C4 gradient to evaluate the potential carbon sequestration in either working lands that intend to reintroduce warm-season grasses to pastures or in restored prairies recolonized by introduced C3 grasses. Our result indicating that the effect of C4 grass annual cover on NEP, ANPP and BNPP was inconsistent across sites suggests that changes in C dynamics may depend not only on the

functional composition and the identity of the dominant species in the mix, but also on the abiotic factors such as nutrient availability, climatic conditions and soil type. Indeed, when we used the tree model to explore which variable most influenced NEP in our study, it was clear that soil parameters like K concentration were splitting the database along sites. Comparing both sites, WICST has more resources available for plant growth (soils with higher O.M., TC and TN content as well as higher water holding capacity) and these differences help explain the stronger relationship of the major components of the C cycle to increasing C4 abundance at that site. While our study did not reveal a relationship between BNPP with plant cover at BR Ranch, a higher proportion of biomass was allocated belowground at the Ranch than at WICST. Using regression trees we can clearly see that aboveground production drives C dynamics at WICST, while at BR Ranch the driver was the belowground production. Others have shown that belowground resource limitation causes plants to invest a higher proportion of their biomass belowground (Reich et al., 2001).

Soil resources may not be the only limiting factor for a higher NEP at BR Ranch. It is known that the amount of SOM retained by grassland soils is highly influenced by management (Jones et al., 2006). Cutting for hay exports a large part of the primary production from the pasture and nutrient removal has to be compensated since net sequestration is a matter of balancing C inputs and outputs. For instance, Franzluebbers et al. (2009) estimated that the removing and redistributing the forage on the land to feed the cattle elsewhere could result in a total of 0.1 Mg of C per hectare per year that is lost from the original land (this was not a complete life cycle analysis where CO₂ emissions resulting from cutting, baling, and transporting operations were discounted).

CONCLUSIONS

Several quantitative observations in this study reveal that NEP and ANPP has the potential to positively change with increasing C4 grass cover, but these relationships appeared to be driven by a single species, *Andropogon gerardii*. The relationships between C parameters (NEP, NPP, and Rs) and C4 cover were modified by site, where C dynamics were driven by BNPP at the low-resource site and ANPP at the high-resource site, but more replication along a gradient of resources availability is needed to determine whether this effect is general.

There are several conclusions in this project that can guide land managers and policy makers regarding mixed C4-C3 grasslands. At the management level, the July C4 grass cover can guide the land managers in assessing the productivity of the grassland before the end of the season when the grasses are very tall and the heat strong. It seems also that low-diversity grasslands that are mainly dominated by productive warm-season grasses, such as the CRP lands, may prove to be a great alternative to improve SOC. At the same token, a low cover of cool-season grasses in restored prairies may not threaten the potential of the restoration to rebuilt SOC if the C4 grasses still the dominating grass. Our results also show that the higher C sequestration in consequence of a higher cover of warm-season grasses is not general across sites and nutrient-poor permanent grasslands may need to be moderately intensified either by increasing organic carbon input or moderate fertilization (Soussana et al., 2004). In a positive note, many forage species such as *Panicum virgatum* L. have been studied as good sources of bioenergy and according to our study, more attention could also be given to the potential of *Andropogon gerardii*. This project shows that research at the farm level, across various soil types and management still necessary if the C sequestered by mixed C4-C3 grasslands is to be considered as an effective strategy to long-term C storage and a key part to climate stabilization.

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THE IMPORTANCE OF SPECIES COMPOSITION VERSUS DIVERSITY IN RESTORED PRAIRIE A DECADE LATER

Nicole Budd¹

INTRODUCTION

Since the 19th century, nearly all of Wisconsin's native grasslands have been transformed into agricultural monocultures. Other human practices such as fire suppression and urban development degraded remaining remnant prairies and significantly altered their structure and function (Anderson et al. 1996). These human-induced changes, combined with the introduction of exotic species, have contributed to an epidemic of invasive species colonization in Wisconsin prairies. A survey carried out in 10 dry prairies throughout southwestern Wisconsin demonstrated that over the last 58 years, mean native species richness has decreased (from 65.2 to 59.7 per ha) while exotic species richness has substantially increased (0.3 to 10.1 per ha) (Kraszewski and Waller, 2008). Subsequently, a large and growing movement to restore the native prairies of Wisconsin is underway.

According to the Elton's (1958) diversity–invasion resistance hypothesis, a diverse natural community of plant species will be more successful in deterring invasive species than a less diverse ecological community. Species-rich communities are thought to be “saturated,” with few open niches for invasive species to exploit (Moore *et al.* 2001; Stachowicz & Tilman 2005). I examined the colonization success of invasive species in prairies with high native diversity and low native diversity plant assemblages in high fertility soils. The experimental setup provides a unique opportunity to observe side by side comparison with replication. I hypothesized that high diversity plots would have fewer nonnative species a decade.

¹ In fulfillment of the requirements for Agronomy 699-Independent Study in Biological Aspects of Conservation

METHODS

Study site

Our research was conducted on the Wisconsin Integrated Cropping Systems Trial (WICST) located at the University of Wisconsin's Agricultural Research Station (ARS) near Arlington, WI. Prior to cultivation in 1840s, the area was a contiguous tallgrass prairie (Curtis 1959). In 1955 the land was purchased by the UW-Madison for the purpose of agricultural research. In 1999, 1.29 hectares of ARS land was converted to native prairie as part of WICST. WICST is a long term study investigating the effects of conventional and alternative cropping systems on productivity and the environment. The prairie is a small component of the entire WICST project. For more information about the design and management of the WICST see Posner et al. (1992).

Experimental Design

The prairie was designed to investigate the restorative success of two native seed mixes of differing compositions. Prior to planting, three randomized treatments; high diversity, low diversity and a control, were assigned to a block of plots (Fig. 1). The block was planted with soybeans the previous year and after the soybeans were removed the area was tilled and sprayed with herbicide. Each plot measured 155 m long by 13.7 m wide. Three plots were planted with a low diversity seed mix containing 6 species and three plots were planted with a high diversity seed mix containing 25 species (Table 1). The low diversity seed mix modeled the seed mix offer by the Conservation Reserve Program for grassland restoration. In addition to 6 species offered in the low diversity mix, the high diversity mix includes 19 additional species with varying flowering times to closely mimic tallgrass prairie and create greater aesthetic appeal. Seeds were planted at rates reflective of their relative weights, importance to the community and aggressiveness in attempt to create a balanced ecosystem (UW-Herbarium). Three plots of switchgrass were planted in 2007, but were not used in this study (Fig. 1). All prairie plots were burned in spring every 2 to 3 years with the last burn occurring in spring 2008.

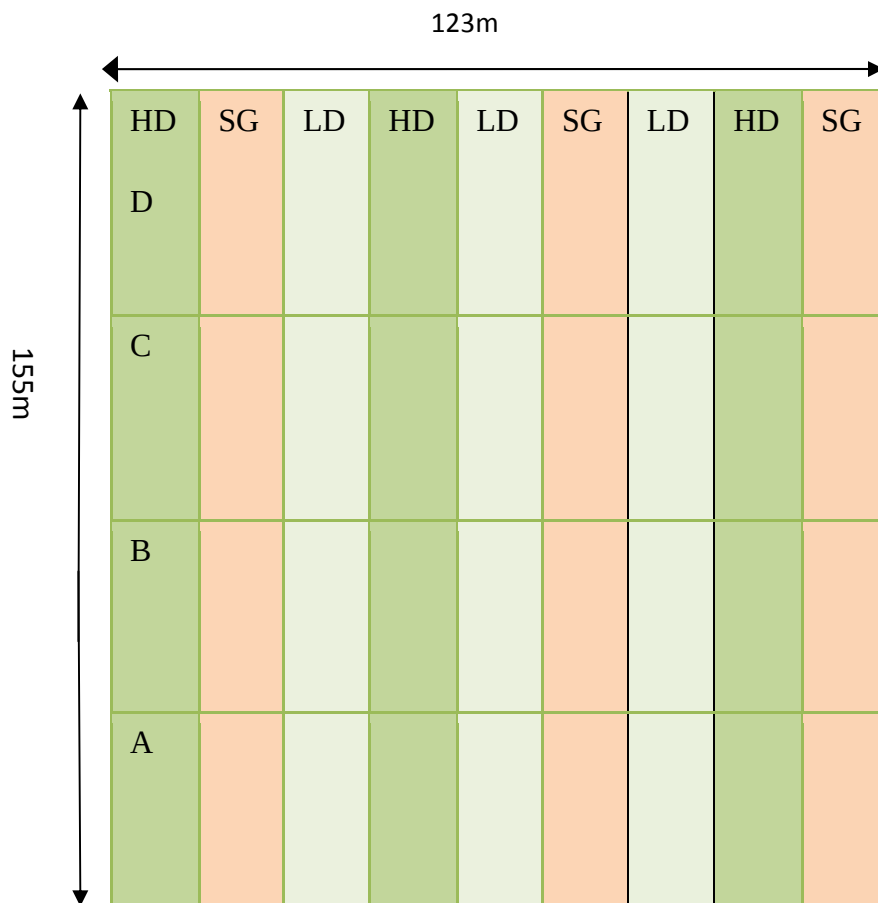


Fig 1: WICST Prairie plot design. Three high diversity (HD), three low diversity (LD), and three control switch grass (SG) plots in randomized complete block.

Vegetation sampling

In August 2008, each of the six plots was divided into four 38.75 m x 13.7 m sections (labeled A, B, C and D in Fig. 1). Within each of the four sections, five 50 x 50-cm quadrats were located in a systematic manner to ensure dispersion and a representative sample. This allotted 20 samples per plot and 120 samples total. Each plant species observed within these quadrats was recorded.

Data analysis

Species richness was calculated as the number of unique species in each quadrat. Each native species was assigned a conservation coefficient (CC, Swink and Wilhelm 1994; Wilhelm and Masters 1995). Conservation coefficient values range from 0 to 10. Plants commonly found in disturbed areas are given lower numerical value than plants restricted to ‘high quality natural’ areas, mimicking ‘pre-settlement’ conditions. Floristic quality index (FQI) was calculated by

multiplying the mean CC for each quadrat by the square root of the total species richness for that quadrat.

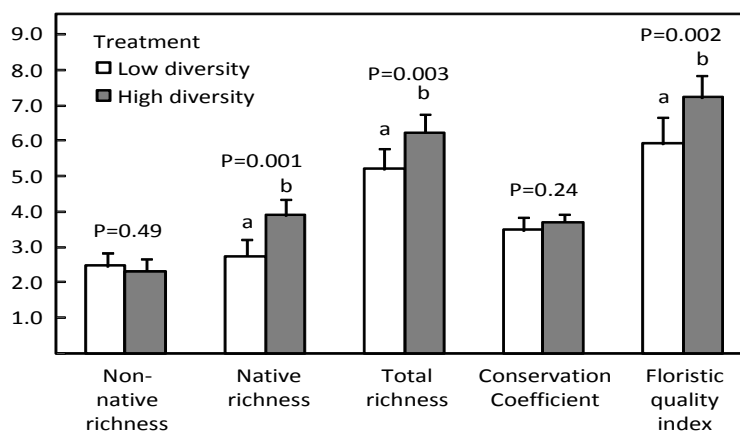
Quadrat-wise data were subjected to linear mixed-effects modeling where differences in response variables (native species richness, nonnative species richness, total species richness, conservation coefficient, and floristic quality index) were assessed between two treatments, low and high diversity. The random effects of block and section within block were modeled with this approach so that use of quadrat-level data for assessing treatment effects was appropriate (Luschei and Jackson 2005).

RESULTS

There was no significant differences in nonnative species richness ($P=0.49$), but there was a significant difference in native species richness ($P=0.001$), with an average of 3.9 species in high diversity plots compared to an average of 2.75 species in low diversity plots (Fig. 2). This resulted in greater total species richness of 6.23 species in high diversity plots versus 5.22 species in low diversity ($P=0.003$). The conservation coefficient was not significantly different between treatments ($P=0.24$), but floristic quality index showed significant differences with a value of 7.24 in high diversity treatments and a value of 5.91 in low diversity treatments ($P=0.002$) indicating that differences in diversity were driving this rather than species composition.

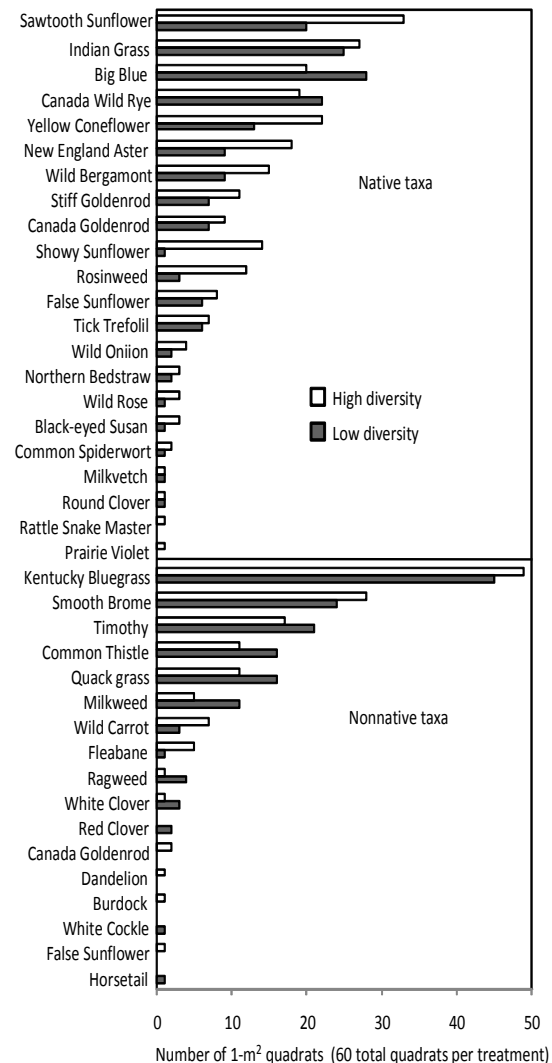
A similar distribution of species was found in low and high diversity treatments. Even species, such as Indian grass and saw-tooth sunflower, which

Fig 2. Averages ($\pm$ SE, $n=15$) of species diversity and composition indices for 1-m² quadrats. Richness values are counts of species per quadrat. See text for description of conservation coefficient and floristic quality. P-values for treatment effects determined with linear mixed-effects models accounting for randomization restrictions due to block and section within block.



were not planted in the low diversity plots, became dominant, reflecting high diversity plot trends (Fig. 3). Some differences were apparent. In particular, showy sunflower and rosinweed were more abundant in high diversity plots.

Fig 3. Number of 1-m² quadrats containing each species across all plots (60 total quadrats per treatment).



DISCUSSION

I hypothesized that higher species diversity within a plant community would increase resistance to exotic species

establishment. However, our data revealed no significant difference in exotic species richness between the plots with varying native species diversity. There was a strikingly similar relative distribution of species between the treatments. This suggests that nonnative species colonization in prairies was not dependent on community diversity.

Although the low diversity plots were numerically less “saturated” than the high diversity plots, the low diversity treatments appeared to offer few niche opportunities not available in the high diversity treatments. A study carried out by Levine (2000) demonstrated that the presence of dominant native species has a negative effect on invasive colonization. Another study showed that the establishment of native perennials effectively limited light and space for exotic seedlings

and shifted competition in the favor of the native (Corbin & D'Antonio, 2004). Considering that both treatments had well established perennials such as big bluestem, it is possible that exotic species experienced equal biological resistance in both plots.

There was no significant difference in mean CC between the treatments, but after native species richness was combined with CC to obtain FQI a significant difference was found. The differences were a product of diversity rather than species composition. Theoretically, higher FQI should represent a site with higher biological integrity (UW-Herbarium, 2008).

The high and low diversity plots have converged in community composition over the past decade. During this period, 12 of the 19 additional species planted in high diversity plots migrated into low diversity plots. Indian grass and saw-tooth sunflower have even become dominant in both treatments. At the same time, a number of species are fading from both treatments. White wild indigo, butterfly weed and prairie smoke were not present in any quadrats. These species are given high CC, indicating that they do not tolerate disturbances well.

SUMMARY

Given the short duration and limited budget of this research project, numerous confounding factors may have influenced the results. The area surrounding WICST prairies is dominated by row crop agriculture. Due to the heavy fertilization occurring in the adjacent test sites, the soils in WICST prairies have high nutrient concentrations. But, species richness increased under low diversity nonetheless.

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Table 1: List of species and guild planted in 1999.

Common Name	Guild	Low Diversity Plots	High Diversity Plots
Canada Wild Rye	C3	X	X
Big Blue	C4	X	X
Indian Grass	C4		X
Milkvetch	Legume		X
Round-Headed Clover	Legume	X	X
Tick Trefoil	Legume	X	X
White Wild Indigo	Legume		X
Prairie Smoke	Forb		X
Prairie Violet	Forb		X
Butterfly Weed	Forb		X
Common Spiderwort	Forb		X
Northern Bedstraw	Forb		X
Prairie Tickseed	Forb		X
Black-eyed Susan	Forb	X	X
New England Aster	Forb		X
Rattle Snake master	Forb		X
Rosinweed	Forb		X
Saw tooth Sunflower	Forb		X
Showy Sunflower	Forb		X
Stiff Goldenrod	Forb		X
Wild Bergamot	Forb		X
Wild Onion	Forb		X
Yellow Coneflower	Forb	X	X
Wild Rose	Woody Shrub		X
Prairie Cinquefoil	Forb		X

Effects of Bioenergy Agroecosystems on Soil Microbial Communities

Laura A. Lipps¹ and Teri C. Balser²

¹ Gaylord Nelson Institute for Environmental Studies, University of Wisconsin, Madison, WI, 53706

² Department of Soil Science, University of Wisconsin, Madison, WI, 53706

INTRODUCTION

There is growing societal interest in management of agricultural systems for bioenergy feedstock production, but further environmental evaluation of these systems is warranted. Measurement of soil microbial communities and activity may be useful in environmental evaluations of alternative bioenergy cropping systems, as they are important components of soil health. We characterized microbial community structure and soil enzyme activities within agricultural systems that represent potential bioenergy cropping scenarios for future corn-based or cellulosic biofuels. Our general hypothesis was that microbial community structure and activity would be distinct under varying vegetation and management treatments.

METHODS

Five cropping system treatments at the Wisconsin Integrated Cropping Systems Trial (WICST) were selected for inclusion due to their potential as bioenergy cropping systems: high-input continuous maize (CS1 - established 1990), the corn phase of a strip-till corn/soy rotation (CS2 - established 1990), switchgrass monoculture (SW-established 2006), and restored low-diversity, and high-diversity, prairie grasses (LP and HP, established 1999).

Samples were collected from three replicate plots ($n=3$) of CS1, CS2, LP, HP, and SW. We collected surface (0-10 cm) and subsurface (10-25 cm) bulk (non-rhizosphere) soils at the height of the growing season, over a period of three days in mid-July 2008. Within each plot, we took samples every 30.5 m along a North-South transect that lay at the center of the plot's long axis (6 m from each edge in the corn plots, 6.9 m from each edge of the prairie plots), for a total of five samples per plot. At each sampling point, five cores of 2.5 cm diameter were separated them into 0-10 cm and 10-25 cm depths, and composited by depth. Cores from the prairie plots were taken at equidistant points on a circle of 1 m² diameter around the sampling point. Samples from the corn and switchgrass plots were collected within the planted rows but not within bare furrows in order to minimize the effects of compaction and to select for vegetation-associated soil.

We measured soil microbial community composition using membrane lipid analysis, as described by Smithwick et al. (2005). Five samples per plot were analyzed and then averaged across each treatment's three replicate plots ($n=3$). We estimated total microbial biomass as total $\mu\text{mol lipid g}^{-1}$ soil. Relative abundance of each lipid was indicated using mole percent (mol %, representing μmol s individual lipid/total lipid biomass) of total fatty acids. Lipids present at less than 0.5 mol % (unless present in a majority of samples from each treatment) were excluded from further analysis.

We chose a subset of the total indicator lipids for further analysis. Generally, gram-positive bacteria can be represented by the branched lipids: i14:0, a15:0, i15:0, i15:1, i16:0, a17:0, i17:0. Gram-negative bacteria are indicated by mono-unsaturated and hydroxy lipids: 16:0 2OH, 16:1 2OH, 16:1 w7c, 17:0 cy, 18:1 w7c, and 19:0cy (Mentzer et al. 2006). Other microbial functional groups can be identified by the following: actinomycetes (16:0 10Me, 17:0 10Me, 18:0 10Me; Santruckova et al. 2003); arbuscular mycorrhizal (AM) fungi (16:1 ω 5c); and saprophytic fungi (18:1 ω 9c and 18:2 ω 6,9c; Mentzer et al. 2006).

Soil samples were also assayed for the activity of five enzymes important in carbon and nutrient cycling: β -glucosidase, cellobiohydrolase, xylosidase, n-acetyl-glucosaminidase, and phosphatase using fluorescently linked enzyme substrates after Sinsabaugh et al. (2003). Total enzyme activity was calculated as nmol substrate consumed h⁻¹ g⁻¹ dry soil weight.

Statistical Analysis

We used principal component analysis on the relative abundance of lipids (arcsin transformed mol fraction) to provide a general microbial lipid ‘fingerprint’ (JMP, SAS Institute, 2002). To assess possible treatment effects on the response variables total microbial biomass, individual lipid biomass and relative abundance, microbial guild biomass and relative abundance, and enzyme activity), we used one-way analysis of variance (ANOVA) followed by Tukey’s post-hoc analysis for pairwise comparisons (JMP, SAS Institute 2002).

RESULTS

Total microbial biomass was significantly higher in prairie treatments than in agricultural plots (Table 1). Principal components analysis of overall microbial community structure showed that microbial communities differed most between prairie treatments and agricultural treatments (Figure 1). In contrast, the corn and switchgrass systems, despite differences in management and vegetation, were similar in microbial community structure. Separation of communities along principal component 1 reflected differences in treatment.

Average total biomass of lipids in a range of microbial functional guilds is shown in Table 1. The abundance (in nmol g⁻¹ soil) of Gm- bacterial and AM fungal lipid indicators was elevated in the prairie treatments relative to the agricultural treatments ($p < 0.001$ for both groups; Figure 2). We calculated fungal to bacterial (F:B) ratios to further investigate treatment effects on microbial communities. The F:B ratio was significantly greater in the low-diversity prairie than in the agricultural treatments ($p < 0.001$, Figure 3), and ranged from 0.6 in the strip-tilled corn treatments to 1.2 in the low-diversity prairie plots. In order to assess whether arbuscular mycorrhizal (AMF) fungi or saprophytic fungi (SF) were contributing more to the F:B ratio, we also calculated AMF:B and SF:B ratios. The AMF:B ratio was significantly elevated in both prairie treatments compared to CS1, CS2, and SW plots ($p < 0.001$). The SF:B ratio, however, only showed a significant elevation in the continuous corn treatment relative to

the strip-till corn plots ($p < 0.05$), indicating that differences in AMF tended to change more dramatically with treatment differences than did SF.

We also calculated several bacteria-specific ratios: the ratio of gram+/gram- bacteria and the ratio of combined cyclopropyl-substituted lipids to their monoenoic precursor lipids, often used as a measure of microbial stress, especially carbon limitation (Bossio and Scow 1998). The Gm+/Gm- ratio was significantly lower in the prairie treatments than in the agricultural treatments ($p < 0.001$). The ratio of combined cyclopropyl-substituted lipids to their monoenoic precursor lipids, 17cy/16:1 ω 7c and 19cy/18:1 ω 7c, was significantly elevated in the agricultural plots compared to prairie plots ($p < 0.001$, Table 1).

In general, total enzyme activities (nmol substrate consumed $\text{h}^{-1} \text{g}^{-1}$ oven dry soil) displayed high variability by sample and plot. Enzyme activities by treatment were not substantially different, indicating that soil enzyme activities were less able to distinguish between cropping systems than microbial community structure.

DISCUSSION

Our results indicate that different types of bioenergy cropping systems may in fact generate distinct soil microbial communities over a period of years. Perennial vegetation-based systems and traditional corn-based systems appear to be most likely to distinctly affect microbial community structure. This is evidenced by our observation that low- and high-diversity prairie treatments had significant differences in overall microbial community structure compared with the other three 'agricultural' treatments (CS1, CS2, and SW).

The three 'agricultural' treatments (CS1, CS2, and SW) displayed similar microbial community structure at each depth. They differed in recent management history but their soil characteristics were likely dominated by a history of corn cropping systems; CS1 and CS2 were planted with corn in 2008, although CS2 had been rotated with soybeans the previous year. While the SW treatment had been planted with switchgrass for two growing seasons, it had previously been managed as a continuous corn system similar to CS1. The similarities in long-term vegetation history, despite CS2 differences in management such as strip-tillage and lower chemical inputs, likely contributed to the similarities in microbial communities relative to the prairie restorations. This finding highlights the importance of considering the impacts of land-use history on soil, as this soil biological 'legacy' may affect current primary productivity.

Biomass data indicated that the shift in microbial community structure in restored prairies relative to cultivated treatments was driven primarily by differences in the abundances of Gm- bacteria and arbuscular mycorrhizal fungi, both of which were significantly elevated in the prairie treatments. The abundant fine root system of prairie plants compared to corn may contribute to the development of a more rhizosphere-centered soil environment. Gm- bacteria tend to rely particularly on low molecular weight carbon compounds that are recently exuded from plants and roots (Kramer and Gleixner 2006). It is likely that increased carbon inputs from the prairie ecosystem result in higher amount of labile, low

molecular weight carbon compounds around the roots, thus elevating populations of Gm-negative bacteria. The microbial community may be responding to higher inputs of labile carbon substrates from the prairie treatments, and experiences a more stressful, carbon-limited environment in the agricultural plots. In fact, differences in vegetation cover have been linked to differences in carbon quality (Wardle 2002). We suggest that elevated Gm- biomass in the prairie treatments reflects a more rhizosphere-dominated environment in the prairie treatments, while cultivated treatments may contain more bulk soil and fewer fine roots.

A soil environment in the agricultural plots that is more limited in labile C substrates could explain our observations of both elevated Gm+/Gm- ratios and bacterial stress ratios in the agricultural plots (Kramer and Gleixner 2006). It is also likely that as the switchgrass treatments mature over a period of years, Gm- bacterial abundance will increase as rhizosphere influence grows and expands. Clearly, one year of switchgrass cultivation is not sufficient for changing microbial communities from the legacy of previous corn cultivation.

The influence of treatments on fungi

It is well-established that fungal biomass tends to increase in the first few years of prairie restorations on ex-arable land (Allison et al. 2005). Our results confirm this. We saw elevated mycorrhizae, indicative of prairie species and rhizosphere development. Agricultural management, on the other hand, impacts several important aspects of the soil habitat, especially pH and soil structure. Fungi are particularly sensitive to alterations in both, and are also sensitive to nitrogen deposition. Previous studies have found that changes in all three of these factors are enough to significantly decrease the F:B ratio in agricultural soils (de Vries et al. 2007). We had expected fungal biomass to be lowest in the most intensively managed system (CS1); however, we found that fungal biomass was instead lower in the strip-till corn and switchgrass treatments, which receive less tillage and lower inputs of fertilizer. These treatments, however, also likely supplied the lowest quantity of carbon substrates during the growing season. This is due to generally small corn yields in CS2 than CS1, and the immature nature of the switchgrass crop in the SW treatment. This suggests that tillage and N fertilization may not always be the most important factors affecting fungal biomass in agricultural systems, or that these factors interact with carbon quality and quantity to regulate fungal abundance. Fungal abundance may also be influenced by competitive interactions with other microbial groups; however, more research is needed to test this hypothesis.

Influence of treatments on bacterial indicators

Under conditions of physiological stress, bacteria have been found to increase production of cyclopropane lipids from their monoenoic precursors (Kieft et al. 1994); thus the measure of the ratio cyclopropyl lipids to their precursors can signify stressful environmental conditions for bacterial communities. Our finding that these ratios were higher in agricultural plots than prairies indicates a potential alleviation of nutritional stress by restoration of perennial vegetation and is consistent with past findings

(McKinley et al. 2005). Interestingly, we did not see significant differences in microbial stress ratios among the corn plots, contradicting previous research that showed differences depending on tillage technique and intensity (Chaer et al. 2009). Again, factors other than disturbance may be controlling C availability, and thus stress, in these treatments.

The elevated Gm+/Gm- bacterial ratios in the agricultural plots may indicate ecological dominance of Gm+ bacteria over Gm- in these systems. The possible ecosystem consequences of microbial community dominance by Gm+ bacteria are several. Evidence from isotopic and other studies supports the hypothesis that different microbial groups in soil utilize different varieties of carbon substrates (Kramer and Gleixner 2006). For example, gram-positive bacteria have been found to have a greater affinity for using existing soil organic matter (SOM), rather than new plant carbon, as a carbon source (Kramer and Gleixner 2006). A higher relative abundance of gram-positive bacteria in the agricultural plots may therefore lead to a greater proportion of recalcitrant carbon being degraded, whereas a lower Gm+/Gm- ratio under prairie treatments may reflect greater decomposition of recently-derived plant material, which tends to correspond to more labile carbon substrates. Additionally, the ratio of various microbial groups to each other may affect the ultimate fate of carbon substrates that enter the soil ecosystem. For example, Gm+ bacteria retain a greater proportion of carbon in their cell walls, converting C to amino sugars which are retained for long periods of time in the soil environment (Liang et al. 2007). A higher microbial biomass in general thus may also result in greater C storage in the prairie environments, due to the same mechanism.

CONCLUSION

In conclusion, our results suggest that prairie restorations of <10 years can in fact cause significant changes to soil microbial communities in comparison with annual crops, and that bioenergy cropping systems based on prairie vegetation have significantly different soil microbial communities than cultivated systems on the same soil series. It is likely that intensively managed plots favor bacterial dominance belowground, and possibly dominance of nutritional stress-tolerant microorganisms. Because bioenergy cropping systems are likely to be evaluated by policy-makers according to environmental criteria including soil quality indices, it is important to gather further information about the links between soil microbial community composition and important ecosystem processes such as decomposition, production and sequestration of recalcitrant carbon compounds, and nutrient mineralization. A greater understanding of the mechanisms by which the soil microbial community interacts with the soil habitat will help inform bioenergy managers as to which types of cropping systems and management practices will in fact contribute to carbon sequestration, soil quality, and other environmental goals of bioenergy proponents.

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Table 1: Effect of Treatment on Total Biomass of Microbial Guilds and Lipid Indicators (0-10 cm depth).

	Continuous Corn	Strip-Till Corn	Switchgrass	Prairie ⁱⁱ
Total microbial ⁱ	254.1 (56.4) ^a	171.6 (10.35) ^a	211.6 (29.03) ^a	408.4 (30.81) ^b
Gm+	37.25 (9.87)	26.69 (2.6)	32.75 (3.57)	37.7 (3.9)
Gm-	38.65 (9.55) ^a	29.97 (2.46) ^a	37.32 (2.99) ^a	72.47 (7.5) ^b
Actinomycetes	12.75 (3.17)	11.56 (1.75)	13.52 (0.68)	7.8 (1.89)
Fungal biomass	83.07 (20.81) ^a	46.04 (5.7) ^a	58.43 (12.8) ^a	151.0 (16.5) ^b
AMF	9.33 (2.55) ^a	9.29 (1.43) ^a	14.22 (4.59) ^a	89.27 (17.4) ^b
SF	73.7 (12.4) ^a	36.7 (6.4) ^b	44.2 (15.0) ^b	58.7 (5.61) ^{ab}
F:B ratio	0.86 (0.10) ^{ab}	0.62 (0.10) ^a	0.63 (0.11) ^a	1.13 (0.10) ^b
17cyclo/16:1 ω 7c	0.35 (0.02) ^a	0.36 (0.03) ^a	0.31 (0.04) ^a	0.17 (0.04) ^b
19cyclo/18:1 ω 7c	0.46 (0.43) ^a	0.46 (0.07) ^a	0.50 (0.06) ^a	0.26 (0.03) ^b

Superscript letters adjacent to values indicate significance levels according to Tukey's post-hoc analysis following one-way ANOVA. Distinct letters indicate significant differences between treatments.

ⁱ Biomass values are reported in nmol lipid g⁻¹ dry soil.

ⁱⁱ Results are averaged from the high-diversity and low-diversity prairie plots.

Figure 1: Ordinate plot of PC1 and PC2 by treatment and depth using Principal Component Analysis. PC1 accounts for 34.9% of the observed variation in communities, while PC2 accounts for 22.1%. Error bars = ± 1 SD. $n=3$. Red dots indicate samples from the 0-10 cm depth and blue indicate samples from the 0-25 cm depth.

Figure 2: Treatment effects on total microbial biomass of microbial guilds, 0-10 cm depth, $n=3$. Letters indicate significant differences between treatments for each guild.

Figure 3: Ratio of fungi:bacteria in the surface layer (0-10 cm), by treatment. Error bars are ± 1 SD. Letters indicate significant differences between treatments.

Figure 1.

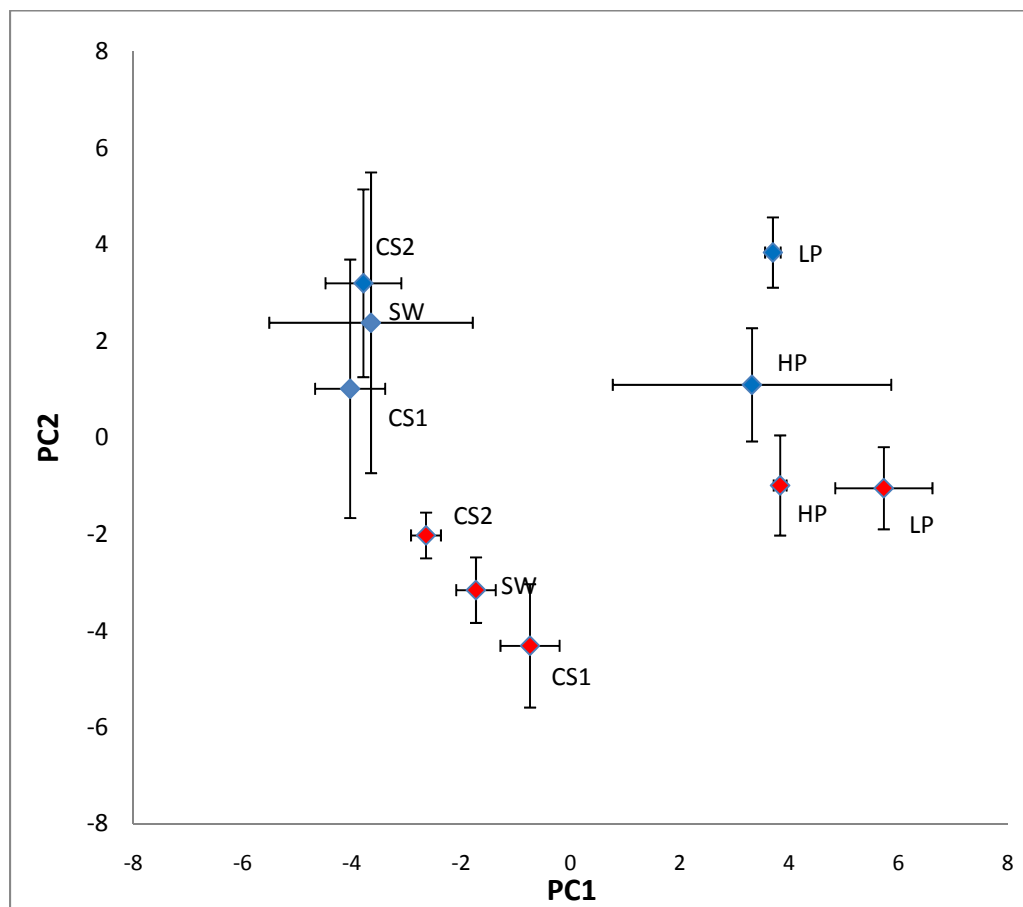


Figure 2.

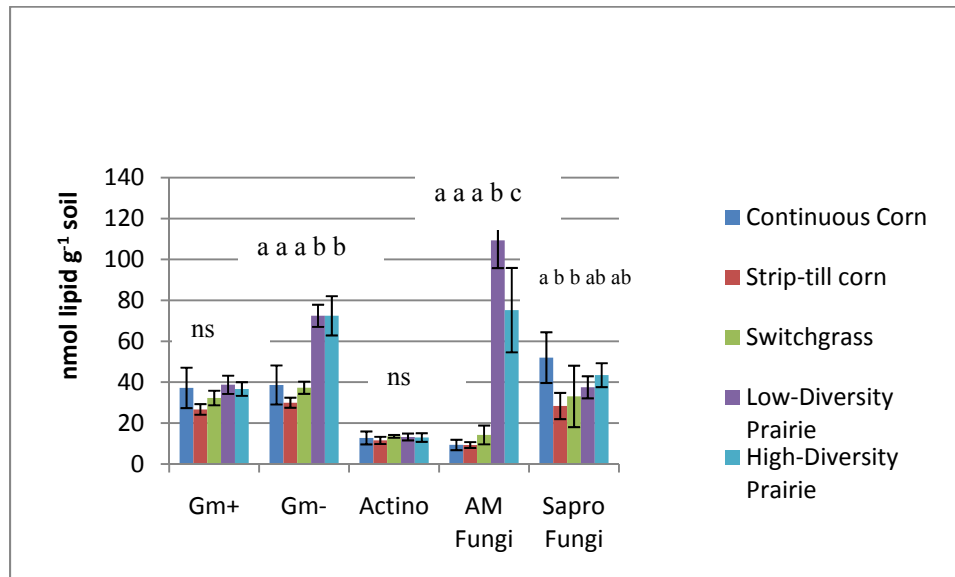
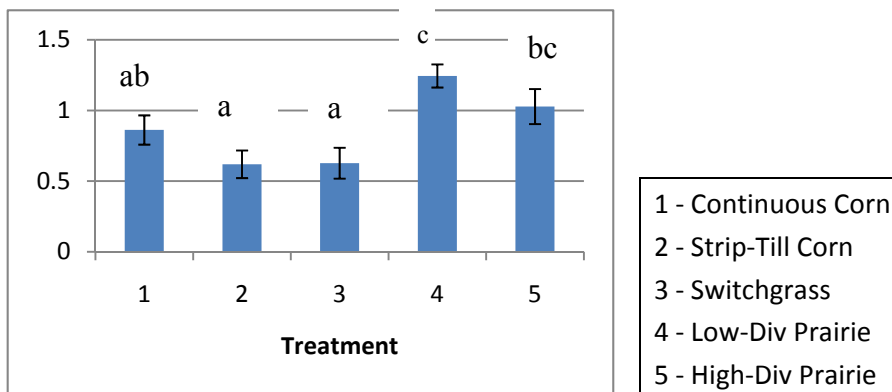


Figure 3.

a)



FORAGE PRODUCTION AND QUALITY OF RESTORED PRAIRIE INTERSEEDED WITH NATIVE LEGUMES

C.M. Maier, R.D. Jackson and J.L. Posner

INTRODUCTION

Motivations for restoring tallgrass prairie in the Upper Midwest range from natural resource conservation to developing new forage and cropping systems. Cropping systems based on the tallgrass prairie may be well-suited to providing reliable summer forage for livestock, feedstocks for home heating, electricity production, and ethanol, as well as ecosystem services such as carbon sequestration. The primary objective of this study is to evaluate restored prairie for summer forage under rotational grazing management.

The tallgrass prairie is a grassland ecosystem shaped by periodic drought, fires, and grazing (Anderson 2006). At the time of European settlement, prairies stretched across much of Iowa, southern Wisconsin, and Illinois (Transeau 1935). In Wisconsin, ecologists have identified approximately 200 native plant species that are prevalent in prairies (Cochrane & Iltis 2000). These plants are adapted to conditions ranging from dry, thin-soil bluffs to seasonally-wet areas with deep organic soils, such as the margins of pothole lakes or river floodplains (Curtis 1959). The most common and productive species in the tallgrass prairie are warm season grasses, including big bluestem (*Andropogon gerardii*), indiangrass (*Sorghastrum nutans*) and switchgrass (*Panicum virgatum*).

Very productive soils were formed through the function of the tallgrass prairie ecosystem. For example, the Plano silt loam soil series found at the Wisconsin Integrated Cropping System Trial (WICST) site at the Arlington Agricultural Research Station is associated with the historic Arlington Prairie and alone covers 426,000 acres in Wisconsin, Illinois, Iowa, and Indiana (Soil Survey Staff). Soils formed under prairies are approximately twice as rich in organic matter as soils formed under forests (4.5 vs 2.5 percent). Matamala et al. (2008) outlined several reasons for this large difference, including high root production in grasslands, close association of soil minerals and decomposing root matter, and the presence of fungi that transfer nutrients to the roots of native grasses and also stimulate formation of soil aggregates.

With the advent of the John Deere steel plow in 1837, the conversion of tallgrass prairie to production of grain, dairy, and livestock feed in the mid- to late-1800s was rapid and nearly total. North and east of the Missouri River, less than one percent of the original prairie remains (Anderson 2006) and in Wisconsin, remnant prairies has been reduced to 0.1 percent of its original cover (Henderson & Sample 1995). The ramifications of this rapid change are broad, including a lack of traditionally- or scientifically-developed knowledge about how to use, sustain, and expand the tallgrass prairie on farms in the Upper Midwest.

Today, perennial grassland is used by a significant number of livestock farmers in the Upper Midwest, but the typical grasslands used for grazing and haying are a low diversity community of non-native, cool-season(C3) grasses and forbs (Sanderson et al. 2004). Because these pasture communities can suffer from reduced productivity and forage quality during hot, dry summer months (Paine Undersander & Casler 1999), farm productivity could be improved by restoration of native warm season grasses (C4) grown either in mixed stands with C3 grasses or in separate, sequentially-grazed stands. C4 grasses utilize a different photosynthetic pathway than C3 grasses, and have evolved to maintain growth and high productivity during warm, dry conditions. This physiological adaptation inherently results in lower forage quality than C3 grasses. Due to higher nitrogen- and water-use-efficiency, carbon:nitrogen ratios (C:N) are higher in C4 forages, which translates to lower digestibility and lower percent protein (N) content (Barbahenn et al. 2004). Sequential grazing trials in Nebraska (Moore et al. 2004) and Wisconsin (Smart Undersander & Keir 1995)—a forage system using C3-dominated pastures to produce forage in spring and fall and utilizing C4-dominated pastures to produce forage in the summer—have demonstrated equivocal results for animal productivity relative to using only cool season grasses.

However, many of the native plant species of the tallgrass prairie have lower C:N ratios than C4 grasses, particularly native legumes (Craine et al. 2002). Growing a mix of native forbs and legumes with C4 grasses may improve productivity and N concentrations compared to growing C4 grasses alone. Pairings of C4 grasses and native legumes in small plot studies demonstrated improved forage quality and production for some pairings (Posler Lenssen & Fine 1993), and several native legume species have been evaluated for forage quality and productivity (Posler Lenssen & Fine 1993; McGraw et al. 2004; Fishbach et al. 2006). However, no published research exists that documents the effect of these species in pastures, or their persistence in a rotational grazing system in the upper Midwest.

The objectives of this study are to document forage quality in restored prairies, to investigate how differences in plant species diversity affect productivity, forage quality, and soil inorganic nitrogen (ammonium and nitrate) in restored mesic tallgrass prairie, and to investigate how management can influence parameters of interest over time. We are comparing management treatments along a diversity gradient, including a native switchgrass monoculture and low diversity and high diversity prairies with six and 26 species planted, respectively. We interseeded a suite of five native legume species to evaluate establishment methods and the effects of increased abundance and cover of this functional group on forage quality and quantity. We employed management intensive rotational grazing (MIRG) and mowing to evaluate management options currently used in grazing and ecological restoration.

We anticipate that the results of this research will be relevant to farmers interested in using native grasses in their production systems, as well as to ecologists interested in the influence of rotational grazing on prairie diversity and structure, and ultimately on ecosystem function and ecosystem services. This paper provides some background details of the study and a brief summary of data collection from the first season.

METHODS

Location

Prairie restoration at WICST began in 1999 (Simonsen Howell & Posner 2002). The primary goal was to restore native plants and a natural process (fire) to restore ecosystem function and provide baseline conditions for comparison with crop and forage systems. The 1999 prairie restoration (WICST Prairie) was implemented as a randomized complete block design with three diversity treatments randomly assigned within each of three blocks: 1) a low diversity (LD) prairie seed mix including six native species, 2) a high diversity (HD) prairie seed mix including 26 species (the LD complement and an additional 19 species), and 3) a control, continuous corn (CC) planted and harvested annually (Simonsen Howell & Posner 2002). The species sown in the prairie treatments are native species found in mesic tallgrass prairie communities; a list of species planted is included in Table 1 (adapted from Simonsen Howell & Posner 2002). The prairie seed was hand broadcast and cultipacked in June 1999, and subsequent management included periodic clipping for weed control from 1999-2002 (Simonsen Howell & Posner 2002). The prairies were burned in 2003, 2005, and 2008; the prairies and switchgrass will be burned annually in 2009 and 2010. Canada thistle has been treated with spot application of herbicide during the growing season. The CC treatment concluded in 2006; in June 2007 the CC plots were planted with switchgrass to include a native monoculture (SG) treatment.

Experimental design

Management treatments and legume interseeding mix were applied in a hierarchical design (split-split). Each diversity treatment (low diversity prairie, high diversity prairie, switchgrass monoculture) within the WICST Prairie experiment was split into three plots to apply disturbance treatments: grazing, mowing, and control treatments. To test the effect of native legumes, each disturbance treatment was split into interseeded (IS) and noninterseeded (NIS) plots, with the legume mix interseeding treatment randomly assigned. This experimental design resulted in 54 experimental units, with 18 experimental units in each block and six experimental units in each diversity treatment (Fig. 1). Each experimental unit measures

12.2 m by 17.5 m, covering approximately 0.021 ha. We are increasing the frequency of prescribed fire management to annual burning to facilitate native legume germination and survival.

Interseeding

We selected five native legume species for the interseeding mix: leadplant (*Amorpha canescens*), Illinois bundleflower (*Desmanthus illinoensis*), showy tick trefoil (*Desmodium canadensis*), round-headed bush clover (*Lespedeza capitata*), and purple prairie clover (*Petalostemum purpureum*). We reviewed research on native legumes for forage quality and productivity to identify species that will likely be most useful to south central Wisconsin farmers (Posler Lenssen & Fine 1993; McGraw et al. 2004; Fishbach et al. 2006). Native legume species differ in maturity rate (number of years between establishment and seed production) and lifespan (R. Henderson, personal communication), and we attempted to include species that will establish quickly and provide significant biomass within one or two growing seasons (e.g. Illinois bundleflower) as well as species that may persist over time even without subsequent seed production and establishment (e.g. leadplant and round-headed bush clover). Because plant maturity affects forage quality, we selected species that ranged in flowering time. We also selected species adapted to local mesic conditions. We purchased local genotype seed, with the exception of Illinois bundleflower, which occurs naturally west and south of Wisconsin (Shooting Star Native Seed, Spring Grove, Minnesota).

We found no peer-reviewed research on germination rate and biomass production of native legumes interseeded into existing prairie. An establishment trial in Minnesota found a linear relationship between seeding rate and plant population when five native legume species were paired with little bluestem (*Schizachyrium scoparium*) and seeded into tilled ground in June (Fischbach 2005). Germination rates showed a significant inverse relationship to seeding rate, with the highest percentage of pure live seeds (PLS) developing into plants occurring at the lowest planting rate (14 PLS m⁻²). We planted 20 PLS m⁻² for each of five species. This resulted in a legume mix seeding rate of 100 PLS m⁻² (3.8 kg ha⁻¹). We used estimates from the seed supplier (number of PLS gram⁻¹) to calculate the weight of seed needed for each species.

We interseeded using a Truax no-till drill (Minneapolis, Minnesota), an implement designed for interseeding in grasslands with minimal disturbance. We interseeded on June 26, 2009, following completion of the June grazing and mowing treatments. Prior to planting, each species was inoculated with appropriate *Rhizobium* bacteria to promote healthy growth of legume seedlings.

Grazing

We employed rotational grazing management methods and tools commonly applied by farmers in the upper Midwest. A three-strand high tensile electric fence surrounds each WICST Prairie block. We used portable electric fencing to define grazing paddocks within each block. Logistics prohibited us from grazing all experimental units on the same day. In order to reduce spatial and temporal variability within grazed treatments, we created paddocks that allowed cattle to simultaneously graze both the legume mix interseeded (IS) and no added legumes (NIS) experimental unit within each diversity treatment. We made water and salt available only at the boundary between IS and NIS experimental units to reduce cattle preference to graze in one experimental unit versus another. This design yielded nine paddocks during each round of grazing management; given our stocking rate, we were able to complete grazing treatments across all plots within 7-9 days.

We stocked the grazing treatment with a cohort of six Holstein heifers (*Bos taurus*) used in the WICST rotational grazing production system. Average animal weight was 230 kg in June and 270 kg in July. Cattle were supplemented with 2 pounds of corn per heifer on a daily basis.

These cattle graze on pasture dominated by cool season grasses and forbs from May to November. We provided acclimation plots within the WICST Prairie blocks, outside of the experimental units, allowing the cattle to graze stands of restored LD and HD prairie and SG monoculture for two days prior to grazing on the first experimental unit. This provided the cattle an opportunity to adapt to new forage species, as well as providing an opportunity for the researchers to observe how the cattle react to prairie and switchgrass swards prior to beginning management treatments on the experimental units.

We followed recent recommendations for managing grazing to optimize forage production and stand vigor (Mousel et al. 2005). We initiated grazing in early June, when warm season grasses were 30-45 cm in height and grasses had matured to the 4-5 leaf stage and were on the verge of the elongation stage. We allowed an average of 35 days of rest for each experimental unit before the second round of grazing, which began in early July. In the grazed treatments, the majority of C4 grass bunches had not matured to the elongation stage. In July, we adjusted the stocking rate due to high refusal rates of native forbs in prairie treatments and higher forage availability in SG plantings. We did not graze in August due to low forage availability in the LD and HD prairie stands.

Mowing

We mowed using a rear-mounted, PTO-driven rotary deck mower, an implement commonly used by a wide range of land managers, including farmers and restoration ecologists. The mower deck was adjusted to leave 15 cm of vegetation, a typical height selected for weed control in establishing prairies and similar to the residual height of warm season grasses observed in this study's grazing treatments. In order to minimize differences between treatments, we timed mowing to closely follow grazing events. In 2009, we mowed in mid-June and mid-July.

Data Collection

Species composition

We estimated species cover using a point-intercept method along transects (Elzinga Salzer & Willoughby 1998). At each point along a transect, we recorded all species intercepted when a thin rod was lowered vertically through layers of the canopy to the ground. In addition to species, we also recorded bare ground or litter if no living plant was intercepted. In each experimental unit, we followed transect observations with a walk through effort to record additional species present in that unit that we had not encountered on any transect.

We sampled at two times. June cover, sampled prior to application of disturbance treatments and legume interseeding, provides a baseline estimate of plant community composition. We sampled again at peak standing biomass in September, following completion of management.

Productivity and Available Forage

We harvested vegetation to estimate aboveground net primary production (ANPP) and available forage quantity. To estimate ANPP, biomass is clipped to ground level in a 0.25 m² quadrat. Sampling occurs in June and July to provide estimates of ANPP during the growing season and in September to estimate peak standing biomass. In grazed and mowed plots, we sample ANPP before and after management to estimate the amount of biomass removed by management.

To estimate available forage parameters, we modified the ANPP sampling protocol to reflect animal behavior as well as our interest in the productivity and forage quality of native warm season grasses. Available forage is a subset of the aboveground biomass pool, due to the ability of cattle to select among species and to harvest select portions of an individual plant. Within a quadrat, we do not clip species that cattle repeatedly refuse to eat, as noted from direct observations of cattle grazing in prairie plots and from observing vegetation patches grazed by cattle. Vegetation is clipped to 10 cm to simulate residual height of grazed vegetation.

Forage quality

Forage samples are analyzed using near infrared reflectance spectroscopy (NIRS) to estimate acid detergent fiber (ADF), neutral detergent fiber (NDF), digestible neutral detergent fiber (dNDF), crude protein (CP), and dry matter (DM). From these parameters we can calculate the relative forage quality (RFQ) of each sample.

Legume Establishment

To estimate native legume germination in the summer of 2009, we used stratified random sampling to locate five 0.5 m² quadrats per IS experimental unit. We used a 1 m by 0.25 m quadrat, a width adequate to for sampling 5 no-till rows per quadrat when the frame was randomly located along an east-west transect. In each quadrat, we identified legume seedlings rooted inside to native or nonnative and recorded counts of native legume seedlings by species. We also recorded presence/absence of mature native legumes and of nonnative legumes of any growth class rooted in each quadrat.

Work will be repeated for another growing season.

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Table 1. Native species seeded in low diversity and high diversity prairies

Common name	Botanical name	Functional group	Low diversity	High diversity
big bluestem	<i>Andropogon gerardii</i>	C4 grass	X	X
Canada wild rye	<i>Elymus canadensis</i>	C3 grass	X	X
indiangrass	<i>Sorghastrum nutans</i>	C4 grass	X	X
wild onion	<i>Allium cernuum</i>	forb		X
butterfly milkweed	<i>Asclepias tuberosa</i>	forb		X
New England aster	<i>Aster novae-angliae</i>	forb		X
Canada milkvetch	<i>Astragalus canadensis</i>	legume		X
white wild indigo	<i>Baptisia leucantha</i>	legume		X
prairie tickseed	<i>Coreopsis palmata</i>	forb		X
showy tick trefoil	<i>Desmodium canadense</i>	legume	X	X
rattlesnake master	<i>Eryngium yuccifolium</i>	forb		X
northern bedstraw	<i>Galium boreale</i>	forb		X
prairie smoke	<i>Geum triflorum</i>	forb		X
sawtooth sunflower	<i>Helianthus grosseserratus</i>	forb		X
showy sunflower	<i>Helianthus pauciflorous</i>	forb		X
round-headed bush clover	<i>Lespedeza capitata</i>	legume	X	X
wild bergamot	<i>Monarda fistulosa</i>	forb		X
prairie cinquefoil	<i>Potentilla arguta</i>	forb		X
yellow coneflower	<i>Ratibida pinnata</i>	forb	X	X
pasture rose	<i>Rosa carolina</i>	woody shrub		X
black-eyed susan	<i>Rudbeckia hirta</i>	forb	X	X
rosinweed	<i>Silphium integrifolium</i>	forb		X
stiff goldenrod	<i>Solidago rigida</i>	forb		X
spiderwort	<i>Tradescantia ohioensis</i>	forb		X
prairie violet	<i>Viola pedatifida</i>	forb		X

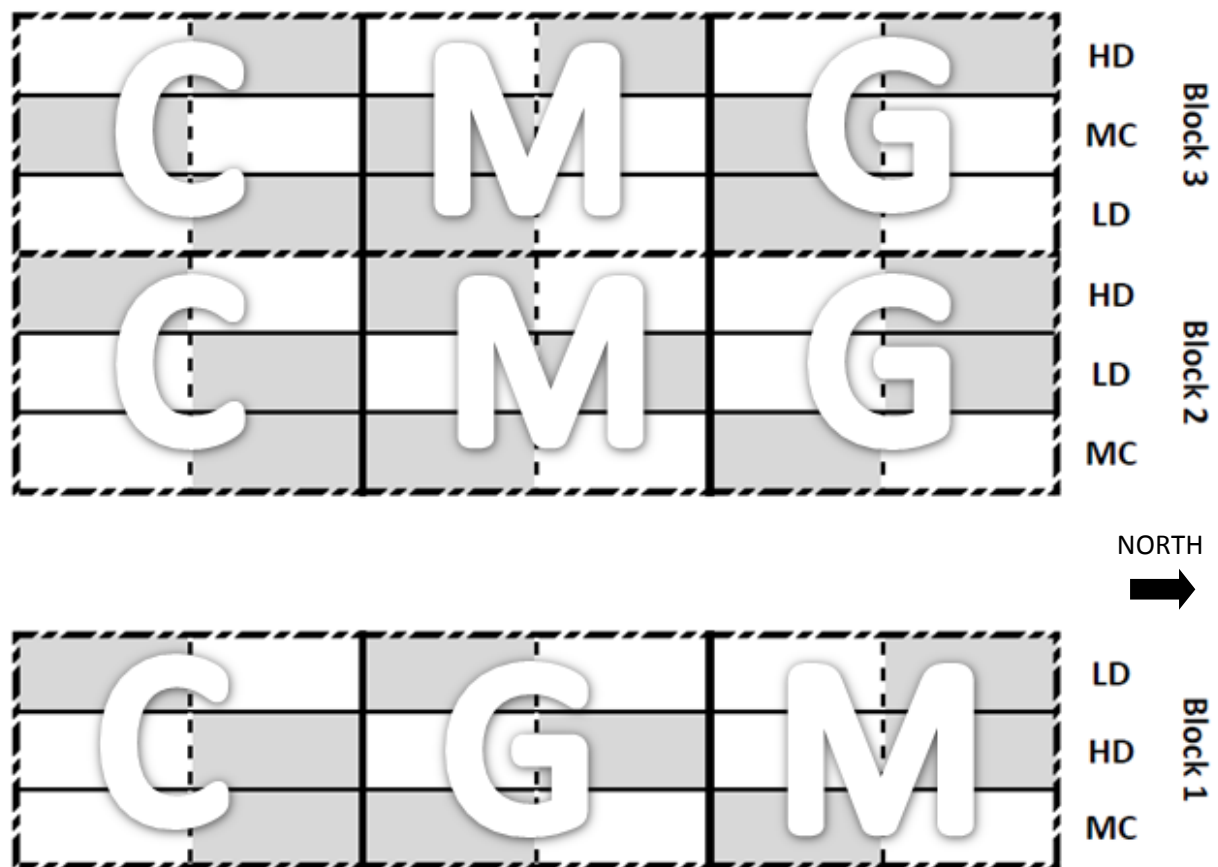


Figure 1. Experimental design at WICST. Original diversity treatments (HD – high diversity prairie; LD – low diversity prairie; MC – switchgrass monoculture) are 105 m by 13 m. Management treatments (C – control; M – mow; G – graze) are applied in a randomized complete block design. Shading indicates legume interseeding in a split plot of management x diversity. Block 1 and Block 2 are 70 m apart, separated by cropped fields. Block 2 and Block 3 are separated by a fence.

EFFECTS OF PLANT DIVERSITY AND MANAGEMENT ON NITROGEN RETENTION IN PERENNIAL BIOMASS PRODUCTION SYSTEMS

Laura Smith and Randy Jackson

JUSTIFICATION

There is increasing pressure on agroecosystems to provide fuel in addition to food. In order to sustainably meet these demands, we must improve the nitrogen use efficiency (NUE) of crops because of the high costs of producing N-fertilizers and the loss of nitrogen to water and atmospheric sinks can be a major problem. One way to achieve this is to use cropping systems that are inherently N-use efficient. Switchgrass and diverse prairie are two such cropping systems that are currently being considered for cellulosic feedstock production. While much is known about these ecosystems in unmanaged settings, it is imperative to understand how biomass can be produced, fertilized, and harvested without reducing their NUE and inherent abilities to recycle N. Biomass yields, efficient use of fertilizers, harvest efficiencies, and harvest schedules that produce adequate yields, but also retain N in the ecosystem, are some of the major constraints of sustainably producing biomass (Sanderson et al., 2006).

PREVIOUS WORK

There have been inconsistent reports on switchgrass (*Panicum virgatum*) biomass response to N fertilization. One study found the highest biomass production with 448 kg N ha⁻¹, but also revealed that applying 0 N produced almost as much biomass, suggesting that switchgrass like other C4 prairie grasses are adapted to low N conditions and have limited responses to N fertilization (Thomason et al., 2004). A lack of response to N fertilization has been found to be attributed to, as yet, uncharacterized microbial processes and the inherent N conservation strategies of the plants (Parrish and Fike, 2005). Warm-season C4 grasses are generally thought of as having a high NUE relative to other species, but it has yet to be determined how their N conservation and NUE strategies are affected when managed for biomass production.

Recommended fertilizer rates for switchgrass are dependent on the various factors such as site, cultivar, and management. Switchgrass grown in the Midwest with a Fall harvest and fertilization level between 56 and 112 kg N ha⁻¹ optimized yields, while still maintaining favorable biomass quality for biofuel conversion (Lemus et al., 2008). Biomass N concentrations increased with N fertilization rates and decreased with later harvests because of decreasing N concentrations in biomass during senescence (Vogel et al., 2002). Although, high rates of N fertilizer increased N removal with harvested biomass, the use of fertilizer was not found to increase the N-storage capacity in roots, which would be a more optimal characteristic to conserve N in these systems (Heggenstaller 2009). Switchgrass harvests in Spring were shown to have the best quality for biofuel biomass (low N concentrations), but had the lowest harvested yield (Adler 2006). Although the N retention is optimized with a Spring harvest, the yield loss may be significant. Balancing the trade-offs between biomass production and nutrient retention for ecosystem function proves to be a continuing challenge.

OBJECTIVES

The main objectives of this research is to identify which management scenarios will promote nitrogen conservation in cellulosic perennial grass cropping systems and how endogenous

nitrogen resources are affected by harvest timing and nitrogen fertility under different levels of stand diversity. Experimental combinations of two levels of plant diversity (switchgrass monoculture and restored prairie), three harvest timings (peak-standing crop, post-frost, and Spring), and three levels of nitrogen fertilizer applications (0, 50, 150kg/ha N) are being tested. Two primary questions are being addressed:

1. How does management and stand diversity affect plant NUE?

Since the NUE of crops is dependent on the amount of above-ground net primary production (ANPP), below-ground net primary production (BNPP) and the N content in the biomass (ANPP-N and BNPP-N), the fertility rates applied to the cropping system will affect the N content of the NPP. NPP-NUE (nitrogen-use efficiency of net primary production) will be measured for all treatments, which is the ratio of total biomass (ANPP and BNPP) to the N content found in the biomass, driven by the amount of production among the treatments and the biomass quality (McCulley et al, 2009). The NUE depends on the amount of nitrogen available to the plant, which is why plant-available inorganic N will also be measured through the use of ion-exchange resin strips. The resin strips will provide an integrated look at the amount of inorganic N (nitrate and ammonium) available to the plants through time. Inorganic and organic soil N will be measured as the soil extractable nitrogen to reflect the changes in soil N pools. Decomposition rates of switchgrass litter are also being monitored to account for potential changes in the timing and quantity of N made available to plants. We hope that integrating these parameters will expose trends in the NUE and N dynamics affected by the management treatments. It is hypothesized that the fertilized plots will decrease in NUE and the plant-available N in soil will decrease as NUE increases. It is also expected that the more diverse stands will have a higher NUE because of increased N uptake and possible resource complementarity.

2. How does management affect N resorption?

Since N resorption is an important mechanism of N conservation, the resorption proficiency (the amount of N retained in a senesced leaf) and the resorption efficiency (the percent of N retranslocated in a senesced leaf before it abscises) will be tested in dominant species of both cropping systems. It is known that N resorption will be affected by the timing of biomass harvest since cutting before senescence will prevent plants from fully retranslocating N, thereby removing a significant source of N and likely reducing the fitness of the individual for the following growing season. Some studies have found plants with high N content resorb a smaller percentage of N (Norris 2009, Huang 2008), so resorption may be affected by fertility levels that increase biomass N content. It is hypothesized that resorption proficiency will increase with fertility and resorption efficiency will decrease with fertility.

METHODS

Study site and experimental design:

This work is being conducted on the WICST switchgrass and High-Diversity Prairie (HDP) plots from 2009-2010. The switchgrass plots were established in 2007, and the HDP plots in 1999. HDP plots were seeded with approximately 25 species, including native warm and cool-season grasses, forbs, and legumes. Although the switchgrass plots were treated with an herbicide application in June 2009, the switchgrass experienced significant weed competition in some

areas, which is why we sampled species composition for each plot in the switchgrass plots in addition to the HDP plots.

The southern eighth of the HDP and switchgrass plots were divided into six replicated blocks. Every combination of fertilizer rate and harvest treatment is represented, along with a “control” plot which received 0N and will never be harvested (Table 1). Treatments were randomized within each block. Three N-fertility treatments (0, 50, and 150 kg N ha⁻¹) and three harvest timings (peak-standing crop, post-frost, and Spring), and the control plot were replicated six times across both diversity levels of switchgrass and HDP. Therefore, there are 120 total experimental units with a plot size of 9.7m². The fertilizer, as NH₄-NO₃, was hand-applied at the corresponding treatment rates in mid- June.

Data Collection:

Species Cover

Species composition data was collected during the first week in August, which closely represented the species present and the time of peak-standing biomass. Data was collected as species cover, using a point-intercept method. A transect was drawn diagonally across each plot from corner to corner. A sharp object was lowered through the canopy every 20cm along the transect and every plant species that came into contact with the sharp object was recorded for that particular plot. Therefore, numerous species throughout the canopy could be recorded for each individual point on the transect, with 25 possible points recorded. Percent cover was calculated for each plot by summing the number of hits for each species, divided by the total number of hits within the plot.

Soil N Pools

Ion-exchange resin strips were deployed from August through November in every experimental unit and replaced approximately once every month. Strips are extracted in 2M KCl for analysis of nitrate and ammonium concentrations. Soil N pools (nitrate, ammonium, and total dissolved nitrogen) will be measured from a composite sample of three soil cores (2.5cm x 15cm) taken from each plot in June (prior fertilization), August, and October. Soil was stored at 4°C until passed through a 2mm sieve to remove organic matter and rocks, and extracted in 2M KCl. Extracts are then filtered and frozen until analysis.

Litter Decomposition

To test decomposition rates, litter bags filled with senesced switchgrass biomass were deployed in July of 2009. All switchgrass biomass was sourced from the same site (Agrecol switchgrass field in Madison, WI). Litter bags will be incubated on the soil surface in all experimental units from July 2009 through Fall 2010, with a total of five collection events. Biomass from the initial litter and litter bag collections are weighed, dried at 60°C, reweighed, and ground for C/N analysis to determine total N content.

N resorption rates

Leaves from the dominant species (*Panicum virgatum*, *Andropogon gerardii*, *Sorghastrum nutans*, *Helianthus grosseserratus*, and *Solidago Canadensis*) are hand-collected from August to senescence to determine resorption proficiency and efficiency. Biomass samples are dried, weighed, and ground for C/N analysis.

Harvested and ANPP biomass

Respective plots were cut at the end of August for the peak-standing crop harvest treatment and the end of October for the post-frost harvest treatment. For the August harvest, there were biomass collections for two separate metrics: harvestable yield for biofuels and ANPP. The biomass was harvested using a sickle-bar mower cutting a 28 inch pathway through the middle of each individual plot. The mower was adjusted to cut biomass that left approximately a 6 inch stubble height. Biomass was manually raked, collected, and weighed in the field to determine the field wet-weight. The biomass from each plot was then chopped using a field flail-chopper to homogenize the total plot harvest for a representative grab sample. The grab sample was weighed, dried for 1 week in a 60° drier, and reweighed to calculate percent moisture. The percent dry matter was then applied to the total harvest weight of each plot, thereby reporting the biomass weight on a dry matter (DM) basis. Since the harvest treatment required a 6 inch stubble height for biofuel management, a sub-sample of the remaining stubble biomass was taken to adjust the harvested yield to total ANPP of the plot. A 20cm² quadrat was systematically placed in the plot and biomass was cut to the ground level. The stubble biomass was weighed and dried in the same manner to calculate the additional DM that was added to the harvested DM yield to determine the total ANPP of each plot. The post-frost harvest was taken the end of October in the same manner as the August harvest. However, only harvestable biomass data was collected (the stubble biomass was not accounted for). A harvest in Spring of 2010 will be taken in a similar manner.

CONCLUSION

NUE, decomposition rates, and N resorption rates are all significant determinants of N retention and we hope will provide conclusions as to how different management scenarios and stand diversity affect N conservation. Results from this study will demonstrate the trade-offs between maximizing biomass production, and nitrogen retention in switchgrass and prairie cropping systems while also determining some best-management recommendations for biomass production.

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Table 1. Treatment combinations for switchgrass monoculture and HDP diversity levels

Harvest Treatment	Fertility Treatment (kg N ha⁻¹)
Peak-standing biomass (August)	0
Post-frost (October)	50
Spring (April)	150
Peak-standing biomass (August)	0
Post-frost (October)	50
Spring (April)	150
Peak-standing biomass (August)	0
Post-frost (October)	50
Spring (April)	150

DUAL-CROPPING TO IMPROVE THE ECONOMIC FEASIBILITY OF SWITCHGRASS ESTABLISHMENT

Rachael Cox, Josh Posner, Janet Hedtcke, and Gregg Sanford

THE CHALLENGE

Switchgrass (*Panicum virgatum*) has been identified as a potential biomass crop for biofuel production. Switchgrass, a native, warm-season perennial, needs approximately two years in Wisconsin in order to be sufficiently established to permit harvesting (Vogel et al. 2002), however may not reach full yield potential until the third year. As the demand grows for switchgrass production, more producers may become interested in establishing switchgrass on their farm, however may be hesitant to do so, due to the lack of income generation during the establishment period. In order for producers to be able to grow switchgrass, economically feasible systems for the establishment period need to be designed. The purpose of this study is to look at several dual cropping options with small grains that will allow farmers to realize economic gains during the establishment phase of switchgrass, but also without reducing early switchgrass productivity.

OBJECTIVES AND OUTCOMES

1. Develop agronomic systems (i.e. small grain systems) which allow for economic gain during the first two years of switchgrass establishment.
2. Develop agronomic systems which meet economic needs of producers in the short and long term of switchgrass production (weed control and stand).

RESEARCH PLAN (SEE FIGURE 1)

The switchgrass establishment systems include planting switchgrass in May following a winter rye crop harvested for biomass or planting in later July following wheat harvested for grain. The second factor will be to see if a crop of winter wheat can be planted in the fall of the seeding year without adversely effecting biomass yields. The resulting six systems being compared are summarized as:

1. The year prior to switchgrass establishment, winter wheat is planted in October, harvested in July, and switchgrass is no-till planted following the harvest. The switchgrass is then allowed to grow to maturity without further intercropping.
2. The year prior to establishment, winter wheat is planted in October, harvested in July, and switchgrass is no-till planted following the harvest. In the October following switchgrass planting, a second crop of wheat is no-till drilled into switchgrass seedlings.
3. The year prior to establishment winter rye is planted in October, harvested in late May for biomass, and switchgrass is no-till planted following the harvest. The switchgrass is then allowed to grow to maturity without further intercropping.
4. The year prior to establishment, winter rye is planted in October, harvested in late May for biomass, and switchgrass is no-till planted following the harvest. In the October following switchgrass planting, winter wheat is no-till drilled into switchgrass seedlings.

5. The control will be to establish switchgrass under best management practices developed by the university. Switchgrass will be planted in June, not following a winter small grain.
6. A second control will include switchgrass established under BMP in year one followed by winter wheat planted into the stand in the fall of the seeding year.

Figure 1: Example of plot layout for one repetition of the six treatments prescribed over the 2 year establishment period.

Year 1					
Winter Wheat Switchgrass planting July		Winter Rye Switchgrass planting June		No Prior Crop Switchgrass planting June	
Year 2					
Switchgrass	Switchgrass and Winter Wheat	Switchgrass	Switchgrass and Winter Wheat	Switchgrass	Switchgrass and Winter Wheat
Tmt 1	Tmt 2	Tmt 3	Tmt 4	Tmt 5	Tmt 6

The study is designed as a randomized complete block, with four replications at each of the three selected sites. One field study will be at Arlington Research Station in conjunction with WICST and GLBRC plots, on well-drained loam soils. Two other sites have been established on-farm in Rio, Wisconsin (sandy soils) and Sugar Creek, Wisconsin (poorly drained soils). Basic site characteristics can be viewed in Table 1 and locations can be viewed in Figure 2.

Table 1: Site characteristics for three trial locations in Wisconsin.

	Arlington	Rio	Sugar Creek
Organic Matter	4.10	1.54	2.35
pH	6.83	6.57	7.33
Phosphorus	114.8	39.1	58.9
Potassium	145.4	155.1	131.5
Soil Texture	Sandy loam	Silt loam	Silt loam
Production practices	tillage and no-till	no-till	no-till
Location	Research station	on-farm	on-farm

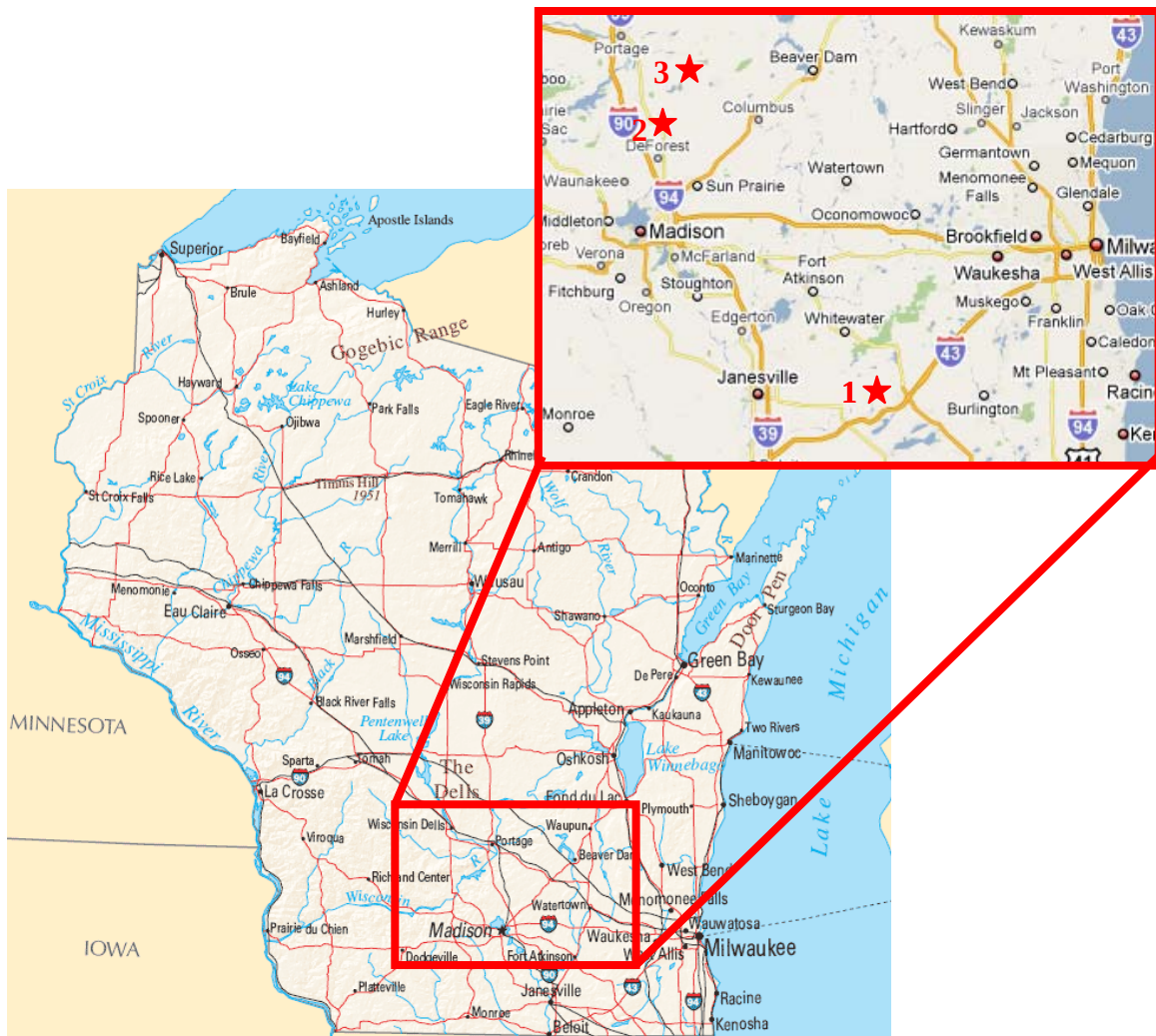


Figure 2: Map of Wisconsin illustrating the location of each of the trials (1- Sugar Creek, 2- Arlington, and 3- Rio).

Weed control is an important aspect of switchgrass establishment, and we intend to use best management practices for weed control in switchgrass as defined by the University of Wisconsin Extension service. This set of practices engages a variety of herbicides which can be viewed in Table 2.

Table 2. Herbicides for use in establishing switchgrass

Herbicides	Active ingredient	Rate product/A	Timing*	Cost/A
Broadleaf and grass control				
Certainty [#]	Sulfosulfuron	0.75-2.0 oz/a	PRE or POST 3-4 leaf	\$50-135
Drive [#]	Quinclorac	0.5-1.0 lbs/A	PRE or POST 3-4 leaf	\$35-75
Journey [@]	glyphosate + imazapic	5.4-10.7 fl oz/A	PRE	\$6-11
Plateau [@]	imazapic	2-4 fl oz/A	POST 3-4 leaf	\$5-10
Pursuit	Imazethapyr	2-4 fl oz/A	PRE or POST 3-4 leaf	\$10-20
Broadleaf control				
2,4-D	2,4-D	1-4 pints/A	POST 3-4 leaf	\$2-8
Ally/Escort	metsulfuron	0.1 oz/A	POST 3-4 leaf	\$2-3
Many	Dicamba	0.5-1.0 pt/A	POST 3-4 leaf	\$5-10
Weedmaster	2,4-D + Dicamba	1-2 pints/A	POST 3-4 leaf	\$4-8
* If post-emergent, addition of a surfactant will improve results, please consult the label. # labeled for use in establishing native grasses in specific situations, please consult the label for additional information. @ Products containing imazapic have shown significant injury that on occasion has resulted in extensive switchgrass mortality at specific locations. Use caution with products containing these active ingredients in switchgrass fields.				

Source: <http://www.uwex.edu/ces/forage/pubs/switchgrass.pdf>

Over the course of the three year establishment period and first biomass harvest, the six systems will be compared using the following criteria:

1. Small grain yields and switchgrass biomass production
2. Economic profitability over the three-year establishment period
3. Switchgrass stand, measured by percent groundcover.
4. Weed stand, as estimated by percent groundcover and biomass in the third year.

The research trial was established in September 2009 at all three locations and we envision a second “start-up” in the fall of 2010. This will ultimately result in testing these systems in 6 environments (3 locations, 2 starting dates).

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INITIATING GREENHOUSE GAS MEASUREMENTS ON SELECTED WICST TREATMENTS

Gary Oates

INTRODUCTION

Carbon dioxide (CO₂), nitrous oxide (N₂O) and methane (CH₄) are greenhouse gases (GHG) that are accumulating in the atmosphere (Robertson *et al.*, 2000; Levitus *et al.*, 2001; Santer *et al.*, 2003; Barnett *et al.*, 2005). Human activities and land use practices have altered local, regional, and global C cycles (Vitousek *et al.*, 1997). Atmospheric concentrations of CO₂ have increased from 280 ppm pre-industrial concentrations (AD 1000 - 1750 [IPCC 2007]) to 385 ppm in 2008 (NOAA 2009). Most of these increases are from fossil fuel burning and land use change (IPCC 2001). In 2001, the Kyoto Protocol was expanded from recognition of C fluxes related to afforestation, deforestation and reforestation; to include terrestrial C fluxes from land management systems including forest management, crop and production systems, and revegetation (Swift, 2001). The terrestrial biosphere is a known sink for CO₂ (IPCC 2001), but annual C balance is strongly dependent on management.

Agriculture plays a major role in the global flux of these gases. Management of agricultural systems has been promoted as a means to mitigate global mean radiative forcing by improving soil organic carbon (SOC) storage, decreasing CH₄ emissions by promoting soil CH₄ oxidation, and decreasing N₂O emissions (Robertson *et al.*, 2000). Management practices that include 1) reduced tillage, 2) reduction or split applications of nitrogen fertilizer, 3) cover crops and perennial vegetation, and 4) manipulation of animal diets and manure handling and application all provide opportunities to reduce environmental impacts of GHG emissions (Johnson *et al.*, 2007).

In order to understand the role agriculture, and specifically crops for biofuels, has on GHG emissions, various bio-energy productions systems (grain-based, perennial, woody, native grassland, and integrated perennial/annual crop) were established in 2008 at the Arlington Agricultural Research Station at the University of Wisconsin as part of the Great Lakes Bioenergy Research Center (GLBRC). Monitoring sites were also established at the WICST and include conventionally managed continuous corn, no-till corn-soybean rotation, fertilized switchgrass monoculture, and both low (~6 species) and high (~25 species) diversity restored prairie. Since spring 2008, fluxes of GHG have been measured on three repetitions of five WICST systems, as well as on all five replicates of the newly established systems (GLBRC). Our objective is to compare the impact of mature systems vs. systems undergoing establishment on GHG emissions, specifically, carbon dioxide, nitrous oxide and methane gases.

METHODS

Vented, static chambers are used to sample CO₂, N₂O, and CH₄ fluxes between the atmosphere and the terrestrial environment (Livingston and Hutchinson, 1994). In each treatment plot, one circular 20-cm diameter × 6-cm deep PVC collar is installed into the ground approximately 2 cm below ground surface. Ideally these are installed once and measurements are always taken from the same location. In the case of machinery traffic, the collars are removed and then re-set. With row crops the collars are located between the rows and in solid seeded crops the vegetation is

hand clipped to 5-cm stubble height and removed to facilitate chamber installation. In an effort to reduce disturbance of the sample area, trampling is minimized during the installation of the chambers and during the sampling period. A 30-min lag period following installation is allowed for equilibration of the soil atmosphere.

Sampling begins with the fitting of 20-cm diameter $\times$ 2-cm deep PVC hats over the previously installed collars. The PVC hats are fitted with a 2-mm diameter vent and a septum for syringe insertion. Immediately following installation of the hat, gas is extracted (t_0) using a 30-ml nylon syringe and a 23-gauge needle, and the procedure will be repeated on the remaining collars. Subsequent extractions are made at 20 (t_1), 40 (t_2) and 60 (t_3) min. intervals. Gas samples are then loaded into 30-ml glass vials fitted with 2-cm rubber septa. Field standards are collected, which consist of ambient air and gas standards (1 ppm N_2O and CH_4) to assess potential storage degradation prior to analysis. Vials are transported to UW-Madison where samples are analyzed by gas chromatography for CO_2 using a Thermal Conductivity Detector (TCD), N_2O using an electron capture detector, and CH_4 with a flame ionization detector (Shimadzu GC-14B, Shimadzu Analytical and Measuring Instruments Division, Kyoto, Japan). Fluxes are determined via linear regression through the 1-h period for each chamber (Robertson, 1999). Sampling takes place bi-weekly starting as soon as the ground has thawed (about April 15) and continues biweekly until the ground freezes (about Nov. 15). After important events like manure or anhydrous nitrogen applications, daily measurements are made for the following 3-5 days.

RESULTS

Data analysis has just begun. Figure 1 shows the mean N_2O emission rates from three of the systems that the two trials have in common during several two sampling dates from the fall of 2008. Production of N_2O was greater in the newly planted prairie treatment at GLBRC, while there are no differences between continuous corn and switchgrass at the two locations.

Methane flux followed a different pattern. Oxidation was observed in both the continuous corn and the prairie at GLBRC, while at WICST, CH_4 was neither oxidized nor produced in these two treatments (Fig. 2). However, methane was produced in the switchgrass plots at WICST, while it was neither oxidized nor produced at GLBRC site (Fig. 2). A possible hypothesis is that the switchgrass at WICST was planted in a former waterway and may have suffered from some microsite anaerobic conditions.

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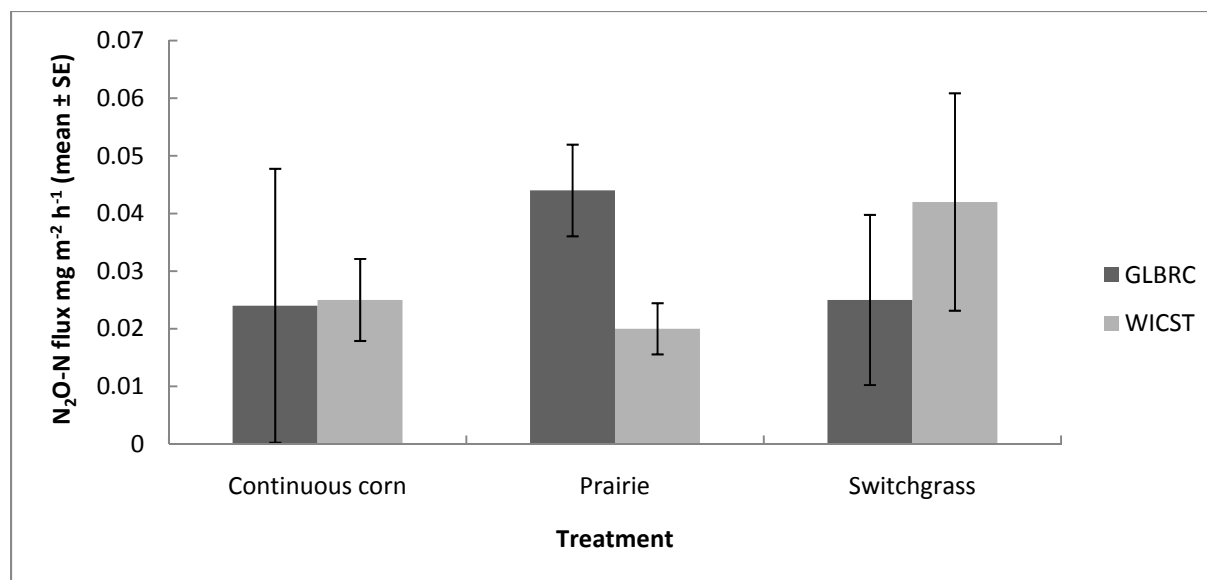


Fig. 1. N_2O production in annual and perennial cropping systems from 2008. Cropping systems at GLBRC were in establishment year, while systems in WICST were 1) continuous corn - 20y, 2) prairie - 10y and, 3) switchgrass - 2y.

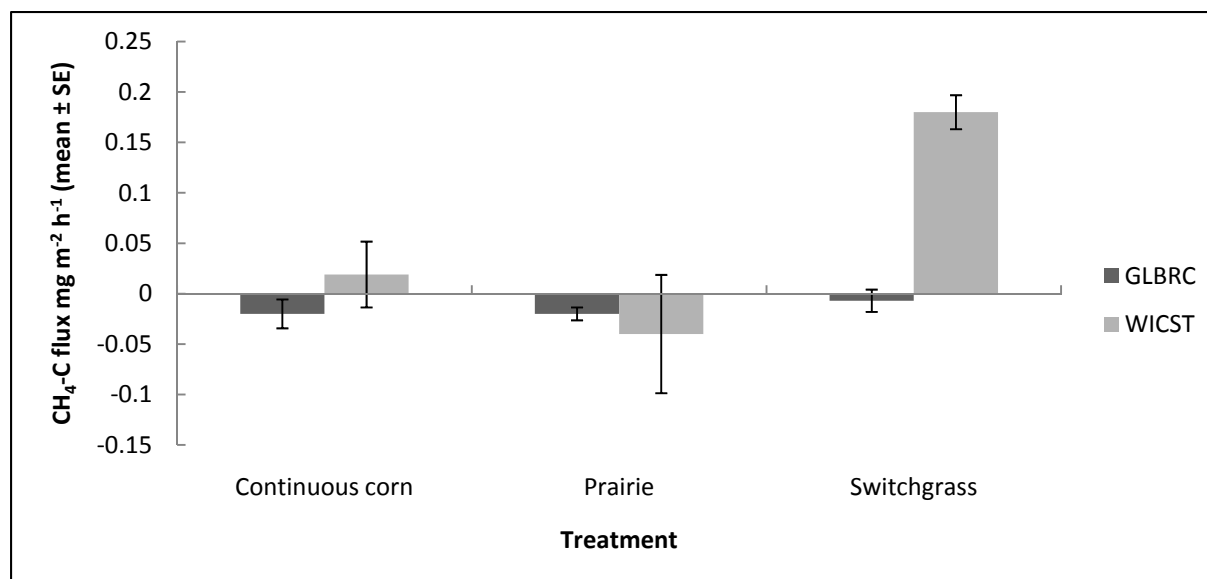


Fig. 2. CH_4 oxidation and production in annual and perennial cropping systems from 2008. Cropping systems at GLBRC were in establishment year, while systems in WICST were 1) continuous corn - 20y, 2) prairie - 10y and, 3) switchgrass - 2y.

PRODUCTION SUMMARY FROM WICST AND THE BIOFUELS TRIAL

Gregg Sanford, Janet Hedtcke, Joshua Posner, and Randy Jackson

INTRODUCTION

The Energy Independence and Security Act of 2007 set a target of 36 billion gallons of biofuel to be produced annually within the USA by 2022. Of the total 36 billion gallons, 16 billion is to come from cellulosic ethanol and 5 billion gallons from biomass-based diesel and other “advanced biofuels” (from feedstocks other than corn starch). As a significant proportion of our fuel demand is mandated to come from renewable energy in the next decade, research was needed to resolve currently limiting factors in biofuel production. In 2007, the U.S. Department of Energy awarded \$125 million to the UW College of Agriculture and Life Sciences to create the Great Lakes Bioenergy Research Center (GLBRC) based at UW-Madison to overcome bottlenecks in commercial production of cellulosic ethanol. The funding was distributed amongst 6 research themes or thrusts. Thrust 4, “Development of a Sustainable Biofuel Economy”, is focused largely on the economic and environmental sustainability of biomass production and is discussed in this report. Two locations were chosen for field trials to evaluate ten model bio-energy production systems (grain-based, perennial, woody, native grassland, and integrated perennial/annual crop): the Michigan State University’s Kellogg Biological Station located in Hickory Corners, MI (KBS at MSU, 42°24’17”N, 85°24’00” W) and the UW’s Arlington Agricultural Research Station located in Arlington, WI (AARS, 43°18’09”N, 89°20’46”W). A summary of the newly established cropping systems can be seen in Fig. 1 and Table 1. This new trial at AARS was merged with some of the same existing systems from the WICST plots established 10 years ago in the case of the native plots and 20 years ago for the crop plots (Fig. 2). These sites will be used to estimate the production potential of biofuel cropping systems, monitor microbial, biogeochemical, and biodiversity indices, evaluate the economic viability of each system, and produce data for regional climate modeling analyses (as described in projects 2-6 of Thrust 4 of the GLBRC).

MATERIALS & METHODS

In the spring of 2008, new plots (140’ x 90’) were established on the west side of the Arlington Research Station (about 5 miles from WICST) in a RCB design replicated in 5 blocks hereafter referred to as the bio-fuels sustainability trial (BST). The WICST plots included in the bioenergy research currently include 3 reps each of continuous corn (CS1), no-till corn-soybean rotation (CS2), switchgrass, and both low (~6 species) and high (~25 species) diversity restored prairie (Fig. 2). Each plot at both trials contains a set of permanent sampling stations at which most within-plot sampling will be performed (Fig. 3). Prior to or just at establishment, baseline soil samples were collected to characterize soil fertility and soil carbon among other things. In addition, greenhouse gas (GHG) chambers were installed in each plot 10m from the southern end of the plots where, bi-weekly measurements of GHG are taken throughout the season. Further description of GHG collection is described by Dr. Oates in this 12th WICST Technical Report.

Year 1 (2008) Objectives:

- 1) Established crop & prairie experimental systems on the BST

- 2) Background soil sampling and assessment of geospatial variability of field site on BST
- 3) Assess annual cropping systems' performance for crop yield and quality on both BST and WICST. Yields reported here are from field-scale machinery and large areas. Crop quality analytical assessment protocols were established for fatty acid profiles of oilseeds, and ethanol yield of starch and cellulosic bioenergy crops were analyzed at MSU (data not discussed here).

Year 2 (2009) Objectives:

- 1) Manage all cropping systems for sustainable production using BMP's
 - a. Plant corn and soybean (same dates and varieties as WICST) and canola
 - b. Inter-seed oat cover crop under poplar trees
 - c. Maintain filler plots and alleys
- 2) Establish subplots on BST:
 - a. Split corn plots into grain only (western 15ft.) and grain+stover (eastern 75ft.) removal: harvest sub-plots in soybean and corn to evaluate crop residue legacy.
 - b. +N and -N treatments applied to the 'old field' system (+N eastern 75ft., -N western 15ft.)
- 3) Modify harvest operations
 - a. On WICST, native plots too small for large truck/chopper traffic so use 7' sickle-bar mower and bar rake and flatbed wagon for biomass
 - b. custom hire swather for canola harvest vs. sickle bar mower
 - c. to improve harvest efficiency, a new flail chopper was purchased for corn stover collection
 - d. subplots harvested with plot combines from other departments
- 4) Establish auxiliary plots on BST
 - a. bio-char switchgrass study (Jessica Miesel)
 - b. miscanthus nursery – transplants from main plots and greenhouse
 - c. switchgrass establishment (Rachael Cox)
- 5) Continue monitoring
 - a. GHG collection
 - b. Weather station
 - c. Soil temperature (2, 10, and 30cm) and volumetric soil water content moisture (20cm)
 - d. Soil –bulk density, fertility
 - e. Nitrogen mineralization (resin strips)

RESULTS & DISCUSSION

Yields of grain and biomass from 2008 and 2009 are reported in Tables 2 and 3. Since corn residue was not harvested from the WICST plots, stover harvest is estimated based on corn harvest indices and subsequent stover harvest efficiencies from the BST. Also, since the perennial systems weren't considered established until year 2 (2009) some seeding year data was not recorded in 2008. Unfortunately the *Miscanthus* winterkilled during the winter of 2008-2009

so no data is available. An observational plot was reestablished however in one of the auxiliary plots with transplants from the surviving plants in reps 1-5 and from greenhouse plugs. Poplar trees won't be harvested until 2012.

Harvest moistures were generally higher in 2009 than 2008 as a result of the cool growing season. Crop yields were good to excellent at both trials but some differences were apparent, especially in 2008 when BST grain yields were uniformly higher than those on WICST.

Suggested reasons for these higher yields at BST include: 1) the shorter legacy of continuous corn or the corn/soybean/canola rotation; 2) the recent application of manure in repetitions 4 & 5 there; 3) the previous 3-year alfalfa/orchardgrass stand where repetitions 1,2,& 3 reside; and 4) no-till transition effects. Over the 2 seasons, biomass yields from fully-established plots ranged from 1.1 tons DM/a for the old field treatment to 3.0 tons DM/a for corn stover.

Baseline soil organic data from the C/N analyzer are shown in Table 4 while routine soil test analyses are shown in Table 5. Soil C and N were generally higher on WICST than BST, primarily influenced by the established prairie treatments. Soil organic matter as measured by loss on ignition ranged from 36.9 g kg⁻¹ (3.69%) on BST to 38.1 g kg⁻¹ (3.81%) on the crop plots and 42.1 g kg⁻¹ (4.2%) on the native plots at WICST. High soil fertility at BST, especially P, shows the legacy of swine manure that was spread prior to the establishment of the trial. At its initiation in 1990, the WICST plots, due to their proximity to the Blaine Dairy facility also had similarly high STP levels.

SUMMARY

The BST was successfully established in 2008 and sampling from both BST and WICST was tightly coordinated between the BST and WICST teams. The use of a new field lab devoted to biofuels research at AARS will facilitate future data processing and storage.

Fig. 1. BST systems gradient across plant diversity (mono to polyculture) and life cycles (annual to perennial).

Project 4.1: Novel Production Systems

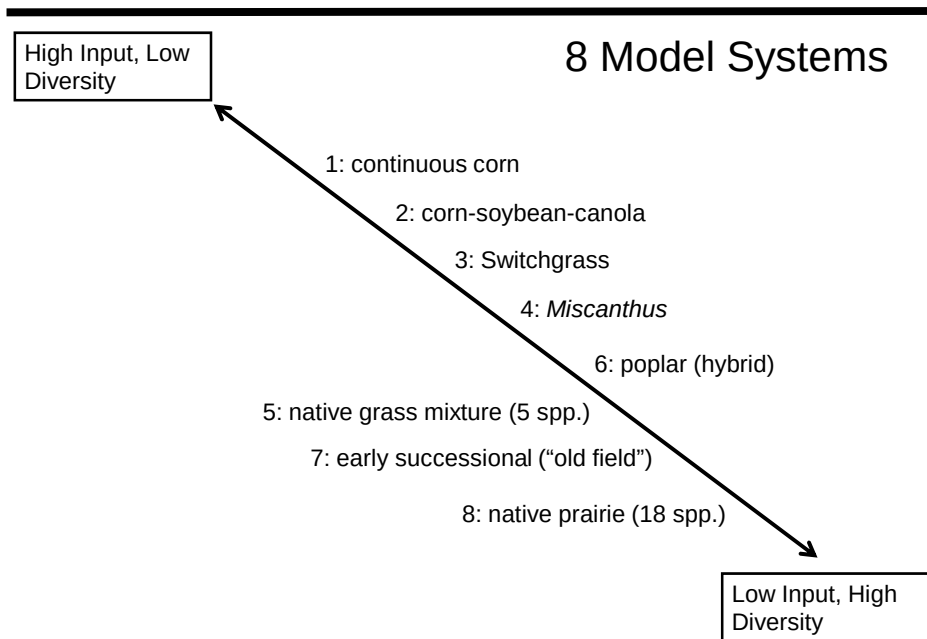
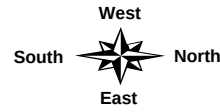


Figure 2. WICST biomass plot map



WICST Plot size = 510' x 60' Prairie Plot sizes = 510' x 45' (501,504-509); 510' x 40' (502-503)
E/W alleys (roadways) are 50' wide; N/S alleys between plots are 8 ft. wide. Metal plates positioned in center of both E/W and N/S alleys

414	CS4	T8	Alfalfa II		408	CS2	T2	No-till Soybeans	
413	CS5	T11	Organic Alfalfa I		407	CS3	T6	Organic Soybeans	
412	CS1	T1	Continuous Corn		406	CS4	T9	Alfalfa I	
411	CS3	T5	Wheat/bers clov-oats		405	CS6	T14	Pasture	
410	CS5	T12	Oatlage/alfalfa		404	CS4	T10	Direct-seed Alfalfa	
409	CS4	T7	Corn		403	CS5	T13	Organic Corn	
509	Native		High Diversity Prairie		402	CS3	T4	Organic Corn	
508	Native		Switchgrass		401	CS2	T3	Strip-till Corn	
507	Native		Low Diversity Prairie		309	CS4	T10	Direct-seed Alfalfa	
506	Native		High Diversity Prairie		308	CS4	T9	Alfalfa I	
505	Native		Low Diversity Prairie		307	CS3	T5	Wheat/bers clov-oats	
504	Native		Switchgrass		306	CS1	T1	Continuous Corn	
314	CS5	T12	Oatlage/alfalfa		305	CS4	T7	Corn	
313	CS3	T6	Organic Soybeans		304	CS5	T11	Organic Alfalfa I	
503	Native		Low Diversity Prairie		303	CS2	T3	Strip-till Corn	
502	Native		High Diversity Prairie		302	CS6	T14	Pasture	
501	Native		Switchgrass		301	CS3	T4	Organic Corn	
312	CS5	T13	Organic Corn		214	CS2	T3	Strip-till Corn	
311	CS4	T8	Alfalfa II		213	CS5	T12	Oatlage/alfalfa	
310	CS2	T2	No-till Soybeans		212	CS3	T6	Organic Soybeans	
114	CS5	T13	Organic Corn		211	CS5	T13	Organic Corn	
113	CS4	T8	Alfalfa II		210	CS4	T8	Alfalfa II	
112	CS6	T14	Pasture		209	CS4	T7	Corn	
111	CS4	T7	Corn		208	CS5	T11	Organic Alfalfa I	
110	CS5	T11	Organic Alfalfa I		207	CS6	T14	Pasture	
109	CS1	T1	Continuous Corn		206	CS2	T2	No-till Soybeans	
108	CS2	T2	No-till Soybeans		205	CS4	T10	Direct-seed Alfalfa	
107	CS4	T10	Direct-seed Alfalfa		204	CS1	T1	Continuous Corn	
106	CS3	T5	Wheat/bers clov-oats		203	CS4	T9	Alfalfa I	
105	CS4	T9	Alfalfa I		202	CS3	T5	Wheat/bers clov-oats	
104	CS3	T4	Organic Corn		201	CS3	T4	Organic Corn	
103	CS5	T12	Oatlage/alfalfa		D	Flextill		Corn	
102	CS3	T6	Organic Soybeans		E	Flextill		Wheat/Red clover	
101	CS2	T3	Strip-till Corn		F	Flextill		No-till Soybeans	
A	Flextill		Wheat/Red clover						
B	Flextill		No-till Soybeans						
C	Flextill		Corn						
<div>Grey Plots are not included in GLBRC monitoring</div>				Comments					Date & Operation:
				Operator					

Field 440 (WICST) 2009

Figure 3a. Permanent sampling stations on WICST

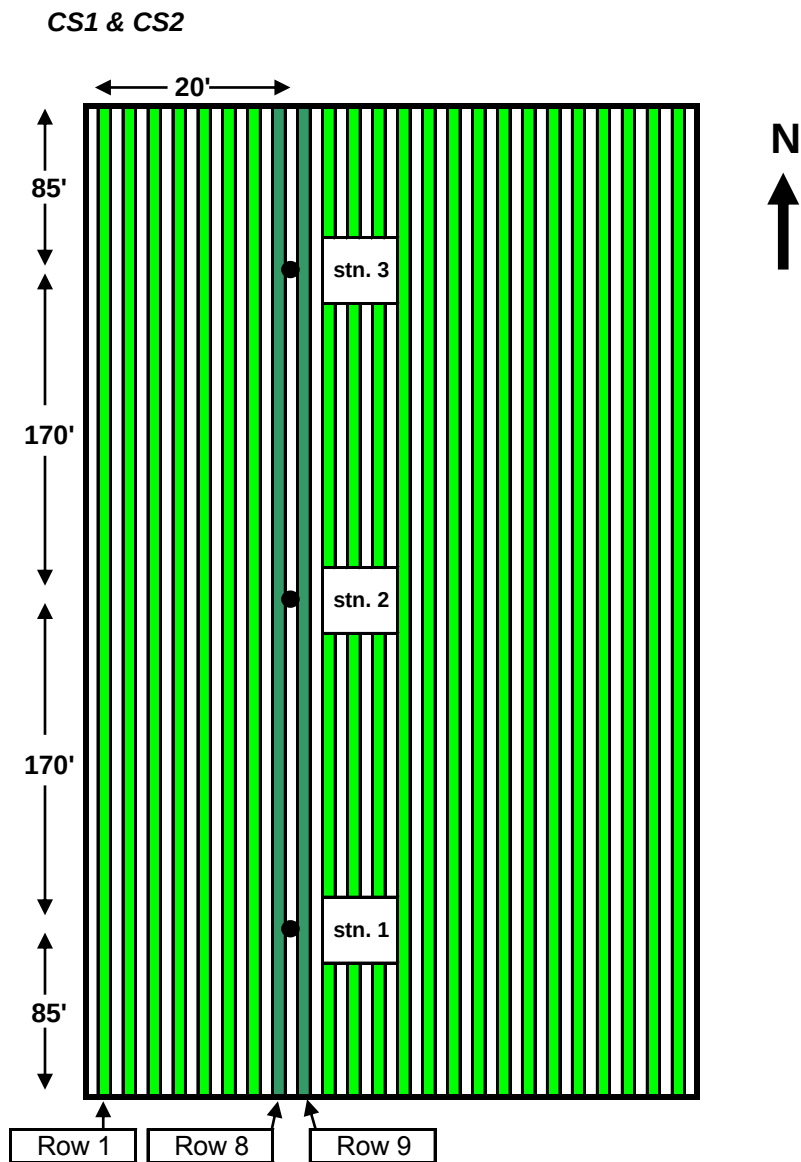


Figure 3b. Permanent sampling stations at BST

GLBRC Plots & WICST Prairie Plots

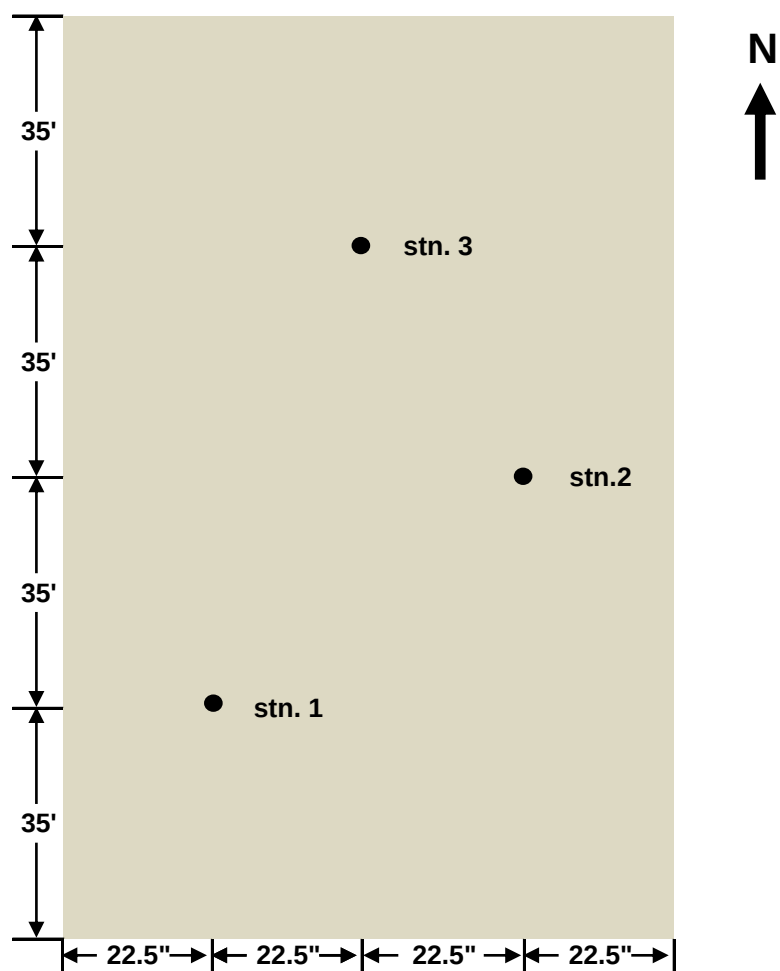


Table 1. Description of treatments on the BST.

System	Treatment	Crop	Details
1	G1	Corn	Continuous Corn (<i>Zea mays</i>)
2	G2	Corn	Corn – Soybean – Canola
	G3	Soybeans	Soybean (<i>Glycine max</i>) – Canola – Corn
	G4	Canola	Canola (<i>Brassica napus</i>) – Corn – Soybean
3	G5	Switchgrass	<i>Panicum virgatum</i> variety “Cave in Rock”
4	G6	Miscanthus	<i>Miscanthus giganteus</i> (<i>M. sinensis</i> x <i>M. Sacchariflorus</i>)
5	G7	Native Grasses	Switchgrass (<i>Panicum virgatum</i>), Canada Wild Rye (<i>Elymus canadensis</i>), Little Bluestem (<i>Schizachyrium scoparium</i>), Big Bluestem (<i>Andropogon gerardii</i>), Indiangrass (<i>Sorghastrum nutans</i>)
6	G8	Poplar	Hybrid poplar – NM6 (<i>Populus maximowiczii</i> x <i>Populus nigra</i>)
7	G9	Old Field	Successional weed community from pre-existing seed bank
8	G10	Native Prairie	<p>Grasses: Switchgrass (<i>Panicum virgatum</i>), Big Bluestem (<i>Andropogon gerardii</i>), Little Bluestem (<i>Schizachyrium scoparium</i>), Indian grass (<i>Sorghastrum nutans</i>), Canada Wild Rye (<i>Elymus canadensis</i>), Prairie Junegrass (<i>Koeleria cristata</i>)</p> <p>Legumes: Showy Ticktrefoil (<i>Desmodium canadense</i>), Round-headed Bushclover (<i>Lespedeza capitata</i>), White Wild Indigo (<i>Baptisia leucantha</i>)</p> <p>Forbes: Blackeyed Susan (<i>Rudbeckia hirta</i>), Canadian Anemone (<i>Anemone canadensis</i>), Butterfly Weed (<i>Asclepiastuberosa</i>), Bergamont (<i>Monarda fistulosa</i>), Cup Plant (<i>Silphium perfoliatum</i>), Prairie Coneflower (<i>Ratibida pinnata</i>), Stiff Goldenrod (<i>Solidago rigida</i>), Showy Goldenrod (<i>Solidago speciosa</i>), New England Aster (<i>Aster novae-angliae</i>)</p>

Table 2. Grain yields from WICST and BST in 2008 and 2009 at Arlington.

Trial	crop	treatment	year	Grain Yield (bu ac ⁻¹)				grain moisture
				n	Mean	SEM	CV	
BST	canola	G4	2008	5	20.9	2.7	28.5%	9.9%
BST	canola	G3	2009	5	36.7	2.5	15.4%	9.2%
BST	corn	G1	2008	5	206.8	12.1	13.1%	22.1%
WICST	corn	CS1 ¹	2008	3	142.1	15.6	19.1%	26.7%
BST	corn	G1	2009	5	199.6	4.0	4.5%	28.6%
WICST	corn	CS1	2009	3	204.1	3.4	2.9%	29.2%
BST	corn	G2	2008	5	192.8	5.5	6.4%	21.8%
WICST	corn	CS2	2008	3	177.5	1.7	1.7%	26.9%
BST	corn	G4	2009	5	208.2	6.8	7.3%	29.1%
WICST	corn	CS2	2009	3	205.6	1.3	1.1%	29.7%
BST	soybean	G3	2008	5	62.3	5.0	18.1%	13.9%
WICST	soybean	CS2	2008	3	46.4	1.7	6.4%	13.4%
BST	soybean	G2	2009	5	52.6	3.0	12.6%	15.4%
WICST	soybean	CS2	2009	3	48.1	0.9	3.1%	16.5%

¹ low yields due to low N in the soil profile from loss of N fertilizer from heavy rainfall in June 2008 and August 2007.

Table 3. Biomass yields at WICST and BST 2008 and 2009.

Trial	year	crop	treatment	Dry Matter Yield (ton ac ⁻¹)				harvest moisture	stover recovery
				n	Mean	SEM‡	CV§		
BST	2008	corn stover	G1	5	2.8	0.21	16.8%	42.0%	62.1%
WICST	2008	corn stover†	CS1	3	2.0	0.20	19.1%	--	--
BST	2009	corn stover	G1	5	3.2	0.10	7.1%	30.4%	78.9%
WICST	2009	corn stover	CS1	3	2.4	0.00	1.7%	--	--
BST	2008	corn stover	G2	5	2.7	0.25	20.8%	38.1%	63.3%
WICST	2008	corn stover	CS2	3	2.8	0.00	2.9%	--	--
BST	2009	corn stover	G4	5	3.0	0.27	20.5%	31.7%	77.2%
WICST	2009	corn stover	CS2	3	2.8	0.00	1.1%	--	--
BST	2008	prairie	G10	--	--	--	--	--	--
WICST	2008	prairie	hdp	3	1.4	0.22	27.0%	14.7%	--
BST	2009	prairie	G10	5	2.7	0.20	16.5%	36.0%	--
WICST	2009	prairie	hdp	3	1.2	0.04	6.1%	33.1%	--
BST	2008	mixed grass	G7	--	--	--	--	--	--
WICST	2008	low div. prairie	ldp	3	1.3	0.11	14.6%	16.2%	--
BST	2009	mixed grass	G7	5	2.0	0.39	44.0%	41.8%	--
WICST	2009	low div. prairie	ldp	3	1.7	0.21	22.1%	30.0%	--
BST	2008	switchgrass	G5	--	--	--	--	--	--
WICST	2008	switchgrass	sg	3	0.4	0.10	40.2%	11.2%	--
BST	2009	switchgrass	G5	5	1.5	0.34	51.5%	35.8%	--
WICST	2009	switchgrass	sg	3	2.0	0.05	4.1%	26.1%	--
BST	2008	miscanthus	G6	5	0.8	0.23	63.2%	36.7%	--
BST	2009	miscanthus	G6	--	--	--	--	--	--
BST	2008	old field	G9	5	1.9	0.28	33.9%	35.3%	--
BST	2009	old field	G9	5	1.1	0.04	8.3%	28.7%	--

†CS1 and CS2 corn stover are estimated based on BST yields: (lbs grain acre⁻¹)*0.492, n=20

‡SEM, standard error of the mean= s/sqrt(n)

§CV, coefficient of variation = s/mean

Table 4. Soil organic matter, carbon and nitrogen at 0-6" depth on WICST and BST, 2008.

Trial	Data	Source	Organic Matter (LOI)			Total Carbon (Dry Combustion)			Total Nitrogen (Dry Combustion)		
			g kg ⁻¹			g kg ⁻¹			g kg ⁻¹		
			AVE	SEM	CV	AVE	SEM	CV	AVE	SEM	CV
BST	Baseline	Rep 1	35.8	0.44	7.3%	19.4	0.36	11.1%	1.7	0.05	19.2%
		Rep 2	36.4	0.76	12.5%	21.1	0.53	14.9%	1.8	0.06	20.1%
		Rep 3	36.8	0.77	12.6%	20.9	0.53	15.1%	1.7	0.06	22.8%
		Rep 4	36.2	0.61	10.1%	20.7	0.38	11.1%	2.0	0.05	15.1%
		Rep 5	39.3	0.63	9.7%	24.1	0.41	10.3%	2.3	0.04	9.8%
WICST	Routine	CS1	39.2	1.60	12.2%	26.6	2.25	14.4%	2.4	0.17	12.1%
		CS2	37.0	0.13	14.3%	23.5	2.08	14.4%	2.3	0.14	10.1%
		hdp	43.2	1.42	9.9%	28.7	0.36	2.2%	2.6	0.06	3.9%
		ldp	42.0	0.97	6.9%	26.9	2.56	16.5%	2.5	0.22	15.1%
		sg	41.2	1.61	11.7%	24.1	1.37	9.9%	2.3	0.14	10.2%

hdp=high diversity prairie, ldp=low diversity prairie, sg=switchgrass

GLBRC soils are converted from 0-10 and 10-25cm horizons into one 15.24cm horizon: (value 0-10cm)*0.6562 + (value 10-25cm)*0.3438

CN samples for WICST are converted from 0-10 and 10-25cm horizons into one 15.25cm horizon: (value 0-10cm)*0.6562 + (value 10-25cm)*0.3438

CS2 values for CN are from plots 108, 310, and 408 only

sg values for CN should be considered baseline values. Samples were taken just prior to sg establishment in 2007.

Table 5. Soil test values at 0-6" depth on WICST and BST, 2008.

Trial	Data	Source	pH			STP			STK		
			mg kg ⁻¹			mg kg ⁻¹			mg kg ⁻¹		
			AVE	SEM	CV	AVE	SEM	CV	AVE	SEM	CV
BST	Baseline	Rep 1	6.5	0.04	3.5%	84.3	8.0	56.9%	134.8	9.7	43.2%
		Rep 2	6.5	0.03	2.4%	142.5	12.3	51.8%	137.0	9.2	40.1%
		Rep 3	6.5	0.05	4.3%	133.3	12.0	53.8%	115.0	8.8	46.0%
		Rep 4	6.6	0.05	4.3%	183.6	11.5	37.4%	206.0	10.1	29.5%
		Rep 5	6.4	0.05	4.7%	197.8	8.1	24.6%	207.3	9.0	25.9%
WICST	Routine	CS1	6.5	0.06	3.0%	56.2	3.1	16.5%	185.4	17.5	28.2%
		CS2	6.5	0.07	4.3%	42.9	3.5	34.2%	128.8	7.9	26.1%
		hdp	6.8	0.05	2.3%	56.0	3.3	17.6%	158.8	14.6	27.5%
		ldp	6.8	0.04	1.9%	57.3	1.6	8.5%	168.6	8.8	15.7%
		sg	6.8	0.05	2.3%	56.8	4.7	24.7%	161.7	14.9	27.6%

hdp=high diversity prairie, ldp=low diversity prairie, sg=switchgrass

RECYCLING MANURE NUTRIENTS



Linking Wisconsin Dairy and Grain Farms via Manure Transfer for Corn Production

Gregg R. Sanford,* Amy R. Cook, Josh L. Posner,
Janet L. Hedtcke, John A. Hall, and Jon O. Baldock

ABSTRACT

One relatively under-used manure management strategy employed by dairy farmers is to transport and apply manure onto the fields of nearby grain farmers. While this system offers advantages to both parties, little of the existing research on manure management has been conducted on grain farms. As part of an effort to link grain and livestock farms in southern Wisconsin, 20 on-farm trials were conducted to study the agronomic and environmental effects of including manure in cash-grain rotations. Manure was applied at a rate of approximately $107 \text{ m}^3 \text{ ha}^{-1}$ as slurry ($11,000 \text{ gal acre}^{-1}$) or 54 Mg ha^{-1} (24 ton acre^{-1}) as a solid. Across-site analysis indicated that the manured treatment increased corn (*Zea mays* L.) yields significantly ($\alpha = 0.05$), by 0.5 Mg ha^{-1} ($11.5 \text{ vs. } 11.0 \text{ Mg ha}^{-1}$), with 67 kg ha^{-1} less purchased fertilizer N during the 3 yr of this study. However, there were environmental concerns: (i) Early fall manure spreading significantly increased fall nitrate (NO_3) levels in the manured plots ($175 \text{ vs. } 87 \text{ kg NO}_3\text{-N ha}^{-1}$); (ii) Following corn harvest, fall NO_3 levels were fairly low and equivalent between treatments with the exception of three sites where manuring resulted in significantly higher $\text{NO}_3\text{-N}$; and (iii) Soil tests following corn harvest indicated a significant increase in soil test phosphorus (STP) on the manured plots. These results indicate that dairy manure can reduce fertilizer inputs although there is a risk of $\text{NO}_3\text{-N}$ leaching and P accumulation. Informal interviews were conducted with farmer-participants following this study to assess current manure use.

CURRENT TRENDS in the Wisconsin dairy sector indicate that average herd size is increasing, with a growing proportion of the milk produced on farms of 200 cows or more (Barham et al., 2005). By 2005, farms with more than 200 cows housed 32% of the state herd and accounted for 34% of the milk production (USDA-NASS, 2006a). These larger farms tend to have an uncovered, lined slurry pit for long-term manure storage (Turnquist et al., 2006), and higher stocking rates than smaller dairy farms according to a study by Saam et al. (2005). This situation can result in dairy farmers having large quantities of manure to manage on an insufficient land base. In addition, stricter nutrient management regulations are now in place, requiring phosphorus-based spreading standards in some cases, which limit the rates, timing, and availability of cropland for manure applications (USDA-Natural Resources Conservation Service, 2005).

At the same time that the state's dairy industry is expanding, cash grain farmers are facing increasing costs for commercial fertilizer. Prices in Wisconsin per kilogram for N increased by 123%, phosphate (P_2O_5) by 89%, and potash (K_2O) by 41%

between 1999 and 2007 (USDA-NASS, 2000–2007). This largely explains why the cost of fertilizer for corn production in Wisconsin nearly doubled from \$86 to \$164 ha^{-1} during approximately the same period (USDA-NASS, 2000, 2006b). As prices for commercial fertilizer increase there is a growing incentive for grain farmers to use alternative nutrient sources such as livestock manure. Manure provides N, P, K, S, and many trace minerals, as well as serving as a soil conditioner by increasing organic matter and improving soil porosity and water-holding capacity (Safley et al., 1986; Eghball and Power, 1994; Eghball et al., 2002).

Comparisons of corn yields in some studies have shown little statistical difference between treatments receiving livestock manure and commercial fertilizer (Motavalli et al., 1989; Jokela, 1992; Eghball and Power, 1999), and in others, the manured corn has outyielded fertilized corn (Ginting et al., 1998). Studies have also shown that grain protein does not differ in a predictable manner between treatments receiving either manure or commercial fertilizer (Evans et al., 1977; Jokela, 1992; Eghball and Power, 1999).

While the potential of manure to produce good corn yields is generally known, many grain farmers are concerned about manure heterogeneity and the difficulties in accurately estimating the amount of nutrients being applied. Estimation of manure nutrient content is generally done in one of three ways: (i) using default "book" values, (ii) conducting manure nutrient analysis and using nutrient availability ratios, or (iii) using the presidedress soil nitrate test (PSNT); alone, each has its drawbacks. Nutrient crediting, using "book" values for plant-

G.R. Sanford, J.L. Posner, and J.L. Hedtcke, Dep. of Agronomy, Univ. of Wisconsin, 1575 Linden Dr., Madison, WI 53706; A.R. Cook, Massachusetts Association of Conservation Districts, 52 Boyden Rd., Holden, MA 01520; J.A. Hall, Michael Fields Agricultural Institute, W2493 County Rd. ES, East Troy, WI 53120; J.O. Baldock, Agstat, 6394 Grandview Rd., Verona, WI 53593. Received 21 Apr. 2008. *Corresponding author (gsanford@wisc.edu).

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Abbreviations: BLUP, best linear unbiased predictors; FC, farmers' check; GDD, growing degree days; M, manure + supplemental fertilizer; PSNT, presidedress soil nitrate test; RCBD, randomized complete block design; RHA, rolling herd average; SFAL, Soil and Forage Analysis Laboratory; SPAL, Soil and Plant Analysis Laboratory; STK, soil test potassium; STP, soil test phosphorus.

available N, P, and K can be risky as these standardized values may not accurately represent the nutrient content of a particular manure; especially in cases of concentrated or dilute material. Manure sampling and analysis can provide a clear picture of nutrients applied, but sampling is an onerous task and due to its heterogeneity, frequent sampling may be required (Dou et al., 2001; Davis et al., 2002). The PSNT taken in the late spring has proven useful in predicting when available $\text{NO}_3\text{-N}$ from manure and legume sources will be adequate for optimum yields (Magdoff et al., 1984; Klausner et al., 1993; Andraski and Bundy, 2002). The test however, is less precise when cold wet springs inhibit N mineralization (Andraski and Bundy, 2002) or when measured $\text{NO}_3\text{-N}$ is below the critical value of 21 mg kg^{-1} . At these lower values, where yields have been shown to decline without supplemental N fertilizer, the PSNT is less precise in predicting the economically optimal fertilizer recommendation (Klausner et al., 1993; Miller, 1996). In addition, the general practicality of this test is somewhat compromised by the narrow window between the time of sampling (V4–V6 corn growth stage) and canopy closure, constraining a farmer's opportunity to sidedress N.

Despite its production potential, the use of manure can also have adverse environmental impacts. In addition to the release of gasses implicated in global climate change and air pollution (Sommer and Olesen, 1991; Lessard et al., 1996), the overapplication of manure can lead to increased nutrient runoff and/or leaching. Bundy et al. (1994a) has shown surface water contamination and eutrophication via runoff of manure. Phosphorus accumulation in the topsoil from repeated manure applications increases the potential for P loss through soil erosion, subsequently increasing the likelihood of eutrophication in freshwater ecosystems (Powell et al., 2001; Bundy and Sturgul, 2001).

Also of concern is the increased risk of mineralized manure N leaching at a time of year when available $\text{NO}_3\text{-N}$ is not in synchrony with corn growth. Measuring residual soil $\text{NO}_3\text{-N}$ in the soil profile following manure applications has been used as an indicator of potential NO_3 leaching in several studies. There seems to be no clear trend regarding the effects of manure vs. N fertilizer on soil NO_3 levels. Many authors have found equivalent levels between the two N sources (Beauchamp, 1986; Jokela, 1992; Zebarth et al., 1996), while some studies have shown either higher residual levels of $\text{NO}_3\text{-N}$ under manure (Evans et al., 1977; Roth and Fox, 1990) or fertilizer treatments (Kimble et al., 1972; Xie and MacKenzie, 1986; Comfort et al., 1987).

In addition to the problems of $\text{NO}_3\text{-N}$ leaching, studies on STP levels have shown significant P accumulation where fields receive frequent manure applications (Proost, 1999; Randall et al., 2000; Ritter, 2000). For example, Proost (1999) surveyed 96 Wisconsin dairy farmers, and found that 77% of the fields had STP levels over the optimal range, as defined by the UW Extension (Kelling et al., 1998). During a 5-yr study in Minnesota, Randall et al. (2000) found that manure applications substantially increased both STP and STK levels when compared to a fertilizer-only treatment. While STP does not take into account landscape information such as field slope, proximity to water, soil erosion potential, or information on the soil's capacity for P sorption: it is a frequently used measure

in nutrient management plans for determining where, when, and how much manure will be spread each year (USDA-NRCS 590).

While it is clear that there are a growing number of dairy operations that need to move manure off their farms, and a growing logic for grain farms to use dairy manure in their rotations, little research on manure management in cash grain systems has been conducted. As part of a larger effort to link grain and livestock farms in southern Wisconsin, six dairy farms and nine grain farm collaborators were invited to participate in a series of on-farm trials ($n = 20$) conducted to address the following questions: (i) What are the effects of manure on corn yield and grain protein? (ii) Do manure applications result in potentially problematic accumulations of $\text{NO}_3\text{-N}$ or P in the soil? (iii) Would these growers, at the end of the research phase be interested in continuing to include manure in their production system? Companion studies to the current work have reported on manure spreading impacts on soil compaction (Sanford et al., 2008), manure's impact on weed populations (Cook et al., 2007), and manure hauling economics (Sanford, G.R., J.L. Posner, and G.L. Hadley. 2008. Economics of hauling dairy slurry and its value in Wisconsin corn (*Zea mays* L.) grain systems. J. Agric. Food Environ. Sci., in review).

MATERIALS AND METHODS

Initial Layout

Between 2004 and 2006 20 corn trials were conducted on cash-grain farms in south-central and southeastern Wisconsin. Each trial was located near one of six cooperating dairy farms in the study. Five of the six cooperating dairies were confinement operations housing their cattle in free-stall barns and using a liquid slurry storage system for their manure. These farms had between 250 and 900 milking cows with a rolling herd average (RHA) of 12,250 kg milk. On one of the six farms, 90 milking cows (RHA of 7260 kg milk) were rotationally grazed, and manure collected from their stanchion barn was spread as a solid. Each year, fields going into corn on the cooperating grain farms were selected. These were large grain farms (490 production hectares on average) and the selected fields were between 0.2 and 12.2 km from the source of manure. The trials were established using a randomized complete block design (RCBD), with three replications. Two treatments were compared: a nonmanured treatment representing the farmers' current corn production practices ("farmers' check" or FC), and a system where the majority of nutrient inputs were applied as manure (M). Plot sizes were determined to accommodate manure spreading, corn planting, and corn harvesting equipment. Plots ranged from 9.1 to 18.3 m wide, and approximately 91 to 152 m long ($0.08\text{--}0.28 \text{ ha plot}^{-1}$). The five cooperating dairy farms using slurry manure systems either owned a tractor-pulled manure tank or hired custom manure haulers with truck-mounted manure tanks. Manure tank capacity ranged in volume from 15 to 27 m^3 . Solid manure was applied with a box spreader. Calibration of manure spreading equipment at each site involved measuring several pilot areas, determining the manure spreader's capacity and spreading width, and then manipulating the tractor drive speed to meet the target application rate on the experimental plots.

Baseline soil fertility samples (0–15 cm depth) were taken from each site before manure applications and analyzed for pH (1:1 soil to water), organic matter (loss on ignition), and STP and STK levels (using Bray P1 extract) at the UW Soil and Plant Analysis Laboratory (SPAL) in Madison, WI. These laboratory methods are cited in Kelling et al. (1998). As a result of the two different manure storage systems used in this study (slurry and solid), slurry was applied at 17 of the on-farm environments while solid manure was applied at the other three. Based on discussions with professional manure applicators and UW Extension personnel, the target application rate for slurry was between 94 and 112 m³ ha⁻¹ (10,000 to 12,000 gal acre⁻¹) and for solid manure between 45 and 56 Mg ha⁻¹ (20–25 ton acre⁻¹). At 19 of the 20 sites manure was either directly injected or incorporated into the soil via tillage. Manure samples were taken directly from the application equipment before spreading. Samples were analyzed for dry matter content and total N, P₂O₅, and K₂O, at the UW Soil and Forage Analysis Laboratory (SFAL) in Marshfield, using total Kjeldahl N for N and dry ash methods for P and K (Association of Official Analytical Chemists, 2008a, 2008b).

To estimate the potential for NO₃ leaching within a soil profile, soil cores were collected in the late fall with a truck-mounted hydraulic probe. Each core was comprised of a homogenized sample taken from 0 to 91 cm. Three paired cores (in-row and between-row) were taken per plot and bulked in this analysis. Samples were analyzed for NO₃-N at the SPAL using automated colorimetric methods at 0 to 30, 31 to 60, and 61 to 90 cm. The sum of these three horizons was termed “profile fall nitrate.”

On-Farm Site Characterization

Corn was planted following either wheat (*Triticum aestivum* L.) ($n = 10$ environments) or soybean [*Glycine max* (L.) Merr.] ($n = 10$ environments) depending on the cooperating grain farmers' rotation. All of the environments were located on prairie-derived loam or silt loam soils typical of south-central Wisconsin with relatively high organic matter concentrations (NO₃ = 30 g kg⁻¹) and modest slopes ranging from 0 to 6%. Both STP and STK in these environments were in the optimum to high range for a typical cash grain rotation with the exception of one environment that had recently come out of the USDA's Conservation Reserve Program. Details regarding soil

Table 1. Soil characteristics and tillage practices for 20 on-farm trials.

Field code	Soil series	Soil classification	Slope %	Manure incorporation and seedbed preparation	
				Fall tillage	Spring tillage
1	Ringwood silt loam	fine-loamy, mixed, superactive, mesic Typic Arguidolls	2–6	chisel plow	disk
	St. Charles silt loam	fine-silty, mixed, superactive, mesic Typic Hapludalfs			
2	McHenry silt loam	fine-loamy, mixed, superactive, mesic Typic Hapludalfs	2–6	chisel plow	field cultivator
	St. Charles silt loam	fine-silty, mixed, superactive, mesic Typic Hapludalfs			
	Dodge silt loam	fine-silty, mixed, superactive, mesic Typic Hapludalfs			
3	Troxel silt loam	fine-silty, mixed, superactive, mesic Pachic Arguidolls	1–3	Aerway†	field cultivator
	St. Charles silt loam	fine-silty, mixed, superactive, mesic Typic Hapludalfs			
4	Plano silt loam	fine-silty, mixed, superactive, mesic Typic Arguidolls	0–2	Aerway†/chisel	disk
5	Plano silt loam	fine-silty, mixed, superactive, mesic Typic Arguidolls	2–6	strip-till‡	–
6	Virgil silt loam	fine-silty, mixed, superactive, mesic Udollic Endoaqualfs	0–3	–	field cultivator
7	Ringwood silt loam	fine-loamy, mixed, superactive, mesic Typic Arguidolls	2–6	–	field cultivator
8	Kegonsa silt loam	fine-silty over sandy, mixed, superactive, mesic Mollic Hapludalfs	2–6	disk	field cultivator
	Plano silt loam	fine-silty, mixed, superactive, mesic Typic Arguidolls			
9	Plano silt loam	fine-silty, mixed, superactive, mesic Typic Arguidolls	0–2	Aerway†	strip-till‡
10	Plano silt loam	fine-silty, mixed, superactive, mesic Typic Arguidolls	2–6	Aerway†	field cultivator
11	Plano silt loam	fine-silty, mixed, superactive, mesic Typic Arguidolls	2–6	–	field cultivator
12	Plano silt loam	fine-silty, mixed, superactive, mesic Typic Arguidolls	2–6	–	field cultivator
13	Lamartine silt loam	fine-silty, mixed, superactive, mesic Aquallic Hapludalfs	2–6	–	soil finisher§
	Virgil silt loam	fine-silty, mixed, superactive, mesic Udollic Endoaqualfs			
14	Theresa silt loam	fine-loamy, mixed, superactive, mesic Typic Hapludalfs	2–6	–	soil finisher§
15	Theresa silt loam	fine-loamy, mixed, superactive, mesic Typic Hapludalfs	2–6	strip-till‡	–
16	Kidami silt loam	fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs	0–2	chisel plow	field cultivator
17	Kidami silt loam	fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs	0–2	–	field cultivator/ soil finisher§
18	Plano silt loam	fine-silty, mixed, superactive, mesic Typic Arguidolls	2–6	disk/subsoiler	–
19	Plano silt loam	fine-silty, mixed, superactive, mesic Typic Arguidolls	2–6	chisel plow	field cultivator
20	Plano silt loam	fine-silty, mixed, superactive, mesic Typic Arguidolls	2–6	chisel plow	field cultivator

† Manure incorporated with and Aerway (Holland Equipment Ltd., Norwich, ON) roller-bar. <http://www.aerway.com>

‡ Tillage limited to strips: ~18-cm tilled strips spaced 76 cm center to center.

§ Implement generally comprised of a row of discs, multiple rows of field cultivator shanks, and a final finishing attachment (i.e., rolling basket).

Table 2. Previous crop, manure, fertilization, and corn yield data for 20 on-farm trials.

Manure type	Field Dairy code	Year	Crop†	Manure information						Corn fertilization mean N rate§			Corn yield§		
				Application			Total nutrients			Starter	M	FC	M	FC	
				Date	Rate	Method‡	N	P	K						
				m ³ ha ⁻¹			kg m ⁻³			kg ha ⁻¹			Mg ha ⁻¹		
Slurry	A	1	2004	w	3 Aug.	112	TM _B	3.67	0.60	2.80	43.7	60	179	12.5	12.3
		2	2005	w	4 Sept.	94	TM _B	3.20	0.64	2.82	0.0	0	179	3.6	4.6
		3	2006	w	4 Sept.	103	TP _I	2.64	0.40	2.18	0.0	0	135	8.2	7.7
		4	2006	s	5 Sept.	112	TP _I	2.68	0.37	2.21	0.0	116	116	12.5	11.9
	B	5	2004	s	3 Oct.	108	TP _B	2.50	0.49	2.03	20.2	50	140	11.7	11.7
		6	2005	s	4 Nov.	103	TP _B	3.93	0.62	2.72	8.4	56	97	14.3	13.0
		7	2005	s	4 Nov.	103	TP _B	4.23	0.64	2.81	7.8	0	47	12.6	10.3
		8	2006	s	5 Nov.	98	TP _B	2.81	0.50	2.25	7.8	45	116	12.5	11.5
	C	9	2005	s	4 Nov.	103	TM _B	2.87	0.50	2.03	6.5	50	95	14.3	14.2
		10	2005	w	4 Nov.	103	TM _B	3.30	0.43	2.20	11.2	0	22	13.6	13.5
		11	2006	s	5 Oct.	103	TM _B	3.25	0.50	2.53	6.5	50	185	12.5	12.4
		12	2006	w	5 Oct.	112	TM _B	3.21	0.51	2.53	0.0	67	179	11.9	12.1
	D	13	2005	s	5 Apr.	112	TP _I	2.38	0.34	1.64	9.0	0	140	13.4	12.9
		14	2005	w	4 Oct.	112	TP _I	2.35	0.34	1.94	9.0	0	0	12.3	12.0
		15	2006	s	5 Oct.	112	TP _I	2.69	0.35	2.16	9.0	19	37	13.4	12.7
	E	16	2005	w/rc	4 Sept.	112	TP _I	3.76	0.64	2.54	10.1	45	45	9.9	9.8
		17	2006	s	5 Oct.	112	TP _I	3.59	0.59	2.27	8.4	0	135	10.2	9.1
Average						107	—	3.12	0.50	2.33	9.27	33	109	11.7	11.3
				Mg ha ⁻¹			kg Mg ⁻¹								
Solid	B	18	2004	w	3 Aug.	69	TP _{SS}	6.50	1.06	7.93	6.5	179	179	12.1	11.4
	F	19	2004	w	3 Oct.	40	TP _{Bx}	7.38	2.37	10.99	11.2	167	167	10.4	9.8
		20	2005	w	4 Oct.	54	TP _{Bx}	5.97	2.06	4.22	9.4	10	70	8.0	6.7
Average						54	—	6.62	1.83	7.71	9.0	119	139	10.2	9.3

† w = wheat, s = soybean, rc = red clover.

‡ TM = truck mounted, TP = tractor pulled; subscripts: _B = broadcast, _I = injected, _{Bx} = box spreader, _{SS} = side slinger.

§ Treatments: FC = farmers' check (fertilizer-only), M = manure + supplemental fertilizer.

characteristics and tillage used for manure incorporation at the 20 on-farm environments can be found in Table 1. Application date, rate, method, and nutrient content of applied manures are specified for each on-farm environment in Table 2.

Weather Data

Weather data (precipitation and temperature) were obtained from the Midwestern Regional Climate Center using the nearest weather station or stations to each site. Overall, cropping season weather for the period of this study was excellent for corn production and typical of the long-term average for southern Wisconsin. Corn yields for south-central Wisconsin during the study period (2004–2006) were 112, 114, and 118% of the 1994 to 2003 average of 8.6 Mg ha⁻¹ (137 bu acre⁻¹) (USDA– National Agricultural Statistics Service, 2007). With the exception of one site, all corn hybrids (RM 96–105) were planted by 10 May in each of the 3 yr. An important difference among the seasons was the cooler, wetter conditions during the spring of 2004 where April through June growing degree days (GDD) were 10% below and rainfall was 50% higher than the 30 yr long-term average (1974–2003). This weather pattern most likely affected N mineralization and the PSNT readings made in early June 2004.

Spring Procedures

The farmer participants were responsible for all corn production decisions including hybrid selection, date of planting,

seeding rates, starter fertilizer additions, and weed control program. Standard PSNT protocol was followed, in which soil cores (0–30 cm deep) were taken when corn was between 15 and 30 cm tall, or between the V4 and V6 stages (Magdoff et al., 1984; Bundy et al., 1994b). Like the profile fall NO₃ samples, these samples were analyzed at SPAL using automated colorimetric methods. These results were then discussed with growers before their making final decisions on N-sidedressing rate.

Harvest and Postharvest Procedures

Depending on the farmers' combine size, the central four to six rows in each plot were harvested and weighed, and a sample was assessed for grain quality at the SFAL, using wet chemistry for P, K, Ca, and Mg assays, and near infra-red reflectance spectrophotometry for crude protein. Another series of soil samples was taken for routine fertility (0–15 cm) and postharvest fall NO₃ (0–91 cm) analysis.

Statistical Analyses

Production variables (yield and grain quality) as well as the environmental variable of fall soil NO₃ levels were analyzed as a RCBD, on a combined-environment basis. That is, the effect of sites (soil, drainage, management, etc.) and years (weather, technology, etc.) were combined into one variable referred to as "environment." The resulting mixed model was

$$y = \mu + \epsilon_j + \beta(\epsilon)_{jk} + \tau_i + (\epsilon\tau)_{ij} + e_{ijk}$$

In this model, μ = the population mean, ε = environment, β = block, τ = treatment, and e = experimental error. Environment and block were treated as random effects to consider the results as valid for an inference zone of all south-central Wisconsin. Treatment (τ) was considered as a fixed effect and tested using the environment by treatment term ($\varepsilon\tau$). The analysis was made using PROC MIXED of SAS Software Version 9.1.3 (SAS Institute, 2004). Best linear unbiased predictors (BLUP's) were used to evaluate the effect of M vs. FC treatments in individual environments (Littell et al., 2006).

Changes in STP and STK were analyzed using a repeated measures design, with PROC MIXED of SAS Software Version 9.1.3 (SAS Institute, 2004). The compound symmetric covariance structure (TYPE = CS), which assumes equal variance and a correlation between sampling times, was used in this analysis to account for natural temporal correlation.

Farmer-Researcher Interaction

Participating farmers were visited or contacted by phone several times during each cropping season and received written annual update reports from the research team. During the winter of 2007 group meetings were organized at three of the cooperating dairy farms where an overview of the results was presented to the farmer-participants, extension personnel, and agriculture consultants. One year after those meetings, a follow-up telephone interview was conducted. Of the nine grain farmers who participated in this study, six agreed to participate in a follow-up survey. The survey was conducted to assess their continuing cultural practices regarding the use of manure.

RESULTS AND DISCUSSION

Manure Analyses

Results from the manure analyses confirm farmers' concerns about the variability of dairy manure as a nutrient source. In the case of dairy slurry, while the average N content from across all environments was relatively close to its "book value," the standard deviation for the 17 environments was 0.57, 0.25, and 0.41 kg m⁻³ for N, P₂O₅, and K₂O, respectively. Solid manure, used at three sites, was particularly variable in K₂O, for which the standard deviation was 4.09 kg Mg⁻¹. This heterogeneity among dairies is typical for manure analyses (Davis et al., 2002; Peters et al., 2003) and is most likely due to differences in animal feeding and manure management. Despite this overall variability, when manure samples were compared within a given dairy, nutrient variability markedly decreased. For example the overall, or across-dairy coefficients of variation (CV), for total manure N, P₂O₅, and K₂O were 27, 26, and 22%, respectively, while the average within dairy CV's were only 9% for N, and somewhat higher for P₂O₅ and K₂O (16 and 19%). This trend lends support to the idea that as long as major dairy management changes do not occur, a grain farmer doing regular business with a single dairy farm could estimate with some accuracy the nutrient content of applied manure based on historical manure analyses.

Nitrogen Sidedressing

The results from the PSNT are presented in Fig. 1. The most striking observation is that the test did not always distinguish between the M and FC treatments, even though total N additions

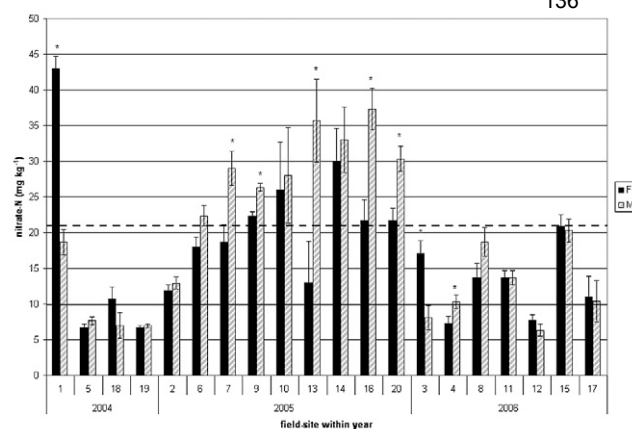


Fig. 1. Presidedress soil nitrate test results (mg kg⁻¹). Solid black line designates the level (10 mg kg⁻¹) below which full rates of N fertilizer are recommended by UW Extension for corn. Dotted black line designates the level (21 mg kg⁻¹) above which no further N fertilizer is recommended by UW Extension for corn (Bundy et al. 1994b). Bars represent standard error for comparison between treatments within a field-site. Asterisks indicate significance within a field-site (alpha = 0.05). FC = farmers' check (fertilizer-only), M = manure + supplemental fertilizer.

from the manure averaged 336 kg ha⁻¹. And, although fall N-additions each year were approximately the same, PSNT results were generally highest in 2005. Nearly 90% of M and more than 50% of FC plots tested above the 21 mg kg⁻¹ threshold- indicating no need for additional N fertilizer. In both 2004 and 2006 however, many sites were below the minimum threshold (10 mg kg⁻¹) indicating that full rates of N were required. These analyses and the resulting N-fertilization recommendations were discussed with each cooperating farmer. In general, growers felt it was necessary to modify "extreme" PSNT results. On their FC plots, even if PSNT levels indicated no additional N was necessary beyond the already added starter fertilizer ($n = 7$), an average of 65 kg N ha⁻¹ was sidedressed. On the M plots, when PSNT readings indicated that no manure N was available and full N rates were required ($n = 6$), they cut N sidedressing from 180 to about 80 kg ha⁻¹. As a result, if PSNT recommendations had been followed to the letter in this set of trials, M plots would have received 90 kg N ha⁻¹ on average

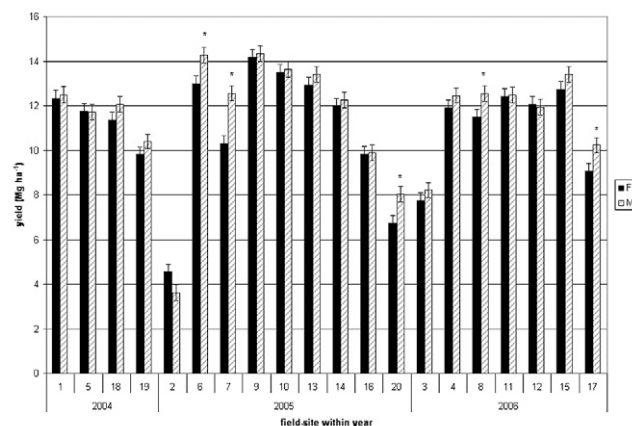


Fig. 2. Corn grain yield at 20 on-farm environments. Bars represent standard error for comparison between treatments within a field-site. Asterisks indicate significance within a field-site (alpha = 0.05). FC = farmers' check (fertilizer-only), M = manure + supplemental fertilizer.

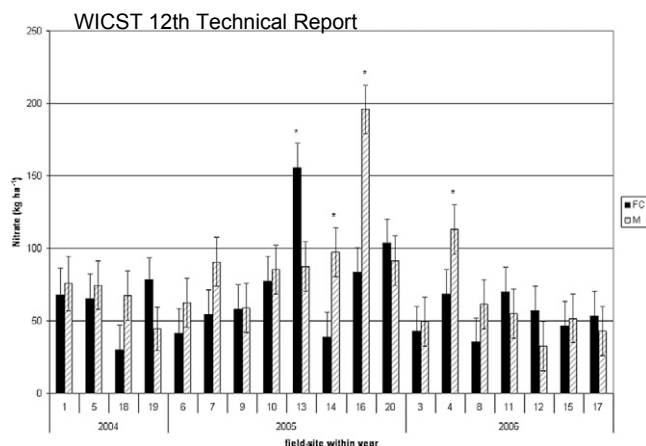


Fig. 3. Postharvest nitrate levels at 19 on-farm environments: total from 0 to 91 cm. Bars represent standard error for comparison between treatments within a field-site. Asterisks indicate significance within a field-site ($\alpha = 0.05$). FC = farmers' check (fertilizer-only), M = manure + supplemental fertilizer.

and FC plots 100 kg N ha^{-1} for a savings of only 10 kg N ha^{-1} . With the modifications that farmers made, actual fertilizer savings on the M plots averaged 67 kg N ha^{-1} over the 20 environments. Not surprisingly, growers had the most confidence in basing their N-sidedressing plan on the nutrient content of the added manure, recent weather, and the crop history of the field. They were less confident of the PSNT recommendations if they deviated markedly from their expectations.

Corn Yields and Crude Protein Percentage

Corn grain yields are summarized in Fig. 2. The results from the combined analysis (all 20 environments) indicated that manure significantly increased ($P = 0.003$) corn yields by 512 kg ha^{-1} (least squares means: M = 11.5 Mg ha^{-1} , FC = 11.0 Mg ha^{-1}) overall. Covariance parameter estimates for the combined analysis model indicated that environmental differences were responsible for the greatest variability in the data, producing an estimate 17 times larger than the residual, which was the second largest estimated covariance parameter (1509 vs. 88, respectively), while the environment $\times$ treatment interaction was responsible for the least amount of variability (environment $\times$ treatment = 29). Wisconsin soil survey data indicated that some sites were in lower yield potential environments, but the lack of an interaction indicates that manuring corn grain production systems has broad applicability. Best linear unbiased predictors within each of the 20 environments showed that corn yields with manure were equal to ($n = 2$) or greater than ($n = 18$) those plots on which only commercial fertilizer was applied. These improved yields may be due to a number of factors including the contributions of other macro- and micro-elements present in the manure, the addition of organic matter to the soil, or increased soil microbial activity (Safley et al., 1986; Eghball and Power, 1994; Eghball et al., 2002). It is unlikely that it was due to higher NO_3 availability under the manured plots since fall NO_3 levels after corn harvest were low and similar to samples taken from the fertilizer only plots (see next section).

Although in this study, crude protein levels were statistically different between M and FC plots, the means from each treatment were quite similar (9.34 and 9.15%, M and FC treatments, respectively). Percent P in corn grain was also analyzed in the

combined-environment analysis but was not found to be statistically different between treatments ($P = 0.2433$). This trend was consistent at all environments between 2004 and 2006.

Profile Fall Nitrate

Results from the combined-environment analysis showed that where manure was applied early in the fall, significantly higher $\text{NO}_3\text{-N}$ levels ($P = 0.0232$) were present under the M treatment than under the FC treatment in the late fall, the year before corn planting. In addition to being statistically different from the FC treatment, mean profile $\text{NO}_3\text{-N}$ levels in the M treatment were also notably high (175 vs. 87 kg ha^{-1} in the FC treatment).

These results indicate that late summer applications of manure are likely to raise soil $\text{NO}_3\text{-N}$ levels in the late fall before planting corn. One strategy to prevent this occurrence is the planting of cover crops, especially grass crops such as rye (*Secale cereale* L.) that can use NO_3 late into the fall (Staver and Brinsfield, 1998; Strock et al., 2004). In a meta-analysis comparing conventional cash crop systems (no-cover crop, with N) to systems using nonleguminous (with N) and leguminous cover crops (no N), Tonitto et al. (2006) showed that while yields did not differ among systems, $\text{NO}_3\text{-N}$ leaching was reduced 70% by the presence of a winter cover. Winter cover crops can also provide the ancillary benefits of decreasing soil erosion, and thus reducing nutrient movement off-site in sediments.

Post harvest fall NO_3 levels are shown in Fig. 3. The combined-environment analysis for postharvest soil NO_3 levels resulted in a nonsignificant effect of treatment overall ($P = 0.2380$), and generally modest levels of profile NO_3 . The mean profile NO_3 load in the M treatment was $75 \text{ kg NO}_3 \text{ ha}^{-1}$, and $65 \text{ kg NO}_3 \text{ ha}^{-1}$ in the FC treatment. However, NO_3 levels were statistically greater under the M treatment in three of the environments.

Phosphorus and Potassium Soil Test Levels

Due to the initial optimum to high soil test levels, the only P and K addition farmers made to the FC treatment was applied in their starter fertilizer. The M plots on the other hand had fairly high additions of P and K (starter + manure). Not surprisingly, the combined environment analysis confirmed that while STP levels did not change significantly on the FC plots during this study ($P = 0.6661$), STP levels on the M plots did increase ($P = 0.0104$) by an estimated 9 mg kg^{-1} with just 1 yr of manure application. Randall et al. (2000) also noted increases in STP and STK on manured fields. Changes in STK were more pronounced than those for STP with a significant increase of 22 mg kg^{-1} in the M treatment ($P = 0.0003$). These effects were due to the high potassium levels of applied manure (Table 2), and the lower potassium buffering capacity of these soils ($8 \text{ kg K}_2\text{O ha}^{-1}$ to change STK by 1 mg kg^{-1}) (Kelling et al., 1998). However, over the length of a grain rotation, P and K accumulations during a manured corn phase would most likely be drawn down by subsequent nonmanured crop phases.

Follow-Up Interviews with Grain Farmer Cooperators

All the participants found that the manured strips produced good to excellent corn yields, and four of the six producers were continuing to use manure as a major part of their fertility

WICST 12th Technical Report program for corn. The two respondents who were not using manure cited sourcing issues as their primary hindrance and commented that they would like to use manure but are not able to get it with any regularity. All the growers saw spreading on wet soils as a potential problem limiting the use of dairy slurry. They all felt however, that they were able to work with their neighboring dairy producer to minimize this problem. The one predominately no-till farmer in the sample remained reluctant to expand his use of manure due to his remaining concerns about compaction and slurry run-off. He did think however, that using a tanker set up with no-till type injection tines that mimicked a strip-till system would work well. He would then consider planting directly into the injection strips the following spring.

Of the farmers that have continued to use manure, all determine their supplementary fertilizer additions after crediting the applied manure. Manure credits in all of these cases are based on lab test results provided by the dairy farm supplying the manure. None of the farmers were continuing to use the PSNT test.

There were a range of opinions on how to value the manure but all producers did agree that they would be willing to “pay” for the manure. In the three cases where farmers were experimenting with manure spreading contracts, two felt that paying for the trucking costs to haul the manure could possibly work. Another participant is paying his neighbor the cost equivalent of 25 kg (1 bushel) of corn per acre. Two of the producers, who have standing spreading contracts, do not pay for the manure but custom grow corn silage on ground that will receive manure from the nearby dairy farm. The dairy farmer selects a corn variety and planting date and in return the grain farmers sell the silage to the dairy farmer based on any market value (bushels of grain equivalence) between 1 January and 1 September.

CONCLUSIONS

On-farm trials and producers’ evaluations indicate that manure is a viable source of crop nutrients in highly productive cash-grain corn systems. Using the PSNT and nutrient crediting to estimate sidedressed fertilizer needs, farmers applied approximately 67 fewer kg N ha⁻¹ on the manured plots. Still, corn yield and crude protein content in the manured treatment showed modest increases over the nonmanured plots. In addition, fall NO₃ levels following the corn phase were nearly equal in the fertilized and manured plots. Manure applied following small grains however, did result in an accumulation of NO₃ N in the soil by the late fall. We found only mediocre agreement between the N recommendations resulting from nutrient crediting and the PSNT, particularly during the wetter springs of 2004 and 2006. Based on our farmer interviews, producers preferred estimating nutrient availability via manure analysis rather than PSNT, and research results suggest that the variability in nutrients, especially N, from the same dairy is relatively low. Interviews with participating grain farmers indicated that they were positive about the prospect of using dairy slurry, particularly given the current (2008) price of fertilizer. The major factor barring the continued use of manure for two of the six producers interviewed was finding a reliable and nearby manure source.

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Economics of hauling dairy slurry and its value in Wisconsin corn grain systems

G.R. Sanford, Research Specialist, UW-Madison, gsanford@wisc.edu

J.L. Posner, Professor, UW-Madison, jlposner@wisc.edu

G.L. Hadley, Assistant Professor, UW-River Falls, gregg.hadley@uwrf.edu

Abstract:

To evaluate the potential of using dairy slurry for corn (*Zea mays L.*) production in Wisconsin grain systems, custom manure hauler bids were combined with corn production expenses to develop enterprise budgets in which slurry provided corn nutrient needs. A scenario was developed in which a recipient grain farmer shares manure hauling costs with the dairy farmer supplying the slurry. Results showed that by sharing manure hauling expenses, profitable hauling distances more than doubled (from 3.2 to 7.6 km). These results suggest that grain and dairy farmers could enter into beneficial manure contracts having both economic and nutrient conservation advantages.

Introduction

Farmers specializing in grain crop production have typically relied solely on commercial fertilizer for their crop nutrient needs. Yet like so many other inputs, fertilizer prices have risen to record high levels in recent years reducing already-tight profit margins. Wisconsin Statistics Service (USDA-NASS, 2000, 2008) shows prices per pound for nitrogen (N), phosphate (P_2O_5), and potash (K_2O) increased by 123%, 89%, and 41% between 1999 and 2007. This largely explains why the cost of fertilizer purchases for corn production in Wisconsin nearly doubled from \$86 to \$164 ha^{-1} (\$35 to \$66 ac^{-1}) during approximately the same period (USDA-NASS, 2000, 2008). As fertilizer prices increase there is a growing incentive for grain farmers to utilize alternative nutrient sources such as manure. Manure provides nitrogen (N), phosphorus (P), potassium (K), sulfur (S), and other nutrients, as well as serving as a soil conditioner by increasing organic matter and improving porosity and water-holding capacity (Safley et al., 1986; Eghball and Power, 1994; Eghball et al., 2002).

At the same time that fertilizer prices are climbing, expansion within the dairy industry has left some dairy farmers confronted with larger and larger quantities of manure to manage. The proportion of dairy farms with more than 200 cows in Wisconsin grew rapidly between 1999 and 2005. By 2005 these larger farms included 32% of the state's cows and accounted for 34% of the state's milk production (USDA-NASS, 2006). These larger farms also tend to have higher stocking rates according to a study by Saam et al. (2005). Approximately 80% of larger farms use a lined slurry pit for long-term manure storage (Turnquist et al., 2006), and custom operators haul a large percent of this slurry in Wisconsin (K. Erb, personal communication, September 2006). The use of custom manure haulers with their specialized labor and equipment makes it easier to envision manure brokering between larger dairies and grain farmers; a transfer that could improve profitability and environmental stewardship for both parties. Cabot et al. (2004) reported that manure brokering is promoted in nine states. In addition, a number of web-based interactive spreadsheets have been developed to calculate the fertilizer value of manure, and to aid dairy farmers in estimating the costs of hauling manure on their own farms.

Factors that influence the potential economic value of manure as a crop input include its nutrient concentration, soil test levels, the crop's nutrient requirements (Araji et al., 2001), and, most importantly, the distance it must be hauled (Flemming et al., 1998; Araji and Stodick, 1990). Manure nutrient content itself is a function of animal species, housing, management, feed ration, manure storage, and climate (Eghball et al., 2002). As a result, manure nutrient content is variable. Peters and Combs (2003) found that while mean total nutrient contents for 746 liquid dairy manure samples in Wisconsin were similar to "book values" reported in the Livestock Waste Facilities Handbook (MWPS, 2000) the standard deviations for those nutrients were between 41% (N) and 78% (P_2O_5) of mean values.

Breakeven hauling distances are also affected by initial soil fertility. If soil test levels are high it means that the P and K present in manure are not actually necessary for maintaining crop yield levels in the short term. Application of these nutrients would therefore not be economical. When Best Management

Practices indicate that a grain farmer should not purchase additional P and K for corn production, the “value” placed on manure as a fertilizer is lowered, decreasing the distance slurry can be hauled.

Work has been done on the management of poultry (Govindasamy and Cochran, 1995; Araj et al., 2001; Paudel et al., 2004), swine (Fleming et al., 1998) and cattle manures (Freeze and Sommerfeldt, 1985; Araj and Stodick, 1990; Adhikari et al., 2005), generally assuming application of those manures to soils with optimum soil test values. Araj and Stodick (1990) working in Idaho found that the breakeven hauling distance for transferring solid beef manure from feedlot to field to replace fertilizer purchases in a grain-grain-fallow rotation averaged 12.9 km. Working in central Texas, with solid dairy manure (50% moisture), Adhikari et al. (2005) found that breakeven hauling distance for corn was 16.6 km (10.3 mi) in the first year of application.

Relatively little work has been done, however, on the economics of hauling dairy slurry and its value as a replacement for commercial fertilizer in grain systems. Slurry is a somewhat unique material due to the high volumes available, specialized equipment for hauling it, and its relatively low nutrient concentration. The objective of this study was to evaluate the economic potential of expanding the sound use of dairy slurry in corn-based production systems in Wisconsin. The following issues are addressed:

1. How much does it cost to load, haul, and spread dairy slurry within 8 km (5 mi) of its source?
2. What is the value of dairy slurry in corn production systems?
3. How far can dairy slurry be hauled, if hauling costs are partitioned between dairy and grain farmers?

Materials and Methods

Costs Associated with Manure Application.

Custom hauler interviews were used to estimate manure hauling rates for Wisconsin. A sample was developed using the Wisconsin Custom Manure Applicators list provided by the Professional Nutrient Applicators Association of Wisconsin (PNAAW, 2008). Operations were chosen that used straight-truck mounted slurry tanks to haul and spread manure. Custom hauler rates include the fixed and variable costs associated with the agitation, loading, hauling and spreading of dairy slurry. In addition to operation specifics, each custom hauler interviewed was asked to develop a bid for emptying a slurry pit onto fields at five different distances (1.6, 3.2, 4.8, 6.4, and 8 km) from the slurry source. An aerial photo showing the slurry pit, the location of five different fields, and the clearly delineated route to those fields was given to each custom hauler. Initial bids were all given in English units and subsequently converted to metric. Total cost for emptying the manure pit was calculated by combining the custom hauler's bid with his estimate of fuel usage (normally paid for directly by the contracting dairy farmer).

Initial assumptions used to determine total costs included (1) a slurry pit capacity of 7571 m³ (2 x 10⁶ gal), and (2) broadcast application of slurry at a rate of 93.5 m³ ha⁻¹ (10,000 gal ac⁻¹) using 11.4 to 15.1 m³ (3000 to 4000 gal) capacity truck mounted slurry tanks. For all the scenarios, a single slurry pump and pit agitator were used. Average haul times and custom hauler charges were calculated for fields at 1.6 km increments from the slurry pit out to 8 km. Total costs to empty the slurry pit were estimated by Equation 1.

$$C_t = Bid + Fuel Cost \quad (1)$$

Where C_t is the total cost to empty the slurry pit and land-apply its contents. This is determined by summing the custom hauler bid (*Bid*) for each distance increment with the total fuel costs. Fuel costs (Equation 2) were calculated as the product of fuel usage rate (r), equipment number (n), fuel price (F_p) and machinery hours (H_m) for slurry trucks (T), pit pumps (P) and pit agitators (A) respectively.

$$Fuel Cost = [(T_f \times T_n \times F_p \times H_m) + (P_f \times P_n \times F_p \times H_m) + (A_f \times A_n \times F_p \times H_m)] \quad (2)$$

Slurry Nutrient Composition.

Data from the University of Wisconsin (UW) Soil and Forage Analysis Laboratory (SFAL) in Marshfield Wisconsin was used to determine typical slurry characteristics and nutrient composition. The data set consisted of 713 dairy slurry analyses conducted at the lab between March of 2002 and September of 2005. Although the percent dry matter of these slurry samples were variable (mean = 5.1; s.d. = 2.8), a

standard specific gravity (994.6 g l⁻¹ or 8.3 lbs gal⁻¹) was used to convert lab results to total nutrients per volume.

Value of Slurry as a Fertilizer Replacement in Cash-Grain Systems.

In this study, slurry value is calculated as the estimated fertilizer replacement savings (1st thru 3rd year manure credits) per hectare, minus the costs a grain farmer is willing to assume in order to transport manure to the field (see Equations 3a and 3b below).

Fertilizer replacement values are based on the assumption that the field is in a corn-soybean rotation and that the slurry is incorporated as part of fall tillage. These values are further modified based on soil test levels (optimum vs. high). The optimum soil test category, as defined by UW Extension, indicate soils on which crop yields are optimized with nutrient additions approximately equal to the amount of nutrients removed by the harvested crop (Kelling et al., 1998). On fields with high soil test levels of P and K these nutrients are less limiting to corn or soybean growth, and therefore have little to no fertilizer replacement value. In some cases, the Wisconsin Nutrient Management 590 Standard criteria for surface water protection, requires that field applications of manure be based on a Soil Test Phosphorus (STP) strategy. While manure may be applied to meet the N needs of a crop on soils that test below 50 mg kg⁻¹ in STP, between 50 and 100 mg kg⁻¹ manure may be applied not to exceed P removal by the crops over a rotation (8 year max), and if STP exceeds 100 mg kg⁻¹ no P additions in manure or fertilizer are permitted (USDA-NRCS, 2005). All additional nutrients required beyond those supplied in the dairy slurry are applied according to UW recommendations. A three-year availability series for manure nutrients (Kelling et al., 1998) is used to determine fertilizer saving in the 2nd year soybean and 3rd year corn phases of the rotation (Table 1). Total slurry value is calculated by estimating the cost savings obtained by using dairy slurry instead of fertilizer over a three year period, including the cost of manure hauling, and for years 2 and 3, assuming a specific required rate of return to equity capital (Equations 3a and 3b).

$$VM = [FC1_{CONV} - FC1_{MAN}] - C_{manure} + PV_{y2\&3} \quad (3a)$$

$$PV_{y2\&3} = [(FC2_{CONV} - FC2_{MAN}) / (1+K)^1] + [(FC3_{CONV} - FC3_{MAN}) / (1+K)^2] \quad (3b)$$

Where *VM* is the one-time fertilizer replacement value of manure used for corn production, *FC* represents the fertilizer costs to produce corn with (*MAN*) and without (*CONV*) dairy slurry, *C_{manure}* is the amount a farmer pays in transportation costs for the slurry, and *PV_{y2&3}* is the present value of fertilizer saved for years two and three defined by Equation 3b. The numbers associated with the fertilizer cost (*FC*) indicate to which year in the rotation the fertilizer costs correspond, with years one and three representing the corn phases of the rotation. The present value of fertilizer saved for years two and three is used to account for future savings in fertilizer obtained from a one-time slurry application assuming soybeans is grown in year two and corn is grown again in year three. In this model (Equation 3b) the required rate of return on equity capital *K* is set at 11%.

Table 1. Average slurry nutrient content and estimated three-year availability of 713 slurry samples submitted to the University of Wisconsin - Soil and Forage Analysis Laboratory (SFAL) in Marshfield, WI[†]

	total nutrients (kg m ⁻³)	1 st year available		2 nd year available		3 rd year available	
		available nutrients (kg m ⁻³)	as % of total [†]	available nutrients (kg m ⁻³)	as % of total [‡]	available nutrients (kg m ⁻³)	as % of total
N	2.48	0.99 [¶]	40.0%	0.28	11.2%	0.14	5.6%
P₂O₅	0.90	0.54	60.0%	0.09	10.5%	0.05	5.3%
K₂O	2.31	1.85	80.0%	0.25	10.7%	0.12	5.3%

[†] Of 713 slurry samples average %DM =5.1

[‡] First year nutrient availability as a percent of total nutrients applied is taken from standards used by the University of Wisconsin - Soil and Forage Analysis Lab (SFAL) in Marshfield, WI.

[‡] Second and third year nutrient availabilities as percent of total nutrients applied are taken from the University of Wisconsin Extension Publication A2809 (Kelling, 1998).

[¶] N availability is for incorporated slurry; un-incorporated slurry N availability is estimated as 30% of total nutrients applied (0.74 kg m⁻³)

Grain Enterprise Budgets.

Enterprise budgets are used to evaluate the profitability of a corn grain system where slurry is the primary nutrient input in the corn phase of a corn-soybean rotation. Here we define profitability as the difference in returns per hectare between this system and the same systems utilizing solely commercial fertilizer. It was assumed that all growers would apply 93.5 l ha⁻¹ of starter fertilizer (7-21-7 weighing 1.34 kg l⁻¹) regardless of subsequent fertilizing practices for corn, would take 44 kg N ha⁻¹ credit for following soybeans, and that corn yields would be at least equal in the manured and fertilizer-only systems (Jokela, 1992; Eghball and Power, 1999, Sanford et al., 2009). Budgets are further supplemented with ten-year statewide average input values (1997 to 2006) for Wisconsin taken from the UW Extension “PEPS” program (Profits through Efficient Productions Systems <http://corn.agronomy.wisc.edu/PEPS/2005.pdf>) for corn grain. These are budgets (n = 323) from top-level corn producers in grain systems. Average yields from PEPS were 12.1 Mg ha⁻¹ during the 10 years of data sampled.

Sensitivity Analysis.

For the manured system, two scenarios are presented. The two scenarios are: (1) “Standard Scenario” - dairy farmer covers all fuel and hauling costs to transport dairy slurry to the field (e.g. dairy farmer applying slurry to his own or rented land), and, (2) “Shared Scenario” - dairy farmer covers loading and hauling costs within the first 1.6 km (1 mile) from the pit (a common limit to which slurry is transported; Jackson-Smith et al., 1997, Powell et al., 2007), and the neighboring grain farmer pays all additional costs to transport dairy slurry to fields beyond that distance. These scenarios are evaluated using three-yr N fertilizer replacement values in both high fertility and optimum fertility soil conditions. In the high fertility case, applications of P and K would not elicit a positive crop response and are therefore not valued (N-only value), whereas in the optimum fertility case all three nutrients are valued (full value) since corn would respond positively in these conditions not only to N but to P and K applications as well. Additional sensitivity analyses are conducted on the “shared scenario” to determine the factors that would most likely affect the profitability of transporting slurry to somewhat distant grain fields.

1. Variable manure nutrients: mean, +1 standard deviation, and -1 standard deviation
2. Variable N price: 1999, 2007, and 2007+20%
3. Variable diesel price: 1999, 2007, and 2007+20%
4. Variable corn yields: 2006 Wisconsin statewide average corn yield of 9.0 Mg ha⁻¹ vs. PEPS average of 12.1 Mg ha⁻¹.

Results and Discussion

Cost of Hauling and Spreading Dairy Slurry.

Of eight custom haulers invited to participate in this project, six returned completed questionnaires after initial phone contact was made. The six custom operators interviewed all used an hourly rate for hauling and spreading dairy slurry and generally daily rates for agitators, pumps and other equipment. All the haulers developed their bids to empty a 7571 m³ slurry pit using truck mounted slurry tanks with 11.4 to 15.1 m³ capacity. Approximately 30% of all custom haulers registered by the Professional Nutrient Applicator Association of Wisconsin in 2007 (PNAAW, 2008) use these truck mounted slurry tanks. Other common systems include large semi-trucks (29%) and tractor pulled dragline systems (30%), particularly in the northeastern part of the state. The custom haulers interviewed owned 57 trucks in total, representing 38% of the registered state fleet (PNAAW, 2008).

Custom hauler bids were variable. For example, when emptying the manure pit and spreading the slurry on approximately 80 ha at 4.8 km distance, bids ranged from \$10,200 to \$19,970 with a median value of \$13,256. The primary reasons for the range in final bids were equipment age, the number of trucks in a hauler's fleet, and their estimated hauling time (road speed) which was largely a function of the tire width and tread used. In our sample, truck fleets ranged from 6 to 16 tankers. A linear model, fit to the log transformed bid data, was chosen over a linear, quadratic and cubic model, fit to the non-transformed bid data, based on its superior fit and a clear exponential trend in the raw data (Table 2). For this analysis, the exponential solution to the selected model was then used to interpolate custom hauling costs within the 8 km

distance from the slurry source for which data was collected. Model fitting was performed using R statistical computing software version 2.6.2 (2008).

Table 2. Summary of regression models fit to custom hauler bid data in order to interpolate between data points collected at 1.6 km (1 mi) increments out to 8 km (5 mi). The exponential model was chosen to best represent the non-linear trend in custom hauler *Bid* with distance.

fit	model [†]	R ²	Adj.-R ²																				
Linear	$Bid = 5457.6 + 1922.9 \cdot km$	0.56	0.54																				
Quadratic	$Bid = 8544.9 + 279.3 \cdot km + 170.2 \cdot km^2$	0.57	0.54																				
Cubic	$Bid = 7176.3 + 1473.5 \cdot km - 112.7 \cdot km^2 + 19.5 \cdot km^3$	0.57	0.52																				
Natural Log	$\ln(Bid) = 8.85592 + 0.13737 \cdot km$	0.60	0.58																				
<table> <tr> <th>Coefficient</th><th>Standard Error</th><th>t-value</th><th>Pr > t </th></tr> <tr> <td>Intercept</td><td>0.11</td><td>77.9</td><td><0.0001</td></tr> <tr> <td>km</td><td>0.02</td><td>6.5</td><td><0.0001</td></tr> <tr> <th>F-Statistic</th><th>Num. d.f</th><th>Den. d.f.</th><th>p-value</th></tr> <tr> <td>41.65</td><td>1</td><td>28</td><td><0.0001</td></tr> </table>				Coefficient	Standard Error	t-value	Pr > t	Intercept	0.11	77.9	<0.0001	km	0.02	6.5	<0.0001	F-Statistic	Num. d.f	Den. d.f.	p-value	41.65	1	28	<0.0001
Coefficient	Standard Error	t-value	Pr > t																				
Intercept	0.11	77.9	<0.0001																				
km	0.02	6.5	<0.0001																				
F-Statistic	Num. d.f	Den. d.f.	p-value																				
41.65	1	28	<0.0001																				
Exponential Model Form[‡] $Bid = 7015.8e^{(0.13737 \cdot km)}$																							

Table 3 shows the hauling, fuel, and total costs per hectare to haul dairy slurry, as well as the cost to go an extra 1 km. For example the cost to load and haul dairy slurry from the pit to a distance of 2 km is approximately \$153 ha⁻¹. This includes \$114 ha⁻¹ custom hauler charges for loading, agitation, hauling, and spreading and \$39 ha⁻¹ for fuel. Of the total cost per hectare to empty the pit, approximately \$118 ha⁻¹ is for agitation and loading and \$35 ha⁻¹ is for transportation and spreading. The cost to go an additional 1 km increased with distance from the slurry pit in this study and ranged from \$19 to \$42 ha⁻¹.

Table 3. Change in dairy slurry application cost with distance from source – Southern Wisconsin.[§]

km	Custom hauler charge per hectare ^{††}	Fuel per hectare [§]	Total cost per hectare (haul + fuel)	Cost difference from previous km (haul + fuel)
1	\$99.33	\$35.02	\$134.35	--
2	\$113.92	\$39.47	\$153.38	\$19.03
3	\$130.64	\$44.48	\$175.12	\$21.74
4	\$149.83	\$50.12	\$199.95	\$24.83
5	\$171.82	\$56.48	\$228.31	\$28.36
6	\$197.05	\$63.65	\$260.71	\$32.40
7	\$225.99	\$71.73	\$297.72	\$37.01
8	\$259.17	\$80.84	\$340.01	\$42.29

Value of Dairy Slurry in Cash Grain Systems.

Based on the spring 2007 market value of N, P₂O₅, and K₂O[¶], the total first year value of manure nutrients in 1 m³ of average dairy slurry is \$2.58. When applied at a standard rate of 93.54 m³ ha⁻¹ the total

[†] bid = estimated hauling cost (less fuel) in U.S. dollars given at 1.6km (1mile) increments out to 8 km (5 mi)

[‡] Used to return custom hauler bids to non-transformed dollar amounts. Obtained by exponentiating both sides of the log linear model.

[§] Equations used for conversion from \$ ac⁻¹ at 1 mile increments to \$ ha⁻¹ at 1km increments are: bid (\$ ac⁻¹) = 86.614e^{0.137km}, and fuel (\$ ac⁻¹) = 31.078e^{0.1195km}

^{††} Wisconsin custom hauler rates: truck mounted slurry tank - \$47 to \$65 hr⁻¹, slurry pit pump - \$300 to \$500 day⁻¹, slurry pit agitator - \$150-300 day⁻¹.

^{§§} \$0.76 l⁻¹: WI Co-op price, summer 2006. Range in equipment fuel usage of interviewed haulers: slurry truck – 19 to 30 l hr⁻¹, tractor for slurry pit pump or agitator 19 to 45 l hr⁻¹.

[¶] \$1.09 kg⁻¹ N (\$0.49 lb⁻¹ N), \$1.16 kg⁻¹ P₂O₅ (\$0.53 lb⁻¹ P₂O₅), \$0.47 kg⁻¹ K₂O (\$0.21 lb⁻¹ K₂O)

fertilizer value of these nutrients would be \$241 ha⁻¹ (Table 4). Over a three-year period in a corn-soybean-corn rotation on a field with optimum soil test values, the fertilizer replacement value of this slurry would increase to \$287 ha⁻¹ before correcting for the 11% required rate of return on equity capital. In economic terms, slurry value can be defined in two ways: (1) the “in use” value of the dairy slurry as a replacement for purchased fertilizer, or (2) the value “in exchange” (the price a “consumer” agrees to pay for the slurry). Frequently a grain farmer’s “willingness to pay” is less than the “in use” value due to quantifiable factors such as inherent nutrient variability, difficulty in calculating actual application rates, potential soil compaction, as well as many non-quantifiable factors like the social costs resulting from odor, risk of potential run-off, and the transaction costs of setting up contracts. In this study we have used the “in use” value, and defined two methods in which the costs associated with agitation/pumping, transportation and spreading of dairy slurry are met: (1) all by the dairy farmer himself, or (2) a shared scenario in which the grain farmer contributes to the overall cost of transporting the slurry.

Table 4. First year available nutrient content (kg m⁻³) and market value (\$ ha⁻¹) of dairy slurry applied at 93.54 m³ ha⁻¹

Nutrient	Nutrient Price \$ kg ⁻¹	Average Manure Nutrient Concentration [†]		High Nutrient Concentration (Mean + 1sd) [‡]		Low Nutrient Concentration (Mean + 1sd)	
		Nutrient Composition kg m ⁻³	Market Value	Nutrient Composition kg m ⁻³	Market Value	Nutrient Composition kg m ⁻³	Market Value
N (incorporated)	1.09	0.99	\$100.94	1.38	\$140.70	0.60	\$61.18
P₂O₅	1.16	0.54	\$58.59	0.81	\$87.89	0.26	\$28.21
K₂O	0.47	1.85	\$81.33	2.61	\$114.75	1.08	\$47.48
Total	--	--	\$240.87	--	\$343.34	--	\$136.87

Corn Production with Commercial Fertilizer.

Baseline returns per hectare for a cash grain system not utilizing manure as a nutrient source, nor including any government payments, were calculated to be \$568 ha⁻¹ based on the PEPS production data and 2007 fertilizer and corn prices (\$0.12 kg⁻¹ [\$3.10 bu⁻¹]). Under these optimum soil test conditions farmers would apply 78 kg P₂O₅ ha⁻¹ and 56 kg K₂O ha⁻¹. However, when P₂O₅ and K₂O are not limiting to corn growth as a result of high soil test levels and therefore are not included in the fertilizer purchases (except as starter) returns per hectare increase significantly to \$650.

Corn Production with Dairy Slurry.

When dairy slurry is the main source of corn nutrients, the greatest factors influencing distance traveled and profitability are: 1) payment scenario, 2) valuation of slurry nutrients (N-only vs. N:P:K), and 3) manure nutrient content. Figure 1 shows the distance that average dairy slurry can be hauled under two payment scenarios at optimum soil test levels (corn responsive to N:P:K additions). In this scenario slurry can be moved approximately 3.2 km to a dairy farmer’s owned or rented land. If a grain farmer pays the additional costs after the first 1.6 km, it can then be hauled 7.6 km. Therefore, on fields that are closer, it could be quite profitable for a grain farmer to enter into this type of agreement with a dairy farmer. When the field is high in available P and exchangeable K however, no additional P and K beyond starter fertilizer is necessary, and returns per hectare for corn production increase to \$650 with fertilizer-only and slurry hauling distances decrease. For the scenario in which the dairy farmer pays all hauling costs, there is no profitable

[†] Average slurry nutrient content of 713 samples collected and analyzed at the UW Soil and Forage Analysis Lab in Marshfield, Wisconsin. 2002 to 2005.

[‡] sd = standard deviation

distance to haul the slurry when it is only valued for its N content. In the shared scenario the breakeven hauling distance drops from 7.6 (with optimum soil nutrient levels) to 5.5 km.

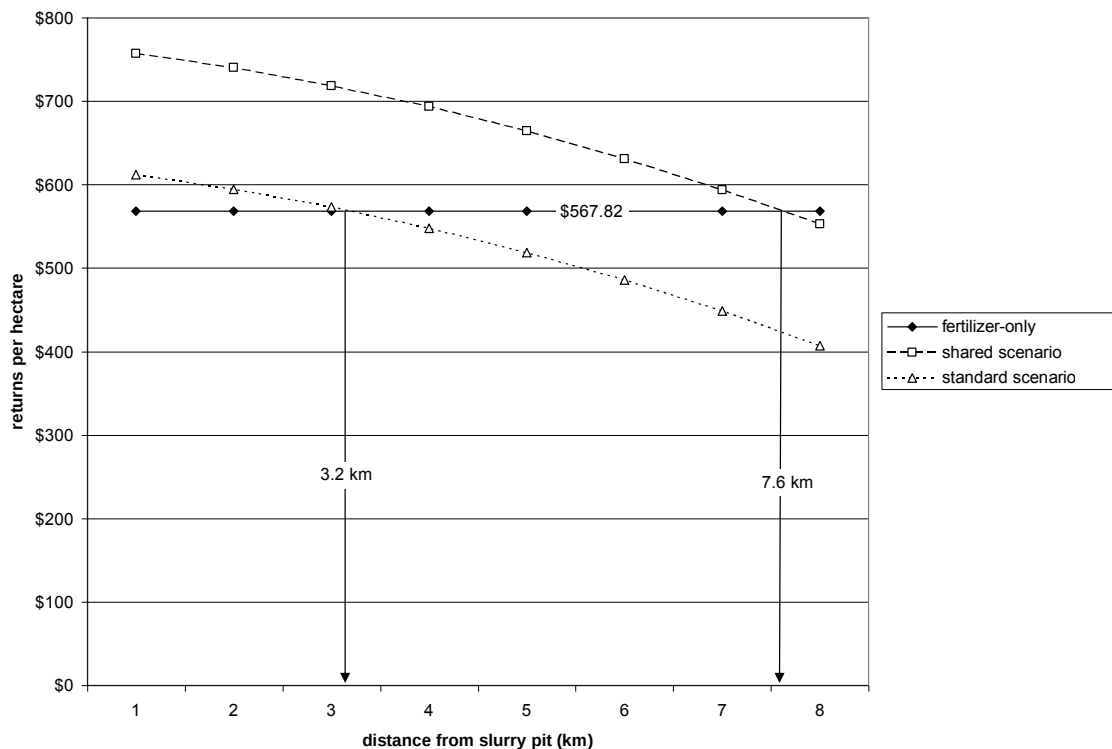


Figure 1. Effect of payment scenario (shared vs. standard) on breakeven hauling distances of dairy slurry in a corn grain system when N, P & K are all required for crop production.

Effect of Slurry Nutrient Composition on Profitability.

In addition to variability in initial soil test levels, not all manure slurry has an average nutrient content. When looking at the shared payment scenario, with soils at optimum fertility (Figure 2), dilute slurry (1 standard deviation below mean nutrient content) can be hauled to approximately 6.9 km, while more concentrated slurry (mean nutrients + 1 standard deviation) could be profitably transported in excess of 8 km from its source.

Effect of Nitrogen and Diesel Price on Hauling Distances.

Fluctuations in N price affect returns in both the fertilized and manured systems. In the shared payment scenario, on high-test soils, when N is the only limiting nutrient to corn growth, slurry can be hauled 3.6 km for lower (1999) N prices ($\$0.48 \text{ kg}^{-1}$ [$\$0.22 \text{ lb}^{-1}$]), and up to approximately 6.1 km for higher N prices (2007 + 20%; $\$1.31 \text{ kg}^{-1}$ [$\$0.59 \text{ lb}^{-1}$]). Both of these distances increase by approximately 2 km when slurry is valued for its N, P, and K content.

When diesel prices were varied from $\$0.19 \text{ l}^{-1}$ (1999 prices) to $\$0.84 \text{ l}^{-1}$ (2007 +20%), there was a 1 km change in hauling distances under both scenarios. This suggests that increasing prices of N-fertilizer will make the shared scenario more attractive to neighboring farmers, even if accompanied by higher diesel prices.

Effect of Corn Yield on Profitability.

Maintaining the assumption that corn produced with manure and commercial fertilizer will yield equivalently, a reduction in corn grain yield from the 10-year PEPS average does not change the economic relationship between the two nutrient sources (i.e. hauling distances are not affected). It does however affect the overall profitability of the two systems, lowering the returns per hectare in both the fertilizer-only

and manured scenarios. Because the PEPS program represents some of the higher yielding grain producers in the state (yield = 12.1 Mg ha^{-1}) a scenario was run using the 2006 Wisconsin statewide yield average of 9.0 Mg ha^{-1} for corn grain. In this situation, corn production prior to government payments results in a greatly reduced return per hectare of \$192 compared to \$568 ha^{-1} when yields are 12.1 Mg ha^{-1} . When hauling costs are shared and slurry is valued for its N, P and K content, it can be profitably hauled up to 7.6 km. This is the same hauling distance reported using PEPS yield data. At 4 km, we see an increase in returns per hectare compared to when purchased fertilizer is used of \$126 ha^{-1} (\$318 vs. \$192 ha^{-1}). Again this is consistent with our findings using the PEPS corn yield data.

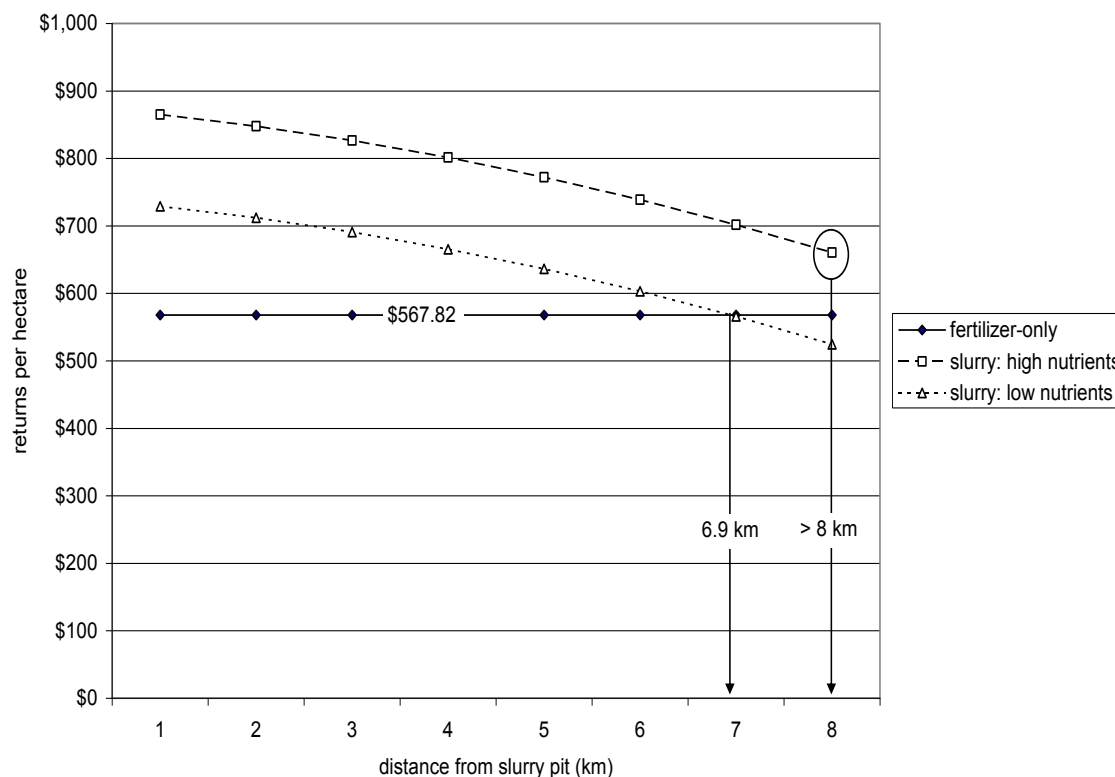


Figure 2. Effect of slurry nutrient content (mean+1 standard deviation, mean-1 standard deviation) on the breakeven hauling distance of dairy slurry in a corn grain system: N:P:K all valued.

Summary and Conclusions

Although the management and hauling of dairy slurry is expensive, this analysis shows that under a number of scenarios returns to a corn production enterprise would increase if slurry is included in the rotation – even if some of the additional transportation and spreading costs were assumed. Moving slurry off the dairy farm could have a major positive impact on the dairy's conservation plan. In the “shared scenario” the neighboring grain farmer pays for additional hauling and spreading costs after the dairy farmer pays for the initial costs of pit agitation, tank loading, and hauling the first 1.6 km. Using 2007 fertilizer prices, and dairy slurry of average composition, the breakeven spreading radius for the dairy farmer increased from 3.2 km when he covered the full costs to 7.6 km when costs were shared.

On production fields that have high soil test values, reducing the fertilizer value of the manure to only its N content, maximum hauling distances in the shared scenario drop from 7.6 to 5.5 km. Looking to the future, this analysis indicates that if N or diesel prices increased by 20% over 2007 prices, the spreading radius would increase by about 0.5 km in the case of the former and decrease by 0.2 km in the case of the latter. Although a reduction in corn grain yield affected the overall profitability of both the fertilizer-only and manured systems, the economic relationship between the two systems did not change.

What the potential consumer (the grain farmer) is willing to pay for slurry may well be lower than its estimated fertilizer replacement value. Nevertheless, this analysis suggests that even with relatively low nutrient concentration in dairy slurry, under modest hauling distances, it would be economically and environmentally advantageous to both dairy and grain farmers to develop manure contracts.

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ORCHARDGRASS (*DACTYLIS GLOMERATA* L.) LEY FOR IMPROVED MANURE MANAGEMENT IN WISCONSIN: I. FORAGE YIELD, ENVIRONMENTAL IMPACT AND PRODUCTION COSTS

Janet Hedtcke, Joshua Posner, John Hall, Richard Walgenbach, Jon Baldock

ABSTRACT

Spreading dairy manure in climatic zones with a short growing season that are dominated by full season crops such as corn (*Zea mays* L.) and alfalfa (*Medicago sativa* L.) is a challenge. However, replacing these with a grass ley does open several windows for manure spreading. The effects of such a strategy were examined in a three-yr, 2x2 factorial trial comparing orchardgrass (*Dactylis glomerata* L.) and corn silage with either manure or fertilizer at two locations in Wisconsin. In the fourth year a test crop of corn silage was grown following both crops. During the first three years, the manured corn plots out-produced the manured grass plots (16.0 vs. 8.6 Mg DM ha⁻¹ yr⁻¹) but in the 4th year the corn following the orchardgrass ley system was more productive than when following corn (20.7 vs. 14.9 Mg DM ha⁻¹). Soil test phosphorus values climbed 2-4 mg kg⁻¹ yr⁻¹ and soil test potassium 14-20 mg kg⁻¹ yr⁻¹ under the manured systems. Variable costs per metric ton of forage dry matter were significantly higher in the manured grass ley compared to manured continuous corn silage system (\$67 vs. \$43 Mg⁻¹). This can be considered a worst case scenario due to the frequent manuring in the ley system. Also, it is difficult to include the managerial and economic advantages of having adequate summer manure spreading locations. Thus, including a grass ley may be an ecologically and economically sound strategy where summer manure spreading is required.

Keywords: grass, slurry, nutrient cycling, dairy rotation, manure spreading

Abbreviations: CS, corn silage; DFRC, Dairy Forage Research Center; DM, dry matter; F, fertilizer; GL, grass ley; M, manure; MFAI, Michael Fields Agricultural Institute; STP, soil test phosphorus; STK, soil test potassium

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INTRODUCTION

Most dairy farms in the north central and northeastern USA continue to grow most of their feed and recycle the manure nutrients on the farm. However, to remain economically viable, many dairy farms are increasing herd size. For example, although the number of Wisconsin dairy operations has declined 58% between 1990 and 2007, total production statewide has remained almost constant and the proportion of milk accounted for by farms with more than 200 animals has increased from less than 1% to 41% in that same period (USDA-NASS, 1995, 2008). Among the challenges these dairymen face, in addition to the cost of storing and moving manure, is finding places and time to apply it (Carpenter et al., 1998).

Wisconsin ranks #1 in the U.S.A. in corn silage production as it is valued for its superior tonnage and energy density, while alfalfa, produced on nearly one million ha in the state (USDA-NASS 2008), is the most common source of protein and fiber in the dairy ration. Unfortunately this common corn and alfalfa crop rotation leaves the dairy farmer with few spreading windows and nitrogen-efficient opportunities for manure application (Sutton et al., 1979; Schmitt et al., 1996). Manuring corn requires either a fall application, about 7 months prior to planting, (Sanford et al., 2009) or preplant applications in the spring when soils are often wet, which can result in soil compaction and delayed planting. In addition, applying heavy rates of manure on plowdown alfalfa can lead to over-application of N for the subsequent corn crop due to the substantial N-credits associated with legume incorporation (Posner 2005; Daliparthi et al., 1994). Even moderate application rates of manure on alfalfa are not recommended because of salt toxicity, potential crown damage (Kelling and Schmitt, 2003) and the preservation as haylage is sensitive to timing the applications prior to alfalfa regrowth (Wiederholt et al., 2002).

Confronted with these limited windows for ecologically and agronomically sound manure spreading, many expanding dairy farmers have been obliged to invest in large, costly concrete holding pits to store manure for periods of 6 to 12 months (Turnquist et al., 2006). For example, in the 2002 Farm Bill, the Natural Resources Conservation Service (NRCS) through cost sharing in the Environmental Quality Improvement Program has allocated approximately \$40 million to Wisconsin dairy farmers for improved manure storage systems (Murphy, 2009). Nevertheless, the majority of Wisconsin dairies still do not have long-term, manure storage facilities and have to spread manure several times a year (Turnquist et al., 2006). Rotz (2005) has suggested that a modified crop rotation including a grass hay phase would create a number of summer spreading windows and might be a logical, cost-effective solution for improved manure management, while also providing feed for a range of livestock classes.

In a grass ley system, the land is planted to grass for several years and then followed by annual crops (Webster et al., 1999; Martin, 1996). Research has shown that grasses are very efficient in capturing soil N (Simmelsgaard, 1998), in increasing P and K uptake (Heathwaite et al., 1998; Gustafson, 1987; Unwin et al., 1986), as well as, improving soil structure and organic matter levels (Min et al., 2003; Nelson et al., 2009; Eekeren et al.,

2008; Riley et al., 2008). Using lysimeters, researchers in New Zealand (Cameron et al., 1996), Texas (Sanderson & Jones 1997) and Minnesota (Randall et al., 1997) for example, found very little nutrient leaching from slurry applied to pastures, orchardgrass, and other grass sods versus annual crops. In addition, orchardgrass itself was reported to be very efficient in manure nutrient uptake in studies from both the east (Kanneganti & Klausner, 1994; Mikhailova et al., 2003) and west (Sullivan et al., 2000) coasts of the U.S.A. However, the role a relatively short duration, heavily-manured grass ley could play in cropping systems for improved manure management and livestock nutrition has received less study.

To meet the need for more information on grass ley systems, the overall goal of this study was to test the effectiveness of a grass ley in helping farmers expand their options for environmentally and agronomically sound, in-season manure applications, while producing high quality feed for their herd. In this paper we report on:

- The productivity (dry matter production) of the grass ley system in comparison with corn for silage;
- The efficacy of the grass ley system in recycling manure nutrients, by monitoring soil test values and fall nitrate levels;
- Characterizing the effect of residual soil fertility on subsequent corn silage yields; and
- The production costs of both systems.

In a second paper we report on orchardgrass forage value and feed acceptance by dairy heifers.

MATERIALS AND METHODS

Treatment Selection

A factorial design was employed to compare the two systems: 1) a short cycle grass ley (GL); and 2) continuous corn silage (CS) under two fertilization strategies: 1) manure (M) or 2) commercial fertilizer (F). As a result, the treatments were:

- 1) 3-yr of orchardgrass (*Dactylis glomerata* L.) including a seeding phase and two established hay phases followed by one year of corn silage grown on residual soil fertility; (hereafter referred to as GL+M or GL+F)
- 2) 3-yr of continuous corn silage (*Zea mays* L.) followed by one year of corn silage grown on residual soil fertility; (hereafter referred to as CS+M or CS+F).

Corn silage served as the 'standard' system since it is commonly a heavily manured forage option in Wisconsin. In this trial, manure was added after each cut (3-4yr⁻¹) in the GL system to meet expected nitrogen needs of the next cutting.

Sites and Experimental Design.

Plots were laid out at two sites: 1) the USDA Dairy Forage Research Center (DFRC) in Prairie du Sac, Wisconsin (43°20'26" N; 89°43'11" W) where slurry was applied; and, 2) at Michael Fields Agricultural Institute (MFAI) in East Troy, Wisconsin (42°46'50"N; 88°24'48"W) where pack manure was applied. Soil type at DFRC was a St. Charles/Richwood silt loam (fine-silty, mixed, superactive, mesic Typic Argiudolls) and at MFAI a Fox silt loam (Fine-loamy over sandy or sandy-skeletal, mixed, superactive,

mesic Typic Hapludalfs); soils at both sites were well drained. Initial soil organic matter levels were 34 and 24 g kg⁻¹, and soil test levels were 32 and 43 mg kg⁻¹ phosphorus and 123 and 98 mg kg⁻¹ potassium at DFRC and MFAI, respectively.

In order to experience a wider range of seasonal rainfall and temperature patterns, as well as soil type, manure type and field management, the trial was initiated in the fall of 2003 (Startup 1) and again in 2004 (Startup 2) at each site resulting in four “environments”. The experimental design was a randomized complete block with the four treatments of the factorial combination randomly assigned to each of the blocks (there were 5 blocks at three environments and 6 blocks at one environment). Plot size (56 m² at DFRC and 111 m² at MFAI) was determined to accommodate manure spreading equipment as well as the width of the corn planter and drill. Surface-banded slurry placement was done in one pass with a 7570 liter Nuhn®¹ research manure tanker (Nuhn Industries, Sebringville, ON, Canada). The pack manure was applied with a 6.9 m³ Knight®¹ box spreader with rear beaters (Kuhn North America, Inc, Broadhead, WI, USA).

Agronomic Practices

Grass ley rotation management. Orchardgrass was chosen for its quick establishment, persistence, and high and consistent seasonal yield (relative to smooth brome grass, *Bromus inermis* L.; perennial ryegrass, *Lolium perenne* L.; and reed canarygrass, *Phalaris arundinacea* L.) (Hall et al., 2005; Moser et al., 1996). Furthermore, its bunch-type, rather than sod-type, growth habit results in a micro topography that allows the manure to trickle or fall off the forage to the soil relatively quickly, reducing the time it stays on the leaves. ‘Elsie’, a mid-maturity variety of orchardgrass, was drilled in 19-cm rows at 13 kg ha⁻¹ at all four environments.

Startup 1 of the orchardgrass was established late August 2003 and startup 2 in late August 2004. Due to poor establishment at both sites and in both years, caused by dry conditions (45-60% of normal rainfall from August to October), the grass was reseeded on April 14 and 29, 2004 and on April 15 and 27, 2005 at MFAI and DFRC, respectively. Recent date-of-planting research has confirmed these findings that delaying orchardgrass seeding into late August and beyond increased the risk of establishment failure, as well as, actually reducing yield of the stand the next year by 1 Mg ha⁻¹ (Undersander and Greubb, 2007). To aid the grass establishment, 22 kg ha⁻¹ of N fertilizer was applied at greenup to both M and F treatments. Glyphosate (at a rate of 1.68 kg ae ha⁻¹) was applied as a burndown prior to reseeding orchardgrass in April. A subsequent post emergence application of a broadleaf herbicide (2,4-D at a rate of 0.53 ae kg ha⁻¹) was applied in both seeding years at DFRC. No herbicide was applied in the established orchardgrass at either site nor was any seeding-year herbicide used at MFAI.

At DFRC, the slurry was surface-banded at a rate of 112 m³ ha⁻¹ (12,000 gal a⁻¹) at initial seeding and again after each cut. At MFAI, the pack manure was applied at 36 Mg ha⁻¹ (16 tons a⁻¹) prior to initial seeding and also after each cut. As can be seen in Table 1, although the pack manure was typical for dairies in the region, the slurry was very dilute compared to University of Wisconsin (UW) Extension standard values reported for

¹ The mention of this product is not for brand promotion but for informational purposes only

Wisconsin farms (Laboski et al., 2006). Estimated total nutrients applied as manure are shown in the top half of Table 2. Manure applications were based on UW Extension recommendations which estimate that 30% of total manure N is available for the first-year crop if not incorporated and 40% if incorporated within 72 hours of application (Laboski et al., 2006). Likewise, 60 and 80% of phosphorus and potassium, respectively, were considered available the first year after application. This translates to approximately 0.55:0.13:1.10 kg m⁻³ of available N:P:K in the slurry and 1.6:0.9:4.1 kg Mg⁻¹ of available N:P:K in the solid manure. The application of pack manure resulted in an uneven distribution with large clumps of manure lying on and sometimes smothering the grass sward, and tire traffic patterns due to repeated passes by the slurry tanker and tractor resulted in some thinning of the stand in all the manured plots at both sites.

Nitrogen fertilizer on the grass ley (GL+F) was applied as either urea or ammonium nitrate and approximately equal that of the manure of 56 kg available N ha⁻¹ per cut (lower half of Table 2). Muriate of potash (KCl, 60% K₂O) was applied according to soil test levels with additions ranging from 47 kg ha⁻¹ for the CS+M to 159 kg ha⁻¹ for the GL+F system.

Corn silage rotation management. For corn, a transgenic full-season (>100 day Relative Maturity) hybrid was chosen for the DFRC site and its non-transgenic sister line was chosen for MFAI site due to concern over pollen drift to the rest of the certified organic farm. Corn silage plots were no-till planted at DFRC and at the low-input MFAI site, the corn was conventionally planted, and tillage and cultivation was used for manure incorporation and weed control. At both sites corn was planted at 89,000 seeds ha⁻¹ in 76-cm rows.

The corn silage plots were planted in early May at DFRC and about two weeks later at MFAI. Starter fertilizer (112 kg ha⁻¹ of 5:14:42) and rootworm insecticide (4 kg ha⁻¹) was added at corn planting to both silage treatments at DFRC, but none was used at MFAI. At the DFRC site, the herbicide program consisted of a burndown of glyphosate (at a rate of 1.68 kg ae ha⁻¹) and a post-emergence application of glyphosate (0.8 kg ae ha⁻¹) or 2,4-D (at a rate of 0.53 kg ae ha⁻¹) each season. At MFAI, generally two rotary hoeings and two cultivations took place for weed control following planting.

The slurry was surface-applied at 112 m³ ha⁻¹ (12,000 gal a⁻¹) the fall prior to corn planting at DFRC and pack manure was applied at 67 Mt ha⁻¹ (30 ton a⁻¹) and incorporated in the spring before planting at MFAI. Due to the dilute nature of the DFRC slurry (see Table 1) and a reluctance to add slurry at higher rates due to the risk of run-off, manure additions were complimented with commercial N fertilizer on CS+M in the spring to bring estimated available N to 180 kg N ha⁻¹. The pre plant nitrate test (Bundy et al., 1995) was used to set N additions for the fertilized plots (CS+F). Muriate of potash was applied according to soil test levels. Estimated total nutrients applied to the corn are shown in Table 2.

Glyphosate (at a rate of 1.68 kg ae ha⁻¹) was used to kill the orchardgrass sward in the fall of the 3rd year and as burndown treatment the following spring on the corn rotation at

DFRC. The plots at MFAI were chisel plowed in the fall followed by a spring field cultivation once following corn or twice after GL.

Corn silage test crops. In the 4th season of each start-up series (2007 & 2008), a test crop of corn was planted across all the plots following best management practices for corn silage with only starter fertilizer (112 kg ha⁻¹ 5:14:42) and no additional nitrogen. At the DFRC site, corn was also planted across all plots in the 5th season (as a second-yr test crop) with just starter (112 kg ha⁻¹ 5:14:42) and 67 kg N ha⁻¹. The objective of planting the test crop in the 4th and 5th seasons was to estimate the residual effect of the systems on silage yields and soil test levels.

Sampling

Forage. When the orchardgrass reached boot stage at first cut and 35-40 cm tall in subsequent cuts, it was harvested with a sickle-bar mower to a 7-cm stubble height. This harvest strategy was shown to maximize seasonal production and total digestible nutrients (Mislevy et al., 1977). In mid-September, at approximately 35% DM, whole-plant corn was chopped at 15-cm stubble height. Samples were collected from the center of the plots in a 6 m² area to eliminate shading and border effects. Samples were weighed fresh and a grab sample was collected to determine water and nutrient concentration. All samples were dried in a 55° C, forced-air oven for one week and yields were recorded on dry matter (DM) basis.

Soil. A composite of 5 soil cores (2-cm diameter) were sampled from the middle of each plot from 0–15 cm depth for routine fertility prior to the trial and each fall following the final crop harvest but before manure application. Soil samples were analyzed for pH, organic matter (OM), available P, and extractable K by the UW Soil and Plant Analysis Laboratory (Madison) using the procedures of Schulte et al. (1987) as reported in Laboski et al. (2006). To measure post-harvest nitrate N in the soil (hereafter referred to as fall nitrates), a tractor-mounted hydraulic probe was used to collect two, one meter-deep cores from the center of each plot that were subsequently bulked in each plot. These cores were taken in late fall before freeze-up. Soil nitrates were only monitored through the end of the 3rd season when manure and fertilizer inputs were applied. Fall soil nitrates were not collected in the 4th year of the studies.

Manure. Manure samples were taken directly from the application equipment. Samples were analyzed for dry matter content and total N, P, and K, at the UW Soil and Forage Analysis Laboratory, using total Kjeldahl N for N and dry ash methods for P and K (Association of Official Analytical Chemists, 2008a, 2008b).

Economic Analysis

Production (variable) costs ha⁻¹ yr⁻¹ and cost Mg DM⁻¹ of forage were averaged across all four years of each cropping system (three years of treatment and one year of the test crop of corn silage) using Agricultural Budget Calculation Software (Frank and Gregory, 2000). These costs included annual inputs such as seed, machinery-use costs (i.e. fuel, energy, repair and maintenance), pesticides, fertilizer, as well as custom fertilizer application and herbicide spraying (WI custom rate guides-USDA-NASS 2004; USDA-

NASS-2007). For this study, the cost of manure, based on its custom application cost, was charged entirely to the forage enterprise. The objective of this analysis was to give dairymen the elements to compare the costs of forage production using a grass ley versus corn silage.

Based on custom-hauler interviews, the custom slurry applications charge was set at \$136 ha⁻¹ (\$55 a⁻¹) assuming the use of 15-m³ (4000 gallon) truck-mounted tankers, broadcast application at a rate of 112 m³ ha⁻¹ (12,000 gal a⁻¹) and situated at 1.5-km (1-mile) distance from the manure pit (Sanford et al., 2009). Solid manure was also based on \$136 ha⁻¹ (\$55 a⁻¹) applied at the rate of 34 Mg ha⁻¹ (Kevin Erb, pers. com. 2009). Fixed costs included labor and management, land charge, property taxes, interest, insurance and depreciation.

Statistical Analysis

Proc mixed of SAS 9.1 software was used to do the analyses of variance for yields, soil test values, profile nitrates, and production costs; and proc univariate was used to examine residual plots for variance assumptions (SAS 2006; Littell et al., 2006). In the mixed model, system (GL, CS), nutrient source (M, F), and phase (1, 2, 3) were fixed effects and environments (site-start combination), blocks, and interactions of environment with system, nutrient, and phase were random effects. Of the 252 total observations, there were three missing observations for corn yield, two due to wildlife damage and one from mis-applied herbicide. Overall three-yr-average-forage yields, test-crop yields, and production costs were analyzed using method=type3 to determine interactions of random factors such as environment with fixed effects. Though there were heterogeneous errors for system, models with and without that correction were comparable and the simpler model was used and its ANOVA structure is shown in Table 3. The repeated measures command was used to account for auto-correlation resulting from sampling from the same plots each year (hereafter year is referred to as phase of rotation) for soil test and yield analyses. Following Littell et al. (2006) regression was used to evaluate trends (testing H₀: slopes equal to zero, and common slopes between treatments) for soil test P and K over the rotations and the bonferroni t-test was used to separate the means of slopes.

RESULTS AND DISCUSSION

Forage Yields

During the seeding year, the orchardgrass was cut up to three times, depending on rainfall. During the subsequent years, four or five cuts were taken. Analysis of the average annual yield over phases and cuts of the three-yr trials revealed that neither the system × nutrient × environment nor the system × nutrient interactions were significant (Table 3). But the system × environment interaction was significant (Table 3). However, it was only one of magnitude such that the advantage of CS compared to GL averaged 9.3 Mg ha⁻¹ at DFRC, but only 4.7 Mg ha⁻¹ at the less productive MFAI site. Hence, the discussion can focus on the significant main effects of system and nutrient (Table 4). Corn silage had nearly double the productivity of orchardgrass across sites (Table 4). Much of this difference came in the seeding year of orchardgrass, which yielded 5.1 Mg ha⁻¹ compared to 9.5 Mg ha⁻¹ in the subsequent two years (Fig. 1). The manured

treatment (M) out yielded the commercially fertilized treatment (F) for both corn silage and orchardgrass by an average of 14% (Table 4). Other researchers applying manure to orchardgrass (Sullivan et al., 2000) and corn (Motavalli et al., 1989; Sanford et al., 2009; Jokela, 1992) have found similar effects of manured plots outperforming commercially fertilized plots.

In order to investigate the hypothesis that there might be a cumulative yield effect, we expanded the analysis to include phase (ANOVA table not shown). Of the nine interactions between the factorial treatment effects, phases, and environments; only the environment $\times$ phase $\times$ system interaction was significant ($p < 0.0001$). Because of this interaction and some heterogeneity in the error between systems, the systems were analyzed separately. For orchardgrass there was a substantial increase in yield over the life of the stand ($p = 0.0055$, Fig. 1), but for corn silage yields there was no increase over time ($p = 0.6851$, Fig. 2). This difference between systems coupled with considerable variability of the phase effect across environments led to the significant three-way interaction. In the split analyses, there was also evidence of a cumulative effect of manure in both systems (Fig. 1 and 2). In orchardgrass, the manure advantage was significant in all three phases and it increased such that by the 3rd season, the manured plots were over 1.9 Mg DM ha⁻¹ more productive than the commercial fertilizer plots ($p = 0.0541$ to < 0.0001 ; Fig. 1). Within the corn silage systems, the manured corn yields were also higher than those in the fertilized corn for every phase, but difference increased from nonsignificant in Phase 1 ($p = 0.1961$, Fig. 2) to highly significant in Phases 2 and 3 ($p = 0.0007$ and $p = 0.0028$, Fig. 2). The delayed response in CS was at least partly due to the fact that the manure was added just once annually to that system. Thus, the length of the grass ley and the frequency of manuring could be adjusted according to the need for P and K additions.

Corn silage production during the 4th year of the trials is shown on Table 5. In this test-crop year, none of the interactions with factorial effects with environments nor the system $\times$ nutrient interaction were significant (Table 3) so the focus can again be put on the main effects (Tables 3 and 5). Combined across environments, there was an effect of previous crop on corn silage yields (GL > CS) as well as nutrient source (M > F). Most striking were the high yields of corn silage with only starter fertilizer when following GL+M, yielding nearly 30% more tonnage than the others. As previously mentioned, a second test crop of corn silage was planted in the 5th year of the trials at DFRC with only the addition of starter fertilizer plus 67 kg N ha⁻¹. The 5th yr test crop yield analysis showed a system $\times$ nutrient interaction ($p < 0.0137$, ANOVA not shown) which showed the impact of GL+M still evident 2 yrs later (Table 5).

Soil test trends for phosphorus and potassium

Due to the differences in manure nutrient density and field management (Table 1) the two sites were analyzed separately for STP and STK. In all cases, the slopes of the lines were different from zero at $p < 0.05$. At both sites, the monthly manuring of the orchardgrass (GL+M) and annual manuring of corn (CS+M), even including a drawdown year (4th year test crop of corn silage) resulted a net accumulation of P and K in most cases, and this was reflected in the positive slopes of the regression equations for the +M treatments

(Table 6 & 7). The one exception was the manured corn at DFRC where the dilute slurry added limited phosphorus and potassium (Table 2). A number of authors have found that manure applications substantially increase both soil test phosphorus (STP) and soil test potassium (STK) levels when compared to a fertilizer-only treatment (Randall et al., 2000; Ritter 2000; Sanderson and Jones, 1997; Sutton et al., 1979). In the same manner, where just P and K were added as fertilizer due to high soil test levels (GL+F, CS+F), there was net removal of P and K as reflected in the negative slopes in Tables 6 and 7. The one exception was positive slope for potassium under corn silage at MFAI, but these plots were low in K when the trial began and did receive a remedial dose of KCl. At both sites, the frequent manuring of the orchardgrass for three years and then the un-manured 4th year of corn silage resulted in average annual increase in STP of 3-4 mg kg⁻¹ and 14-20 mg kg⁻¹ for STK. Consequently, the GL+M system would not be recommended on sites prone to erosion, adjacent to streams or other surface waters, or excessively high in STP (>100 mg kg⁻¹) per the nutrient management standards set for Wisconsin (USDA-NRCS 590). It could however be considered for use on neighboring grain farms as an approach for building soil fertility or as part of a longer rotation where subsequent crops would continue to draw down soil test levels.

Fall Nitrates

No clear trend was found for the residual fall nitrate levels under the four systems and most of the values were close to the estimated background level of 56 kg ha⁻¹ meter depth (Bundy et al., 1995). Levels under the orchardgrass plots were not consistently higher than with corn silage nor did the manured plots have consistently higher NO₃⁻-N levels than the fertilized plots (data not shown). Several other authors working with corn have found equivalent levels of fall nitrate levels between manure and fertilizer sources (Jokela, 1992; Zebarth et al., 1996). In this study, only 31% of fall nitrates were below 30-cm in the GL treatments compared to 45% for the CS treatments (trt $p < 0.0001$) suggesting that the nitrates were more at risk of leaching during the off-season under the annual silage systems. This observation helps to explain the findings from several lysimeter studies that report reduced nitrate leaching under manured orchardgrass as well as grass sods vs. annual crops (Anderson-Teixeira et al., 2009); Thomsen et al., 1993; Cameron et al., 1996; Simmelsgaard, 1998).

Production Cost Analysis

As expected with the cost analysis, with little variability of inputs between blocks, there were many significant main effects of system and nutrient strategy but no interactions (ANOVAs not shown other than for cost per ton of forage in Table 3). Average annual nutrient costs were highest in the GL+M system due to repeated application of manure while the remaining three systems were similar to each other (Table 8). For machinery-use/fuel costs (Table 8) and operator labor costs (data not shown), both grass ley systems (both GL+M and GL+F) were about 50% higher than that of the corn silage systems (CS+M and CS+F), largely due to multiple orchardgrass harvests per season compared to just one harvest per year with the continuous corn silage systems. In the GL systems, higher nutrient and harvest costs were partially offset by the high cost of annual seed bed preparation, seed, and herbicides in the CS treatments (Table 8). As a result, total variable costs per hectare per year were relatively similar between the perennial and

annual systems ($p < 0.7490$). Variable costs per metric ton of forage during the 4-yr rotation were the highest, however, with the grass ley system using manure (GL+M), even with the low-cost and high yielding 4th-yr corn silage grown on residual soil fertility. Variable costs per ton of corn silage in our study (\$46 Mg⁻¹) were similar to that reported by the UW Center for Dairy Profitability (<http://cdp.wisc.edu/>). The \$25 per metric ton increase in the cost of forage production for the GL+M system is however, somewhat misleading. In this study, manure was applied after each cut of orchardgrass, a practice many producers would probably choose not to follow, perhaps affecting yield, but definitely reducing the costs (e.g. lagoon agitation, hauling, etc.) associated with frequent applications. Also, in this study, all of the manure and its application costs were charged to the crop enterprise which had a larger impact on the cost per ton of forage under the frequently manured GL system. Other researchers (Sanford et al 2009; Cabot et al, 2004) have, for example, looked at payment scenarios that share the hauling cost between the dairy and cropping enterprises. Also, it is not easy to quantify all the economic and management advantages to the dairy of having, for example, a field in grass that is open for manure spreading almost continuously between April and October. It is also interesting to note that not only in the first year following the GL+M was there an important yield bump but in the second “residual” year, at the one site it was tested (Table 5), there was still an impressive yield advantage to using a manured grass ley.

CONCLUSION

A longer crop rotation including grass ley phases may fit on a range of farms as an ecological and economical way of dealing with part of the dairy manure stream. Although not as productive a forage as corn silage, an orchardgrass ley is productive once established, and offers several summer windows for spreading manure. The accumulation of P and K associated with heavy manuring can be drawn down during subsequent cropping phases or the ley can be located on lower fertility soils. In addition, the potential for nitrate leaching is not higher than under corn silage. In these trials, the first corn silage crop following the orchardgrass phases with manure was produced without additional fertilizer and yields were above 20 Mg DM ha⁻¹ and a second crop with only 60 kg N ha⁻¹ produced over 18 Mg DM ha⁻¹. Compared to growing corn after the CS +M system, the residual fertility and previous crop effect from the GL+M system increased corn silage production by 5 Mg DM ha⁻¹ in each of the following two years.

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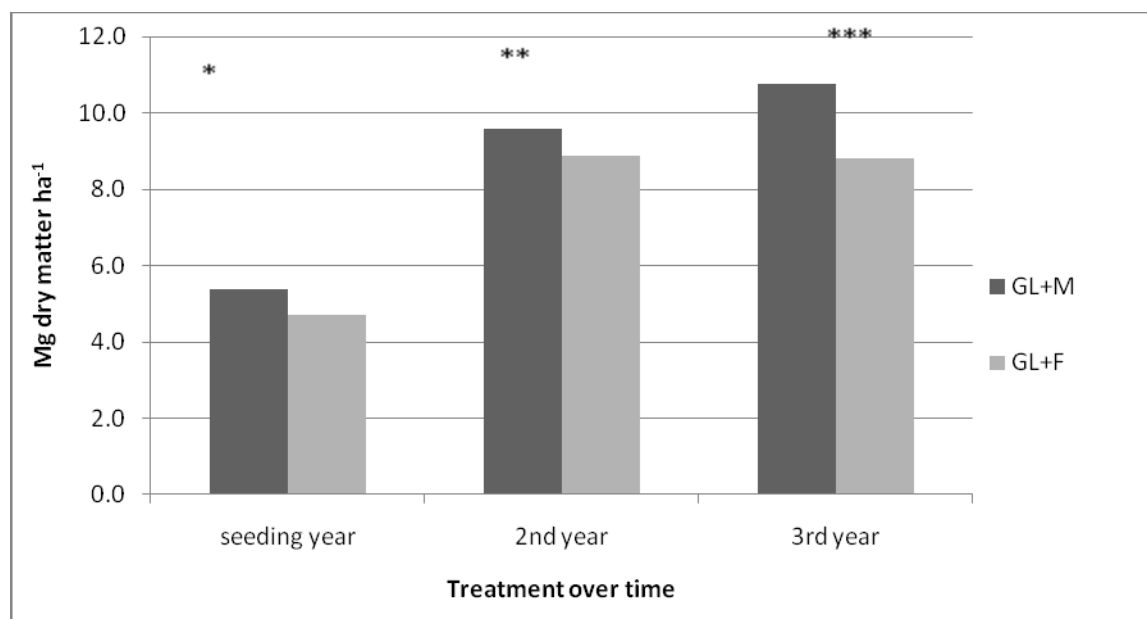
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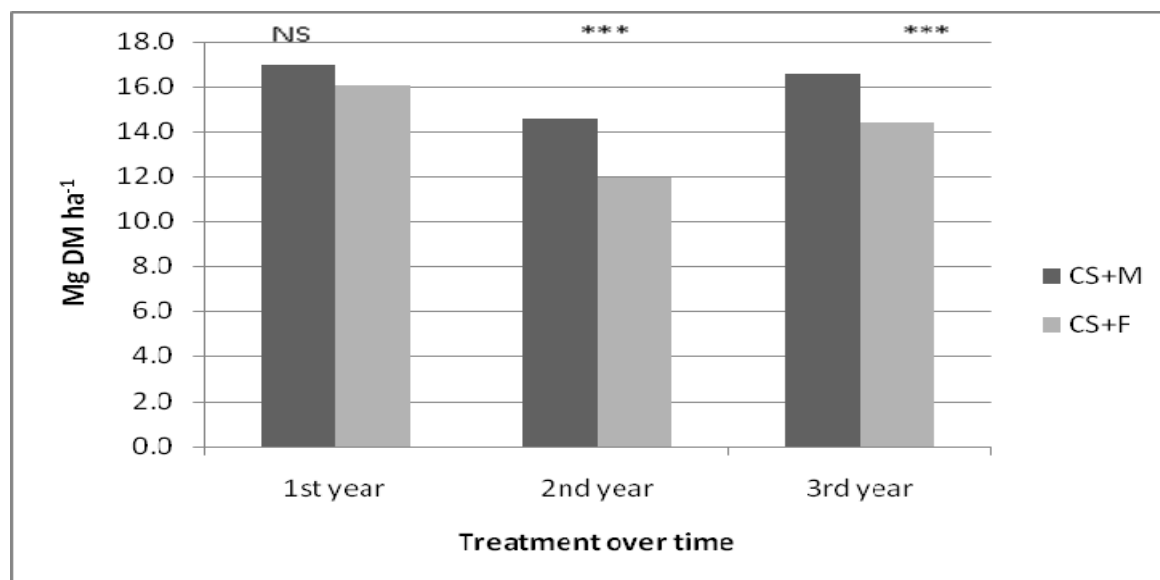
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Fig 2. Corn silage yields over time with manure vs. fertilizer across four environments. CS+M = corn silage + manure; CS+F = corn silage plus fertilizer.



* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 1. Average nutrient concentration for slurry and solid manure (standard error in parenthesis).

Slurry	DM†	Total N	Total P	Total K
	g kg ⁻¹	-----	kg m ⁻³ -----	
Dairy Forage Research Center ‡	26 (1.6)	1.84 (0.05)	0.22 (0.02)	1.38 (0.04)
University of Wisconsin Extension standard for slurry§ Solid	60.0	2.88	0.48	1.99
	g kg ⁻¹	-----	kg Mg ⁻¹ -----	
Michael Fields Agricultural Institute ¶	273 (21.4)	5.36 (0.31)	1.50 (0.21)	5.16 (0.37)
University of Wisconsin Extension standard for solid§	240	5.01	1.10	3.66

† DM, dry matter.

‡ Mean of 32 samples taken prior to application, 2003-2007

§ Laboski et al., 2006.

¶ Mean of 28 samples taken prior to application 2003-2007

Table 2. Average annual nutrient application during years 1-3 at the Dairy Forage Research Center (DFRC) and Michael Fields Agricultural Institute (MFAI) (standard error in parenthesis).

		Orchardgrass†			Corn†		
		Grass ley + manure			Corn silage + manure		
Site	Nutrient	N	P	K	N	P	K
		-----kg ha ⁻¹ -----					
DFRC	Manure‡	832 (54)	99 (7)	638 (40)	294 (20)§	34 (2)	210 (11)
MFAI		555 (30)	179 (7)	732 (47)	344 (14)	85 (6)	310 (10)
		Grass ley + fertilizer			Corn silage + fertilizer		
		N	P	K	N	P	K
DFRC	Commercial fertilizer¶	191 (9)	0	74 (15)	165 (9)	7 (0)	80 (10)
MFAI		167 (8)	0	71 (14)	158 (7)	0	71 (14)

†At the DFRC there was an average of 12 applications over the three years in both start-ups and at MFAI, there was an average of 10.5 applications. There was only one annual application for corn silage.

‡ 112 m³ ha⁻¹ as slurry on orchardgrass after each cut and prior to planting on corn at DFRC and 36 Mg ha⁻¹ on orchardgrass after each cut and 67 Mg ha⁻¹ prior to planting on corn at MFAI

§ due to dilute nature of slurry, approximately 95 kg ha⁻¹ of additional fertilizer N was added to the corn silage each spring

¶ Rates based on pre-plant nitrate test and annual soil test levels

Table 3. ANOVA outline (proc mixed method=type3) for forage yields and production costs.

	3-yr average annual yield				1 st -yr test crop			Cost Mg ⁻¹ DM		
Source	df	Mean Square		Prob>F	Mean Square		Prob>F	Mean Square		Prob>F
Environment, E	3	12.2756		0.4258	146.4933		0.0128	31,647		0.1925
Block(E)	17†	1.1089		0.0001	3.7443		0.0539	1,458.34		0.0004
Treatment, T	3	70.9983		0.0002	39.4974		0.0054	55,674		0.0003
System, S	1		204.0508	0.0187		67.4922	0.0503		166,049	0.0210
Nutrient, N	1		8.5230	0.0013		38.4114	0.0596		1,564.72	0.6465
S x N	1		0.4211	0.3401		12.5888	0.1235		186.5705	0.7766
T x E	9	3.2890		0.0001	4.6512		0.0341	5528.8		0.0001
S x E	3		9.4708	0.0104		6.7361	0.2450		8,401.161	0.1305
N x E	3		0.0664	0.8896		4.4162	0.3588		6,100.249	0.1867
S x N x E	3		0.3299	0.3055		2.8013	0.2690		1947.154	0.0069
Residual Error	51	0.2664			2.0771			429.008		

†5 blocks at 3 environments; 6 blocks at 1 environment

Table 4. 3-yr average annual forage yields by system and nutrient strategy across four environments.

Nutrient Strategy	Cropping system		Nutrient mean***
	Grass Ley (GL)	Corn Silage (CS)	
	-----Mg DM ha ⁻¹ -----		
Manure (M)	8.59	15.95	12.27
Fertilizer (F)	7.45	14.12	10.79
Crop system mean**	8.02	15.04	

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 5. Average test crop yields by system and nutrient strategy across four environments in 1st yr test crop and across two environments in 2nd yr test crop.

	Cropping system		
Nutrient Strategy	Grass Ley (GL)	Corn Silage (CS)	Nutrient mean*
1 st yr test corn yields			
	-----Mg DM ha ⁻¹ †-----		
Manure (M)	20.66	14.91	17.79
Fertilizer (F)	15.87	13.56	14.72
Crop system mean**	18.27	14.24	
	Grass Ley (GL)	Corn Silage (CS)	Nutrient mean***
2 nd yr test corn yields			
	-----Mg DM ha ⁻¹ †-----		
Manure (M)	20.60	13.91	17.26
Fertilizer (F)	15.82	14.03	14.92
Crop system mean	18.21	13.97	

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

†1st yr test crop grown with no additional N other than starter fertilizer

‡2nd yr test crop data is from 2 environments (DFRC start-up #1 & #2) and all plots were fertilized with 67 kg N ha⁻¹.

Table 6. Soil test phosphorus regression equations over the four year cropping cycle at Dairy Forage Research Center and Michael Fields Agricultural Institute across blocks and starts †.		
System/nutrient strategy‡	Dairy Forage Research Center (DFRC)	Michael Fields Agricultural Institute (MFAI)
GL+M	$y = 37 + 3.0x$ a	$y = 50 + 4.0x$ a
GL+F	$y = 32 - 2.9x$ c	$y = 40 - 1.9x$ bc
CS+M	$y = 30 - 0.7x$ b	$y = 49 + 2.3x$ ab
CS+F	$y = 29 - 2.1x$ bc	$y = 43 - 3.6x$ c

† slopes different from zero at $p < 0.0001$ at DFRC and $p < 0.0040$ at MFAI; slope values within a column followed by the same letter do not differ at $p < 0.0001$ at DFRC and $p < 0.0016$ at MFAI using the bonferroni t-test to separate means between treatments.

‡ GL+M = grass ley + manure; GL+F = grass ley + fertilizer; CS+M = corn silage + manure; CS+F = corn silage + fertilizer.

Table 7. Soil test potassium regression equations over the four year cropping cycle at Dairy Forage Research Center and Michael Fields Agricultural Institute across blocks and starts †.		
System/nutrient strategy‡	Dairy Forage Research Center (DFRC)	Michael Fields Agricultural Institute (MFAI)
GL+M	$y = 144 + 20x$ a	$y = 144 + 13.8x$ a
GL+F	$y = 120 - 9x$ c	$y = 98 + 1.1x$ a
CS+M	$y = 126 + 0.3x$ b	$y = 117 + 13.5x$ a
CS+F	$y = 125 - 5x$ bc	$y = 100 - 3.4x$ b

† slopes different from zero at $p < 0.0001$ at DFRC and $p < 0.0026$ at MFAI; slope values within a column followed by the same letter do not differ at $p < 0.0001$ at DFRC and $p < 0.0200$ at MFAI using the bonferroni t-test to separate means between treatments.

‡ GL+M = grass ley + manure; GL+F = grass ley + fertilizer; CS+M = corn silage + manure; CS+F = corn silage + fertilizer.

Table 8. Average annual production costs over 4-yr rotation and costs per metric ton of forage across four environments.

System/Nutrient †	Nutrient costs‡	Machinery use/fuel costs	Seed, pesticides, and all other inputs	Total Variable costs	Variable costs per Mg of forage
	\$ ha ⁻¹				\$ Mg DM ⁻¹
GL+M	369	90	160	619	70
GL+F	289	90	155	534	72
CS+M	290	57	257	604	44
CS+F	255	57	256	567	48

† GL+M = grass ley + manure; GL+F = grass ley + fertilizer; CS+M = corn silage + manure; CS+F = corn silage + fertilizer.

‡ Includes custom nutrient application and commercial fertilizer

ORGANIC RESEARCH

FIELD ASSESSMENT OF ORGANIC SEED TREATMENTS FOR ENHANCED CORN ESTABLISHMENT AND EARLY SEASON GROWTH

N.J. Goeser, E.C. Luschei, J.L. Posner, and J.L. Hedtcke

INTRODUCTION, SUMMARY OF PREVIOUS WORK, AND OBJECTIVES

Organic markets, not only for fruits and vegetables, but also for corn (*Zea mays*) continue to expand in the United States and there is a great need for additional research. In fact, the organic food markets have been expanding annually by close to 20% from 1996 to 2006, and are projected to continue increasing into the future (OTA 2007). With expanding production has come an increasing number of organically certified inputs and there is a need to verifying the efficacy of these products. As is often the case, many of these materials are part of a more subtle, ecologically based, pest management system. Thus, specific mechanisms of action are often difficult to observe or discern (Maxwell 1999). For example, the success of organic weed control is particularly sensitive to spring weather as frequent rainfall can reduce mechanical weed control effectiveness. With 37 site years of data, Posner et al. (2008) reported that in 34% of the site years studied, poor weed control, as a result of wet weather and reduced efficacy of mechanical control options, organic cereal system yields to 74% of conventional system yields. However, the same study noted that when mechanical weed control was otherwise successful, conventional and organic system yields were comparable.

Variation in the competitiveness of the established crop can also stem from the weather. Variable or poor crop establishment provides weed populations more resources and a relative competitive advantage over crops such as corn (Harper 1977, Radosevich 1997). Cool, wet soil environments reduce corn germination, emergence rates, and can increase the susceptibility to pre-emergence pathogen pressures from strains of *Rhizoctonia*, *Fusarium* and *Pythium* (Lauer 1997). However, while delayed planting can positively affect corn seed germination, emergence rate, and seedling growth, it can negatively affect corn yield potential (Lauer 1999).

Seed treatments are used to help protect seed to establish proper crop density, however, few organically approved seed treatments are available. A few such seed treatments include planter-box dust treatments, seed priming, polymer coating, and bio-control coating. Within our study, we chose to evaluate two planter-box dust treatments (Bioworks T-22 and Agrienergy Resources Myco Seed Treat) and a biological liquid coating (Agricoat LLC Natural II). Based upon company claims, the T-22 and Natural II seed treatments exhibit biocontrol activity surrounding the seed, and all three seed treatments promote early seedling growth and general plant protection qualities. Due to the inability to discern, or acquire active ingredient lists, specific mechanisms of action, and methods of coating for the biological liquid coating, we present a review of relevant organically certified seed treatments.

Planter-box dust treatments are powders that usually contain the biocontrol agent in an inert ingredient such as clay. These treatments are applied to the seed in the planter box at immediately prior to planting. A potential drawback to this treatment is the lack of uniformity in seed coating (Harman and Kubicek 1998).

Seed priming is the controlled moisturization of seeds that does not permit radicle emergence (Bennet et al. 1992). Priming can increase crop establishment uniformity through increases in

emergence rate (Murray 1990). Priming can also include the use of gibberellic acid, di-sodium hydrogen phosphate, or sugars to help subsequent seedling growth after rapid germination and emergence (Basu et al. 2004).

Another type of seed treatment is a polymer or film coating that surrounds the seed coat to protect and enhance establishment. Polymer seed coatings can alter seed-water interactions and ultimately water uptake by the seed. West et al (1985) hypothesized that seed coatings may act as a collector of water by capillary action, and increase the germination rate. In addition, after artificial seed aging, the germination of non-coated seeds decreased by forty-four percent while coated seeds decreased by only twenty-six percent (West et al. 1985).

Bio-control agents can be applied via seed treatments to protect against soil mycoparasitic infections. Biocontrol agents are the use of living organisms to manage a pest (Lazarovits et al. 2007). In the case of corn seed, biocontrols are commonly bacterial or fungal agents used to protect against pathogenic races of *Fusarium* and *Pythium* (Mao et al. 1998, Pandey et al. 2001, Harman et al. 2004, Cavaglieri et al. 2005). For example, after coating seeds with *Trichoderma harzianum*, strain T-22, corn seedlings infected with *Colletotrichum graminicola* displayed lesions that were 33% shorter in length, and displayed an increase in enzymatic activity compared to a control (Harman et al. 2004). In a petri dish study, corn seed treated with one of two strains of *Pseudomonas corrugata* and planted in soil inoculated with a mixture of *Pythium ultimum*, *P. arrhenomanes* and *Fusarium graminearum* exhibited decreased disease severity, increased plant height, and increased fresh weight when compared to a non-treated control (Pandey et al. 2001). In the absence of pathogens, biocontrol agents have shown increases in corn seedling vigor characteristics. For example, coating corn seeds with *Bacillus subtilis* increased root growth and fresh weight, when compared to a control (Chang and Kommedahl 1968). Corn seed treated with *Trichoderma harzianum*, strain T-22, displayed an increase in total root area and volume as well as an increase in shoot growth (Harman et al. 2004). In addition, *Trichoderma* strains have been documented to display several antagonistic mechanisms, which can include antibiosis, mycoparasitism, and competition for resources (Harman and Kubicek 1998).

Organic seed treatments can prove to be beneficial, but additional research is needed on field crops such as corn (*Zea mays* L.). The majority of the current research has been conducted within the laboratory, on a small plot scale, or on vegetable crops. There are few published accounts evaluating organic seed treatments for enhanced corn emergence, seedling growth, and grain yield in the field and on a farm scale level. The objectives of our study were to evaluate the effects of several commercially available organic seed treatments on establishment, early season growth, and yield on a farm scale level.

MATERIALS AND METHODS

Field trials for evaluation of several seed treatments were conducted in 2007 and 2008. The experiment was replicated over three sites in two years. In 2007, a trial was conducted at Arlington, WI (AR). In 2008 trials were conducted at Columbus, WI (CL) and LaValle, WI (LV). At each site, two planting dates (early and late May) were selected. Seed treatments consisted of organic corn seed with a coating of Agricoat LLC Natural II (a biological liquid seed treatment), Bioworks T-22 (a planter box seed treatment), and Agrienergy Resources Myco Seed Treat (a planter box seed treatment). In 2007, the organic corn hybrid was Blue River

hybrid 43B19 lot 1B43-3 and in 2008, the organic corn hybrid was Viking hybrid O7292 (95 day hybrid). Specific site characteristics and agronomic practices are outlined in Table 1.

Weed Control

In both years weed control management strategies were typical of organic corn growers in the region. Weed control was comprised of tillage. Depending on the site and location, tillage regimes included multiple passes of rotary hoeing, tine weeding, disc harrowing, cultivating, rear-tine tilling (Table 1).

Measurements

In both years, at the AR, CL, and LV sites, measures of early seedling vigor and growth were recorded, including a measure of plant emergence variation (relative emergence date measured by recording the number of days between an individual plant's emergence and the first emerging plant) and plant height. In addition, within both years at the AR, CL, and LV sites grain yield data were measured. Emergence counts were conducted every three days from planting until no additional plants emerged. Emergence counts were used to subsequently calculate average plant density. In 2008, the CL and LV sites received approximately 13 inches of rain between May 10, and June 12. This provoked considerable flooding and ponding at the sites so emergence timing measurements were not possible.

Plant height data was recorded to assess product claims of improved seedling vigor. Plant height was measured and recorded for both early and late planting dates, at the V3 and V5 growth stages. When fifty percent of the plants in the field reached the V3 and, later, the V5 growth stage, plant height data was measured by extending the last collared leaf upright and measuring from the soil surface to the tip of the leaf. Plant heights were then averaged across data collection stations for statistical analysis.

Experimental Design and Data Analysis

Experimental design at all sites in both years was a randomized complete block in a split plot arrangement with four replications. Planting date was assigned to whole plots and seed treatments were assigned to subplots. Whole plots ranged from 200 to 300 feet in length and 60 to 144 feet in width. Subplots were the same length, but ranged from 15 to 36 feet in width. We analyzed this experiment as a split plot design using SAS Proc Mixed (SAS, Cary, NC).

RESULTS

Early Growing Season Conditions

In 2007 and 2008, the early growing season environmental conditions, from planting until V5 growth stage, varied by year, site, and planting date. In general, corn planted at a later date accumulated the GDD units necessary for emergence and early season growth at a greater rate than corn planted at an earlier date. When compared to 20-yr average two inch soil temperatures recorded in Arlington, WI, 2007 and 2008 were, and remained unseasonably warm at the time of early planting until corn emergence (from May 7-May 14). Total accumulated precipitation varied by location and planting date. The accumulated precipitation was adequate for emergence at each location in both years, and as mentioned previously precipitation was excessive at the CL and LV sites in 2008.

Emergence Date

Planting date effects on average emergence date were significant. Emergence date was significantly less for the late planting date (Table 2).

Plant Height

At the V3 growth stage, mean plant height was not affected by planting date or seed treatment (Table 3). Similarly, at the V5 growth stage, mean plant height was not affected by planting date or seed treatment.

Grain Yield

In the analysis of grain yield data, seed treatment effects on the overall mean were significant. However, planting date effects on the overall mean were not significant. Corn yields in plots treated with Natural II were significantly greater than corn yields in plots treated with Myco Seed treat, or a non-treated control (Table 4). Corn yields in plots treated with T22 were significantly greater than the non-treated control.

DISCUSSION

Within this experiment, grain yields were significantly greater for plants grown from Natural II and T-22 treated seeds. While this is statistically significant, inferences regarding grain yield increases as a result of seed treatment effects should be made with caution. If seed treatment effects (on seedling vigor) were to affect grain yields, one would expect these influences would affect other aspects of corn growth leading to grain yield production (TeKrony and Egli 1991). However, in this field experiment, we did not see biologically significant seed treatment effects on aspects of early seedling corn growth that could influence yield (corn emergence, establishment, and early season growth characteristics).

The majority of results show that there were no significant statistical and biological seed treatment effects on establishment or early season growth. This does not indicate that effects do not exist in all environments, but that detection was not possible given the measurement protocols, sample size and statistical power of the tests. As such, we recommend further evaluation before conclusive recommendations can be made regarding the seed treatment efficacy.

The seed treatments evaluated in this study were part of a more subtle, ecologically based, pest management system within the organic certification guidelines. As such, the specific mechanisms of action employed by the seed treatments evaluated were part of a broader pest management system and were difficult to observe at the field scale over the sites and environmental conditions experienced. This work further corroborates the need for a study of the more general patterns of variation in pest communities and populations to input manipulations expressed in Maxwell (1999). This includes long-term experiments with a primary focus on variation (predominantly environmental), rather than the mean response of a prescribed treatment. Pursuing long-term experiments, with a focus on variation, reduce the possibility of false inferences and expectations regarding seed treatments of the type studied in these experiments.

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Table 1: Site characteristics, agronomic practices, and weed control measures by site and year.

Site Characteristics					
Site	Soil Type(s)	Soil Drainage Characteristics	Previous Crop(s)	Planting Dates	Planting Density
AR	Plano silt loam	Well drained, with no frequency of ponding or flooding and high water capacity	Alfalfa (<i>Medicago sativa</i>)	Early- May 7, 2007 Late- May 23, 2007	34,000 plants/ha in 30 in. rows
CL	Atterberry silt loam, Ossian silt loam, Charles silt loam	Somewhat poorly drained to poorly drained , with occasional flooding, frequent ponding and very high water capacity	Red clover (<i>Trifolium pretense</i>), Alfalfa (<i>Medicago sativa</i>)	Early- May 10, 2008 Late- May 24, 2008	34,000 plants/ha in 30 in. rows
LV	Valton silt loam	Well drained, with no frequency of flooding or ponding and a moderate water capacity	Alfalfa (<i>Medicago sativa</i>)	Early- May 9, 2008 Late- May 23, 2008	33,5000 plants/ha in 36 in. rows
Weed Control					
Site	Planting Date	Year	Practice		
AR	Early	2007	Rotary hoe- May 18		
			Tine weed- May 24		
			Disk harrow- June 14, June 18		
CL	Late	2008	Rotary hoe- June 8		
			Disk harrow- June 14		
			Rotary hoe- May 16, May 25		
LV	Early	2008	Roto-till- June 20		
			Cultivation- June 20, July 1		
			Roto-till- June 23		
LV	Late	2008	Cultivation- July 1		
			Rotary hoe- May 15, 20, 27		
			Cultivation- June 17		
LV	Early	2008	Rotary hoe- May 28		
	Late		Cultivation- June 17		

Table 2: Relative emergence date (days after first emerging plant) by planting date. Letters signify significant differences within site at the $P<0.05$ level.

Planting Date	Average Emergence date (days)
Early	2.16 A
Late	1.38 B
LSD = 0.295	

Table 3: V3 and V5 average plant height by seed treatment. Letters signify significant differences within a site and growth stage at the $P<0.05$ level

Seed Treatment	V3	V5
Average Plant Height (inches)		
Natural II	11.57	23.86
T22	11.30	23.58
Myco	11.14	23.54
Control	11.02	23.15

Table 4: Average grain yield by seed treatment. Letters signify significant differences within site at the $P<0.05$ level.

Seed Treatment	Average Grain Yield (bu/acre)
Natural II	140.9 A
T22	138.2 AB
Myco	136.5 BC
Control	134.4 C
LSD = 3.8	

ORGANIC NO-TILLAGE WINTER RYE-SOYBEAN SYSTEMS: AGRONOMIC, ECONOMIC, AND ENVIRONMENTAL ASSESSMENT

Emily Bernstein¹, Josh Posner², Dave Stoltenberg², Janet Hedtcke³

INTRODUCTION

Organic soybean and corn production in Wisconsin has rapidly increased to meet demand of the expanding organic dairy industry (USDA-ERS 2006). A major challenge that organic row crop growers face is the intensive tillage needed for successful weed management (Posner et al. 2008). The use of a rye cover crop to facilitate no-till organic soybean production may eliminate the need for tillage, and provide additional ecosystem services including improved weed management, reduced soil erosion and runoff, increased soil organic matter and water infiltration, and trapping of excess nitrogen (Hartwig and Ammon 2002; Kaspar et al. 2001; Ruffo et al. 2004). This organic no-till rye mulch system has been limited in part due to uncertainty regarding the reliability of mechanical methods of terminating the cover crop, difficulty in establishing soybeans in the rye residue (Williams et al. 2000; Reddy et al. 2003), and the potential risk of competition between the rye cover crop and soybeans for soil moisture and nutrients resulting in reduced yields and economic returns (De Bruin et al. 2005; Westgate 2005).

We conducted research to determine some of the agronomic, economic, and environmental risks associated with the use of winter rye cover crop in no-till organic soybean production systems. Our objectives were to determine the effect of rye management (plowing, crimping, and mowing), and soybean planting date (mid-May or early June) on soil moisture availability, soybean stand establishment, and soybean yield. Treatment effects on economic gross margins, soil loss, and soil quality were also predicted.

MATERIALS AND METHODS

Research was conducted at the University of Wisconsin Arlington Agricultural Research Station (UWAARS) near Arlington, WI in 2008 and 2009. The soil type was a Plano silt loam (fine-silty mesic Typic Argiudoll) with 4.7% organic matter and pH 6.7 in 2008 and 3.6% organic matter and pH 6.0 in 2009. Research sites changed each year to place the study following corn silage. The experimental design was a randomized complete block with four replications of six treatments (Table 1). The tilled treatment represented a typical organic soybean production system, while the other five treatments were no-till rye cover crop treatments with varying factors of rye management, soybean planting date, and row spacing (seeding rate). Plot size was 30-ft wide by 180-ft long in 2008 (0.12 acres) and 30-ft wide by 165-ft long (0.11 acres) in 2009.

Winter rye variety 'Rymin' was planted in early-October (Oct. 5, 2007 and Oct. 10, 2008) at a rate of 160 lb acre⁻¹. Rye in the tilled treatment was disk-chiseled in mid-April at the second node growth stage (Feekes growth stage 7; Apr. 23, 2008) or at tillering (Feekes growth stage 4; Apr. 17, 2009) (Zadoks et al. 1974). The subsequent stale seedbed was lightly disked (two passes) and field cultivated (two passes) for weed management and seedbed preparation prior to soybean planting. Organic feed-grade soybean varieties (Maturity Group I) 'Viking 0.1832' in 2008 and 'Blue River 16A7' in 2009 (due to unavailability of 'Viking 0.1832' in 2009) were planted with a

¹ Graduate Research Assistant, Department of Agronomy, Univ. of Wisconsin-Madison.

² Professor, Department of Agronomy, Univ. of Wisconsin-Madison.

³ Senior Research Specialist, Department of Agronomy, Univ. of Wisconsin-Madison.

conservation corn planter (30-inch row spacing) or no-till drill (7.5-inch row spacing). In the mowed, crimped drilled, and mowed drilled treatments, soybeans were seeded approximately two weeks prior to crimping or mowing the rye, on the same date soybeans were planted in the tilled treatment. Rye in the five no-till treatments was roller-crimped or sickle-bar mowed in early June after the rye reached late anthesis (Feekes stage 10.5.1) (Ashford and Reeves 2003; De Bruin et al. 2005). Each year, immediately after the rye was crimped or mowed, soybeans were drilled into the remaining two treatments (crimped drilled late and mowed drilled late treatments) (see Table 1). In the tilled treatment, flex-tine weeding, rotary hoeing, and inter-row cultivation were used for weed management as needed, typically 2-3 passes each, spaced a week apart from mid-May until soybean canopy closure in July.

Table 1. Treatments for experiments conducted at the UW-Arlington Agricultural Research Station in 2008 and 2009.

Treatment	Rye management (month)	Soybean planting date month	Soybean row spacing inches	Soybean viable seeding rate seeds acre ⁻¹
Tilled	Tilled (April)	Mid-May	30	225,000
Mowed	Mowed (June)	Mid-May	30	225,000
Crimped Drilled	Crimped (June)	Mid-May	7.5	275,000
Mowed Drilled	Mowed (June)	Mid-May	7.5	275,000
Crimped Drilled Late	Crimped (June)	Early June	7.5	275,000
Mowed Drilled Late	Mowed (June)	Early June	7.5	275,000

Rye shoot mass was harvested immediately prior to rye management in April (tilled treatment) or June (no-till treatments). Volumetric soil moisture was measured in tilled and crimped drilled late treatments at 0- to 2-, 8- to 10-, 15- to 17- and 20- to 22-inch depths in late May. Soybean plant density was measured in mid-July. Soybean grain was harvested by machine from the center 15 ft of each plot in late October, weighed, and adjusted to 13% moisture. The number and type of field operations, inputs, and the local November price for organic feed grade soybean were used to estimate gross margins using the Agricultural Budget Calculation Software (Frank and Gregory 2000). The Revised Universal Soil Loss Equation 2 (USDA 2005) model was used to predict treatment effects on soil loss and organic matter (soil conditioning index, SCI) based on a run of 200 feet, contours of 0.5%, and 1 and 4.5% slopes.

Data were pooled across the two site-years and analysis of variance was conducted using the MIXED procedure in SAS/STAT (SAS Institute 2007) to test the effect of treatments on soybean establishment, yield, and profitability. Random effects were year, block within year, and year by treatment. Site-years were not pooled to test the effects of treatment on soil moisture data since the year-to-year variability was high. The random effect for these models was block. Treatment comparisons were made using Fisher's Protected LSD method ($\alpha = 0.05$). Pre-planned contrasts were made to compare rye and soybean management effects within no-till treatments, and between tilled and no-till treatments.

RESULTS

At the time of rye management (plowing, crimping, or mowing), rye mass was 7 to 10-fold greater in no-till than tilled systems in each year (Table 2). In no-till systems, rye mass exceeded the minimum (1.5 ton acre⁻¹) considered necessary for effective weed suppression (Doll and

Mueller 2005). Greater rye mass in 2008 was likely due to more timely precipitation and warmer spring temperatures as well as greater soil fertility than in 2009 (data not shown).

Table 2. Rye cover crop dry shoot mass at the time of plowing (4/23/08 and 4/17/09) and mowing or crimping (6/11/08 and 5/29/2009).

Rye management	Rye dry shoot mass	
	2008	2009
	tons acre ⁻¹	
Tilled (mid-April)	0.7	0.2
No-till (June)	4.8	1.9

At soybean planting, soil moisture was the similar at the surface in no-till rye and tilled systems (Figure 1), indicating that a reduction in soybean germination due to soil moisture use by rye would not be expected in no-till rye systems relative to the tilled system. However, at deeper depths, soil moisture was less in no-till rye than tilled systems. This reduction in available soil water at deeper depths was likely due to the growing rye cover crop, which in years of inadequate rainfall could pose a risk to early-season soybean growth in no-till rye systems.

On May 28, 2008 moisture was near field capacity at the 8-10 inch soil depth in the tilled system and below the permanent wilting point in the no-till rye system (Figure 1). Precipitation in 2008 was 0.2 inches in the two weeks prior to May 28 which did not replenish the soil moisture used by rye; however, 10 inches of precipitation fell during the two weeks following May 28, which was adequate to saturate the entire soil profile. On June 1, 2009, there was no difference between systems at the 8-10 inch depth. Precipitation of 0.5 inches in the two weeks prior to June 1 may have infiltrated to the 8-10 inch depth, in addition to less rye biomass in 2009 than 2008 (Table 2), accounting for the similar moisture levels at this depth. Rainfall in the two weeks following June 1 was 2.6 inches.

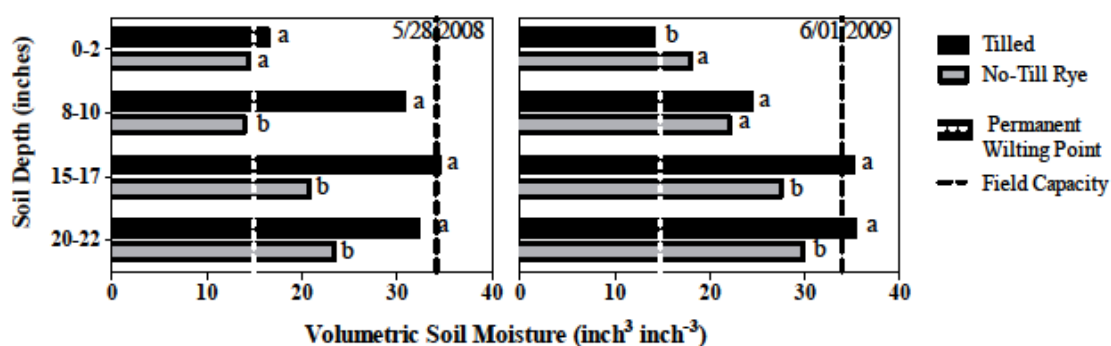


Figure 1. Mean early-season volumetric soil moisture content at 0- to 22-inch depths for tilled and no-till (crimped drilled late) systems on 5/28/08 and 6/1/09. Values within depth and date followed by the same letter do not differ at $p < 0.05$ (Fishers Protected LSD test).

Soybean establishment (stand density as a percent of viable seeding rate) did not differ between tilled and no-till systems, suggesting that rye had little adverse effect on soybean germination and

emergence ($p=0.3822$; data not shown). However, within the no-till drilled treatments, contrasts indicated that soybean establishment was affected by planting date. Establishment in treatments planted prior to rye crimping or mowing (crimped drilled and mowed drilled) was 80%, whereas establishment was only 60% in treatments in which planting was delayed until after crimping or mowing (crimped drilled late and mowed drilled late) ($p = 0.0406$; data not shown). Lower stand density was likely due to poor seed placement through the rye mulch, particularly in 2008. Soybean establishment was not affected by rye management (crimped or mowed, $p=0.5423$) or row spacing (30 or 7.5 inches, $p=0.9317$) (data not shown).

The tilled system was drier than no-till rye at both depths and in both years by the end of July, except the 8-10 inch depth in 2009 (Figure 2). This time period corresponds with early to mid reproductive stages when soybean productivity is the most sensitive to moisture availability (Pederson 2004). However, despite lower soil moisture in the tilled system, yield was also greater (Figure 3). Sufficient July rainfall (4.6 inches in 2008 and 2.3 inches in 2009) rewet the profile, and soil moisture was primarily driven by soybean transpiration as well as reduced evaporation under the rye cover crop. These results suggest that rye did not pose a large risk to soybean productivity due to moisture competition in the years studied.

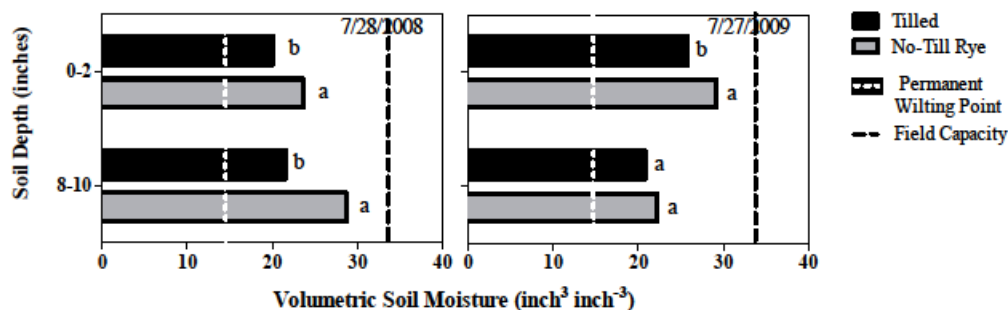


Figure 2. Mean late-season volumetric soil moisture content at 0- to 10-inch depths on 7/28/08 and 7/27/09. Values within depth and date followed by the same letter do not differ at $p<0.05$ (Fishers Protected LSD test).

Soybean yield across years was greater for the tilled system than no-till systems ($p = 0.0041$) (Figure 3). Contrasts indicated that among no-till systems, yield was greater for narrow- than wide-row spacing ($p = 0.0883$), but yield was not affected by planting date ($p = 0.1636$) or rye management ($p = 0.7667$). Tilled rye was more profitable than no-till rye treatments ($p = 0.0054$) (Figure 4). However, profitability was not affected by rye or soybean management among no-till systems.

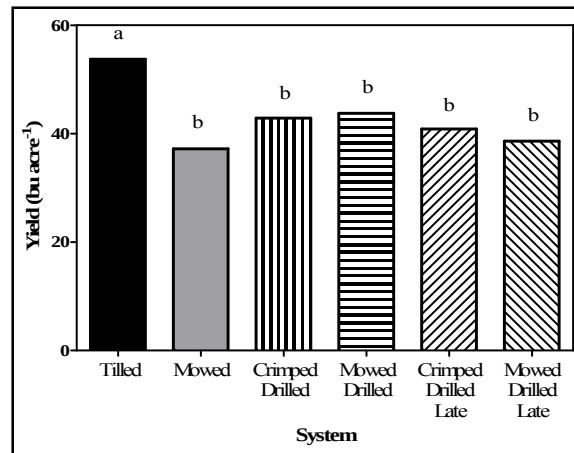


Figure 3. Mean soybean grain yield adjusted to 13% moisture in 2008 and 2009. Values designated by the same letter do not differ at $p < 0.05$ (Fishers Protected LSD test).

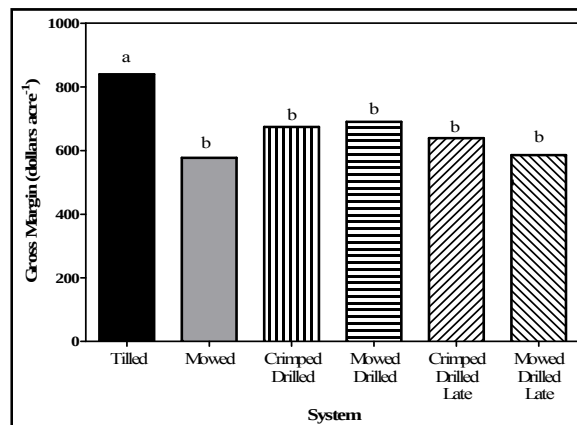


Figure 4. Mean estimated economic gross margins in 2008 and 2009. Values designated by the same letter do not differ at $p < 0.05$ (Fishers Protected LSD test).

The no-till systems required less labor and fuel than the tilled system, due to fewer implement passes for tillage (Figure 5C). Labor inputs were 46% less (one hour less per acre) in the no-till than the tilled system (Figure 5A). Six gallons per acre of diesel fuel was used in the no-till system, 42% less than the 10 gallons per acre in the tilled system (Figure 5B).

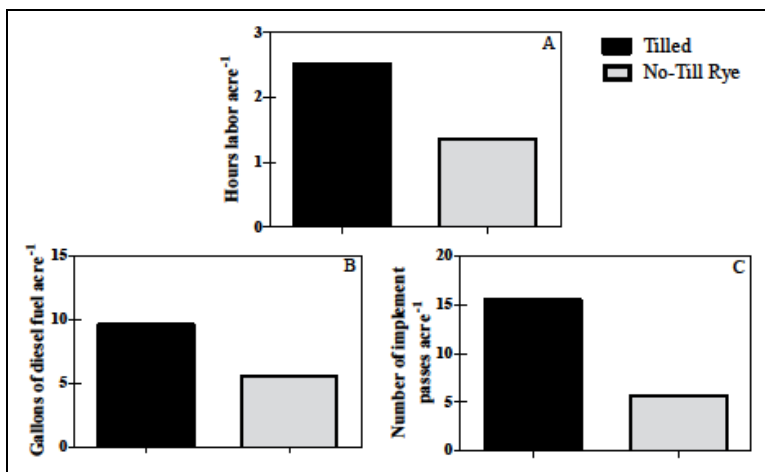


Figure 5. Mean estimated (A) labor inputs, (B) diesel fuel inputs, and (C) number of implement passes.

Predicted soil loss was several-fold greater in tilled rye than in no-till rye systems for both 1 and 4.5% slopes (Figures 6A and 6B). Soil loss in no-till rye was less than T (5 tons acre⁻¹ year⁻¹) in each scenario. Predicted changes in soil organic matter (soil conditioning index, SCI) were positive in no-till rye systems and negative in the tilled rye system for both 1 and 4.5% slopes; SCI was highly negative for plowed rye on a 4.5% slope (Figures 6C and 6D).

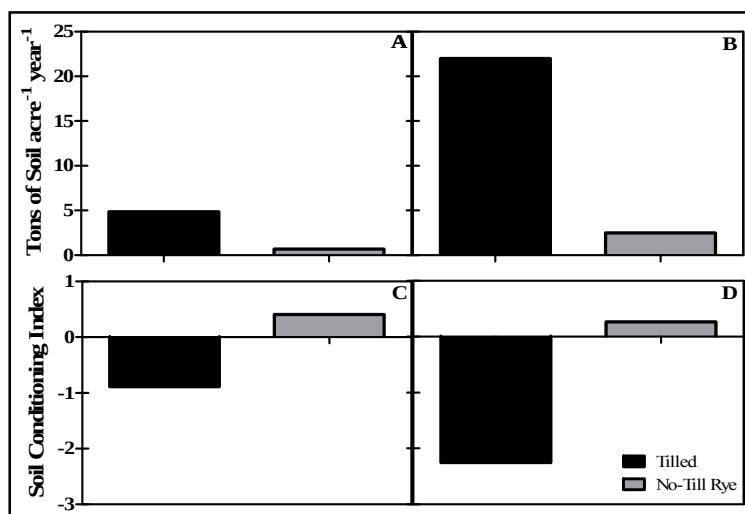


Figure 6. Predicted soil loss on (A) 1% slope and (B) 4.5% slope, and soil conditioning index on (C) 1% slope and (D) 4.5% slope for tilled and no-till rye systems.

CONCLUSIONS

Early-season soil moisture availability did not appear to be an important risk factor affecting soybean stand establishment in no-till rye systems, although rye depleted moisture deeper in the soil profile. While rye depleted available soil water at depths of 6-22 inches in late May, by late-July when moisture availability is critical to soybean productivity, adequate rainfall had

replenished the soil moisture in each year. Soybean stand establishment was not affected by the rye cover crop between no-till and tilled systems.

Within no-till systems, soybean stand establishment was greater when planted into standing rye two weeks prior to crimping or mowing (crimped drilled and mowed drilled treatments) than when planted after crimping or mowing at rye anthesis (crimped drilled late and mowed drilled late treatments). Soybean grain yield was greater in narrow- than wide-row spacing. However, neither row spacing nor planting date affected economic returns. Soybean stand establishment, grain yield and economic returns were similar between crimped and mowed rye, although the sickle-bar mower may be preferable to growers since it cost half as much as the roller-crimper.

Organic no-till rye-soybean systems were associated with greater weed suppression (data not shown), less soil loss and greater soil organic matter, and less labor and fuel inputs. However, these potentially long-term benefits were offset by 24% less soybean yield and 25% less economic return (due largely to high prices for organically-grown, feed-grade soybean). Even so, the no-tillage systems were highly profitable and represent economically viable alternatives to a tillage-intensive approach. These systems are particularly attractive to organic growers due to the 46% reduction in labor inputs.

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ORGANIC NO-TILLAGE WINTER RYE-SOYBEAN SYSTEMS: WEED COMMUNITY DYNAMICS

Emily Bernstein¹, Dave Stoltenberg², Josh Posner², Janet Hedtcke³

In Wisconsin, organic soybean and corn production has rapidly increased to meet demand of the expanding organic dairy industry (USDA-ERS 2006). A major challenge that organic row crop growers face is the intensive tillage needed for weed management (Posner et al. 2008), spurring interest by growers in improving weed management techniques (Walz 1999). An alternative, multitactic approach based on no-till crop establishment into a winter rye mulch may improve weed management; however, little is known about the effectiveness of such an approach compared to tillage-intensive approaches typically used for organic soybean production. In the no-till rye approach, no-tillage, rye mulch, and soybean competitive ability are the principal tactics relied upon for weed management, whereas in the tillage-intensive approach, tine weeding and cultivation are the principal tactics. These contrasting tactics could potentially shift the weed community, as has been demonstrated in research of weed management tactics in conventional systems (Mulugeta and Stoltenberg 1997; Sosnoskie et al. 2006; Légère et al. 2008). Use of a winter rye mulch may provide additional ecosystem services beyond competition with weeds, including reduced soil erosion and runoff, increased soil organic matter and water infiltration and trapping of excess nitrogen (Hartwig and Ammon 2002; Kaspar et al. 2001; Ruffo et al. 2004).

We conducted research in 2008 and 2009 near Arlington, Wisconsin to determine the effects of a winter rye cover crop for no-tillage organic soybean production on weed management and the weed community dynamics relative to a tillage-intensive approach (plowing, tine weeding, and cultivation). Our specific objectives were to determine the effect of rye management (tilling, crimping, and mowing), soybean planting date (mid-May or early June), and soybean row spacing (19 or 76 cm) on weed emergence, weed suppression (density and mass), and weed community structure (species diversity, richness and evenness) and assembly (species composition). Treatment effects on soybean yield, economic gross margins, soil loss, and soil quality are summarized elsewhere in this report (Bernstein et al. 2010).

MATERIALS AND METHODS

Research was conducted at the University of Wisconsin Arlington Agricultural Research Station (UWAARS) near Arlington, WI in 2008 and 2009. The soil type was a Plano silt loam (fine-silty mesic Typic Argiudoll) with 4.7% organic matter and pH 6.7 in 2008 and 3.6% organic matter and pH 6.0 in 2009. Research sites changed each year in order to conduct the study following corn silage. The experimental design was a randomized complete block with four replications of six treatments (Table 1). The tilled treatment represented a typical organic soybean production system, while the other five treatments were no-till rye cover crop treatments with varying factors of rye management, soybean planting date, and row spacing (seeding rate). Plot size was 30-ft wide by 180-ft long in 2008 (0.12 acres) and 30-ft wide by 165-ft long (0.11 acres) in 2009.

Winter rye variety 'Rymin' was planted in early-October (Oct. 5, 2007 and Oct. 10, 2008) at a rate of 160 lb acre⁻¹. Rye in the tilled treatment was disk-chiseled in mid-April (April 23, 2008 and April 17, 2009). The subsequent stale seedbed was lightly disked (two passes) and field cultivated (two passes) for weed management and seedbed preparation prior to soybean planting (Table 2). Organic feed-grade soybean varieties (Maturity Group I) 'Viking 0.1832' in 2008 and 'Blue River 16A7' in 2009 (due to unavailability

¹ Graduate Research Assistant, Department of Agronomy, Univ. of Wisconsin-Madison.

² Professor, Department of Agronomy, Univ. of Wisconsin-Madison.

³ Senior Research Specialist, Department of Agronomy, Univ. of Wisconsin-Madison.

of 'Viking 0.1832' in 2009) were planted with a conservation corn planter (30-inch row spacing) or no-till drill (7.5-inch row spacing). In the mowed, crimped drilled, and mowed drilled treatments, soybeans were seeded approximately two weeks prior to crimping or mowing the rye, on the same date that soybeans were planted in the tilled treatment. Rye in the five no-till treatments was roller-crimped or sickle-bar mowed in early June after the rye reached late anthesis (June 17, 2008 and June 6, 2009) (Ashford and Reeves 2003; De Bruin et al. 2005). Each year, immediately after the rye was crimped or mowed, soybeans were drilled into the remaining two treatments (crimped drilled late and mowed drilled late treatments) (see Table 1). In the tilled treatment, flex-tine weeding, rotary hoeing, and inter-row cultivation were used for weed management as needed, typically 2-3 passes each, spaced a week apart from mid-May until soybean canopy closure in July (Table 2).

Table 1. Treatments for experiments conducted at the UW-Arlington Agricultural Research Station in 2008 and 2009.

Treatment	Rye management	Soybean planting date	Soybean row spacing	Soybean viable seeding rate
	method (month)	month	inches	seeds acre ⁻¹
Tilled	Tilled (April)	Mid-May	30	225,000
Mowed	Mowed (June)	Mid-May	30	225,000
Crimped Drilled	Crimped (June)	Mid-May	7.5	275,000
Mowed Drilled	Mowed (June)	Mid-May	7.5	275,000
Crimped Drilled Late	Crimped (June)	Early June	7.5	275,000
Mowed Drilled Late	Mowed (June)	Early June	7.5	275,000

Table 2. Tillage implements and dates used in the Tilled treatment at UW-AARS in 2008 and 2009.

Year	Spring pre-plant tillage				In-crop tillage		
	Primary		Secondary		Tine weeding	Rotary hoeing	Inter-row cultivation
	implement	date	implement	date	date	date	date
2008	Chisel-disk	4/23	Disk	5/2	5/28	-	6/24
			Disk	5/9	6/16 (2x) ^a	-	7/2
			Soil finisher	5/21 (2x)	-	-	7/15
2009	Chisel-disk	4/17	Disk	5/12 (2x)	5/22	6/1	6/26
			Field cultivator	5/18 (2x)	-	6/12	7/7
			Cultipacker	5/18	-	6/18	-

^a '2x' indicates two passes.

After treatments were established in early June, weed species density was determined in four permanent 1-m² quadrats per plot every 7 days from June to mid-July and then every 14 days until September, at which time aboveground weed mass was harvested, separated by species, dried at 21 C until a constant mass was achieved, and weighed.

Analysis of variance (ANOVA) was conducted using the MIXED procedure in SAS/STAT (SAS Institute 2007) to test the effect of treatments on weed density at each measurement date and late-season weed mass. Density and mass data were log transformed to meet the assumptions of ANOVA. Site-years were analyzed separately to test the effects of treatment on weed density. The random effect for these models was block. Site-years were pooled to analyze late-season weed mass using random effects of year, block

nested within year, and year by treatment. Pre-planned contrasts were made to compare rye and soybean management effects within no-till treatments, and between tilled and no-till treatments.

K-dominance curves, cumulative ranked abundance plotted against the $\log_{10}$ species rank, were created to analyze species diversity, evenness and richness using PRIMER-E (Lambshead et al. 1983; Clarke and Gorley 2006; Clarke and Warwick 2001). One-way analysis of similarity (ANOSIM) was conducted on a dissimilarity matrix of the distances between curves of separate plots in each year to test the null hypothesis that curves of different treatments were the same (Clarke 1990). Non-metric multidimensional scaling (NMDS), a multivariate ordination method, was used to examine the similarities in the weed community assembly among treatments (Clarke 1993). Years were pooled, and a 2-dimensional NMDS plot was created using the default parameters in PRIMER-E. The data were square root transformed in order to reduce the influence of very abundant species. Species occurring in less than three plots were considered rare and omitted from the species matrix, reducing it from 35 to 28 species. The similarity matrix for the NMDS was based on Sørensen (Bray-curtis) distance. Two-way ANOSIM with treatment and years as factors and blocks as replications was conducted to determine whether treatment effects were significant (Clarke 1993; Clarke and Warwick 2001). Plots were further classified as tilled or no-till rye in order to determine the significance of tillage/rye as a treatment factor in ANOSIM analogous to the pre-planned contrast in ANOVA. Two-way contribution of species to similarity (SIMPER) with year and tillage as factors was conducted to determine which species were contributing to the dissimilarity between the tilled and no-till rye systems, and which species contributed to similarity within the tilled and no-till rye systems.

RESULTS

Weed Emergence and Density

Patterns of weed emergence and density differed between tilled and no-till treatments in 2008 (Figure 1). Weed density peaked in the tilled system at 44 plants m^{-2} on June 18 (V2 soybean), then declined throughout the season to 4.5 plants m^{-2} by August 19 (Figure 1A). In the no-till rye treatments, weed densities were low early in the season, averaging 0.2 plants m^{-2} on June 18 (VE-V2 soybean). Later in the season, densities increased to 1.8 plants m^{-2} by August 19. Treatment contrasts for each date of measurement in 2008 indicated that weed densities were greater in the tilled than no-till rye systems at $p < 0.05$, except on August 19, $p = 0.0509$. Contrasts among the no-till rye treatments indicated that at all dates except June 18 and July 8, weed densities were greater in the mowed than crimped no-till rye treatments. Soybean planting date and row spacing did not affect weed densities in the no-till rye treatments at any date in 2008.

A similar pattern of weed emergence occurred in the tilled treatment in 2009 as in 2008 (Figure 1), except that weed densities were greater in the no-till rye systems in 2009 than 2008, potentially due to the presence of 2.5 times more rye mulch in 2008 (Bernstein et al. 2010). Weed density in the tilled treatment peaked early in the season at 9.5 plants m^{-2} on June 11 (VC soybean), then declined to 3.2 plants m^{-2} by the end of the season on September 2 (Figure 1B). Weed emergence in the no-till rye treatments peaked later in the season than in the tilled system, averaging 24 plants m^{-2} on September 2, similar to 2008. However, in 2009, weed density also peaked in mid-season in the no-till rye treatments, averaging 20 plants m^{-2} on June 30 (V1-V5 soybean), and was due in large part to winter annual species. Treatment contrasts for each date of measurement indicated that weed densities were lower in the tilled system than in the no-till rye systems at each date, except June 11 and June 22. Other management factors (rye management, soybean planting date, and soybean row spacing) did not affect weed densities, except on August 11, when weed densities were less in early- than late-planted soybeans, and less in narrow- than wide-row soybeans.

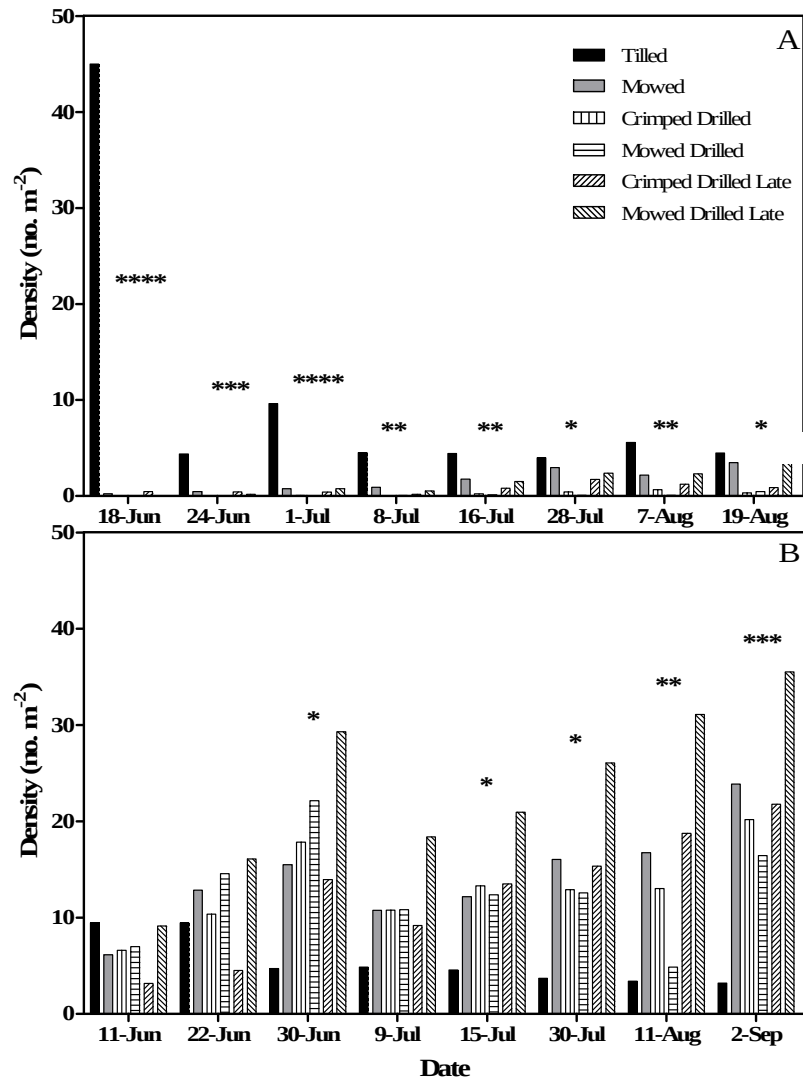


Figure 1. LSmean values for weed density in (A) 2008 and (B) 2009. Significant ANOVA F-test of treatments indicated by (*) $p < 0.05$, () $p < 0.01$, (***) $p < 0.001$ and (****) $p < 0.0001$.**

Late-Season Weed Mass

Weed shoot mass across years was several-fold greater in the tilled system than in no-till rye systems ($p = 0.0058$; Figure 2), even though weed densities were similar among systems in 2008, and less in tilled than no-till rye systems in 2009 (Figure 1). Contrasts indicated that weed mass among no-till rye systems was less for early- than late-planted soybean ($p = 0.0612$) and less for narrow- than wide-row spacing ($p = 0.0991$). Weed mass did not differ between crimped and mowed rye treatments ($p = 0.9566$).

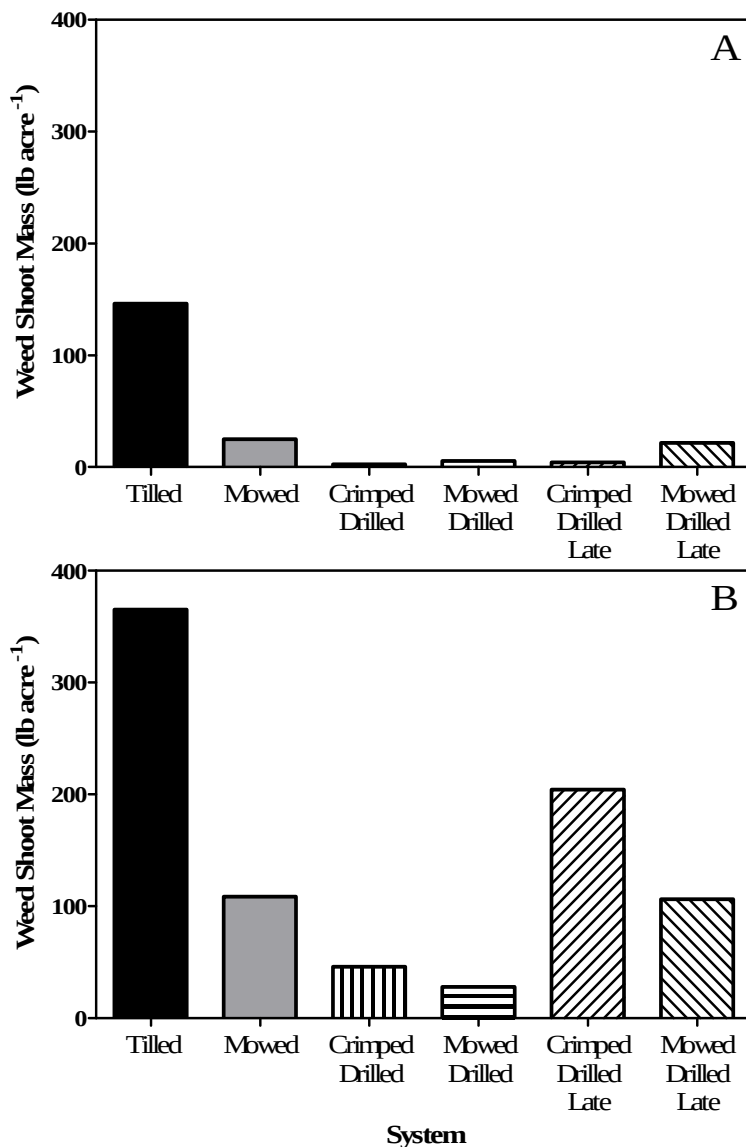


Figure 2. LSmean values for late-season (late August) weed shoot mass in (A) 2008 and (B) 2009.

Weed Community Structure

Treatment effects on weed community structure were assessed using k-dominance curves (Figures 3 and 4). The cumulative dominance axis (the y-axis) shows each species' portion of abundance (based on late-season shoot mass) in rank order of the most abundant species to the least abundant, extending across the species rank axis (the x-axis). The most abundant species at the first rank is the most dominant species, and the greater the proportion of total weed mass attributed to this species indicates lower species evenness in the weed community. Therefore, curves which begin lower on the cumulative dominance axis at the first rank are considered to have a more even structure among species. Species richness (the number of weed species) is indicated by the length of the curve across the species rank axis. The two indices together, evenness and richness, determine diversity. ANOSIM tests whether (treatment) groups are the same using a nonparametric permutation procedure. R is the ANOSIM test statistic in the range (-1,1). R equals one if data values among replicates within a treatment are more similar to each other than

to data of other treatments. Conversely, if R equals negative one, then data values among replicates within a treatment are more similar to data of other treatments than to each other. If R is near zero, then data values among replicates within and between treatments are the same, indicating no treatment effect (the null hypothesis).

In 2008, treatments had little effect on weed species diversity ($R=0.146$, $p=0.059$) and tillage was not a significant treatment factor ($R=-0.144$, $p=0.713$) (Figure 3A). Some no-till rye treatments (mowed, mowed drilled, and mowed drilled late) exhibited greater species evenness and richness than the tilled treatment, but the other no-till rye treatments (crimped drilled and crimped drilled late) were less diverse than the tilled treatment. In contrast, treatments significantly affected diversity in 2009 ($R=0.3$, $p=0.002$) (Figure 3B). Pairwise comparison of treatments indicated that the tilled treatment was different from each of the no-till rye treatments, but that no-till rye treatments were not different, except mowed versus crimped drilled late. The tillage effect was marginally significant ($R=0.245$, $p=0.093$). Greater treatment effects in 2009 than 2008 may have been due to greater weed densities, particularly in the no-till rye treatments in 2009 than 2008 (Figure 1).

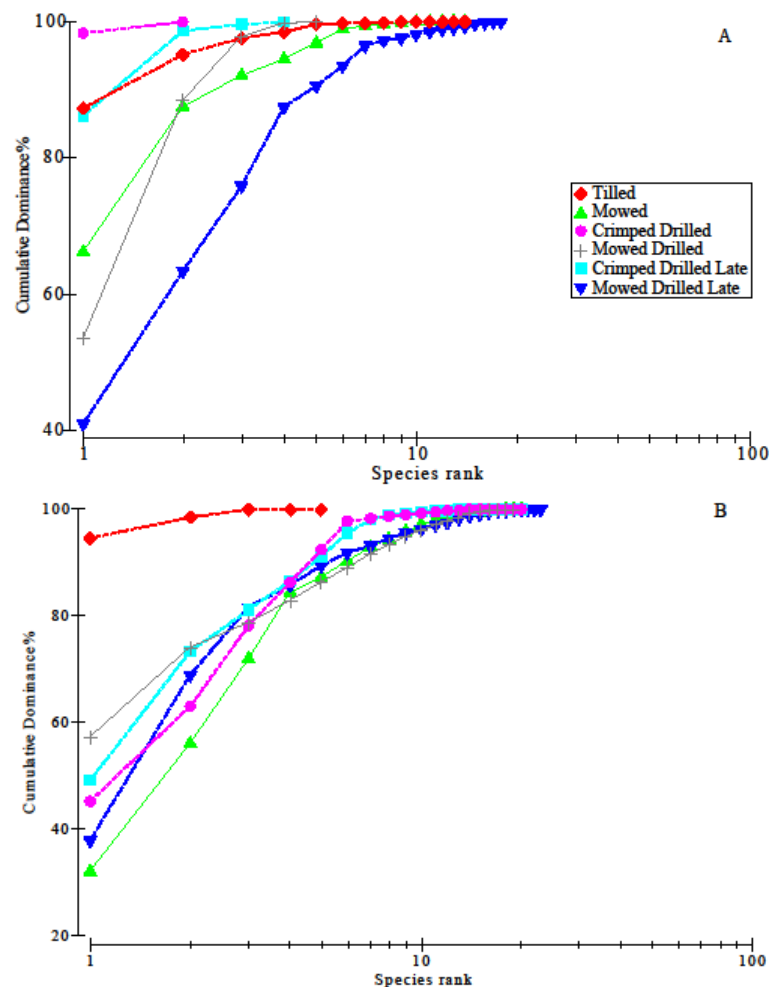


Figure 3. Average cumulative ranked abundance (k-dominance curves) of the species distribution of the late-season weed shoot mass of each treatment in (A) 2008 and (B) 2009.

Weed Community Assembly

Tillage and rye cover crop affected weed community assembly, as shown by the ordination of late-season weed mass in 2008 and 2009 (Figure 4). For this analysis, each species present and its abundance in each research plot was used to calculate the degree of similarity among plots (each plot was compared to every other plot). The ordination represents the dimensional relationship between communities in plots by matching the distance between points in the figure (each representing a research plot) to these similarity values. Thus, points which are closer to each other in the ordination are more similar in species composition and abundance. The points representing the eight tilled plots appear in two clusters (four replicate plots in each of two years) and are separate from those of the no-till rye plots. The stress of the two-dimensional ordination was 0.15, which indicates that the ordination in this instance is a useful but not conclusive for assessing the multidimensional relationship among research plots. In contrast, the ANOSIM test on the similarity values between research plots showed that treatments significantly affected the weed community ($R=0.382$; $p=0.001$), as did tillage as a contrast factor ($R=0.439$, $p=0.001$). This test confirms that the weed communities in the tilled plots were different from the weed communities of the no-till plots, substantiating the ordination (Figure 4).

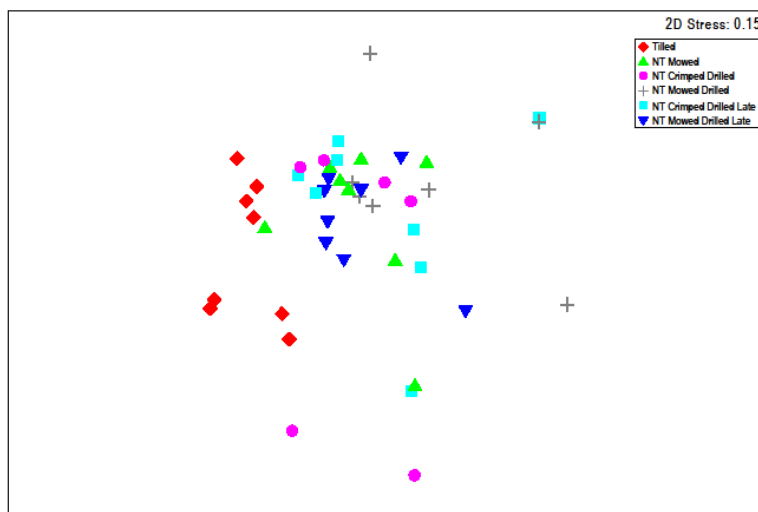


Figure 4. Ordination plot from non-metric multidimensional scaling of late-season weed shoot mass in 2008 and 2009. Each point represents a single research plot.

Our analysis of the individual species accounting for these changes in the weed community indicates that summer annual weed species dominated the weed community in the tilled system (Table 3). In contrast, perennials and *Polygonum* species, which are typically associated with less soil disturbance, were common in the no-till rye system in addition to summer annuals. Similarity values are restricted to between 0 and 100%, with 0% indicating that the same species did not occur among plots, and 100% indicating that the same species occurred in the same abundance among plots. Tilled plots were 61% similar, with common lambsquarters and velvetleaf contributing the most to the similarity. In contrast, no-till rye plots were only 36% similar, with common lambsquarters and prostrate knotweed contributing the most to similarity. Dissimilarity is the inverse of similarity, 0% indicating that species were identical among plots and 100% indicating dissimilar weed communities. Dissimilarity of the tilled compared to the no-till plots was 79%, with velvetleaf contributing the most to dissimilarity.

Table 3. Contribution of species to the similarity and dissimilarity of tilled and no-till rye plots based on late-season weed shoot mass in 2008 and 2009.

Similarity of tilled plots			Similarity of no-till rye plots			Dissimilarity of tilled and no-till plots			
Species ^a	Mass	Contribution	Species	Mass	Contribution	Species	Mass in tilled	Mass in no-till	Contribution
	g m ⁻²	%		g m ⁻²	%		g m ⁻²		%
CHEAL	30.1	52	CHEAL	4.1	38	ABUTH	16.2	0.1	32
ABUTH	16.2	39	POLAV	0.7	16	CHEAL	30.1	4.1	28
AMARE	1.0	4	TRFPR	0.5	9	AMARE	1.0	0.1	8
SETFA	0.1	2	POLPA	0.4	8	POLAV	0.0	0.7	5
POLPA	0.3	1	TAROF	0.1	6	ECHCG	0.1	0.0	5

^a Abbreviations: ABUTH, velvetleaf; AMARE, redroot pigweed; CHEAL, common lambsquarters; ECHCG, barnyardgrass; POLAV, prostrate knotweed; POLPA, ladythumb; SETFA, giant foxtail; TAROF, dandelion; and TRFRE, white clover.

CONCLUSIONS

Patterns of weed emergence and density throughout the season differed between tilled and no-till rye systems. In both years, weed density peaked early in the season in the tilled system, and then declined. In contrast, weed density in the no-till rye systems peaked late-season in 2008, and mid-season and late-season in 2009. In 2008, weed densities were typically greater in the tilled than in the no-till rye systems, whereas in 2009, weed densities were greater in the no-till rye systems and was likely due to less rye mulch mass in 2009 than 2008.

Weed management was more effective in the no-till rye systems than in the tilled system, with an average of 86% less late-season weed mass shoot in the no-till systems across years. Greater weed mass occurred consistently in the tilled system each year even though weed densities were similar between systems in 2008 and greater in rye no-till systems in 2009. Within the no-till systems, weed mass was less for early (May) than late (June) planted soybean, and for narrow-than wide-row soybean.

Weed community diversity was not affected by tillage in 2008, but was less for tilled than no-tilled systems in 2009. Greater diversity in the no-till rye systems in 2009 was likely due to less soil disturbance associated with no-till. Despite greater weed community diversity in the no-till rye systems, particularly in 2009, weed management was more effective in these systems than in the tilled system.

Summer annual weed species such as common lambsquarters and velvetleaf were highly abundant and similar among tilled plots, whereas the no-till plots were associated with more diverse annual and perennial species. Velvetleaf was the largest contributor to the dissimilarity of tilled and no-till plots. The greater frequency of disturbance in the tilled system likely increased selection pressure for summer annual species. The high abundance and dominance of summer annuals, particularly velvetleaf, indicates a potential for a long-term weed management problem in the tilled system due to longevity of velvetleaf seeds in the soil seedbank and the high competitive ability of velvetleaf with soybean.

Multiple tactics that included winter rye mulch, no-tillage planting, and competitive crop canopies were associated with greater weed suppression and weed community dynamics, less soil loss, greater soil organic matter, and less labor and fuel inputs (Bernstein et al. 2010) than a tillage-intensive approach to organic soybean production. However, these potentially long-term benefits were offset by 24% less soybean yield and 25% less profit (Bernstein et al. 2010). Even so, these rye mulch, no-tillage soybean systems appear to be economically viable alternatives to the tillage-intensive approach; they are

particularly attractive to growers due to reduced labor inputs, and require less organic matter inputs over the crop rotation in order to maintain long-term soil quality.

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RECENT TREND IN ORGANIC CORN AND SOYBEAN YIELDS ON WICST (2002-2009)

Janet Hedtcke and Joshua Posner

INTRODUCTION

Consumer demand has driven the continued growth of the organic market with dairy being the fastest growing sector. Organic dairy farms increased by 79 percent from 2002 to 2007 (USDA Agricultural Census, 2007). Wisconsin ranks first in total organic dairy farms (433 farms; 87,000 acres) with New York coming in a close second (ERS, 2009). As a result of the increasing number of dairies, there has been a growing demand for organically grown feed, opening an additional market for organic grain farmers. The National Organic Program (NOP) was implemented in 2002, defining clear-cut rules for organic crop production. This paper reviews the yield trends of corn and soybeans from the organic systems since 2003.

MANAGEMENT MODIFICATIONS

Since their initiation in 1990, through 2002, two of the WICST systems, CS3 (corn-soybeans-wheat+plowdown red clover) and CS5 (corn-oats/alfalfa-alfalfa+manure) had been managed with a low-input philosophy, without chemicals or synthetic fertilizers. System 5 had dairy manure and alfalfa plowdown which provided substantial N for the corn while CS3 relied only on plowdown red clover for N, which was often a limiting factor in corn vigor. Though seed was not transgenic it was often treated with standard fungicides. Planting date was generally delayed in these systems to encourage rapid emergence. However, since 2003, although not certified organic due to inadequate buffer zones (30 feet) between plots and machinery cleaning before entering the plots, management on the two WICST organic systems has strictly adhered to the NOP rules. This includes using certified organic seed and organically-approved inputs when necessary.

Several factors have been identified that were limiting grain yield. They included insufficient weed control, poor seedling emergence, inadequate stand densities, and declining soil fertility. Weed control was a continuous struggle, especially in wet springs (Posner et al 2008). In 2006, corn seeding rates were increased from 34,000 to 38,000 seeds per acre and a tine weeder, a high-residue rotary hoe, and a disk-hiller row cultivator were purchased. Weeding frequency was increased and earlier timing was initiated to keep weeds from getting too big or numerous. For example, tine weeding or rotary hoeing was done just before emergence and 2-3 times post-emergence until the plants were large enough to handle the more aggressive row cultivation. Corn and soybean stands were monitored closely in 2007 and 2008 by setting up 5 permanent sampling stations (17'5" long) per plot that were repeatedly counted after each weed control operation. This stand data was analyzed across years using Proc Mixed with a repeated measures covariance structure of ante-dependence. Another factor that has improved corn densities was a seed coating called Natural II, later renamed to NII Film coat. It was shown to improve seedling vigor and yield on neighboring on-farm trials (Goesser 2008). In a superimposed trial of adding manure to cash-grain systems on WICST, manure has been applied to the eastern 15' (6 rows) (12,000 gal/a) in front of the corn phase in the CS 3 rotation since 2003. This rate has typically

provided about 100 lbs N/a and grain yields have improved significantly in CS3 under the manured vs. non manured plots (see Fig. 3).

Plot alleys maintenance with a roto-vator and hand-weeding of plot border rows were heightened to keep weeds from encroaching from the edges.

RESULTS

There was a learning curve to achieving healthy, vigorous stands using untreated, organic seed. In 2004, corn was planted into wet and cold soils and the emergence was spotty and weak. A decision was made to replant but the summer that followed was cooler than normal and the corn did not mature before a killing frost. Ear corn (or snaplage) was harvested and those yields converted to grain but grain quality was very poor. In 2005, weed control in the organic soybeans was very poor and yields suffered tremendously and samples contained heavy weed seed.

Monitoring data for corn populations after each rotary hoeing or tine weeding is shown in Fig. 1. Though the first corn count tended to be a bit lower than the subsequent counts in 2007, there was no loss in stand over time due to mechanical weeding in either system and no difference between systems. The 2007 stand was generally higher than the 2008 stand as a result of the more rapid emergence (~7 vs. 15 days) in the warmer dryer spring of 2007. Nonetheless, stands were at an acceptable level of ~ 33,000 corn plants/acre and comparable to the conventional systems. Soybean stands were also favorable for the organic plots (> 140,000 plants/a) in light of all the weed control passes conducted and there was no effect on stand over time ($p < 0.1895$; data not shown). Careful calibration of the equipment and tractor speed were important at each time of operation to account for soil condition and to protect the crop while being aggressive on the weeds.

For the past four years, as shown in Figs. 2 and 3, yields have been excellent, around 150-200 bu/a for the organic corn and 50-55 bu/a for the organic soybeans. Historically the corn following alfalfa in CS5 has had the highest yields, but recently, the corn in the grain system with manure has produced equal yields. In the system with soybeans yields have become equal to or surpass no-till conventional practices.

As corn yields have improved in recent years, the N-deficiency in CS3 without manure has become very evident. Poultry manure was added at a low rate (~1 ton/a) to CS3 corn as soil test P and K have fallen into the yield response range which also provides a good source of N. Though the summer seeded cover crop of berseem clover and oats has less time to fix N and is generally lower in biomass production than the spring-seeded red clover, this management change has worked in our situation for improved weed control. Summer tillage following wheat in the CS3 system has prevented weeds, especially foxtails from going to seed while a sequentially planted cover crop of oats and berseem clover has served to smother new weed seedlings while serving as a nutrient source (berseem) and nutrient sponge (oats) for next year's corn crop.

SUMMARY

Improved agronomy has been reflected in higher yields in recent years. It has been very useful to have the UW Organic corn and soybean variety data available to base selection upon. Aside from monitoring plant populations in spring, more thorough scouting throughout the season for aphids and white mold have improved our skills at monitoring growth stage and assessment of the crops.

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Fig. 1. Corn density after each mechanical weed control pass averaged over 2007 and 2008. No change in stand over time across systems ($p < 0.4510$). Organic forage system lowest at count 1 vs. all other counts ($\text{system} \times \text{count } p < 0.0133$) due to delayed emergence from aggressive tine weeding.

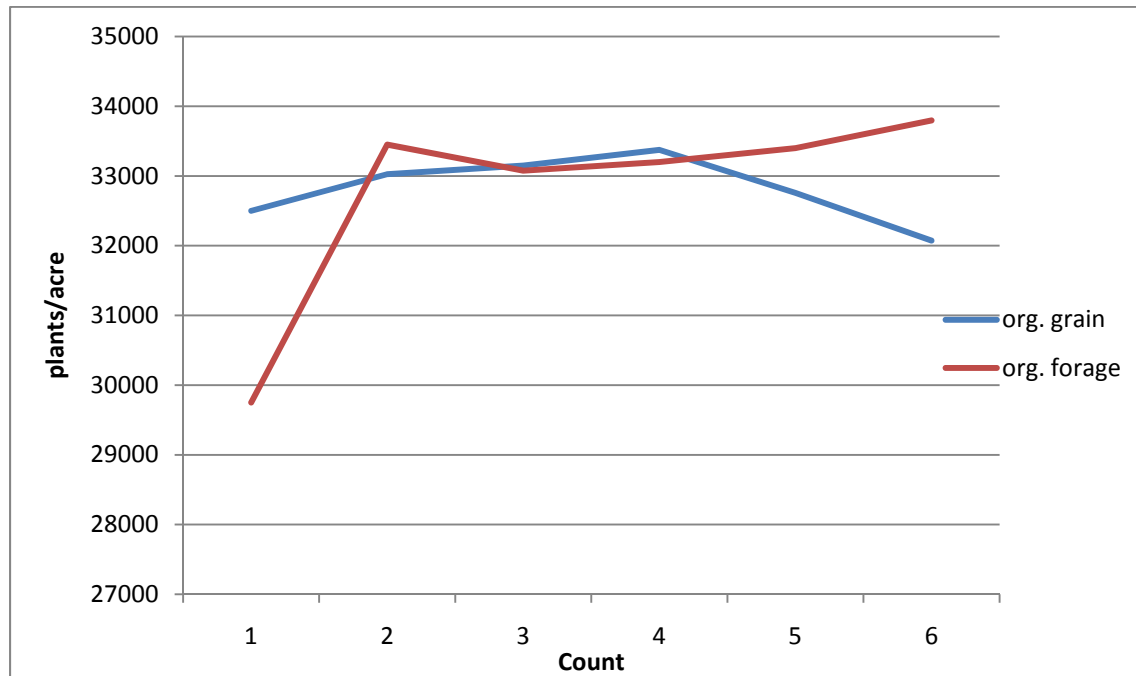


Fig. 2. Corn grain yields on organic systems 2003-2009 (all yrs $p < 0.05$)

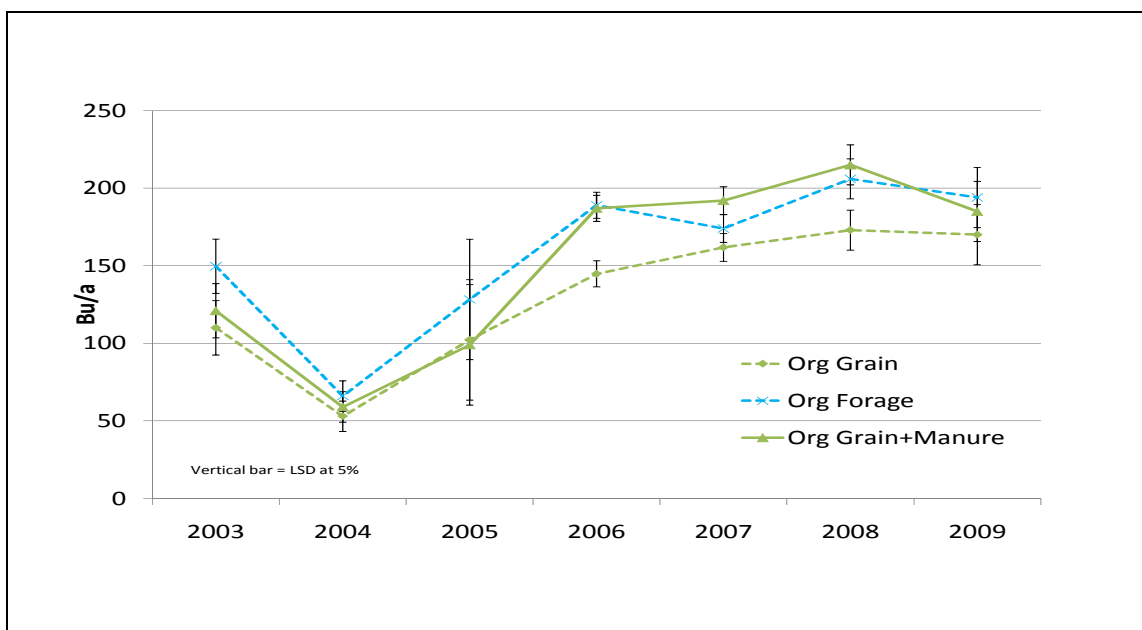
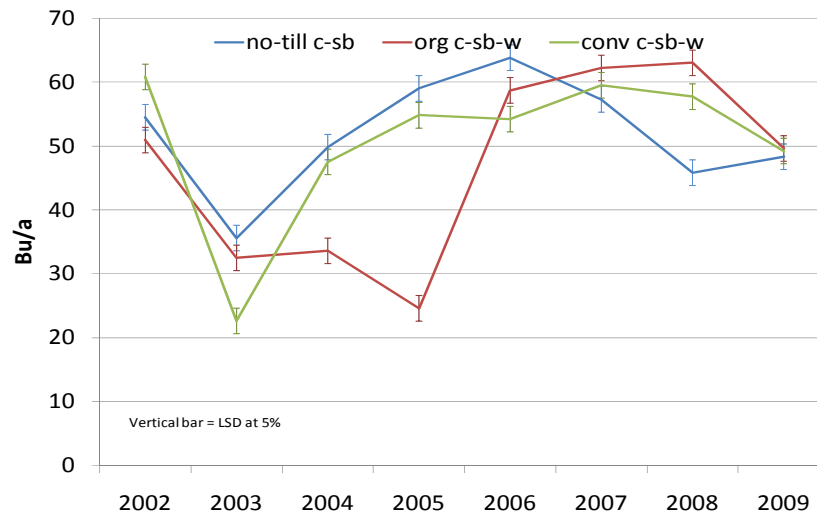


Fig. 3. Soybean yields across systems 2003-2009 ($p < 0.05$)

Response of herbivores and natural enemies to organic and conventional management of field crops

R.E. Mallinger and D.B. Hogg

Background

Organic agricultural production in the United States has continued to expand; the amount of organically managed land doubled from 1990-2002 and again from 2002-2005 (USDA 2009). The rising prevalence of organic farming systems in the agricultural landscape has necessitated efforts to understand their ecological impacts. Numerous studies have found greater abundances of predatory or beneficial insects on organic compared to conventional farms (Drinkwater et al. 1995; Letourneau and Goldstein 2001; Bengtsson et al. 2005). However, many of these same studies found no significant effect of farm management on insect pest abundances (Bengtsson 2005). Variable within-crop and off-crop plant diversity associated with farm management can affect insect populations through reducing the concentration of host plants for herbivores and increasing the diversity and stability of resources for natural enemies. Increased within-crop plant diversity, including weed diversity, is commonly attributed to organic farming systems and has been correlated with greater abundances of natural enemies and lower abundances of herbivores (Degooyer et al. 1999; Skelton and Barrett 2004; Cai et al. 2007; Brewer et al. 2009; Lundgren et al. 2009).

Study objective and hypotheses

The objective of this study was to examine how conventional and organic management of alfalfa and soybean crops at the Wisconsin Integrated Cropping Systems Trial (WICST) affect herbivores and their natural enemies. The major herbivorous pest of soybean is the soybean aphid, *Aphis glycines* Matsumura, which upon arrival in North America in 2000, has reduced soybean yields and vectored pathogens (Wedberg 2000; DiFonzo and Hines 2002; Clark and Perry 2002; Wang and Ghabrial 2002). Alfalfa is host to the potato leafhopper, *Empoasca fabae* (Harris), a phloem-feeding insect that can damage forage quantity and quality (Kindler et al. 1973; Hutchison and Hogg 1984, 1985; Cuperus et al. 1992; Lefko et al. 1999). A community of generalist natural enemies, including lady beetles (Coleoptera: Coccinellidae), lacewings (Neuroptera), syrphid flies (Diptera: Syrphidae), spiders, and predatory bugs (Hemiptera) have been shown to predate on these field crop pests (Fluke 1929; Wheeler 1977; Barney et al. 1984; Hutchison and Hogg 1985; Fox et al. 2004; Rutledge et al. 2004; Costamagna and Landis 2006; Costamagna et al. 2007).

In comparing the organic and conventional cropping systems, it was hypothesized that 1) organic systems of both soybean and alfalfa would have overall higher abundances of natural enemies compared to conventional systems due to greater within-crop plant diversity and the absence of insecticides, 2) overall pest abundance would be lower in organic systems due to the higher abundance of natural enemies and the reduced concentration of host plants in such systems, 3) the natural enemy communities would differ between organic and conventional systems due to distinct weed and insect control practices. To address these hypotheses, pests and natural enemies were sampled in soybean and alfalfa cropping systems at the WICST during 2007 and 2008. The specific cropping systems examined included comparisons between no-till, conventional soybean (CS2) and soybean in the organic grain rotation (CS3), and between conventional "Green Gold" alfalfa (CS4) and alfalfa in the organic dairy rotation (CS5).

Methods

Agronomic treatments

All experiments were conducted at the WICST in Arlington, WI. For this study, we utilized the plots in the soybean phase of the CS2 and CS3 systems as well as plots in two alfalfa phases of the CS4 and CS5 systems: the seeding-year alfalfa phase and the established, first-year alfalfa phase. In 2008, the established first-year alfalfa plots were sampled throughout the first three crops of the growing season. The crops were harvested on May 29, July 1 and August 7, 2008. No insecticides or herbicides were used in any of the established first-year alfalfa plots during the 2008 season. Alfalfa in the seeding-year phase of both CS4 and CS5 systems was sampled during the first crop of 2008. On April 30, 2008, alfalfa was direct-seeded in the conventional (CS4) system and planted along with oats in the organic system (CS5). No pesticides were used in any plots during this sampling period, but “Warrior” (Syngenta Co.), was applied in the CS4 plots on June 26, 2008 along with an herbicide.

Conventional, CS2, and organic, CS3, soybeans were sampled from June – August during 2007 and 2008. In 2007, CS2 soybeans were planted in 7” rows in no-till plots that received an herbicide application on May 31. The CS3 soybeans were planted in wide, 30” rows and the plots were rotary hoed, tine weeded and cultivated to control for weeds. In 2008, the CS2 soybeans received herbicide applications on June 7 and July 10, and the CS3 soybeans were again treated with tine weeding and cultivation during May and June. No insecticides were applied in any plots during 2007 or 2008.

Insect sampling

In alfalfa systems, pests and natural enemies were sampled by sweep-net sampling. On each sampling date, 4 sets of 25 pendulum sweeps were taken randomly throughout the interior of each conventional and organic plot. Insect pests in samples were identified to species level and natural enemies identified to the family or species level. Natural enemies from all life stages were recorded and included in total natural enemy abundances. While samples were taken on multiple dates for each crop, data shown are of insect populations on the date when abundances were highest for each crop or on the date most immediately preceding the crop harvest.

In the soybean systems, whole-plant sampling analyzed populations of pest and beneficial insects. On each whole-plant sampling date, 15-50 plants were randomly selected within each plot, with the sample size dependent on the growth stage of the plants and therefore the time needed to sample each plant. Plants were selected from the interior of the plots so as to avoid the edge effects on insect populations. All life stages of all natural enemies were recorded and included in total natural enemy abundances.

Statistical procedures

For data taken repeatedly throughout a season, repeated measures, mixed model analyses of variance were conducted. Fixed effects included plot treatment (conventional or organic), date, and the interaction between these two variables, while random effects included plot treatment replicate nested within block. Date was treated as the repeated variable (nlme package, R). Pre-planned contrasts were conducted for populations on specific dates using mixed model analyses of variance with plot treatment as a fixed effect and plot treatment replicate nested within block as a random effect (nlme package,

R). Data for which there were no repeated measures were also analyzed using mixed model analyses of variance with fixed and random effects identical to those for planned contrasts. Response variables were log or square root transformed prior to analyses to meet assumptions of normality and homogeneity of variance when necessary.

Additionally, analyses of similarity (ANOSIM) using a Bray-Curtis similarity matrix were conducted to determine significance in the differences between natural enemy community compositions in organic and conventional systems (Primer v.6). Abundances of specific natural enemy groups or taxa were standardized for the total natural enemy abundance in each plot so that differences detected would be those of community composition and not related to overall natural enemy abundance.

Results

Alfalfa pests and natural enemies

In 2008, the abundance of potato leafhoppers did not differ significantly between organically (CS5) and conventionally (CS4) managed established-alfalfa plots ($F_{1,3}=3.0$; $P=0.19$; Figure 1A), and while the effect of time was significant ($P<0.001$), there was no significant time x treatment interaction ($P=0.48$). Furthermore, there was no overall significant difference in natural enemy abundance between conventional and organic established-alfalfa plots ($F_{1,3}=6.0$; $P=0.10$; Figure 1B), nor was there a significant effect of time ($P=0.13$). However, there was a significant time x treatment interaction ($P=0.03$). During the first and second crops of 2008, there were no significant differences in natural enemy abundances between organic and conventional systems ($P=0.98$, $P=0.45$, respectively; Figure 1B). However, organic plots had significantly more natural enemies during the third crop of 2008 ($P=0.04$; Figure 1B). There were no significant differences in natural enemy community compositions between conventional and organic plots in any of the three crops as revealed by ANOSIM (crop 1: $R=0.15$; $P=0.17$, crop 2: $R=0.10$; $P=0.31$, crop 3: $R=-0.02$; $P=0.49$, Table 1).

Potato leafhoppers were significantly more abundant in the conventional direct-seeded alfalfa plots (CS4) as compared to the organic oats-alfalfa intercropped plots (CS5) during the first crop of 2008 ($F_1=15.2$; $P=0.02$; Figure 2A). No significant difference was found in natural enemy abundance between these same plots during the first 2008 crop ($F_1=5.45$; $P=0.08$; Figure 2B). However, the community compositions between the conventional and organic plots were significantly different as shown by ANOSIM ($R=0.80$; $P=0.003$; Table 1). Syrphid flies were more predominate in the conventional plots while lady beetles, lacewings and spiders were more predominate in organic plots (Table 1).

Soybean pests and natural enemies

In 2007, there were significantly more soybean aphids in organic plots as compared to conventional plots ($F_{1,3}=12.0$; $P<0.001$; Figure 4A) with a significant effect of time ($P<0.001$) and significant time x treatment interaction ($P<0.001$). Natural enemies sampled by whole plant sampling in 2007 were also significantly more abundant in organic plots as compared to conventional plots ($F_{1,3}=10.0$; $P=0.05$; Figure 4C), with a significant effect of time ($P<0.001$) and significant time x treatment interaction ($P=0.01$). ANOSIM was used to compare the natural enemy community compositions when natural enemies were at their peak abundances in whole plant samples. The natural enemy

community composition did not significantly differ between conventional and organic plots ($R=-0.18$; $P=0.94$; Table 2).

Alternatively, in 2008, conventional plots had significantly more aphids ($F_{1,3}=12.0$; $P<0.001$; Figure 4B), and there was also a significant effect of time ($P<0.001$) and significant interaction between time and treatment ($P<0.001$). In 2008, conventional plots also had significantly more natural enemies as sampled by whole plant sampling ($F_{1,3}=10.0$; $P=0.05$; Figure 4D), with a significant effect of time ($P<0.001$) and significant time x treatment interaction ($P=0.015$). Once again, however, there were no significant differences in natural enemy community compositions between the two farming systems when populations were at peak abundances ($R=0.38$; $P=0.06$; Table 2).

Discussion and Conclusion

We hypothesized that organic cropping systems would have greater natural enemy abundances due primarily to greater within-crop plant and insect diversity. We also hypothesized that pest abundances would be lower in organic cropping systems due to their lower densities of host plant resources and greater numbers of natural enemies. Natural enemy abundances were not, however, consistently higher in organic plots. Any differences found depended on the crop and the year and varied in favor of both conventional and organic management. Pest abundances were also inconsistently or not different between conventional and organic crops.

Individual studies that have found insect populations to differ between farming systems attributed such differences to the off-crop habitat (Drinkwater et al. 1995; Letourneau and Goldstein 2001; Purtauf et al. 2005). One explanation for why we did not see conclusive differences in insect populations is that the surrounding landscape was kept constant for all treatments, as all plots were located at the WICST. The results of this study suggest that off-crop habitat may have a greater impact on insect populations in comparison to farm management.

While off-crop plant diversity did not vary at the WICST, within-crop plant diversity differed between the alfalfa monocrop and the oats-alfalfa intercrop and was associated with dissimilar pest abundances. Potato leafhoppers were more abundant in conventional, monocropped alfalfa (CS4) as compared to the organic, intercropped oats-alfalfa (CS5). Conversely, natural enemy abundances did not differ between the two systems, suggesting that the intercrop provided alternative food resources for the natural enemies. The lower abundance of herbivores in the oats-alfalfa intercrop could be due to the higher natural enemy to herbivore ratio, or due to the reduced concentration of alfalfa within the intercrop (Root 1973). Additionally, herbivores may be less abundant in an intercrop where host plants, stressed by interspecific competition, are of lower nutritional value (Bach 1981). In the established-alfalfa phase, where within-crop plant diversity did not differ, there were no overall significant differences in leafhopper or natural enemy abundances.

Differences in community composition between the organic, oats-alfalfa intercrop and the conventional, alfalfa monocrop were also significant. In the conventional monocrop, syrphids dominated the natural enemy community, whereas the organic intercrop had higher percentages of spiders, lacewings and lady beetles. Spiders have responded favorably to interspersed plant diversification in approximately 80% of studies reviewed (Sunderland and Samu 2000), preferring intercrops or weedy fields.

Alternatively, syrphid fly densities depended on the concentration of a primary food source and not on landscape diversity (Meyer et al. 2009), suggesting that they would prefer monocrops with high herbivore densities. Again, in the established-alfalfa phase, there were no significant differences in natural enemy community composition between organic and conventional treatment.

In the soybean cropping systems, results of natural enemy and aphid abundances were highly variable. In 2007, these beneficial and pestiferous insects were both more abundant in organic (CS3) plots whereas in 2008, they were more abundant in conventional (CS2) systems. The population dynamics of the non-native soybean aphid are still not well understood and abundances of the aphid within soybean crops have fluctuated greatly over the past nine years (North Central Soybean Research Program 2008). The variability of our results suggests that studies examining the effects of management on the soybean aphid be conducted over a long-term period. The natural enemy community compositions in soybean also did not significantly differ between treatment in either 2007 or 2008. This may be due to a lack of other significant differences between the two systems such as weed density and insecticide use. Differing weed communities have been shown to significantly affect natural enemy diversity and composition in soybean (Shelton et al. 1983), but we did not observe significant differences in weed densities between the organic and conventional plots (Mallinger and Hogg, unpublished data).

Comparisons between conventional and organic management of established-alfalfa revealed no consistent, significant differences in pest and natural enemy abundances or community compositions, while significant differences were found between conventional, alfalfa monocrops and organic, oats-alfalfa intercrops. Abundances of pests and natural enemies in soybean showed no correlation with farming system, but rather varied significantly from year to year. The highly variable results illustrate the need for long-term comparisons of farming systems. The differences documented also suggest that intercropping or practices that affect within-crop plant diversity are likely to have a significant effect on herbivore and natural enemy populations.

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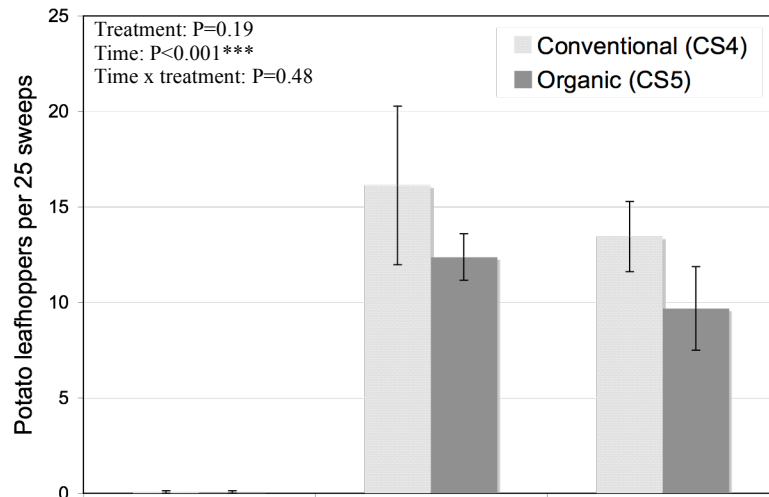
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A.



B.

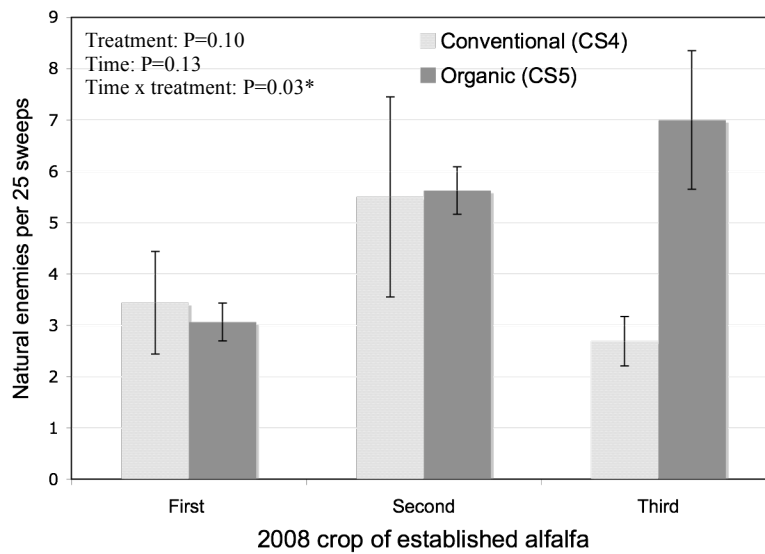


Figure 1. Abundances of potato leafhoppers (A) and natural enemies (B) in organically managed (CS5) and conventionally managed (CS4) alfalfa in the first established-year phase. Samples were taken for each of three crops during the 2008 growing season, and abundances shown are those of populations at peak abundances, or most immediately prior to the harvesting of the crop.

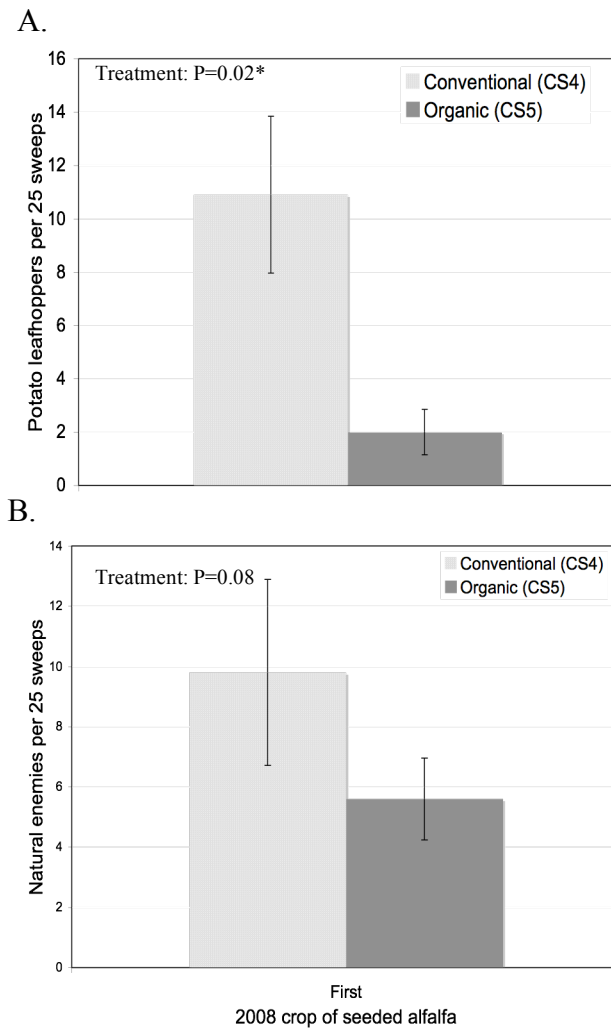


Figure 2. Abundances of potato leafhoppers (A) and natural enemies (B) in organically managed (CS5) and conventionally managed (CS4) alfalfa in the seeding-year phase. The organically managed alfalfa was planted as an oats-alfalfa intercrop while the conventionally managed alfalfa was direct-seeded as a monocrop. Samples were taken for the first crop during the 2008 growing season, and abundances shown are those of populations at peak abundances, or most immediately prior to the harvesting of the crop.

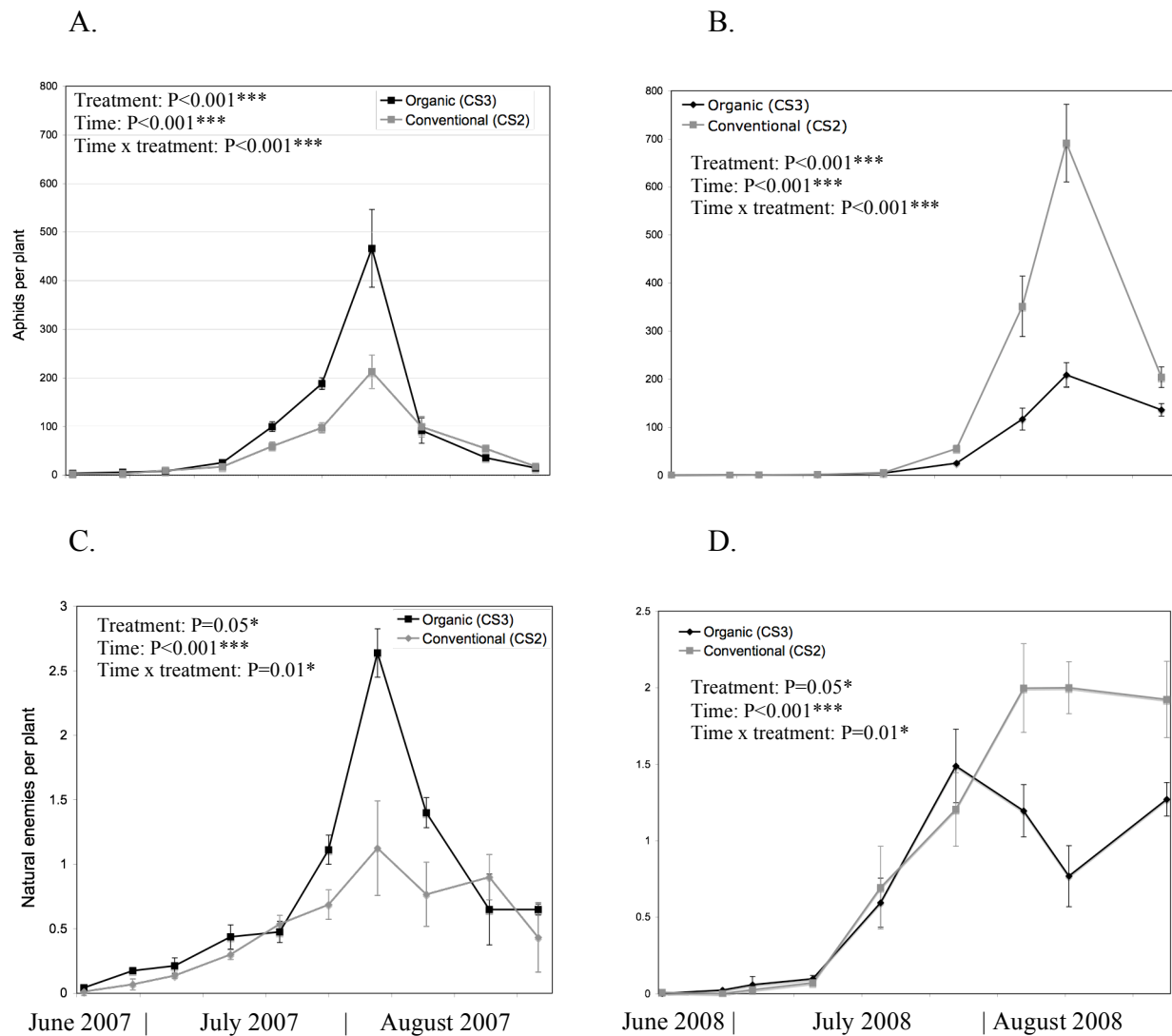


Figure 3. Abundances of soybean aphids in conventionally and organically managed soybean fields during 2007 (A) and 2008 (B), and abundances of natural enemies in these same fields during 2007 (C) and 2008 (D). Samples were taken by whole plant sampling and conducted on ten dates during the 2007 growing season and nine dates during the 2008 growing season.

Table 1. Natural enemy community compositions in organically (CS5) and conventionally (CS4) managed established alfalfa and alfalfa in the seeding-year phase. Data shown are of natural enemy communities when populations reached peak abundances, or on the sampling data most immediately before the harvesting of the crop. Abundances of natural enemy taxa were standardized for the total natural enemy abundance in each plot. Analyses of similarity (ANOSIM) were conducted between organic and conventional plots with significance defined at the $P < 0.05$ level.

<u>Natural enemy taxa</u>	Average standardized abundances							
	<u>2008 seeded-alfalfa crop 1</u>		<u>2008 established-alfalfa crop 1</u>		<u>2008 established-alfalfa crop 2</u>		<u>2008 established-alfalfa crop 3</u>	
	Organic (CS5)	Conventional (CS4)	Organic (CS5)	Conventional (CS4)	Organic (CS5)	Conventional (CS4)	Organic (CS5)	Conventional (CS4)
syrphid flies	44.8	82.2	0	0	59.2	34.1	63.3	37.8
lady beetles	34.5	8.05	3.3	1.9	3.97	12.7	1.3	11.3
lacewings	9.2	1.8	0	0	3.6	2.5	1.2	0
spiders	10.7	7	76.3	69.1	18.9	15.8	10.1	12.7
predatory bugs	0	0	17.2	29	10	17.8	24.2	36.6
other	0.96	0.91	3.13	0	4.3	17.05	1.7	0
ANOSIM P-value	0.003**		0.17		0.31		0.49	

Table 2. Natural enemy community compositions in organically (CS3) and conventionally (CS2) managed soybean during both 2007 and 2008. Data shown are of natural enemy communities when populations reached peak abundances in early to mid August. Abundances of natural enemy taxa were standardized for the total natural enemy abundance in each plot. Analyses of similarity (ANOSIM) were conducted between organic and conventional plots with significance defined at the $P < 0.05$ level.

<u>Natural enemy taxa</u>	Average standardized abundances			
	<u>2007 soybeans</u>		<u>2008 soybeans</u>	
	Organic (CS3)	Conventional (CS2)	Organic (CS3)	Conventional (CS2)
syrphid flies	13.5	17.3	29.8	18.9
lady beetles	14.5	12.1	25.6	57.6
lacewings	16.3	14.8	27.9	7.44
predatory bugs	29.3	28.8	15.5	11
other	25.1	26.1	1.3	5.2
ANOSIM P-value	0.94		0.06	

APPENDIX

2007 Inputs/Outputs for WICST (Fld 440)

Corn rotations					
CROP-2007 Rotation Treatment #	CORN CS1 1	CORN CS2 3	CORN CS3 5	CORN CS4 9	CORN CS5 11
Plot #'s	109,204,306,412	101,214,303,401	106,202,307,411	105, 203, 308,406	110, 208, 304,413
Primary Tillage	Fall chisel plowed 11-30-06	Strip tilled 5-3-07	chisel plowed 4-18-07	Disk-chiseled 1-2-07	Fall MB plowed 11-26-06
Secondary Tillage	Field cultivated 4-20-07 and 5-3-07	None	Field cultivated 5-1-07 & 5-11-07; cultimulch 5-11-07	Field cultivated 5-3-07	Field cultivated 4-20-07, 5-1-07, 5-11-07
Variety Planting Date Rate	Pion. 35Y67 LL 5-3-07 34,000 s/a	Pion. 35Y67 LL 5-3-07 34,000 s/a	BR 42A32 (NII) 5-14-07 38,000 s/a	Pion. 35Y67 LL 5-3-07 34,000 s/a	BR 42A32 (NII) 5-14-07 38,000 s/a
Starter Fertilizer	100 lb/a 5-14-42	100 lb/a 5-14-42	None	100 lb/a 5-14-42	None
Fertilizer	82% 5-1-07 125 lb N/a	46% 5-2-07 125 lb N/a	150 lb/a 0-0-50 plots 106, 202 (in planter)	None	150 lb/a 0-0-50 plot 110 (in planter)
Manure Credit	None	None	None	4,000 gpa (11-06)	4,000 gpa (11-06)
Pesticides/ Herbicides	Force 3G 4.4 lb/a Pre-emrg: 5-10-07 Credit Extra, Dual II Mag @ 16 oz/a ea.; Post-emrg: 6-9-07 Harness, Liberty @ 32 oz/a ea.	Pre-emrg: 5-10-07 Credit Extra, Dual II Mag @ 16 oz/a ea.; Post-emrg: 6-9-07 Liberty @ 32 oz/a	None	Pre-emrg: 5-10-07 Credit Extra, Dual II Mag @ 16 oz/a ea.; Post-emrg: 5-30-07 Callisto @ 1oz/a; Dual II Mg @ 12 oz/a; Liberty @ 28 oz/a	None
Rotary hoe (RH) /tine weed (TW)	None	None	RH: 5-18, 5-31, 6-7 TW: 5-24-07	None	RH: 5-18-07, 6-7-07 TW: 5-24-07
Cultivation	None	None	'Wilrich' 6-13-07 'Yetter' 6-20-07	None	'Wilrich' 6-13-07 'Yetter' 6-20-07
Hand weed	No	No	None	No	None
Harvest & Yield	10-17-07 204 bu/a	10-17-07 189 bu/a	10-17-05 162 bu/a	10-17-07 215 bu/a	10-17-05 174 bu/a
Fall Practices	10-18-07 Chop stalks; 11-7-07 chisel plow	None	10-18-07 Chop stalks; 11-9-07 MB plow	10-18-07 Chop stalks; 10-29-07 Manure (12k gpa); 11-8-07 chisel plow	10-18-07 Chop stalks; 10-29-07 Manure (8k gpa); 11-9-07 chisel plow
Crop 2008	Corn	Soybean	Soybean	D.S. Alfalfa	Oats/Alfalfa

MISC:

Baited ground squirrels burrows with 'Revenge' of no-till corn and pasture plots on 4-18, 4-19, 4-20, 4-21, 4-27.
5-31 hand ranked soil off buried corn in CS5 from 5-24 TW; Anthracnose/stalk rot(?) was observed on CS5 corn in particular.
Alleys: Sprayed when cs2, cs4 and CL corn plots were sprayed; till throughout summer; Spot sprayed c. thistle on west edge of plot 109 and throughout prairie plots in mid-June; hand pulled c. thistles from wheat in plot 212.

2007 Inputs/Outputs for WICST (Fld 440)

Soybean and Wheat Rotations			
CROP-2007 Rotation Treatment #	NR Soybean CS2 2	WR Soybean/Winter Wheat CS3 4	Wheat/Berseem Clover+oats CS3 6
Plot #'s	108,206,310,408	104,201,301,402	102, 212, 313, 407
Primary Tillage	None	Fall MB plowed 11-26-06	Fall disked & Field cult. 1x after soybean harvest to prep seedbed
Secondary Tillage	None	Field cultivated 4-20-07, 5-1-07, 5-11-07	None
Planting Date	5-11-07	SB: 5-14-07 WW: 10-6-07	WW: 10-9-06 Red clover (accidentally planted) 4-21-07 with no-till drill Berseem clover/oats: 8-13-07
Variety Rate	KB244 RR K (2680 seed/lb) inoc=cell tech 200,000 seed/a	Sb: 'Viking 1832' (2550 seed/lb) 190,000 seeds/a, cell tech inocul; WW: untrd'd Pion 25R47	'Pion. 25R47' untrt WW: 1.6 mill seeds/a (150 lb/a) Berseem/oats: 10 and 32 lb/a
Fertilizer	Plot 108 got 200 lb/a 0-0-60	150 lb/a 0-0-50 on plots 104, 402 (in planter)	None
Pesticides/ Herbicides	Burndown: 5-22-07 Credit extra @ 32 oz/a; Post-emrg: 5-31-07 Credit extra @ 32 oz/a	None	None
Rotary Hoe (RH) /tine weed (TW)	None	RH: 5-18-07 TW: 5-24-07, 5-31-07, 6-7-07, 6-11-07	None
Cultivation	None	1x – Wilrich 6-14-07 1x – Wilrich 6-22-07 (not plot 402)	None
Hand weed	None	None	None
Harvest & Yield	10-5-07 57 bu/a	10-5-07 62 bu/a	Wheat: 7-17-07 84 bu/a Straw: 7-18-07 0.87 tons DM/a
Fall Practices	11-9-07 Strip till	Disk 1x, spread 0-0-50; No-till drill wheat 148 lb/a 10-6-07	Quack digger 2x and field cultivator 1x before summer seeding berseem clover/oats; Disk chisel 11-9-07
Crop 2008	Corn	Wheat / Clover	Corn

2007 Inputs/Outputs for WICST (Fld 440)

Forage rotations						
CROP-2007 Rotation Treatment #	Dir. Sd. Alfalfa CS4 8	Estab. Alfalfa I CS4 7	Estab. Alfalfa II CS4 10	Oats/Alfalfa CS5 13	Estab. Alfalfa I CS5 12	Pasture CS6 14
Plot #'s	113, 210, 311, 414	111, 209, 305, 409	107, 205, 309, 404	114, 211, 312, 403	103, 213, 314, 410	112, 207, 302, 405
Primary Tillage	chisel plowed 11- 30-06	None	None	chisel plowed 11-30-06	None	None
Secondary Tillage	Disk and cultimulcher 4-21-07	None	None	Disk and cultimulcher 4-21-07	None	None
Variety Planting Date	Golden Harvest 707 4-21-07 (no-till drill)	Magnum V 4-6-06	'Magnum V' 4-14-05	'Forage+' oats and untreated 'Pion. 54H91' 4-21-07 (brillion seeder)	'Forage Plus' oats, 'WL346 LH' alf, 4-6-06	-----
Rate	12 lb/a	12 lb/a	12 lb/a	50 and 12 lb/a	62 and 12 lb/a	
Fertilizer (see map for rates)	None	0-0-60 after 2 nd & 4 th cuts	0-0-60 after 2 nd & 4 th cuts	None	0-0-50 after 2 nd & 3 rd cuts	230 lb/a 0-0-60 on 112 6-6-07; 50 lb N/a (urea) on each, mid-May to early June
Manure credit	12,000 gpa 11-06	None	None	8,000 gpa 11-06	None	Graze May 2- Oct
Pesticides/ Herbicides	Herbicide Post-emrg:5-21-07 Raptor @ 4 oz/a Insecticide 6-11-07, 7-7-07 Warrior 2 oz/a	Insecticide 7-7-07 Warrior 2 oz/a	Insecticide: 7-7-07 Warrior 2 oz/a Herbicide: 9-30-07 Credit @ 48oz/a; Express @ 0.125 oz/a	None	None	Spot spray thistles with Stinger or curtail
Harvest & Yield	<u>Date & T DM/a</u> 6-26 1.16 7-26 1.11 8-31 1.13 total=3.40 T/a	<u>Date & T DM/a</u> 5-23 1.50 6-26 1.27 7-26 0.82 8-31 1.06 total=4.64 T/a	<u>Date & T DM/a</u> 5-23 1.30 6-26 1.03 7-26 0.57 8-31 0.96 total=3.87 T/a	<u>Date & T DM/a</u> 6-29 1.59 8-31 1.71 total=3.31 T/a	<u>Date & T DM/a</u> 5-30 2.01 7-10 0.99 8-31 1.03 total=4.03 T/a	Hayed 207 5-23-07; other plots clipped post graze 1 st cycle
Fall Practices	None	None	10-30-07 Manure (4k gpa); 11-9-07 chisel plow	None	10-29-07 Manure (4k gpa); 11-9-07 chisel plow w/sweeps	Renovated 302 in late August
Crop 2008	Alf I	Alf II	Corn	Alf I	Corn	Pasture

2007 Inputs/Outputs for WICST (Fld 440)

Satellite – Chemlite plots			
CROP-2007 Rotation Treatment #	Corn (cs3 w/chemical inputs)	WR Soybean/Winter Wheat (cs3 w/chemical inputs)	Wheat/Red Clover (cs3 w/chemical inputs)
Plot #'s	SAT A, E	SAT C, D	SAT B, F
Primary Tillage	Disk ripper on red clover 1-2-07	Fall chisel plowed 11-30-06	Fall disked and field cult. 1x in prep for wheat planting 10-9-06
Secondary Tillage	Field cultivated 5-3-07	Field cultivated 5-14-07	None
Planting Date	5-3-07	SB: 5-14-07 WW: 10-6-07	WW: 10-9-06 Red clover: 4-21-07
Variety Rate	Pioneer 35Y67 LL (Bt) 34,000 seed/a	NK Brand S19-R5 RR 175,000 seed/a; Pioneer 25R47 winter wheat	Pioneer 25R47, 150 lb/a 'Arlington RC', 12 lb/a
Fertilizer	starter: 100 lb 5-14-42 + 50 lb N/a (46% 5-14-07)	150 lb/a 0-0-50 in starter box	60 lb N/a 4-18-07
Pesticides/ Herbicides	Pre emrg: 5-10-07 Credit Extra + Dual II Mag @ 16 oz/a ea.; Post emrg: 6-9-07 Liberty @ 32 oz/a	Post emrg: 6-11-07 Credit Extra @ 32 oz/a	None
Rotary Hoe	None	Tine weeded 6-7-07	None
Cultivation	None	'Wilrich' 7-10-07	None
Harvest & Yield	10-17-07 197 bu/a	10-5-07 60 bu/a	Wheat: 7-17-07 97 bu/a Straw: 7-18-07 0.96 tons DM/a
Fall Practices	10-18-07 Chop stalks; 11-8-07 Chisel plow with twisted shank	160 lb/a K2O; 30 lb N/a; No-till drill wheat 154 lb/a 10-6-07	11-9-07 disk-chisel
Crop 2008	WR Soybeans	Wheat / Red Clover	Corn

2008 Inputs/Outputs for WICST (Fld 440)

Corn Phase					
CROP-2008 Rotation Treatment #	CORN CS1 1	CORN CS2 2	CORN CS3 6	CORN CS4 10	CORN CS5 12
Previous crop	Corn	Soybeans	Wheat then berseem+oat cover crop	Alfalfa II	Alfalfa I
Plot #'s	109,204,306,412	108,206,310,408	102,212,313,407	107,205,309,404	103,213,314,410
Primary Tillage	Chisel plow 11-7-07	None	Disk-chisel 11-9-07	Chisel plow 11-7-07	Chisel plow 11-9-07
Secondary Tillage	Field cultivator 2x 5-6-08	Strip tilled 4-24-08 (DW's 4-row unit)	Field cultivator 1x 4-24-08 5-6-08 5-12-08, 5-16-08	Field cultivator 2x 5-6-08	Field cultivator 1x 4-24-08 5-12-08, 5-16-08
Variety Planting Date Rate	Pioneer 35A34 (RR/LL) May 6 34,000 sd/a	Pioneer 35A34 (RR/LL) May 6 34,000 sd/a	Viking 5305 (NII) May 16 38,000 sd/a	Pioneer 35A34 (RR/LL) May 6 34,000 sd/a	Viking 5305 (NII) May 16 38,000 sd/a
Starter Fertilizer	100 lb/a 5-14-42	100 lb/a 5-14-42	None	100 lb/a 5-14-42	None
Fertilizer (per soil test)	160 lb N/a (46-0-0 per PPNT) 5-13-08	160 lb N/a (46-0-0 per PPNT) 5-13-08	1.25 ton/a pelletized poultry manure 4-29-08	None	None
Manure Credit	None	None	None	4,000 gpa (10-30-07)	4,000 gpa (10-29-07)
Pesticides	Pre-emrg: 5-10-08 Dual II Magnum @ 16oz/a; Post-emrg: 6-17-08 Harness @ 2 pt/a (412 only); Honcho+ @ 24 oz/a; AMS @ 3.4 lb/a	Pre-emrg: 5-9-08 Honcho+ @ 18 oz/a; Dual II Magnum @ 16 oz/a; Speedway 3.2 oz/a Post-emrg: 6-7-08 Honcho+ @ 24 oz/a; Resource @ 4 oz/a; AMS @ 2 lb/a	None	Pre-emrg: 5-10-08 Dual II Magnum @ 16oz/a; Post-emrg: 6-17-08 Honcho+ @ 24 oz/a; AMS 3.4 lb/a	None
Rotary hoe (RH)/tine weed (TW)	None	None	RH: 5-23, 6-2, 6-17 TW: 5-28 (spiking)	None	RH: 5-23, 5-28, 6-2, 6-17 TW: 0 (too much residue clogs tines)
Cultivation	None	None	'Wilrich' 6-25-08 'Yetter' 7-3-08	None	'Wilrich' 6-25-08 'Yetter' 7-3-08
Hand weed	None	None	None	None	None
Harvest & Yield	10-28-08 141.8 bu/a ¹	10-28-08 175.3 bu/a	10-28-08 173.5 bu/a	10-28-08 208.6 bu/a	10-28-08 205.7 bu/a
Fall Practices	Chop stalks 10-29-08 Disk-chisel 11-10-08	None	Chop stalks 10-29-08 Disk-chisel 11-10-08	Chop stalks 10-29-08 Manure 16,000 gpa; Disk-chisel 11-10-08	Chop stalks 10-29-08 Manure 16,000 gpa; Disk-chisel 11-10-08
Crop 2009	Corn	Soybean	Soybean	D.S. Alfalfa	Oats/Alfalfa

Bait ground squirrels burrows with 'Revenge' on and around no-till corn and pasture plots in April and May

Alleys: Spray when cs2, cs4 and CL corn plots are sprayed; till throughout summer

¹ Great Flood of 2008 started June 7-8th. Most of Rep 2 was flooded for 6 weeks; plot 204 omitted from yield average

2008 Inputs/Outputs for WICST (Fld 440)

Soybean and Wheat Phases			
CROP-2008 Rotation Treatment #	No-till Soybean CS2 3	WR Soybean/Winter Wheat CS3 5	Wheat/Berseem Clover+oats CS3 4
Plot #'s	101,214,303,401	106,202,307,411	104,201,301,402
Previous crop	Corn	Corn	Soybeans
Primary Tillage	None	Fall MB plowed 11-9-07	Fall disked 1x after soybean harvest to prep seedbed 10-6-07
Secondary Tillage	None	Field cultivator 1x 4-24-08 5-6-08 5-12-08 5-21-08	None
Planting Date	May 13, 2008	SB: 5-21-08 WW: 10-13-08	WW: 10-6-07 Berseem clover/oats: 8-13-08
Variety Rate	Renk RS223RR (3000 sd/lb) 225,000 seed/a, cell tech inoculant	Sb: Viking 1832 (2600 sd/lb; 92% germ) 190,000 seeds/a, cell tech inocul WW: untrd'd Pion 25R47	WW: 1.6 mill seeds/a Berseem/oats: 10 and 32 lb/a
Fertilizer (per soil test)	None	200 lb/a 0-0-50 (in starter box); all but plot 307	None
Pesticides	Burndown: 6-7-08 Honcho+ @ 24 oz/a; Resource @ 4 oz/a; AMS @ 2 lb/a Post-emrg: 7-10-08 Honcho+ @ 24 oz/a; AMS @ 2 lb/a	None	None
Rotary Hoe (RH) /tine weed (TW)	None	RH: 0 TW: 5-28, 6-2, 6-16 (2x on 6-16)	TW 1x 4-24-08
Cultivation	None	'Wilrich' c-shank 6-24-08, 7-2-08, 7-15-08	None
Hand weed	None	Border rows 7-21-08 and 7-25-08	None
Harvest & Yield	10-13-08 45.8 bu/a	10-10-08 63.0 bu/a	Wheat: 7-30-08 63.8 bu/a Straw: 8-8-08 0.62 T DM/a
Fall Practices	Strip tilled 11-10-08	Flatten ridges w/ disk 10-10-08; No-till drill untrt'd Pioneer 25R47 wheat 10-13-08 @ 150 lb/a	Disk 1x and field cultivator 1x 8-13-08; Disk-chisel 11-11-08
Crop 2009	Corn	Wheat / Clover	Corn

2008 Inputs/Outputs for WICST (Fld 440)

Forage Phases						
CROP-2008 Rotation Treatment #	Dir. Sd. Alfalfa CS4 9	Estab. Alfalfa I CS4 8	Estab. Alfalfa II CS4 7	Oats/Alfalfa CS5 11	Estab. Alfalfa I CS5 13	Pasture CS6 14
Previous crop	Corn	D.S. Alfalfa	Alfalfa I	Corn	Oat/Alfalfa	Pasture
Plot #'s	105, 203*, 308, 406	113, 210, 311, 414	111, 209, 305, 409	110, 208, 304, 413	114, 211, 312, 403	112, 207, 302, 405
Primary Tillage	chisel plow 11-8-07	None	None	chisel plow 11-9-07	None	None
Secondary Tillage	Field cultivator 4-24-08; cultimulcher 4-30-08	None	None	Field cultivator 4-24-08 and cultimulcher 4-30-08	None	None
Variety Planting Date	'Golden Harv 707' (Brillion) 4-30-08	Golden Harv 707 4-21-07	Magnum V 4-6-06	'Esker' oats & untreated 'Pion. 54H91' (NT drill) 4-30-08	'Forage+' oats and untreated 'Pion. 54H91' 4-21-07	Kopu II White clover 4-16-08
Rate	12 lb/a	12 lb/a	12 lb/a	40 and 12 lb/a	50 and 12 lb/a	3 lb/a
Fertilizer (per soil test)	None	300 lb/a 0-0-60 6-2-08 & 8-11-08	300 lb/a 0-0-60 6-2-08 & 8-11-08	None	300 lb/a 0-0-50 6-2-08 & 8-11-08	50 lb N/a (urea) on each plot, mid-May and Aug
Manure credit	12,000 gpa 10-29-07	None	None	8,000 gpa 10-29-07	None	Graze May 4- Oct 27 th
Pesticides (as needed)	Herbicide Post-emrg: 6-25-08 Raptor @ 4 oz/a; NIS @ 6.4 oz/a 28%N 2 qt/a Insecticide Warrior 2.4 oz/a	None	Insecticide: None Herbicide (fall kill): Honcho+ @ 48oz/a; 2,4-D low vol ester @ 16 oz/a; NIS 3.2 oz/a; AMS 10 lb/a	None	None	Spot sprayed thistles with Stinger in May and September
Harvest & Yield	1 st 7-17-08 2 nd 8-19-08 sum=2.55 T dm/a	1 st 5-29-08 2 nd 7-1-08 3 rd 8-7-08 4 th 9-10-08 sum=5.86 T dm/a	1 st 5-29-08 2 nd 7-1-08 3 rd 8-7-08 4 th 9-10-08 sum=5.53 T dm/a	1 st 7-10-08 2 nd 8-19-08 sum=2.88 T dm/a	1 st 5-29-08 2 nd 7-1-08 3 rd 8-7-08 4 th 9-10-08 sum=5.34 T dm/a	Take Hay on plot 405 5-29; Clip 1 st cycle post-graze 112 on 6-2, 302 on 6-18
Fall Practices	None	None	Manure 16K gpa 11-5-08 Disk-chisel 11-10-08	None	Manure 8K gpa 11-4-08; chisel plow w/sweep 11-10-08	Reseeded south half of 207 8-15-08
Crop 2009	Alf I	Alf II	Corn	Alf I	Corn	Pasture

*plot 203 was flooded on North half so only half the plot got planted with other plots; N end was seeded later but flooding of June 7-8-08 killed it; reseeded again 8-15-08

2008 Inputs/Outputs for WICST (Fld 440)

Satellites				
	Flex-till 3-phase system**			Biofuel
CROP-2008	Corn	No-till Soybean/Winter Wheat	No-till Wheat/Red Clover	Switchgrass
Previous crop	Wheat/red clover	Corn	Soybeans	corn
Plot #'s	B, F**	A, E**	C, D	501, 504, 508
Primary Tillage	Disk-chiseled 11-9-07	Chisel plowed 11-8-07	None	None
Secondary Tillage	Field cultivator 5-6-08 2x	Field cultivator 2x 5-12-08	None	None
Planting Date	5-6-08	5-13-08;	No-till drilled wheat 11-6-07 No-till drill clover 4-16-08	Planted August 2007
Variety Rate	Pioneer 35A34 (RR/LL) 34,000 sd/a	Kaltenberg KB196RR 225,000 sd/a cell tech inoculant	WW: Pion 25R47 (150 lb/a) RC: 'Arlington' 12 lb/a	'Forestberg' 10 lb PLS/a
Fertilizer	100 lb/a 5-14-42, and 75 lb N/a as urea 5-13-08	None	30 lb N/a and 130 lb K2O applied 10-6-07; 50 lbs N/a (urea) 4-24-08	30 lbs N/a at greenup 6-2-08
Pesticides	<u>Pre-plant:</u> none <u>Post emrg:</u> 6-7-08 Honcho + @ 32 oz/a; Resource at 5.3 oz/a; AMS @ 2.3 lb/a	<u>Pre-plant:</u> none <u>Post emrg:</u> 7-10-08 Honcho+ @ 24 oz/a; AMS @ 2 lb/a	None	5-6-08 Banvel @16 oz/a, Harness @ 30oz/a, Pursuit @ 1.44 oz/a Clipped weeds 6-17-08; 7-10-08 2-4,D 3 pt/a
Rotary Hoe/Tine	None	None	None	None
Cultivation	Yetter 7-3-08	None	None	None
Harvest & Yield	10-28-08 180.9 bu/a	10-10-08 58.2 bu/a	Grain: 7-30-08 84.3 bu/a Straw: 8-8-08 0.94 T DM/a	10-31-08; southern ¼ of plot 0.43 tons DM/a
Fall Practices	Chop stalks 10-29-08	Disk 1x; drilled trt'd Pioneer 25R47 wheat @ 160 lb/a 10-13-08	Disk-chisel 11-10-08	None
Crop 2009	NT Soybeans	Wheat / Red Clover	Corn	Switchgrass

** North 100' of plot F was flooded most of season – area was kept fallow with tillage.

Appendix 3. Soil test potassium, STK, (0-6" depth) on WICST at Arlington Research Station (1992-2008).																	
System/plot#	STK (ppm)																
	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08
CS1 trt 1 109,204,306,412	219	295	228	241	257	254	229	217	203	194	202	225	227	246	244	214	206
CS2 trt 2 108,206,310,408	239	229	183	182	214	178	184	197	169	153	179	172	177	194	180	124	144
CS2 trt 3 101,214,303,401	198	264	214	208	230	224	212	164	128	126	131	138	154	148	161	162	139
CS3 trt 4 104,201,301,402	189	251	182	175	209	166	180	124	104	109	95	102	125	113	128	96	103
CS3 trt 5 106,202,307,411	---	226	171	164	191	172	150	174	145	136	140	152	154	165	163	106	132
CS3 trt 6 102,212,313,407	---	201	142	149	155	136	131	149	130	110	133	132	125	133	155	137	108
CHEMLITE trt 4 C, D	---	---	---	183	---	---	---	144	142	140	133	127	137	145	130	148	131
CHEMLITE trt 5 A, E	---	---	---	190	---	---	---	152	123	127	130	116	95	113	100	88	115
CHEMLITE trt 6 B, F	---	---	---	138	---	---	---	101	136	112	124	112	123	117	110	89	92
CS4 trt 7 111,209,305,409	175	216	171	157	180	212	200	168	116	127	146	131	122	158	178	127	130
CS4 trt 8 113,210,311,414	203	170	154	184	189	153	166	179	128	96	142	156	112	124	169	120	124
CS4 trt 9 105,203,308,406	---	170	128	160	228	143	115	134	133	107	91	153	135	131	149	128	148
CS4 trt 10 107,205,309,404	189	224	155	153	196	205	141	133	137	163	111	124	153	180	175	140	131
CS5 trt 11 110,208,304,413	198	236	172	185	201	153	154	135	95	108	122	98	115	126	118	94	121
CS5 trt 12 103,213,314,410	181	210	144	127	143	128	98	110	87	75	103	121	89	127	106	97	111
CS5 trt 13 114,211,312,403	---	211	173	180	174	153	153	130	120	110	101	117	117	132	134	105	114
CS6 trt 14 112,207,302,405	---	186	157	176	208	210	180	202	148	153	163	175	174	165	180	141	141
Corn'98-06 Switchgrass'07on 501, 504, 508	---	---	---	---	---	---	182	130	160	155	168	156	145	164	191	168	167
High div. prairie 502, 506, 509	---	---	---	---	---	---	230	163	151	178	183	165	156	161	193	148	160
Low div. prairie 503, 505, 507	---	---	---	---	---	---	203	170	168	139	169	154	151	158	190	162	162

Appendix 4. Soil test phosphorus, STP, (0-6" depth) on WICST at Arlington Research Station (1992-2008).																	
System/plot#	STP (ppm)																
	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08
CS1 trt 1 109,204,306,412	93	84	91	88	91	83	82	80	76	85	91	79	83	87	70	67	63
CS2 trt 2 108,206,310,408	79	65	68	67	66	61	59	75	69	70	77	63	77	71	61	57	55
CS2 trt 3 101,214,303,401	89	78	89	72	83	72	75	62	53	57	59	52	55	59	74	38	38
CS3 trt 4 104,201,301,402	69	64	68	65	66	55	55	46	43	48	45	36	48	44	39	34	32
CS3 trt 5 106,202,307,411	--	57	63	52	57	56	47	67	49	55	64	49	61	61	48	46	42
CS3 trt 6 102,212,313,407	--	53	57	49	49	48	45	52	51	51	59	54	51	50	48	37	40
CHEMLITE trt 4 C, D	---	---	---	57	---	---	---	59	61	64	62	56	55	58	48	44	41
CHEMLITE trt 5 A, E	---	---	---	56	---	---	---	56	50	53	58	45	46	51	32	33	33
CHEMLITE trt 6 B, F	---	---	---	40	---	---	---	47	53	48	57	45	52	44	33	31	27
CS4 trt 7 111,209,305,409	94	85	99	84	90	90	90	81	80	95	111	85	93	98	91	77	69
CS4 trt 8 113,210,311,414	105	81	92	93	94	81	91	93	81	81	101	97	95	93	95	85	74
CS4 trt 9 105,203,308,406	--	62	65	74	91	72	66	79	78	80	83	80	90	92	72	72	66
CS4 trt 10 107,205,309,404	77	71	72	67	77	76	63	66	74	86	84	73	91	94	79	64	63
CS5 trt 11 110,208,304,413	103	88	93	91	96	82	90	81	75	95	103	83	93	107	90	79	79
CS5 trt 12 103,213,314,410	72	67	72	64	72	66	59	68	60	65	80	70	70	75	58	50	57
CS5 trt 13 114,211,312,403	--	73	83	78	76	71	66	68	71	77	80	74	86	82	71	62	56
CS6 trt 14 112,207,302,405	--	82	84	75	74	73	64	68	64	73	54	69	78	76	90	55	60
Corn'98-06 Switchgrass'07 on 501, 504, 508	---	---	---	---	---	---	67	63	61	75	75	65	63	73	56	58	59
High div. prairie 502, 506, 509	---	---	---	---	---	---	67	68	60	70	74	61	69	70	54	50	56
Low div. prairie 503, 505, 507	---	---	---	---	---	---	62	65	65	68	69	59	61	69	58	55	55

Appendix 5. Fall nitrates in the top 3-ft of soil at Arlington Research Station in 2000-2008.

Crop	System	Stage	<u>2000</u>	<u>2001</u>	<u>2002</u>	<u>2003</u>	<u>2004</u>	<u>2005</u>	<u>2006</u>	<u>2007</u>	<u>2008</u>
			lbs NO-N/acre at 3-ft depth								
Corn	CS1	Cont. Corn	130	79	110	110	82	116	67	42	18
	CS2	After Soybeans	107	68	55	59	77	91	76	40	17
	CS3	After clover/oats	61	81	44	96	70	66	56	47	23
	Flextill	After red clover	50	58	52	111	57	97	94	49	26
	CS4	After 3 yrs. Alf	189	171	140	187	142	148	170	84	35
	CS5	After 2 yrs. Alf	120	154	121	142	151	160	139	127	60
Soybean	CS2	After Corn - drilled	81	101	71	108	61	83	74	57	29
	CS3	After Corn-wide-row	68	53	64	100	55	76	99	59	44
	Flextill	After Corn-wide-row	84	61	64	97	63	64	69	87	41
Wheat	CS3	Wheat - Clover/oats	57	53	37	46	45	39	52	28	15
		Wheat - Red Clover	49	65	33	45	46	43	65	49	17
Alfalfa	CS4	Dir-seeded Alfalfa	69	101	96	101	75	89	84	59	38
	CS4	Alfalfa Hay I	66	85	66	93	69	64	78	47	31
	CS4	Alfalfa Hay II	98	83	87	58	87	54	81	80	45
	CS5	Alfalfa seeded with Oats	65	72	77	98	69	96	77	50	35
	CS5	Alfalfa Hay	70	71	57	79	56	54	85	51	29
Pasture	CS6	Rotational Grazing	59	50	50	76	88	78	86	66	28
Check	native	High diversity Prairie	45	26	19	37	32	27	63	21	13

Appendix 6. Manure nutrient analysis from the Arlington Research Station¹

Year	DM%	Total N	Total P205	Total K20
-----lbs/ton-----				
1990 ²	19.4	11.9	7.1	10.1
1991	17.0	13.2	7.4	12.9
1992 ²	17.0	10.7	7.5	16.0
1993 ³	-	-	-	-
1994	12.1	8.9	4.5	11.3
1995	15.6	10.6	5.8	10.4
1996	15.3	9.8	7.2	9.8
1997	11.7	9.2	3.6	8.8
1998	14.3	10.3	3.7	9.9
1999	16.8	11.1	3.8	7.1
2000	13.2	11.6	3.1	6.8
2001	11.8	13.2	4.8	11.4
2002	14.6	9.6	3.2	6.0
2003	16.1	7.9	3.6	7.1
2004	13.8	8.6	4.2	7.2
2005	23.6	49.0	21.8	37.7
-----lbs/1000 gal-----				
2006 ⁴	9.6	31.7	11.9	27.1
2007	8.6	31.2	12.0	24.0
2008	8.0	27.5	14.2	29.3
2009 ⁵	1.3	9.4	2.5	11.2

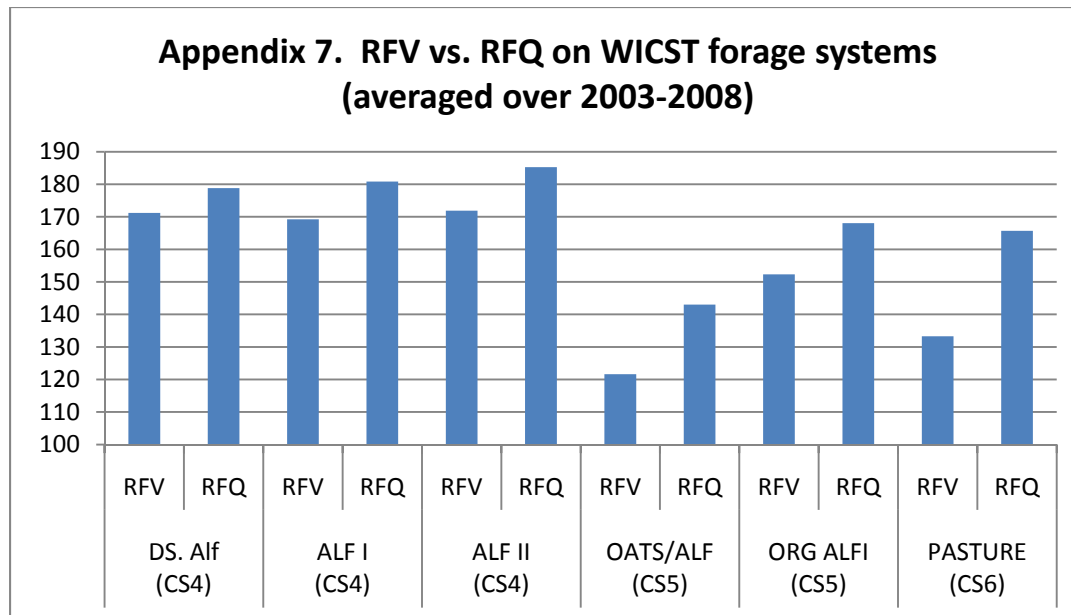
1 Manure applied previous fall before tillage unless otherwise noted. Year of credit for corn shown.

2 Manure applied prior to spring planting.

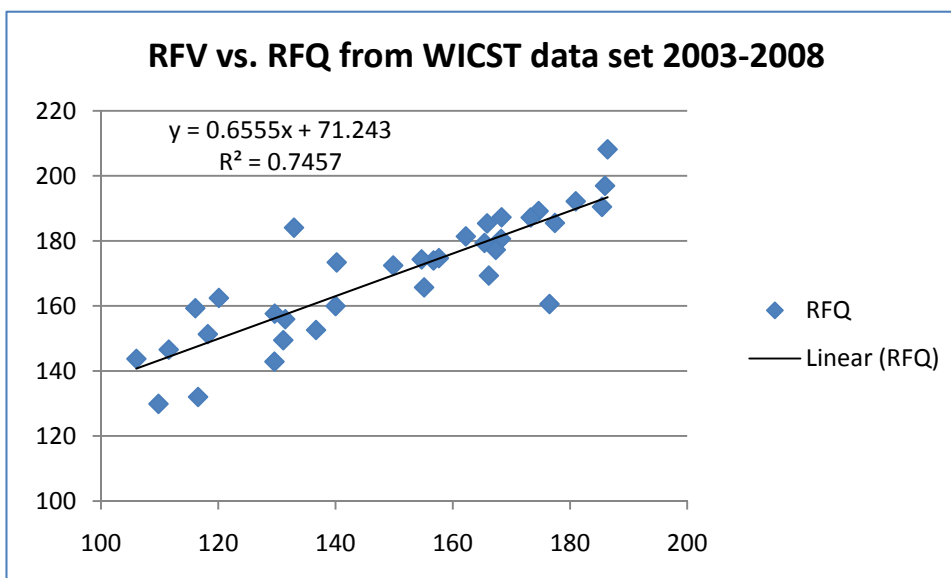
3 Missing or not sampled. The average value from 1992-1995 was used for the nutrient credit.

4 Manure had been taken from the West Pit at Blaine Dairy and applied with a slinger spreader though the Fall of 2004; in Fall 2005, slurry manure taken from East Pit at Blaine Dairy and applied with a broadcast tanker.

5 Heavy rains in June 2008 and understocked new freestall barn (holds ~500 hd; housed 275 hd) resulted in very dilute manure



The difference between RFV-RFQ is smaller for CS4 -green gold pure alfalfa (~10 pts) than in CS5 and CS6 (~15-30 pts) both which have a higher grass component. Also, note that overall, RFQ is lower in CS5 than in CS4 (159 vs. 182). From the figure below, it appears that RFV and RFQ are fairly well correlated.



Appendix 8. Heifer and steer performance during growing season since 2000 (ADG=average daily gain in lbs/head/day) at 4 locations in southern WI.						
	TMR†			Grain supplemented at ~ 2 lbs/head/day		
Year	Confinement heifers (control group)			WICST pasture heifers at Arlington Research station		
	N	# of Days	ADG	N	# of Days	ADG
2000	6	161	2.2	4	161	1.8
2001	6	153	1.7	4	153	1.6
2002	6	163	2.2	4	163	1.8
2003	6	139	2.2	5	139	2.0
2004	5	169	1.6	5	167	1.9
2005	5	168	2.0	5	168	1.4
2006	5	183	1.7	5	176	2.2
2007	5	179	1.4	5	175	2.3
2008	5	174	1.8	5	175	2.4
2009	6	168	1.6	6	153	2.1
Mean	6	166	1.8	5	163	2.0
	On-farm organic grass-fed dairy cattle					
	KBM heifers			VDB steers		
	N	# of Days	ADG	N	# of Days	ADG
2006	44	205	1.7	28	205	1.9
2007	36	176	1.6	25	176	1.9
2008	54	200	1.5	34	174	1.7
2009	44	195	1.6	28	195	2.0
Mean	45	194	1.6	29	188	1.9

† TMR = total mixed ration consists of roughly 53% haylage, 21% oat or rye, 21% corn silage, 5% grain (shelled corn, soybean meal, minerals) fed at ~ 13 lbs dry matter/hd/day

Generally, grazing season was early May to mid-October

starting in 2005, source of on-station heifers was Marshfield, WI.

Average starting weight was 491 lbs/hd on-station and 600 lbs/hd on-farm

Appendix 9. WICST Fall Legume Nitrogen from Plowdown Crop Preceding Corn Phase at Arlington (2003-2008).

Year	Crop System	Crop ¹	Foliage (Tops)		Roots		Total
			lb DM/a	%N ²	lb DM/a	%N ²	lb N/a
2003	3	Red clover	816	3.43	roots not sampled		28
2003	FT	Red clover	579	3.60	roots not sampled		21
2003	4	3-yr Alfalfa	1545	3.00	roots not sampled		46
2003	5	2-yr Alfalfa	1060	2.95	roots not sampled		31
2004	3	Red clover	5893	2.03	roots not sampled		119
2004	FT	Red clover	5571	1.95	roots not sampled		109
2004	4	3-yr Alfalfa	1348	3.10	roots not sampled		41
2004	5	2-yr Alfalfa	1054	2.85	roots not sampled		30
2005	3	Berseem clover/oats	4770	1.76	1979	0.95	103
2005	FT	Red clover	2210	2.75	657	2.12	74
2005	4	3-yr Alfalfa	0	0.00	5633	2.23	126
2005	5	2-yr Alfalfa	0	0.00	6396	2.23	143
2006	3	Berseem clover/oats	2549	2.17	1254	1.08	67
2006	FT	Red clover	5858	2.28	1632	2.55	176
2006	4	3-yr Alfalfa	1639	3.33	2686	1.69	100
2006	5	2-yr Alfalfa	1425	3.75	2194	1.83	93
2007	3	Berseem clover/oats	4847	2.09	2068	0.91	120
2007	FT	Red clover	2343	2.75	1760	2.63	110
2007	4	3-yr Alfalfa	0	0.00	3142	1.82	58
2007	5	2-yr Alfalfa	2159	3.18	5498	2.10	185
2008	3	Berseem clover/oats	1441	3.23	428	2.07	54
2008	FT	Red clover	3608	3.02	2760	2.55	177
2008	4	3-yr Alfalfa	1885	2.92	3399	1.73	114
2008	5	2-yr Alfalfa	1914	3.63	3097	2.63	154

¹ Berseem clover/oats (organic system) seeded in August after wheat harvest and plowed down at end of growing season; FT=flex till: red clover interseeded with wheat in early spring and plowed down at end of growing season; 3-yr alfalfa (conventional system) was direct seeded; 2-yr alfalfa (organic system) companion seeded with oats.

² % N is weighted across weight of botanical components (legume, oats, weeds, quack, etc)

Appendix 10. List of Publications involving WICST project in past 5 years (posters, abstracts and theses).

2005**Abstracts:**

Cook A., J. Posner, J. Hedtcke, J. Baldock, J. Doll, and H. Kummel. 2005. Assessing weed management risks of importing dairy manure onto grain farms in Wisconsin [Abstract] 97th Annual Meeting of American Society of Agronomy (Nov. 6-10 2005, Salt Lake City, Utah) CD-ROM abstract 135B

Kummel, H., J. Doll, J. Posner, J. Hedtcke, J. Baldock, and A. Cook. 2005. Weed seed bank changes in chemical-free corn production systems of the upper Midwest: Results from the first 15 years. [Abstract] 97th Annual Meeting of American Society of Agronomy (Nov. 6-10, 2005, Salt Lake City, Utah) CD-ROM abstract 335A

Journal Articles:

Saam, H., J.M. Powell, D.B. Jackson-Smith, W. Bland, and J. Posner. 2005. Use of animal density to estimate manure nutrient recycling ability of Wisconsin dairy farms. *Agricultural Systems*. 84:343-357.

2006**Theses:**

Cook, Amy. Jan. 2006. Lessons from Linking Farms: Effects of dairy manure on corn production, nutrient accumulation and weed pressure on Wisconsin cash-grain farms [MSc Thesis]. Madison, WI. University of Wisconsin 163 pp

Osterhaus, Jeffery. Dec. 2005. Evaluation of the Illinois Soil Nitrogen Test in Wisconsin cropping systems. [MSc thesis]. Madison, WI University of Wisconsin. 100 pp

Abstracts:

Baldock, J., J. Posner, J. Hedtcke. 2006. Evolving soil test P and K levels on the Wisconsin Integrated Cropping Systems Trial. [Abstract] 98th ASA-CSSA-SSSA International Annual Meetings (November 12-16, 2006, Indianapolis, Indiana) CD-ROM abstract 154-8.

Baldock, J., J. Posner, J. Hedtcke. 2006. Understanding organic corn and soybean yields: The importance of weed pressure. [Abstract] 98th ASA-CSSA-SSSA International Annual Meetings (November 12-16, 2006, Indianapolis, Indiana) CD-ROM abstract 245-9.

Hedtcke, J., J. Posner, J. Baldock. 2006. Evaluation of forage-based cropping systems: Data from WICST. [Abstract] 98th ASA-CSSA-SSSA International Annual Meetings (November 12-16, 2006, Indianapolis, Indiana) CD-ROM abstract 55-6.

Hedtcke, J., G. Sanford, A. Cook, J. Posner, J. Hall, and J. Baldock. Including manure in cash-grain rotations: Lessons from on-farm trials in Wisconsin. [Abstract] 98th ASA-CSSA-SSSA International Annual Meetings (November 12-16, 2006, Indianapolis, Indiana) CD-ROM abstract 53-5.

Mueller, D., B. Stangel, D. Frye, J. Hedtcke, J. Posner, J. Hall. 2006. Developing an Organic Crop Research Program at the University of Wisconsin Arlington Agricultural Research Station. [Abstract] 98th ASA-CSSA-SSSA International Annual Meetings (November 12-16, 2006, Indianapolis, Indiana) CD-ROM abstract 150-5.

Sanford, G., J. Posner, J. Hedtcke, R. Schuler, J. Baldock. 2006. Manure spreading and its effects on soil compaction and corn yield in southern Wisconsin. [Abstract] 98th ASA-CSSA-SSSA International Annual Meetings (November 12-16, 2006, Indianapolis, Indiana) CD-ROM abstract 154-9.

Journal articles:

Betcher, J., G. Hadley, J. Posner, G. Sanford. 2006. Linking Farms: A financial solution. *In* Proceedings of the 2006 Wisconsin Fertilizer, Aglime, and Pest Management Conference. Vol 45. p 189. Jan. 17-19, 2006. Madison, WI

Hedtcke, J., J. Posner, M. Rosemeyer. 2006. Using Cattle to Reduce Oak Savanna Understory Shrub Abundance: Stocking Rates and Weight Gains. *In* Proceedings of the 19th North American Prairie Conference. Aug 8-12, 2004. Madison, WI: University of Wisconsin–Madison.

Osterhaus, J.T., L.G. Bundy, and T. W. Andraski. 2006. Evaluation of the Illinois Soil Nitrogen Test and soil organic nitrogen fractions for predicting corn nitrogen needs. Submitted to Soil Sci. Soc. Am J.

Osterhaus, J.T., and L.G. Bundy. 2006. Using the Illinois Soil Nitrogen Test to predict optimum nitrogen rates for corn in Wisconsin. *In* Proceedings of the 2006 Wisconsin Fertilizer, Aglime, and Pest Management Conference. Vol 45. p 61. Jan. 17-19, 2006. Madison, WI.

Sanford, G. J. Posner, R. Schuler. 2006. Manure spreading effects on soil compaction and crop yield. *In* Proceedings of the 2006 Wisconsin Fertilizer, Aglime, and Pest Management Conference. Vol 45. p 192. Jan. 17-19, 2006. Madison, WI

2007

Theses:

Sanford, Gregg. Jan. 2007. Dairy slurry in corn based systems: Impacts on profitability and soil compaction. [MSc Thesis]. Madison, WI University of Wisconsin. 80 pp

Abstracts:

Arlington Organic Field Day August 30, 2007:

- Bernstein, E. No-tillage organic soybean production in winter rye
- Goeser, N. Assessing organic seed treatments for enhanced corn establishment
- Hedtcke. Long term (1992-2006) yield results from organic rotations on WICST

Journal/Proceedings articles:

Cook, A.R., J.L. Posner, J.O. Baldock. 2007. Effects of dairy manure and weed management on weed communities in corn (*zea mays*) on Wisconsin cash-grain farms. *Weed Technology*. 21(2): 389-395.

2008**Abstracts:**

Bernstein, E.R., J.L. Posner, D.E. Stoltenberg, and J.L. Hedtcke. 2008. No-tillage organic soybean production in winter rye for improved weed management in south central Wisconsin. *In* Midwest Organic Research Symposium at the 19th Annual Organic Farming Conference Feb 21-23. 2008. La Crosse, WI.

Goeser, N., E. Luschei, E. Silva, J. Posner, and J. Hedtcke. 2008. An assessment standard for organic seed treatments for enhanced crop establishment. *In* Midwest Organic Research Symposium at the 19th Annual Organic Farming Conference Feb 21-23. 2008. La Crosse, WI.

Hedtcke J, J. Posner, B. Stangel, G. Sanford, D. Mueller. 2008. Yield, Environmental and Economic Comparison of Three Organic Cropping Systems of the Upper Midwest (2004-2007). *In* Midwest Organic Research Symposium at the 19th Annual Organic Farming Conference Feb 21-23. 2008. La Crosse, WI.

Journal/Proceedings articles:

Sanford, G.R., J.L. Posner, R.T. Schuler, and J.O. Baldock. 2008. Effect of dairy slurry application on soil compaction and corn (*Zea mays L.*) yield in Southern Wisconsin. *Soil and Till. Res.* 100: 42-53.

Posner, J.L., J.O. Baldock, and J.L. Hedtcke. 2008. Organic and conventional production systems in the Wisconsin Integrated Cropping Systems Trials: I. Productivity 1990–2002. *Agron. J.* 100:253–260.

Wagner, T., J. Posner, and L. Paine. 2008. Manure management on a township scale: Using a land evaluation approach in Wisconsin. *J. Ag. Food. and Env. Sciences.* 2(1):

Posner, J.L., G.G. Frank, K.V. Norlund, and R.T. Schuler. 2008. A constant goal, changing tactics: The Krusenbaum dairy farm (1996–2005). *Renewable Agriculture and Food Systems* 24(1):8–18

2009**Abstracts:**

Bernstein, E.R., D.E. Stoltenberg, J.L. Posner, and J.L. Hedtcke. 2009. No-tillage winter rye cover crop systems for organically-managed soybean production. North-central branch of ASA annual meeting. July 22-24, 2009. Wisconsin Dells, WI.

Hedtcke, J. WICST .North-central branch of ASA annual meeting. July 22-24, 2009. Wisconsin Dells, WI.

Bernstein, E.R., J.L. Posner, D.E. Stoltenberg, and J.L. Hedtcke. 2009. Organic no-tillage winter rye-soybean systems: Agronomic, economic, and environmental assessment. *In Annual meetings abstracts [CD-ROM]*. Nov. 1-4. Pittsburgh, PA. ASA, CSSA, and SSSA, Madison, WI.

Bernstein, E.R., D.E. Stoltenberg, J.L. Posner, and J.L. Hedtcke. 2009. Multitactic weed management in organic soybean production systems. *In Proceedings of the annual meetings vol. 64. [CD-ROM]*. Dec 7-10. Kansas City, MO. North Central Weed Science Society.

Hedtcke, J.L., J.L. Posner, J. Hall, R. Walgenbach, G. Sanford, and E. Bernstein. 2009. Orchardgrass Ley for Improved Manure Management: Residual Corn Yields. *In Annual meetings abstracts [CD-ROM]*. Nov. 1-4. Pittsburgh, PA. ASA, CSSA, and SSSA, Madison, WI.

Sanford, G.R., J.L. Posner, and G.L. Hadley. 2009. Economics of hauling dairy slurry and its value in Wisconsin corn grain systems. *In Annual meetings abstracts [CD-ROM]*. Nov. 1-4. Pittsburgh, PA. ASA, CSSA, and SSSA, Madison, WI.

Journal/Proceedings articles:

Sanford, G.R., A.R. Cook, J.L. Posner, J.L. Hedtcke, J.A. Hall, and J.O. Baldock. 2009. Linking Wisconsin dairy and grain farms via manure transfer for corn production. *Agron. J.* 101: 167-174.

Chavas, J.P., J.L. Posner, and J.L. Hedtcke. 2009. Organic and conventional production systems in the Wisconsin Integrated Cropping Systems Trial: II. Economic and risk analysis 1993–2006. *Agron. J.* 101:288–295

Sanford, G.R., J.L. Posner, and G.L. Hadley. 2009. Economics of hauling dairy slurry and its value in Wisconsin corn grain systems. *J. Ag. Food. and Env. Sciences.* 3: 1-10.

Hedtcke, J.L., J.L. Posner, M. Rosemeyer, and K. Albrecht. 2009. Browsing for conservation: Springtime forage value of midstory shrubs of degraded oak savannas in southern Wisconsin. *Renewable Agriculture and Food Systems* 24(4):293-299.

Sanford, G.R., J.L. Posner, and G.L. Hadley. 2009. Linking Cash Grain and Dairy Farms via Manure Transfers: Economic considerations for grain enterprise profitability. *In 2009 Symposium and Annual Meeting of Wisconsin Custom Operators, Professional Nutrient Applicators Association of Wisconsin & Midwest Forage Association. In 'Equipped for Success' [CD-ROM]*. January 26-28, 2009. Wisconsin Dells, WI.

Simonsen, J., J.L. Posner, M. Rosemeyer, and J.O. Baldock. *In press*. Endogeic and anecic earthworm abundance in six midwestern cropping systems. *J. Applied Soil Ecology*.