

THE WISCONSIN INTEGRATED CROPPING SYSTEMS TRIAL
Thirteenth Report - 2009 & 2010

Edited by Joshua L. Posner and Janet L. Hedtcke
Compiled March 2012

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PROLOGUE

This is the thirteenth 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 nineteen production years (1990 – 2008). In this report, we discuss the results of the 2009 & 2010 growing seasons. This is the eighteenth 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 2010, 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 on biofuels, prairies, and cover crops.

Funding for the project continues to come primarily from the USDA-ARS's national program on food and animal production entitled 'Pasture'. 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 2009 & 201 Collaborators and Authors in this volume

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We also acknowledge with many thanks, the contributions of those who assisted at the Arlington and West Madison Research Stations and at Michael Fields Ag Institute in managing the crops and animals related to this project. Specifically, Matt Repking, Darwin Frye and Paul Bergum and the crew at Arlington; Dave Combs and Mike Peters and the staff at Blaine Dairy; and the Jackson lab field staff. 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.

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. Some of the anticipated differences between the rotations are outlined in Table i. Annual yields are shown in Table 1. The six rotations are schematically displayed just after Table 1.



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

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.

Yearly Crop Yields on the WI Integrated Cropping Systems Trial

Table 1. Yields on WICST at the Arlington Research Station 1995-2011 (4 rep average)

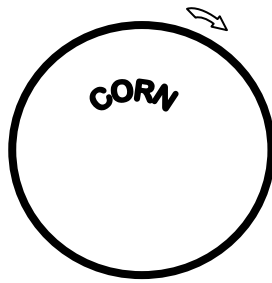
Crop	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Corn	Bu/acre																
Continuous corn	143.1	131.5	128.6	196.2	170.4	161.6	193.6	192.2	175.0	193.9	197.3	192.7	204.0	141.7	196.8	206.3	211.4
After sb (No Till)	167.7	140.0	157.4	212.6	162.9	162.9	207.7	159.2 ¹	176.5	189.0	210.2	190.6 ¹	189.2	175.3	205.2	214.6	202.4
Organic 3-crop	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	170.2	183.3	158.2
After 3-yr alfalfa	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	210 ³	222.5	229.2
After 2-yr alfalfa (organic)	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	194.2	182.0	174.5
<i>LSD (0.05)</i>	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	15.9	8.4	8.1
Soybeans	Bu/acre																
Drilled – No till	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	48.3	65.5	55.4
Organic 3-crop	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	49.6	61.9	58.9
<i>LSD (0.05)</i>	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	NS	2.8	2.8
Wheat grain	Bu/acre																
Organic 3-crop	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	57.8	59.9	66.6
Wheat straw	Tons DM/acre																
Organic 3-crop	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	0.83	1.11	1.06
Seeding yr. Forage	Tons DM/acre																
Direct seeded alf	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	1.35	2.20	2.60
Org. Oat /alf	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	2.14	3.39	3.24
<i>LSD (0.05)</i>	NS	0.90	NS	0.67	0.34	0.24	1.27	NS	NS	1.06	0.19	0.43	0.25	0.34	0.48	0.72	0.54
Estab'd Forage	Tons DM/acre																
Conv. Hay I	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	5.63	6.07	5.22
Org. Hay I	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	4.53	5.66	5.22
Conv. Hay II	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	5.14	6.19	4.24
Pasture	-	-	-	-	-	-	-	-	-	5.48	2.61	5.80	3.37	3.23	2.87	3.05	2.59
<i>LSD (0.05)</i>	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	0.82	0.92	0.68

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

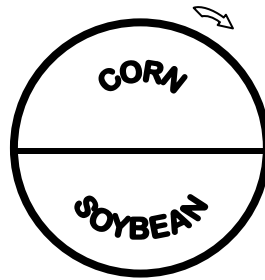
² Due to poor stand and late replanting date, corn did not make blacklayer before end of season and was harvested as snaplage (cob+husk+ear) yielding 1.07 and 1.36 ton DM/a for CS3 and CS5, respectively then converted to grain.

3 mis-applied herbicide product from fall of 2008 killed corn crop; it was replanted but did not fully recover; yield is from unaffected area of one plot (not included in analysis). Whole plant biomass estimate was 6.9 tons DM/a across the 4 plots.

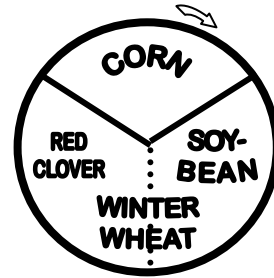
Cash-grain Cropping Systems:



CS1
Continuous corn

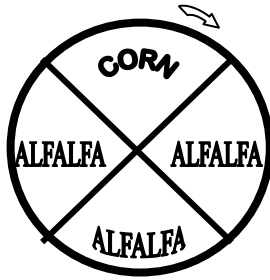


CS2
No-till

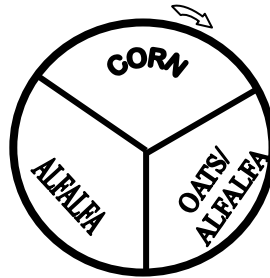


CS3
Organic Grain Rotation

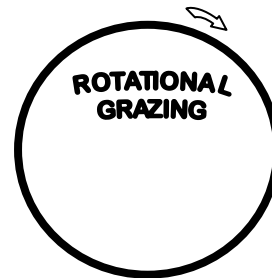
Forage-based (dairy) Cropping Systems:



CS4
"Green Gold"

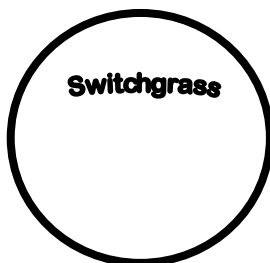
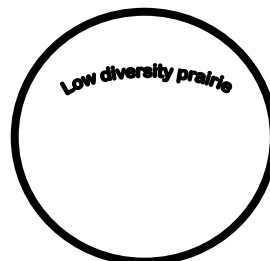
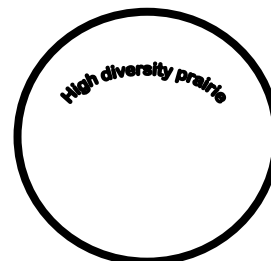


CS5
Organic Dairy Rotation



CS6
Grass-legume pasture
with dairy heifers

Native Systems:



Increasingly perennial

Increasingly diverse

CROPPING SYSTEMS TRIAL DATA

Arlington Agricultural Research Station – 2009 Report

Janet Hedtcke and Josh Posner

Weather

As shown in Table 1 and Fig. 1, the 2009 season was fairly typical in total rainfall (25 inches from April through October) but while the first half of the season was normal, the latter half was very dry with 2 distinct dry spells: there was essentially no precipitation from June 20 to July 20 and again from Aug 30 to Sept 21 which affected summer growth of the pastures and the summer seeded cover crops. The July drought also likely affected soybean yield potential as moisture is critical as the pods begin to fill. Heat units were below average from July forward (Fig. 2); there was just one day all summer above 90°F. The first killing frost of 27°F was Oct 9th followed by lows of 24 and 22°F the next two nights, before some corn reached full maturity. This resulted in delayed dry down of the grain and delayed corn harvest until Nov 11th, and still the corn grain moistures were close to 30% with mold being a common issue. A mold test on 2 corn samples revealed T-2 toxin present at moderately high levels (270-290 ppb) and above the 200 ppb ‘safe’ level. Like corn, soybean moistures were a bit high for full season varieties and harvest windows were hard to come by. Some soybeans needed to be bin-dried. After soybean harvest, winter wheat got planted on Oct 13th, a respectable date in an overall late harvest year. All tillage was completed in late November just before the ground froze up.

Changes

2009 also marks the final year of the Chemlite/Flex till study on the east end of the trial. As these 6 plots were originally laid out 5 years after WICST was initiated, the plots were not randomized within the rest of the WICST trial. Besides that, continued comparisons to WICST are more difficult for two reasons: After 15 years of management in a 3-phase rotation, soil fertility levels have been drawn down to yield response range more quickly than the shorter rotations on WICST and thus higher P and K inputs are necessary to maintain yields. Also, the north end of the north tier has been flooded in the recent years as can be seen in the gray color to the soils at depth. As a result, this area often has to be managed differently than the rest of the plot. So a decision was made that this 4-acre area will be used for future trials still to be determined.

Weed Quantification

Weed biomass was collected in August from the plot centers in the corn and soybean phases across the 5 systems (not pasture) and on the east and west edges in the corn of the cash-grain systems to test the effect of manure additions. Weed control was good this season across all systems but generally higher in the organic systems. Grass weed biomass in corn was lowest in the cash-grain systems while the organic forage system had significantly higher grass biomass, and both the organic grain and organic forage systems had higher broadleaf weed biomass than the conventional systems (Table 2). In the soybean phase, the organic plots had significantly higher grass and broadleaf pressure than the conventional beans (Table 3) but again, weed biomass was relatively in-line with that of the past two years. There was no effect on weed biomass due to manure in any system (Table 4). The analysis also showed the plot edges tended to be 2x higher in weed pressure than the plot centers for broadleaf weeds ($p < 0.0804$) but not grasses (data not shown).

Manure

Manure applied in the fall of 2008 (credit for 2009) is described here. The manure was very dilute during fall application (total nutrients were N: 9.5, P₂O₅: 2.5, K₂O: 11.2 lbs/1000 gal with 1.3% solids). This was a result of a combination of factors. In the summer of 2008, the new dairy expansion project was finished and all the livestock was consolidated into the 'Blaine Dairy Complex'. The barn was understocked that season so manure levels were low in the pit. Furthermore, just before the cattle moved into the new barn, the manure pit received a lot of rain water from heavy storms in early June. 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. 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

A triple-stack GMO corn (roundup-ready/liberty link and Bt for corn rootworm and European corn borer) with Poncho1250 seed treatment was planted on May 4th in the conventional systems and an organic variety with NII film coat was planted on May 18th to the organic systems. This year, the ground squirrels were kept under control probably from both baiting and natural predators (raptors, foxes, cats). The PPNT showed no residual N carried over from last fall and N rates were applied accordingly. Nitrogen was applied at 160 lb N/a as anhydrous in continuous corn and 132 lb N/a as 28% strip-till corn following soybeans and 60 lb N/a on Flexitill, respectively. The manured edges of CS1 and CS2 were topped off with 100 lb N/a. Plant densities were excellent at 30,250 and 34,425 plants/acre for conventional and organic, respectively. The green-gold corn grain was lost due to an error in herbicide application last fall when killing out the alfalfa stand. It was replanted with a Clearfield variety (tolerant to imidazolinone ALS-inhibitors) but it didn't establish well. A chemical known as 'Express' (tribenuron, a sulfonyleurea ALS-inhibitor) was later found at trace levels in the soil which has a 9-month residual activity. Whole plant biomass was harvested in October on these plots to maintain nutrient balances.

Soybean Phase

Soybean yields were about 10 bu/a lower than the previous 3 years but for the 4th consecutive year, the organic compared very well with the glyphosate-tolerant and longer maturity beans, all averaging 50 bu/a. Emergence was quicker and more uniform for the wide row beans than the drilled beans and in this relatively cool summer, soil temperature was more likely favorable in the tillage-intense organic system. Mid-summer drought stress likely impacted yields across all systems. Timely and frequent mechanical weed control this spring helped keep weed pressure down but was too aggressive in some cases which reduced the soybean population to lower than desirable at just under 100,000 plants/acre after row cultivation was complete vs. 141,963

plants/acre in the no-till system. Soybean aphid levels did not reach threshold until after the R2 stage in which there are no recommended economic thresholds so no insecticide was applied. White mold was a common problem across southern Wisconsin this season but the WICST plots had only minor incidence of it.

Wheat/Clover Phase

Winter wheat had moderate to severe winterkill from the open/icy January and February of 2009. Rep 3 plot had the most winterkill and should have been reseeded to spring wheat. This was not done and the weed biomass was chopped and removed in July (this will be considered missing data vs. zero yield). Nonetheless, yields of the other plots were fairly good averaging 50 bu/a for organic and 72 bu/a for the Flextill plots, respectively. While the Flextill wheat benefited from the N application of 50 lb/a, the organic wheat did receive some (~ 1 ton/a) poultry manure to help stimulate tillering in late April but the stands were generally thinner in the organic plots. 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. Like the summer of 2008, August and September of 2009 were dry. The summer seeding of oats and berseem cover crop did not establish well although there was a lot of volunteer and diseased winter wheat present although there weren't many annual weeds present. Biomass estimates from the berseem/oats mix were much less than the spring established red clover and only provided a nitrogen credit of 58 vs. 129 lb N/a.

Forage Phases

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. The organic alfalfa is a leaf-hopper resistant variety. Two cuts were taken on the seeding year plots while four cuts were taken on all the established plots. Alfalfa in the green-gold system that was in its final hay year was sprayed with glyphosate but the temperatures were too cool and the application was ineffective at killing the stand. Later in the fall, we used the chisel plow with sweeps instead of straight shanks to get a more effective kill.

Because of the uneven distribution of rainfall, the pasture yielded less than the established alfalfa systems (2.9 vs. 5.1 tons DM/a). Heifers had excellent performance on pasture (2.12 vs. 1.62 lbs/head/d in confinement; 695 lbs/a on pasture) with modest grain supplementation. This included a few weeks of grazing the native prairie and switchgrass plots as part of the rotation in June and July. The cattle liked the warm-season grasses in their juvenile stage and nutrient analysis from June sampling showed this forage to be good feed.

Native Perennial Systems

The prairie plots were burned on April 11 and since herbicide wasn't an option with the ongoing research in the plots, Canada thistles were rouged from the plots after a saturating rain in mid-June. In collaboration with Randy Jackson, the native plots were divided into quarters for 2 concurrent studies: the southern ¼ will continue to be harvested for biomass (GLBRC project)

while the northern $\frac{3}{4}$ will be used for establishing native legumes via various management treatments (grazing, mowing, control (SARE project)).

Table 1. Growing season and annual rainfall (inches) at Arlington.

Month	2009	(*)	2008	(*)	30-yr norm 1971 - 2000
April	4.37	1.13	7.33	4.09	3.24
May	3.60	0.17	3.20	-0.23	3.43
June	4.29	0.25	13.68	9.64	4.04
July	2.32	-1.54	4.91	1.05	3.86
August	3.22	-1.02	1.70	-2.54	4.24
September	2.38	-1.26	1.53	-2.11	3.64
October	4.61	2.18	2.39	-0.04	2.43
Growing Season Total	24.79	-0.09	34.74	9.86	24.88
Yearly Total	35.82	3.02	45.20	12.40	32.80

*Deviation from 30-yr norm

Fig. 1. Seasonal precipitation in 2009 vs. the 30-yr norm (1971-2000).

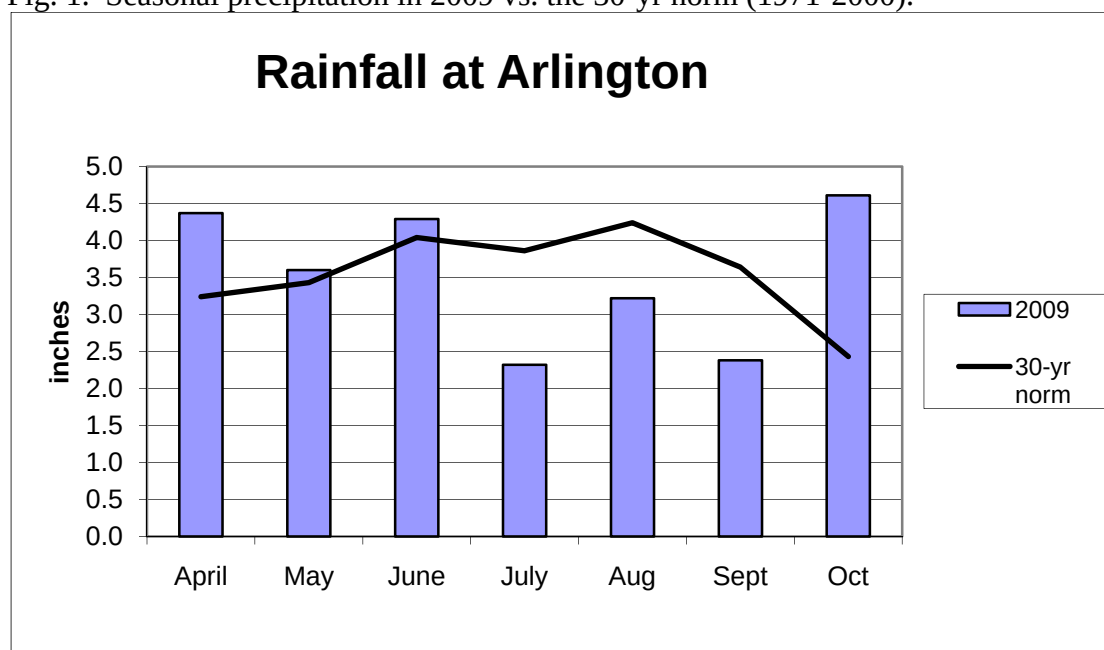


Fig. 2. Seasonal heat unit accumulation in 2009 vs. the 30-yr norm (1971-2000).

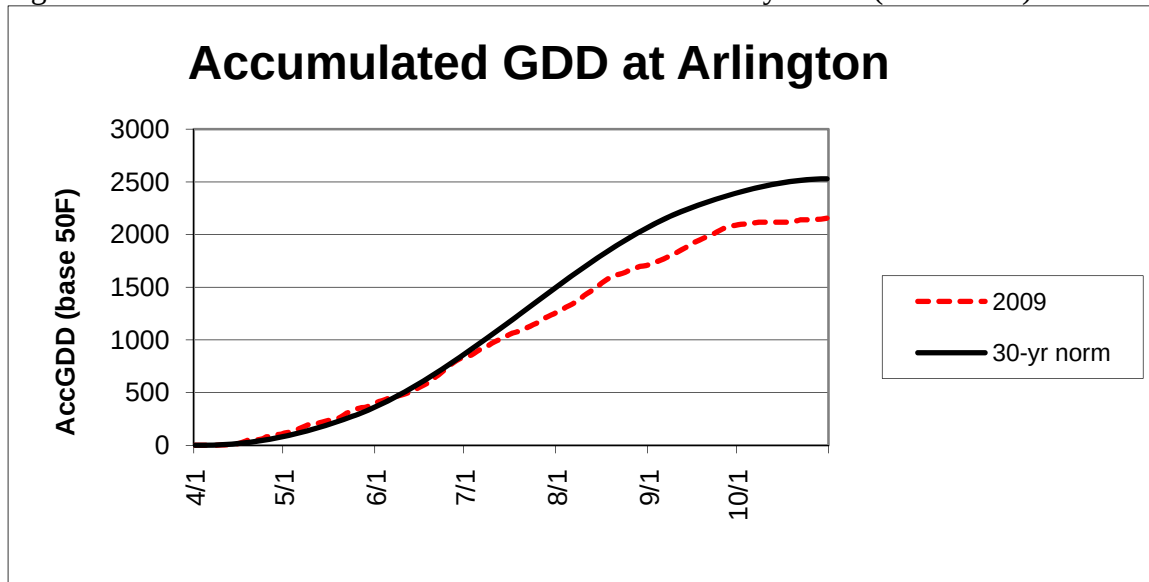


Table 2. Weed pressure in corn across systems from middle of plot in 2009.

	Grass	Broadleaf
	Dry biomass (g m ⁻²)	
CS1 (conventional)	0.2b	1.4b
CS2 (conventional)	<0.1b	1.5b
CS3 (organic)	3.2b	13.1a
CS4 (conventional)†	na	na
CS5 (organic)	7.3a	10.9a
Overall p-value	<i>0.0072</i>	<i>0.0015</i>

† na: not available: no data for CS4 corn as crop was severely affected by residual herbicide carryover from fall of 2008

Table 3. Weed pressure in soybeans across systems from middle of plot in 2009.

	Grass	Broadleaf
	Dry biomass (g m ⁻²)	
CS2 (conventional)	<0.1	1.8
CS3 (organic)	12.0	26.4
Overall p-value	<i>0.0532</i>	<i>0.0139</i>

Table 4. Weed pressure in manured vs. not manured corn in 2009.

	Manured	Not Manured
System	Dry grass weed biomass (g m ⁻²)	
CS1 (conventional)	2.9	0.2
CS2 (conventional)	<0.1	<0.1
CS3 (organic)	3.1	4.9
Sys*manure_ trt p-value	0.1502	
No main effect of manure		
	Manured	Not Manured
	Dry broadleaf weed biomass (g m ⁻²)	
CS1 (conventional)	0.8	2.6
CS2 (conventional)	1.0	1.9
CS3 (organic)	20.8	21.8
Sys*manure_ trt p-value	0.9904	
No main effect of manure		

Arlington Agricultural Research Station – 2010 Report

Janet Hedtcke and Josh Posner

Weather

The 2010 season resulted in excellent growing conditions for both grain and forage crops. Rainfall and growing degree units are shown in Figs 1-2. Though there was high snowfall amounts (~80 inches) for the winter of 2009-10, it melted rapidly and by mid-March, field operations commenced starting with some no-till drilling of legumes into the pasture. Tillage began at the end of March to prepare for alfalfa seedings. April was a good month for field progress, particularly manure spreading and early corn planting and in general, the 2010 growing season was ideal and most crops had excellent yields.

Changes/Updates

The old Chemlite/Flexitill study area on the east end of the trial was homogenized with a planting of spring wheat across the plots on March 30. After harvest, weeds were tilled under in preparation for the Annual Forage Trial, a randomized complete block design. Manure treatments were imposed on September 20 and winter rye was seeded to the entire area on September 22. Cropping treatments will be imposed in the spring of 2011.

Greenhouse gases were sampled from all of the core plots biweekly from April 15 – Nov 22.

Weed Quantification

Weed biomass was collected in August from the plot centers in the corn and soybean phases across the 5 systems (not pasture) and on the east and west edges in the corn of the cash-grain systems to test the effect of manure additions. Harvest area was 25 sq ft or 2.32 sq meters. Weed control was good this season across all systems but somewhat higher than in 2009. More frequent rainfall in 2010 was probably the difference. As has been the trend, weed biomass was typically higher in the organic systems for corn and soybeans (Tables 2, 3). In support of our observations throughout the season, the corn in the organic forage system had higher weed biomass than the organic grain system. Quackgrass was very aggressive in the organic forage system early in the season due to wet conditions. No effect of manure was found for either grass or broadleaf weeds for the 3 grain systems (Table 4). The analysis also showed the plot edges were not different in weed pressure than the plot centers for either broadleaf weeds or grasses (data not shown) which shows our improved effort on alley maintenance.

Manure

Manure applied in the fall of 2009 (credit for 2010) showed total nutrients of 19.8 N: 7.6 P₂O₅: 18.1 K₂O (in lbs/1000 gal with 4.7% solids). On November 17+18th, manure was broadcast onto the WICST plots with tractor-pulled tankers. Because of the low nutrient value of the 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. In addition to the usual manure application in the dairy systems, we continued to apply slurry in front of the corn in the grain systems as part of the Linking Farms Project. In addition to the manure, we'll

need to top off the plots with commercial N next spring to meet the corn requirement. The continuous corn which receives manure every other year did not receive manure in the fall of 2009.

Corn Phase

A triple-stack GMO corn (roundup-ready/liberty link and Bt for corn rootworm and European corn borer) with Poncho 250 seed treatment was planted on April 29th in the conventional systems and an organic variety with Guardian 3 seed coating was planted on May 19th to the organic systems. The PPNT showed little residual N carried over from last fall and N rates were applied accordingly: Nitrogen was applied at 160 lb N/a as anhydrous ammonia in 3 reps of continuous corn and 120 lb N/a on rep 2; and 135 lb N/a as 28% on the strip-till corn following soybeans. The manured edges of strip till corn plots were topped off with 40 lb N/a while a full rate was applied to the biennially-manured continuous corn. Plant densities were excellent for both conventional and organic systems. Whole plant biomass was harvested in October on all corn systems, including the manure strips to simulate and compare corn silage harvest.

Soybean Phase

Soybean yields were nearly superb this season due to timely rainfall all season and little to no pest pressure. Mechanical weed control consisted of a rotary hoeing, 2 tine weedings and one row cultivation. Weed pressure remained low all season and the stand density was excellent for both systems.

Wheat/Clover Phase

Winter wheat got an excellent start in the fall of 2009 and came through the winter very healthy and weed pressure was modest. However, wheat yields were a bit lower than expected with 60 bu/a and the associated crude protein was very low (mean of 7.8%) suggesting a nitrogen deficiency. Summer tillage after wheat harvest in CS3 was continued this summer and the cover crop was established in mid-August. The summer seeding of oats and berseem cover crop was excellent due to a late killing frost and sufficient moisture. Biomass estimates averaged 585 lbs/a for the berseem clover and 2664 lbs/a for the oats for a total of 3249 lbs DM/a.

Forage Phases

Alfalfa yields were very impressive this season with over 2 tons DM/a for first crop and over a ton DM/a for the subsequent 3 cuts. Most of the forage plots are in 'maintenance' management for potassium fertilization as soil test levels have dropped into the yield response range. Leafhoppers were controlled with pesticide in the seeding of CS4 but the established alfalfa plots were managed by cutting. The organic alfalfa is a leaf-hopper resistant variety. Two cuts were taken on the seeding year plots while four cuts were taken on all the established plots. The pasture yielded about half that of the established alfalfa systems (3.1 vs. 6.2 tons DM/a). Heifers had excellent performance on pasture (1.88 lbs/head/d in confinement vs. 1.98 lbs/head/d on pasture) with modest grain supplementation. This included a few weeks of grazing the native prairie and switchgrass plots as part of the rotation in June, July, and October. The cattle liked the warm-season grasses in their juvenile stage and nutrient analysis showed this forage to be good feed in June but declined rapidly over the summer. Alfalfa in the green-gold system that was in its final hay year was sprayed with glyphosate and 2,4-D in October and the kill was excellent.

Native Systems

The prairie plots were burned on April 5th and since broadcast application of herbicide wasn't an option with the ongoing research in the plots, canada thistles were spot sprayed or rouged from the plots after a saturating rain in mid-June. The prairie plots continue to be used for 2 purposes: GLBRC biofuels research on the southern $\frac{1}{4}$ of the plots and a SARE project examining establishment of native legumes into existing prairie via grazing or mowing on the remaining $\frac{3}{4}$ of the plots.

Fig.1. Seasonal rainfall pattern at Arlington Research Station in 2010 vs. 30-yr norm.

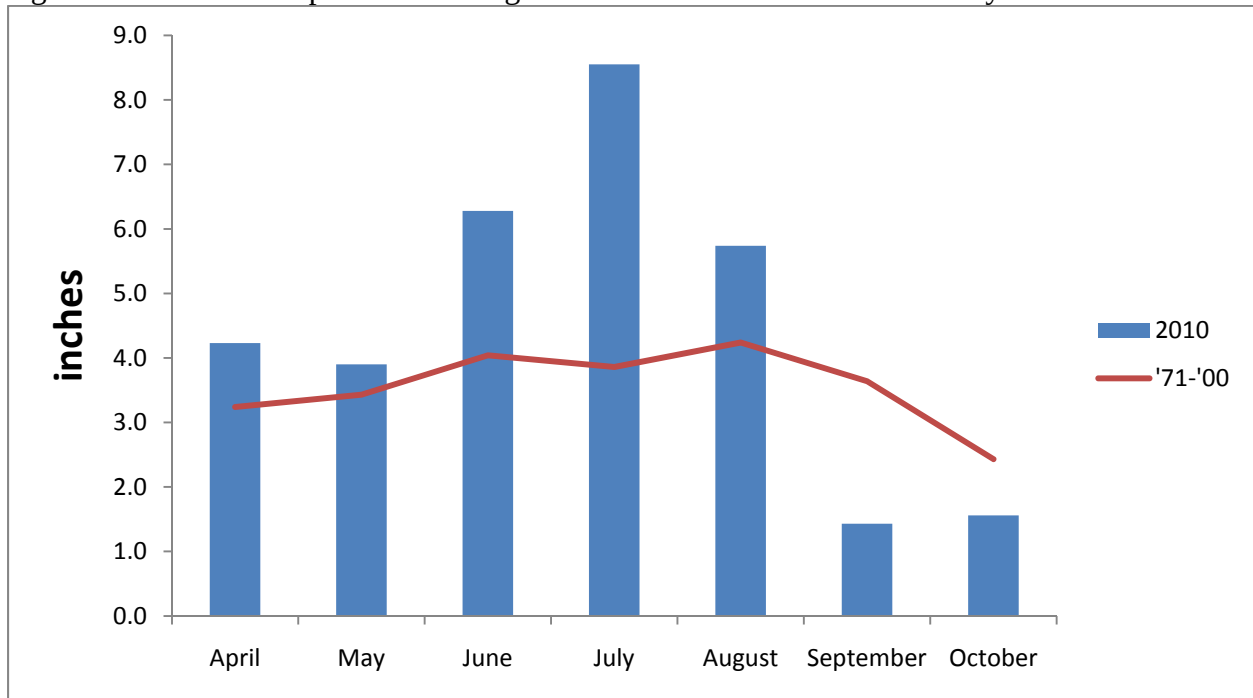


Fig. 2. Accumulated growing degree units at Arlington Research Station in 2010 vs. 30-yr norm.

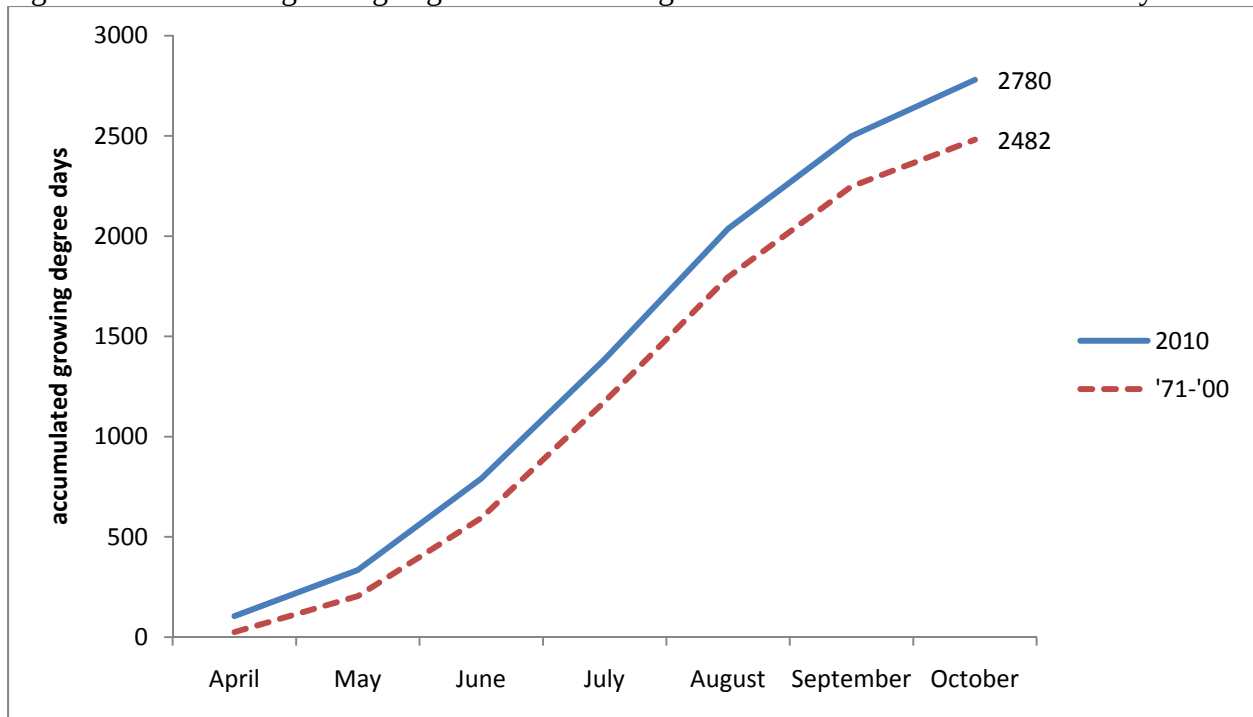


Table 2. Weed pressure in corn across systems from middle of plot in 2010.

	Grass	Broadleaf
	Dry biomass (g m⁻²)	
CS1 (conventional)	3.5bc	1.1b
CS2 (conventional)	<0.1c	0.1b
CS3 (organic)	14.1b	4.3a
CS4 (conventional)	0.2c	0.3b
CS5 (organic)	25.6 a	6.8a
Overall p-value	0.0026	0.0016

Table 3. Weed pressure in soybeans across systems from middle of plot in 2010.

	Grass	Broadleaf
	Dry biomass (g m⁻²)	
CS2 (conventional)	5.3	0.9
CS3 (organic)	16.8	12.5
Overall p-value	0.1352	0.0256

Table 4. Weed pressure in manured vs. not manured corn in 2010.

	Manured	Not Manured
System	Dry grass weed biomass (g m⁻²)	
CS1 (conventional)	0.1b	0.1b
CS2 (conventional)	0.1b	0.1b
CS3 (organic)	6.3a	6.9a
Sys p-value (No manure effect)	0.0001	
	Manured	Not Manured
	Dry broadleaf weed biomass (g m⁻²)	
CS1 (conventional)	0.1b	0.1b
CS2 (conventional)	0.8b	0.4b
CS3 (organic)	3.7a	4.7a
Sys p-value (No manure effect)	0.0002	

Arlington Agricultural Research Station – 2011 Report from WICST

Janet Hedtcke and Josh Posner

Weather

2011 started off unseasonable cold well into May resulting in delayed start to the cropping season. For example, the new seedings of alfalfa established very slowly in April, corn planting was a week later than 2010, and grazing was delayed until adequate forage was available (May 13). Organic corn was planted on a typical timeline but emergence was affected by black cutworm. Rainfall was consistent with the long term average in April but the rest of the season very dry with no significant rainfall events until late September. Rainfall and growing degree units are shown in Figs 1&2.

Changes/Updates

The eastern 6 plots (formerly known as Chemlite) were converted into the Annual Forages Trial. The native plots were re-fenced to just the northern half of the plots to reduce fenceline mowing maintenance and to facilitate biomass harvest on the southern quarter where biofuels research continues. A 'control' area was set-aside within each native plot where no grazing or mowing takes place.

Greenhouse gases were sampled from all of the core plots biweekly and after some N or tillage events from April 4– Nov 28.

Weed Quantification

Weed biomass was again collected in August from the plot centers in the corn and soybean phases across the systems and on the east and west edges in the corn of the cash-grain systems to test the effect of manure additions. Harvest area was 25 sq ft (5 ft x 2-30" rows) or 2.32 sq meters. Weed control was impressive this season across all systems very similar to previous years. As expected, weed biomass was typically higher in the organic systems for corn and soybeans (Tables 1 & 2), especially for broadleaf weeds in CS3 –maybe an artifact of the poor stand in that system. No effect of manure was found for either grass or broadleaf weeds for the 3 grain systems however there was a system x treatment interaction where CS3 manured corn had higher weed biomass than the non-manured organic corn (Table 3). The analysis also showed the plot edges were not higher in weed pressure than the plot centers for either broadleaf weeds or grass weeds (data not shown) in any system as has been the case in recent years.

Manure

Manure applied in the fall of 2010 (credit for 2011) showed total nutrients of 19.9 N: 7.9 P₂O₅: 21.3 K₂O (in lbs/1000 gal with 4.9% solids). On November 2nd, manure was broadcast onto the WICST plots with tractor-pulled tankers and it was incorporated 3-5 days later. The CS4 (c-a-a-a) corn, and the CS5 (c-o/a-a) corn and plowdown alfalfa each received 11,800 gal/acre. A reduced rate of 8000 gal/a was applied to CS4's Alfalfa II plowdown. In addition to the usual manure application in the dairy systems, we continued to apply about 12,000 gal/a slurry in front of the corn in the grain systems as part of the Linking Farms Project.

Corn Phase

A triple-stack GMO corn (roundup-ready/liberty link and Bt for corn rootworm and European corn borer) with Poncho 250 seed treatment was planted on May 6 in the conventional systems and an organic variety with Guardian 3 seed coating was planted on May 20th to the organic systems. The PPNT showed little residual N carried over from last fall (only 1 plot out of 12 had some N carryover) and N rates were applied accordingly. Nitrogen was applied at 160 lb N/a as anhydrous ammonia in 3 reps of continuous corn and 135 lb N/a on rep 4; and 135 lb N/a as 28% on the strip-till corn following soybeans. The manured edges of strip till corn plots were topped off with 40-60 lb N/a. Plant densities were affected by slow emergence and insect pressure (primarily black cutworm is suspected) with the lowest stand densities in CS3 at 26,600 plants/a. Corn in CS4 had excellent stands at near 34,000 plants/a. No whole plant corn biomass was harvested this fall to simulate corn silage harvest. In late September, strong winds knocked down a lot of corn, especially the organic corn in CS5 which was tall, had big ears way up high, and thin stalks. Observation from other fields suggests that in this year with stressful growing conditions, high nutrient fields were more prone to being blown down as the stalks were weakened during grain fill from cannibalization. Nonetheless, most of the corn was retrieved by the combine. There were significant differences in yields across the systems.

Soybean Phase

Planting of soybeans occurred in mid-May and plants had emerged by the end of May. Though the weather was hot and dry during flowering, the soybean yielded well in both systems. Mechanical weed control consisted of 2 rotary hoeing, 2 tine weedings and 2 row cultivation in the 30" beans and 2 applications of glyphosate in the drilled beans. Weed pressure remained low all season and the stand density was decent in both systems.

Wheat/Clover Phase

Winter wheat stands were in good condition this spring but to improve protein content of the grain, and to address declining P and K values in the soil, 0.5 tons/a of composted poultry manure was applied in mid-May. Wheat yields were slightly higher than in 2010 at 67 bu/a and protein did improve to 12.2% (vs. 7.8% in 2010). After straw was baled, wheat stubble and roots were sampled for the 3rd year in a row to estimate N content in this plowdown material. Then, summer tillage consisted of a pass with the "quack digger" and then the field cultivator to prepare for the cover crop seeding of oats and berseem clover on August 11. Unlike last year however, the soil conditions were very dry and the berseem clover didn't establish well. By the end of the season, it was evident that oats were short on nutrients (compared to the neighboring oat plots in the manured AFT) and biomass amounts were below average.

Forage Phases

This season was tough on the new alfalfa seeding as evident by the high weed component. Both treatments were planted the 2nd week of April but the alfalfa was slow to emerge due to very cold temperatures. Only 2 cuts in the CS4 seeding were taken and only 1 cut (and 1 weed clipping operation) were achieved in the oat-alfalfa companion seeding. Broadleaf weeds were especially prevalent well into the summer in spite of an herbicide application and clipping in early August. Compaction in the established fields was evident during fall soil sampling which is likely related to the wet 2010 season.

Native Systems

The switchgrass and prairie plots were burned at various times in April and May according to biomass load and weed pressure. The native plots continue to be used for 2 purposes: 1) GLBRC biofuels research on the southern ¼ of the plots and 2) to extend the rest period on the cool-season pastures (CS6) during the summer slump.

Fig.1. Seasonal rainfall pattern at Arlington Research Station in 2011 vs. 30-yr norm.

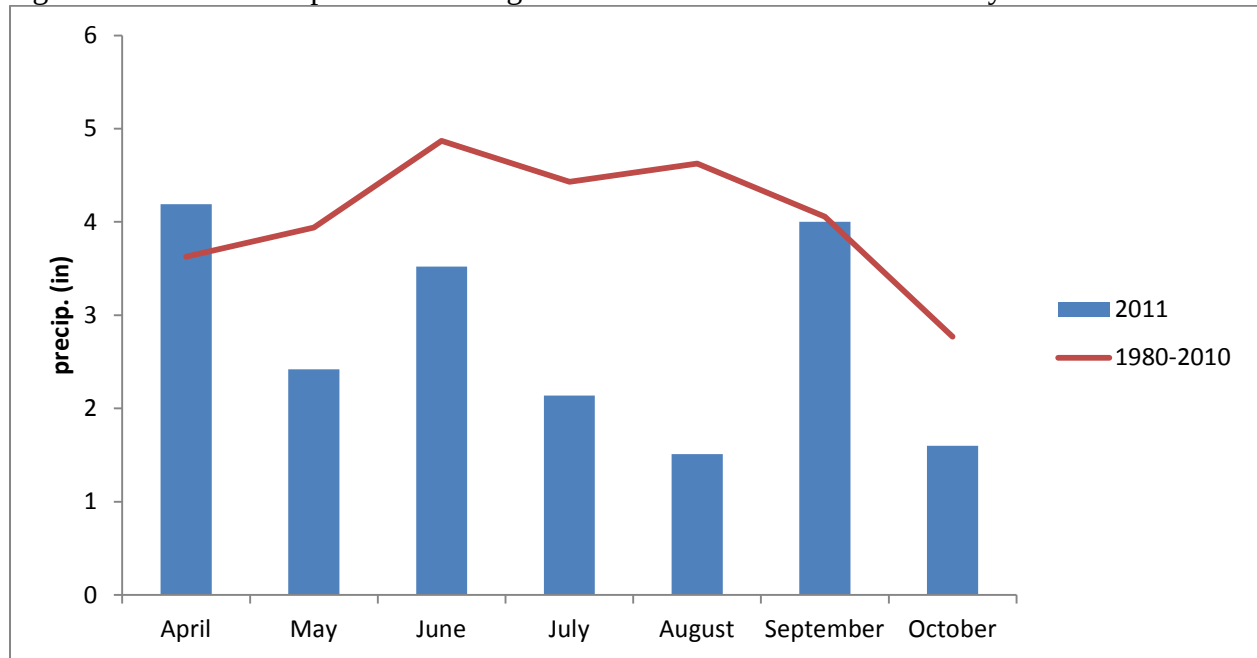


Fig. 2. Accumulated growing degree (AccGDU) units at Arlington Research Station in 2011 vs. 30-yr norm.

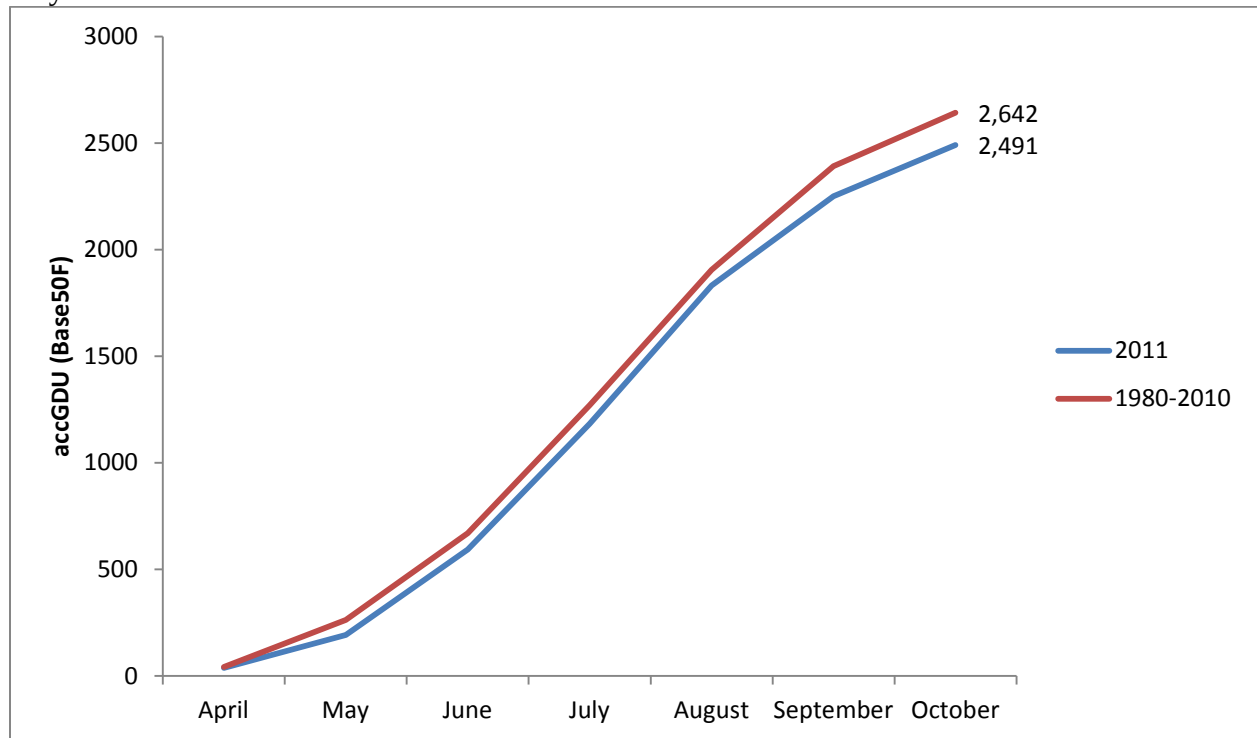


Table 1. Weed pressure in corn across systems from middle 12 rows of plot in 2011.

	Grass	Broadleaf
	Dry biomass (g m ⁻²)	
CS1 (conventional)	0.2	~0.0
CS2 (conventional)	~0.0	0.5
CS3 (organic)	11.3	28.2
CS4 (conventional)	~0.0	~0.0
CS5 (organic)	22.4	2.6
Overall p-value	<i>0.0244</i>	<i>0.0001</i>

Table 2. Weed pressure in soybeans across systems from middle 30' or 12 rows of plot in 2011.

	Grass	Broadleaf
	Dry biomass (g m ⁻²)	
CS2 (conventional)	~0.0	0.2
CS3 (organic)	11.5	10.4
Overall p-value	<i>0.0401</i>	<i>0.0584</i>

Table 3. Weed pressure in manured vs. not manured corn in 2011.

	Manured (East 6 rows)	Not Manured (West 6 rows)
System	Dry grass weed biomass (g m ⁻²)	
CS1 (conventional)	~0.0	~0.0
CS2 (conventional)	~0.0	~0.0
CS3 (organic)	8.6	3.8
Sys p-value	<i>0.0001</i>	
Sys*trt p-value	<i>NS</i>	
	Manured (East 6 rows)	Not Manured (West 6 rows)
	Dry broadleaf weed biomass (g m ⁻²)	
CS1 (conventional)	0.4	1.3
CS2 (conventional)	0.2	0.0
CS3 (organic)	25.0	14.9
Sys p-value	<i>0.0001</i>	
Sys*trt p-value	<i>0.1001</i>	

OUTREACH ACTIVITY ON THE WICST PLOTS 2009-2011

Janet Hedtcke and Joshua Posner

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 our research results at regional events (Wisconsin Grazing Conference, WI Crop Management Conference), as well as scientific meetings (NC Weed Society and ASA/CCSA,SSSA). Table 1 summarizes the outreach and educational activities for WICST 2009, 2010 and 2011.

Table 1. Outreach activities involving the WICST project in 2009 – 2011.

EVENT	LOCATION	DATE	ATTENDANCE
2009			
WICST Winter Meeting	Arlington	February 16	30
UW Dairy Science	Madison	April 8	17
Local Grade School Tours	Arlington	April/May	200
GLBRC Retreat	Kellogg Biological Station, MI	May 4-6	100
UW Soils of Wisconsin Class tour	Arlington	May 26	12
North Central-ASA Field Day	Arlington	July 23	25
UW Organic Field Day	Arlington	August 26	125
Town & Country RC&D Field trip	Arlington	October 5	20
ASA/CCSA/SSSA	Pittsburgh, PA	Nov 1-5	1500
North Central Weed Society Meetings	Champaign, IL	Dec 7-10	300
2010			
WI Crop Management Conf	Madison	January 12-14	500
WI Grazing Conference	Madison	February 19	30
Field crew update	Arlington	March 22	30
Local Grade School Tours	Arlington	May 4,6,18,20	100
UW Soils of Wisconsin Class tour	Arlington	May 24	15
Luther College, Milwaukee, WI	Arlington	June 10	20
Farm Credit Service	Arlington	June 15, 17	30
Prairie Enthusiasts	Arlington	June 23	5
Columbia/Dodge Grazing Network	Arlington	June 23	30
DNR Ag Waste Advisory Panel	Arlington	July 7	20
UW-Agronomy/Soils Field Day	Arlington	August 25	300
North Central Weed Society Meetings	Lexington, KY	Dec 12-16	300
2011			
WICST Winter Meeting	Arlington	March 30	30
Organic Farming Systems Conference	Washington DC	March 16-18	300
Local Grade School Tours	Arlington	May	200
UW Soils of Wisconsin Class tour	Arlington	May 23	12
Ag 101 workshop w/National Guard	Arlington	July 25	50
De Forest Teacher Tour	Arlington	August 24	12
Longterm Trial Network meeting	Madison/Arlington	Sept 1-2	12

Oral Extension–local

- Bernstein, E. No-tillage organic soybean production in winter rye. Arlington Organic Field Day August 26, 2009
- Hedtcke, J.L. 2010. Presentation at the Wisconsin Grazing Conference. Feb 19, 2010. Wisconsin Rapids.
- Hedtcke, J.L. and J.L. Posner. Reducing N purchases with soil testing and manure applications. Arlington Organic Field Day August 25, 2010.

Peer Audience-regional

- Bernstein, E.R., J.L. Posner, D.E. Stoltenberg, and J.L. Hedtcke. 2009. Organic no-till winter rye-soybean systems: agronomic, economic and environmental assessment. ASA-CSSA-SSSA International Annual Meetings Pittsburg, PA Nov 1-5, 2009.
- Bernstein, E. R., D. E. Stoltenberg, J. L. Posner, and J. L. Hedtcke. 2009. Multitactic weed management in organic soybean production systems. North Central Weed Sci. Soc. Abstr. 64: (CD-ROM computer file) North Central Weed Sci. Soc. Champaign, IL (Dec 2009).
- Chavas, JP., 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(2):288-295.
- Hedtcke, J.L., J.L. Posner, J.A. Hall, and R.P. Walgenbach. 2009. Orchardgrass Ley for Improved Manure Management: Residual Corn Yields. ASA-CSSA-SSSA International Annual Meetings. Pittsburg, PA Nov 1-5, 2009.
- Hedtcke, J.H, J.L. Posner, M. E. 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., A.R. Cook, J.L. Posner, J.L. Hedtcke, J.A. Hall, J.O. Baldock. 2009. Linking Wisconsin Dairy and grain farms via manure transfer for corn production. Agron. J. 101:1:167-174
- 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
- Bernstein, E. R., J. L. Posner, D. E. Stoltenberg, J. L. Hedtcke. 2010. Organic no-tillage winter rye-soybean systems: agronomic, economic, and environmental assessment. Proc. Wisc. Crop Management Conf. 49:152-158.
- Bernstein, E. R., D. E. Stoltenberg, J. L. Posner, J. L. Hedtcke. 2010. Weed suppression in transitional organic, no-tillage winter rye-soybean systems. North Central Weed Sci. Soc. Abstr 65. (CD-ROM computer file) North Central Weed Sci. Soc. Lexington, KT (Dec 2010).
- Hedtcke, J.L., J.L. Posner, J.A. Hall, R.P. Walgenbach, and J.O. Baldock. 2010. Orchardgrass (*Dactylis glomerata* L.) ley for improved manure management in Wisconsin: I. Forage yield, environmental impact and production costs. Agron. J. 102:956-963.
- Simonsen, J., J. Posner, M. Rosemeyer, and J. Baldock. 2010. Endogeic and anecic earthworm abundance in six Midwestern cropping systems. Applied Soil Ecology 44:147-155.

- Avila-Segura, M, P. Barak, J. Hedtcke and J.L. Posner. 2011. Nutrient and alkalinity removal by corn grain, stover and cob harvest in Upper Midwest USA. *Biomass and Bioenergy* 35:1190-1195.
- Baldock, J., J. Posner, J. Hall, J. Hedtcke. 2011. Organic system yields and yield trends in the Wisconsin Integrated Cropping Systems Trials. USDA-ERS 2011 Organic Farming Systems Conference. March 16-18, 2011.
- Hedtcke, J. J. Posner, J. Hall, J. Baldock. 2011. Profitability of organic farming systems in Wisconsin. USDA-ERS 2011 Organic Farming Systems Conference. March 16-18, 2011.
- Midwest Cover Crop Council. Feb 1, 2011. Green manure crops for organic grain systems: 20 yr summary from WICST. Abstract.
- Bernstein, E.R., J.L. Posner, D.E. Stoltenberg, and J. Hedtcke. 2011. Organically Managed No-Tillage Rye–Soybean Systems: Agronomic, Economic, and Environmental Assessment. *Agron. J.* 103:1169-1179.
- Hedtcke, J.L., J.L. Posner, W. Coblenz, J.Hall, R.Walgenbach, and J. Davidson. 2011. Orchardgrass ley for improved manure management in Wisconsin: II. Nutritive value and voluntary intake by dairy heifers. *Agron. J.* 103:1106-1114.
- Jokela, W., J.L. Posner, and J.L. Hedtcke. T. Balser, and H. Read 2011. Midwest cropping systems effects on soil properties and on a soil quality index. *Agron. J.* 103:1552-1562.

ORGANIC AND CONVENTIONAL PRODUCTION SYSTEMS: CORN AND SOYBEAN YIELD TRENDS 1990-2010.

Jon Baldock, Josh Posner, Janet Hedtcke, and John Hall

INTRODUCTION AND OBJECTIVES

Over the past two decades agronomists have used steady to positive yield trends as evidence of a sustainable cropping system (Jenkinson, 1991; Singh and Jones, 2002; and Bundy et al., 2011). However, some writers have suggested modern agriculture is predisposed to, unsustainable negative yield trends because it relies on large machinery, manufactured pesticides, and commercial fertilizer, which they claim have an adverse effect on soil health. On the other hand, the recent advances in agricultural biotechnology may be accelerating yield increases, especially in the major crops such as corn, which may lead to a widening advantage for conventional cropping systems relative to organic systems. Hence in long-term crop trials it is important to not only determine mean yields that tell what has happened on average, but also examine any yield trends that give more insight into the sustainability of the systems. In a previous paper we reported on the mean crop yields from the WICST (Posner et al., 2008); in this paper we update those mean yields for corn and soybeans, determine if any crop yield trends occurred and if they did, were there any negative trends and were there differences among cropping systems – especially between conventional and organic systems.

MATERIALS AND METHODS

Experimental Design, Establishment, and Management

The WICST study consists of six cropping systems, replicated four times, at two sites in southern Wisconsin. An agroecological approach was used in the selection and design of the three cash grain systems and three forage systems (Table 1). Although there were at least eight criteria in this process (Posner et al. 1995), the two key criteria were crop diversity and level of external inputs. A major contribution of the WICST was to also use this agroecological approach to define an overall management philosophy for each cropping system that guides it through the inevitable maze of changes in agriculture (Jenkinson, 1991). Table 1 summarizes the key differences in cultural practices among the treatments. The trials were established in 1989 with all 60 acres at each site planted to corn to improve the uniformity of crop history and allow baseline measurements to be taken. Some of the baseline variables, especially yield, were used to group the plots into four blocks of 14 plots (0.75 acre per plot) for the 14 total phases in the six cropping systems.

Except during the staggered start, which was completed in 1993 (Table 2), every phase was present every year for all the crop rotations, thus meeting a core requirement of a crop rotation trial (Cady, 1991). The staggered start was used to replicate each phase of the crop rotations in time as well as space, thus providing a more powerful analysis of time trends by cycle than could be accomplished with a fixed start of all possible crop sequences for a crop rotation (Cady, 1991; Loughin, 2006).

We tilled, planted, and harvested the crops, with production-sized equipment and estimated yields at 15.5% and 13.0% moisture content for corn and soybeans, respectively, by weighing the harvest wagons on a farm scale and determining grain moisture content from crop samples. Phosphorus and potassium fertilizer have been applied according to UW recommendations (Laboski et al., 2006). Likewise, N fertilizer for conventional corn has been based on the preplant N test recommendation (Bundy, 1994). Additional details on the design and conduct of the WICST trial are provided in Posner et al (1995). Definitions of the terms: crop rotation, crop sequence, phase, cycle, and test crop; are consistent with those in Yates (1954) and Cady (1991).

Statistical Analyses

We investigated yield trends at ARS and not LAC because changes in rotations and management in 1999 at LAC reduced the number of cycles. The pasture system was also omitted because it did not contain either corn or soybeans. A necessary feature of yield-trend analyses is repeatedly taking yield data from the same plots, which may cause the data to be correlated and thus may violate the assumption of independent errors (Cady, 1991; Loughin, 2006). Mixed model analyses with the Restricted Maximum Likelihood (REML) with covariance structures method simultaneously estimates these correlations and the fixed effects (cropping system and time trends) and has statistical advantages over the four traditional methods Cady (1991) summarized (Littell et al., 2006 and Loughin; 2006). We attempted to apply the mixed model REML with covariance structure procedure to this set of WICST data; however, the correlations among the errors were too small and inconsistent to get stable estimates of the fixed effects and covariance structure simultaneously. Consequently, we used a two-step process. First, we analyzed a series of analysis of covariance models with REML in JMP 9.0 (SAS Institute Inc., 2010) to determine the effects of cropping system and whether a linear or quadratic trend best described the cropping system-time relationship. Littell et al. (2006) describe the analyses of covariance techniques to examine the relationship of the fixed effects in the model, which should not be confused with the covariance structures that describe relationships in the random error portions of the model. Then we looked for correlation of errors with a direct test of the correlation among the residuals within each plot with the time series-autoregression routine in JMP 9.0 (SAS Institute Inc., 2010).

Except for CS3 and CS5, the cropping systems in this report differ in cycle length, which means the best comparisons can only be done in common multiples of their cycle lengths (Yates, 1954; Patterson, 1964). For corn and soybeans in the WICST, these common multiples would be 6, 8, or 12 years (except for continuous corn in CS1), which leaves very few common cycles to estimate yield trends. However for corn, by grouping the continuous corn system yields to match the cycle lengths of the other systems, which is an extension of the common multiple method of Patterson (1964), we have been able to compare the systems containing corn in pairwise manner (Posner et al., 2003). In these analyses plot, block, and year were considered random factors; cropping system and cycle were considered fixed. Probability levels of 10% or less were regarded as significant.

RESULTS AND DISCUSSION

Corn

There was no evidence of the positively correlated errors problem in either the ANOVA to determine the mean corn yields or in the ANCOVAs used to determine the time-trends. The first-order correlation coefficients for the residuals from the individual plots in the ANCOVAs were approximately two-thirds negative and one-third positive. None of the positive autocorrelations were significant and only about 20% of the negative ones were significant. This mix of small, positive and negative correlations probably explains why the covariance structure approach and the intraclass correlation method, both of which assume the same correlation values across all plots did not work well.

The high-input, conventional, forage based system, CS4, had the largest mean corn yield and the organic, grain system, CS3, had the lowest over the 18 years after the staggered start (Table 3). This result was the same as reported for the 12-year means (Posner et al., 2008). There were no significant differences among the middle three systems, but the conventional soybean-corn system, CS2, again produced the second largest corn yields; whereas, the continuous corn system, CS1, moved up from 4th place to 3rd while the organic, forage system, CS5, dropped from 3rd to 4th. This change was predicted in an earlier examination of the yield trends even though the 10-year means at the time favored CS5 (Posner et al., 2003).

The foregoing difference in results between mean yields and time-trends supports our contention that although long-term-mean yields are important statistics, it is also essential to determine if the yields are stable over time or if there are time-trends that could eventually change the mean yields and differences among the treatments. In this study such time-trends continue to be evident (Table 4, Fig. 1-4). Over the 21 years, CS1 corn yields increased 3.01 bushels/acre/year. This rate of increase is slightly more than the 2.4 bushels/acre/year achieved in production agriculture in the US from 1981 through 2010 (based on USDA-NASS, 2011) and the 2.3 bushels/acre/year observed over 50 years in another long-term trial on continuous corn at Arlington, Wisconsin (Bundy et al. 2011). However, not all trials show such yield trends. Stanger and Lauer (2008) did not find a time-trend for continuous corn yields or for corn yields other than for the first year of corn following a legume crop. Edaphic factors, such as organic matter and seasonal water table levels, have been shown to influence corn yield stability (Williams et al., 2008), which may help explain why some studies show substantial time-trends for corn yield and others do not.

Comparison of the conventional soybean-corn system, CS2, to CS1 using the 2-year simulated cycle length for CS1 revealed the slope of CS2 to be about 70% of the slope of CS1 (Table 4, Fig. 1). However, this difference was barely significant ($p=0.1$) and the least-square, cycle means have moved from significantly in favor of CS2 for Cycles 1 through 5 to a small (4.7), nonsignificant difference in favor of CS1 at Cycle 10. Thus, it will be important to watch this comparison as the trial progresses to see if a continuous corn system can actually produce more corn grain than a soybean-corn system as predicted by these 20-year yield trends. The slope of the time-trend for other conventional system, CS4, was not significantly different from the slope of CS1 (Table 4, Fig. 2). This result contradicts the result of the earlier trend analyses over 2.5 cycles where CS4 yields were not increasing as fast as those in CS1. Overall the yields were increasing faster in the actual and simulated 4-phase, conventional systems than in the 2-phase or

3-phase, organic systems. This difference may be due in part to both CS1 and CS4 being high-input systems and in part due to using the mean of the few poor yield years with more average and above average yields. The evidence for the latter argument is that the annualized rate of yield increase for CS1 was 3.01 bushels/acre/year for a cycle length of one year, but 4.13 bushels/acre/year for a cycle length of 4 years.

In contrast to the slopes of the time-trends, the intercepts for both CS2 and CS4 were significantly different from the intercept for CS1 (Table 4; Fig. 1 and 2). Because N was applied at best management practice rates or above in these conventional systems it was not yield-limiting, thus, the difference in intercepts quantifies the additional effect (non N) of corn following a legume crop (Baldock et al., 1981) or as some prefer to call it the negative effect of monoculture (Porter et al., 1997). This effect, measured by the difference in intercepts, was 16.0 bushels/acre for CS2, which was 11% of the mean yields in the first cycle and in line with the 12 to 14% Baldock et al. (1981) estimated for the additional or rotation effect. However, as discussed above, this difference diminished to zero after Cycle 5. The most likely cause for this change was the conversion of CS2 to completely no-till in the mid-1990s. Apparently, the slightly lower corn yields often observed in no-till corn in the North Central US (DeFelice et al., 2006; Archer and Reicosky, 2009) was enough to negate the advantage of crop rotation. Due to the problems with no-till corn the tillage was changed to strip-tillage in 2008. It will be interesting to see if this change restores the rotation effect of CS2 compared to CS1.

The intercept for the 4-year, forage based cropping system, CS4, was 23.0 bushels per acre greater than that for CS1 (Table 4; Fig. 2). This was 13% more than the mean yields, which was in agreement with the 12-14% Baldock et al. (1981) determined. In contrast to CS2, the yield trend for CS4 was parallel to CS1, thus the estimate of this additive effect of rotation remained steady over all four cycles. This consistency contradicts the assumption by many that the cumulative effect of crop rotations would diminish over time and eventually reach a plateau. Cady, (1991) postulated a Mitscherlich exponential model to quantify such a decay and equilibrium. One could also argue that if the rotation effect is primarily due to avoiding pest problems associated with monoculture that it would start small and build up. However, in the WICST the difference between CS4 and CS1 did not display a diminishing effect or a buildup. In fact, the difference was fully realized at Cycle 1 and remained constant through 4 cycles as evidenced by the best fitting model being parallel lines and the mean differences between CS4 and CS1 corn yields being 26.0, 24.6, 15.7, and 26.3 bushels/acre for Cycle 1 through Cycle 4, respectively.

There is also the question of whether the advent of transgenic and other genetically engineered corn hybrids in the late 1990s has accelerated the increase in yield. Although these hybrids were introduced into the conventional systems as they became available, the time trends for CS1 and the other conventional systems remained linear and did not exhibit an acceleration or deceleration (Table 4, Fig. 1 and 2).

The consequence of biotechnology may be to exacerbate the differences between conventional and organic cropping systems to organic systems. However, these data dispute such a claim. Although the rate of increase in corn yields was less in the organic systems than in the conventional systems, the rate differences were steady and not accelerating (Table 4, Fig. 3 and

4). The largest difference was for the organic grain system, CS3, which had the smallest slope of the five systems of 1.99 bushels/acre/year on an annualized basis. The annualized yield increase for CS5 was also relatively small, 2.51 bushels/acre/year. The more robust annualized trend for CS1 of 3.96 bushels/acre/year (based on a 3-year cycle, Table 4) suggests that corn in the conventional systems will out yield corn in the organic systems by a larger and larger margin over time. Time will tell if this prediction plays out or if organic technology will find a way to narrow the gap.

Soybeans

The cycle length of the conventional soybean-corn system, CS2, was 2-years and the cycle length of the organic soybean-wheat (legume cover crop) system, CS3, was 3-years. Consequently, we used three complete 6-year cycles (the common multiple) to analyze the soybean yields. As with corn, there was no evidence of the positively correlated errors problem in either the ANOVA to determine the mean soybean yields or in the ANCOVA used to determine the time-trends. In both analyses 80% of the first-order correlation coefficients for the residuals from the individual plots were negative and 20% positive. None of the positive autocorrelations were significant and only 2 of the negative ones were significant.

Over the 18 years in the ANOVA, the conventional system, CS2, produced larger grain yields than the organic system: 53 bushels/acre versus 46 ($p < 0.01$). Initially, both systems yielded approximately 50 bushels/acre; however, the ANCOVA showed divergent trends (Fig. 5) with CS2 increasing yields at a rate of 0.30 bushels/acre/year and CS3 decreasing at 0.48 bushels/acre/year. The CS2 rate is slightly less than the 0.40 bushel/acre/year realized in production agriculture for the 1991 to 2010 period (based on USDA-NASS, 2011). The cause of the negative trend for the organic system was likely years with wet early seasons interfering with mechanical weed control (Posner et al., 2008). Beginning in 2006 several changes were made to improve weed control in CS3. Within the soybean phase, preplant tillage was done early enough so that soybeans weren't planted into decaying biomass which has been shown to attract the destructive seedcorn maggot. Weed control was improved with the purchase of a tine weeder that was used two to three times between emergence and before row cultivation. Within the other phases of the system, weed control was also improved. In the corn phase, earlier rotary hoeings and a pass with a disk hiller cultivator reduced weed pressure. Within the wheat phase, summer tillage followed by seeding an oat/berseem cover crop reduced the foxtail and quackgrass population. Another possible cause of the negative trend in this system was limited plant nutrient availability. By 2005, 16 years without fertilization had drawn down soil test P and K levels. Where soil test P was still excessively high at 45 ppm, soil test K was near the yield response range on some plots so they were fertilized with an organically approved source of K₂O (potassium sulfate, 0-0-50-18(S)). Beginning in 2008, 1.3 tons/a of organically approved pelleted chicken manure was applied during the corn phase. This addition not only improved the corn vigor, but also may have increased soybean yields. Collectively, these changes appear to have been successful as the mean yields for CS3 for 2008-2010 were 58.2 bushels/acre compared to only 53.2 for CS2. This difference was significant for the specific three years tested ($p < 0.01$), but not if one attempts project the difference to any set of years. Thus, the difference shows how dynamic technology can be even for organic systems as well as conventional systems. It also suggests these changes not only turned the organic soybean yield

trend from negative to positive, but also may have given this system an advantage over the conventional system for soybeans. It will take several more cycles of data to see if either of these short-term implications are born out in the long run.

Sustainability

While there were differences in the time trends for corn yields among these systems it is important to note that all were positive and significantly greater than zero. This means that all were likely sustainable in the sense that productivity increased over approximately 20 years in all five systems. The time trends in soybeans showed CS2 to likely be sustainable, while CS3 was likely unsustainable. On the other hand, recent changes to CS3 may have turned that system around and produced yields equal or greater than those in CS2. Hence the modified CS3 may be sustainable. Some may argue that increases in technology have masked the detrimental effects of some cropping systems, especially in the conventional systems. Cropping systems are such a complex of physical, chemical, and biological processes that they may well have many consequences. However, we would argue that yield trends are a good measure the net effect of most of these consequences and that if there were major negative effects they likely would have been manifest after 20 years. Thus, at least in terms of productivity we judge these systems, with the possible exception of CS3, to be sustainable and take some comfort that there are a number of long-term trials such as WICST that continue to monitor cropping systems and changes in technology for negative effects on productivity and other factors of the sustainability.

CONCLUSIONS

- 1- Positive corn yield trends occurred in all five systems suggesting all five were sustainable in terms of corn productivity.
- 2- The rate of yield increase was greatest for the high input conventional systems, CS1 and CS4, at 4.13 bushel/acre/year.
- 3- The rate of yield increase for the no-till, soybean-corn system, CS2, was only 2.36 bushels/acre/year; which predicts the continuous corn system will eventually out-yield the soybean corn system. However, the no-till regime has been replaced by strip tillage, which may restore the advantage of the soybean-corn system.
- 4- The rate of corn yield increase in the high input, conventional systems was nearly double that in the organic systems suggesting a larger and larger advantage accruing to the conventional systems. But the yield increase was steady and not accelerating as some had feared.
- 5- The CS2 soybean yield trends were positive and thus sustainability.
- 6- The organic system, CS3, displayed decreasing soybeans yields over the first 18 years, indicating this system was not sustainable in terms of soybeans productivity. However, changes to weed control measures and variety selection have shown substantial increases in soybean yields over the last three years.

LITERATURE CITED

- Archer, D.W., D.C. Reicosky. 2009. Economic performance of alternative tillage systems in the northern corn belt. *Agron. J.* 101:296-304.
- Baldock, J.O., R.L. Higgs, W.H. Paulson, J.A. Jackobs, and W.D. Shrader. 1981. Legume and mineral N effects on crop yields in several crop sequences in the upper Mississippi Valley. *Agron. J.* 73:886-890.
- Bundy, L. 1994. Soil nitrate test for Wisconsin cropping systems. UW Extension Bulletin A3624. University of Wisconsin Madison, WI.
- Bundy, L.G., T.W. Andraski, M.D. Ruark, and A.E. Peterson. 2011. Long-term continuous corn and nitrogen fertilizer effects on productivity and soil properties. *Agron. J.* 103: 1346-1351.
- Cady, Foster B. 1991. Experimental design and data management of rotation experiments. *Agron. J.* 83:50-56.
- Cochran, W.G. 1939. Long-term agricultural experiments. *J. Royal Statis. Soc. Suppl.* 6:104-148.
- 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 DOI: 10.1094/CM-2006-0626-01-RS
- Jenkinson, D.S. 1991. The Rothamsted long-term experiments: are they still of use? *Agron. J.* 83:2-10.
- Laboski, C. A. M., J. B. Peters, and L. G. Bundy. 2006. Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin. Univ. of Wisconsin Cooperative Extension Publications, Univ. of Wisconsin-Madison, Madison, WI.
- Little, R.C., G.A. Milliken, W.W. Stroup, R.D. Wolfinger, and O.S. Schabenberger. 2006. SAS system for mixed models. 2nd Edition SAS Institute Inc. Cary, NC.
- Loughin, T.M. 2006. Improved experimental design and analysis for long-term experiments. *Crop Sci.* 46:2492-2502.
- Patterson, H.D. 1964. Theory of cyclical rotation experiments. *J. Royal Stat. Soc. Series B.* 26(1):1-45.
- Porter, P.M., R.K. Crookston, J.H. Ford, D.R. Huggins, and W.E. Lueschen. 1997. Interrupting yield depression in monoculture corn: comparative effectiveness of grasses and dicots. *Agron. J.* 89:247-250.
- Posner, J.L., J.O. Baldock, and J.L. Hedtcke. 2003. The Wisconsin Integrated Cropping Systems Trial: I. Corn Yields and Yield Variability (1992-2002). In J.L. Posner and J.L. Hedtcke. WICST 9th Technical Report. Agron. Dept. Univ. Wisconsin-Madison.
- 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.
- Posner, J.L., M.D. Casler, and J.O. Baldock. 1995. Wisconsin integrated cropping system trial: combining agro-ecology with production agronomy. *J. Alternative Agric.* 10:98-107.

- SAS Institute, Inc. 2010. JMP 9 modeling and multivariate methods. Cary, NC, SAS Institute, Inc..
- Shrader, W.D., W.A. Fuller, and F.B. Cady. 1966. Estimation of a common N response function for corn (*Zea mays*) in different crop rotations. *Agron. J.* 58:397-401.
- Singh, Murari, and Michael J. Jones. 2002. Modeling yield sustainability for different rotations in long-term barley trials. *J. Agric. Biological, and Environ. Statistics.* 7:525-535.
- USDA, National Agricultural Statistics Service. 2011. Crop production: Historical Track Records. Available at www.nass-usda.gov/pubs (accessed 9 Mar 2012, verified 19 March, 2012). USDA-NASS, Washington, DC.
- Yates, F. 1954. The analysis of experiments containing different crop rotations. *Biometrics* 10:324-346.

Table 1. Description of the six cropping systems in the WICST project.

System	Type	Phase	Crop†	Use of External Inputs	Key cultural practices					
					Primary Tillage	Starter Fertilizer	Basis for N-P-K fertilizer rates	Manure rate, tons/a	Weed Control	Soil Insectide
CS1	Grain	1	C	High	Chisel plow	Yes	Soil tests‡	0	Herbicides	Yes
CS2	Grain	1	Sb	Medium	No-till§	None	Soil tests	0	Herbicides	None
		2	C		No-till	Yes	Soil tests‡	0	Herbicides	None
CS3	Grain	1	Sb	Low	Chisel plow¶	None	None#	0	Mechanical	None
		2	Wrc††		Field cultivate	None	None#	0	None	None
		3	C		Chisel plow	None	None#	0‡‡	Mechanical	None
CS4	Forage	1	A††	High	Chisel plow	None	Soil tests	0	Herbicides	None
		2	A		None	None	Soil tests	0	Herbicides	None
		3	A		None	None	Soil tests	0	Herbicides	None
		4	C		Chisel plow	Yes	Soil tests‡	20	Herbicides	None
CS5	Forage	1	Op††	Low	Chisel plow	None	None#	0	None	None
		2	A		None	None	None#	0	None	None
		3	C		Chisel plow	None	None#	15	Mechanical	None
CS6	Forage	1	RC/Og/T/B	Low	None	None	Soil tests‡	0	None	None

† Corn (*Zea mays*) = C; soybean (*Glycine max*) = Sb; winter wheat (*Triticum aestivum*) with frost seeded red clover (*Trifolium pratense*) = Wrc; alfalfa (*Medicago sativa*) = A; oat (*Avena sativa*) and pea (*Pisum sativum*) mix = Op; mixture of red clover, orchardgrass (*Dactylis glomerata*), timothy (*Phleum pratense*), and brome (*Bromis inermis*) = RC/Og/T/B.

‡ Nitrogen rates adjusted according to soil nitrate-N tests, legume credits, and manure credits where applicable. Phosphorus and potassium fertilizer applied per soil test recommendation beginning in 2009 and 2003, respectively.

§ Prior to 1994, conventional tillage and drilling were used in the soybean phase.

¶ Soybeans planted in 30-inch rows.

For most of the trial, soil test levels were excessively high so no fertilizer was added until 2005 when organically approved K₂SO₄ was added per soil test recommendation.

†† The red clover was frost seeded into the winter wheat, the alfalfa in phase one of CS4 was sole seeded, and the alfalfa in phase 1 of CS5 was companion seeded with the oat-pea mix.

‡‡ Starting in the Spring of 2008, 1.3 tons/a of organically approved composted poultry manure was added

Table 2. Example of staggered start and cycles for the soybean-corn rotation in CS2†.

System	Plot	Year					
		1989	1990	1991	1992	1993	1994
CS2	101	F	Sb:1	C:1	Sb:2	C:2	Sb:3
	108	F	F	Sb:1	C:1	Sb:2	C:2

† F, background or filler corn; Sb soybeans; C, corn; and the number following the colon denotes the cycle.

Table 3. Least square mean corn yields: WICST at Arlington, WI (1993-2010).

System	n	Mean
		bushels/acre [†]
CS1	70	175 b
CS2	71	180 b
CS3	68	148 c
CS4	72	194 a
CS5	68	170 b
Mean	349	173
LSD(10%)		11 [‡]

[†] Means followed by the same letter are not significantly different at 10% level.

[‡] The LSD varied from 10.4 to 10.7 bushels/acre due to different n.

Table 4. Comparison of linear models for corn yield trends by system in the WICST at Arlington, WI.

Comparison	System	Years	Cycles	n	Coefficients by System		Difference v. CS1		Annualized Slope
					Intercept	Slope	Intercept	Slope	
					bushels/a	bu/a/cycle	bushels/a	bu/a/cycle	bu/a/yr
CS1	CS1	21	21	82	140**	3.01**			3.01
CS2 v CS1	CS1	20	10	78	136**	6.69**	16.04*	-1.97#	3.34
	CS2			79					2.36
CS3 v CS1	CS1	18	6	70	131**	11.87**	-8.65ns	-5.89*	3.96
	CS3			68					1.99
CS5 v CS1	CS1	18	6	70	131**	11.87**	9.10ns	-4.34#	3.96
	CS5			68					2.51
CS4 v CS1	CS1	16	4	62	131**	16.54**	22.98**	0.00	4.13
	CS4			64					4.13

ns not significant at the 10% level.

significant at the 10% level.

*, ** significant at the 5% and 1% levels, respectively.

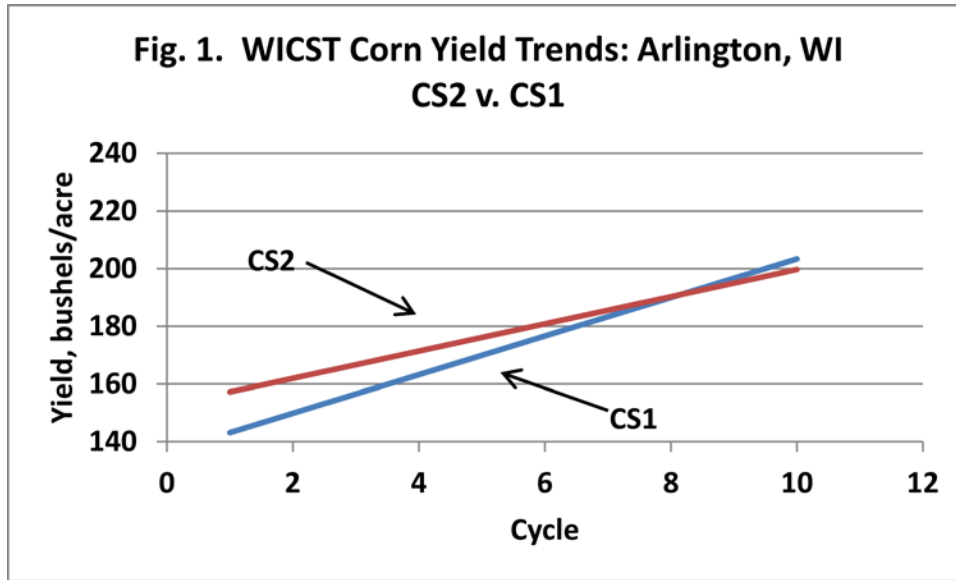
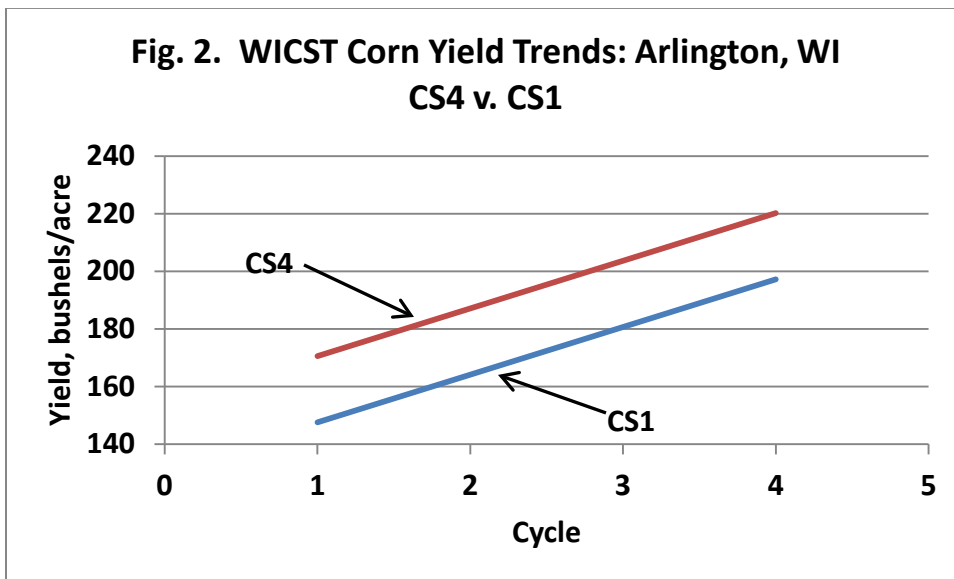


**Fig. 3. WICST Corn Yield Trends: Arlington, WI
CS3 v. CS1**

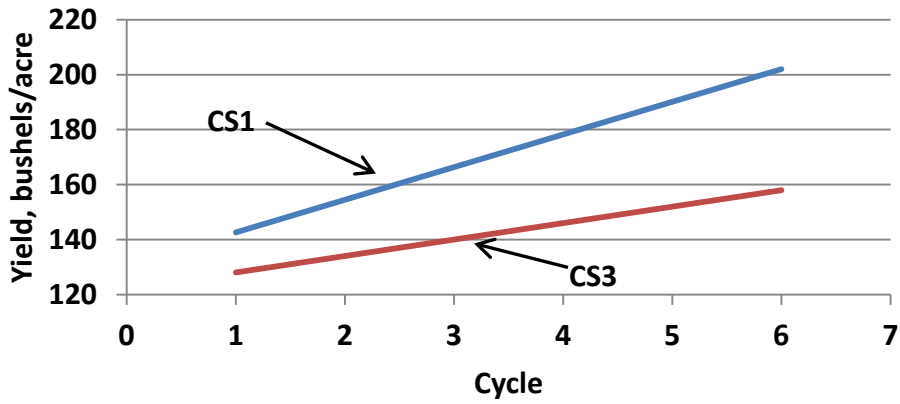
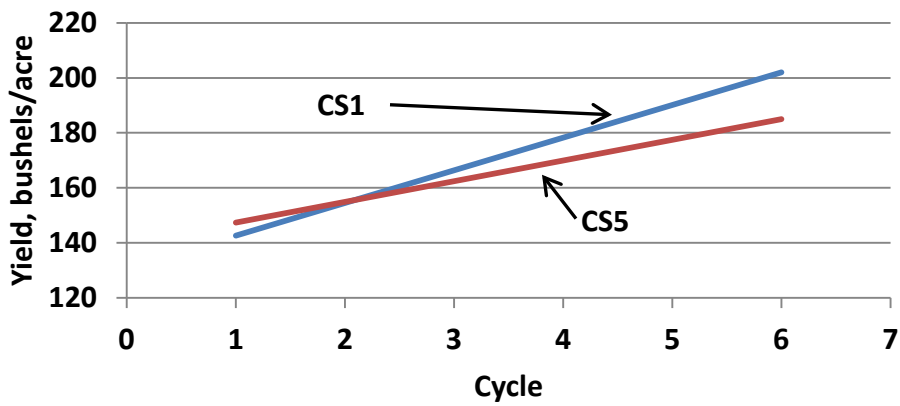
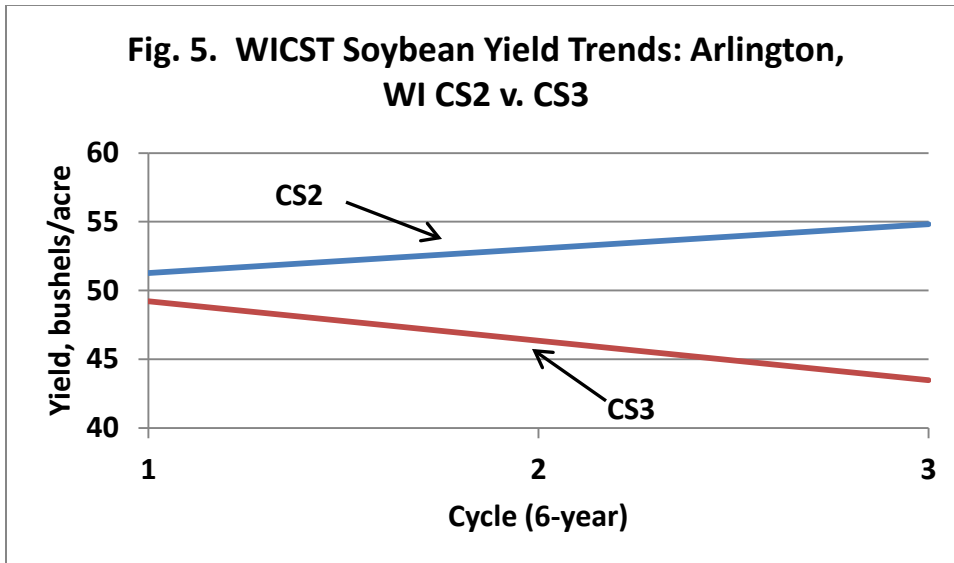


**Fig. 4. WICST Corn Yield Trends: Arlington, WI
CS5 v. CS1**





LONG TERM EFFECTS OF COMMON MIDWESTERN AGROECOSYSTEMS ON SOIL ORGANIC CARBON

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ABSTRACT

Soil organic carbon (SOC) is highly sensitive to agricultural land management. As a result there is a great deal of interest in using cultivated soils to sequester atmospheric CO₂. In this study we evaluate the impact of six cropping systems on SOC levels at the Wisconsin Integrated Cropping System Trial (WICST) over a 20 year period. Analysis of SOC (g kg⁻¹ or Mg ha⁻¹) showed a significant loss in all of the systems at WICST. While the rotationally grazed pasture system sequestered carbon (C) in the top 30 cm of the soil (9 Mg ha⁻¹) these gains were offset by losses at depth (-9.3 Mg ha⁻¹). Both no-till (NT) practices and inclusion of perennial crops reduced SOC loss, but neither resulted in C sequestration in the soil profile. Results from this study demonstrate the importance of i) comparing current and initial soil samples when evaluating SOC sequestration and ii) evaluating SOC changes at depth. We hypothesize that the losses of SOC observed at WICST are primarily the result of insufficient C allocation below ground to offset C losses via oxidation. While Wisconsin's warming climate may be accelerating the mineralization of soil organic matter (SOM), the evidence for such a causal relationship is not sufficient at this point to support such a hypothesis.

Key Words: Soil Organic Carbon, Carbon Sequestration, Agroecosystem, Ecosystem Services
Abbreviations: C, carbon; CT, conventional tillage; IPCC, Intergovernmental Panel on Climate Change; NT, no-till; SOC, soil organic carbon; SOM, soil organic matter; WICST, Wisconsin Integrated Cropping Systems Trial.

The world's soils contain 2500 Pg of C, almost twice the combined amount of C stored in the atmosphere or vegetation worldwide (Batjes, 1996; Lal, 2008). The soil organic C pool (SOC) makes up sixty percent of this total, 170 Pg of which are stored in the 1.7 billion hectares of agricultural cropland worldwide (Lal, 2008; Paustian et al., 2000). As a result, changes in soil C content can have a large effect on the global C budget (Bellamy et al., 2005). Historically the contribution of agriculture to global CO₂ emissions via the oxidative loss of SOC has been quite significant (55-78 Pg)(Collins et al., 1999; Lal, 2004; Lal, 2008). Grace et al. (2006) using the SOCRATES model estimated that C stocks in Wisconsin in the upper 10 cm of soil have decreased by 67 Tg (14%) since conversion of native prairie and forest systems to agricultural production beginning in 1850's. This is consistent with findings reported by Collins et al. (1999) showing that soil samples (0 to 20 cm) taken from continuous corn plots initiated in 1958 at the University of Wisconsin's Arlington Research Station had 18% less soil C than an adjacent non-cultivated site. These estimates are modest however compared to those of Kucharik et al. (2001) who estimated SOC losses as large as 63% from a historically cropped prairie restoration site adjacent to the University of Wisconsin's Arlington agricultural research station. There is currently a great deal of interest in managing agricultural soils as C sinks to help offset rising levels of atmospheric CO₂. This approach to CO₂ mitigation is an attractive option in that it is cost effective, and can be implemented immediately using current agricultural technologies (Conant et al., 2007; Lal, 2008). Improvements in agricultural genetics and technology over the past 50 years have drastically increased the crop residue contribution to SOC and enabled wide spread adoption of conservation and NT farming practices both of which are thought to promote C sequestration or slow its loss (Buyanovsky and Wagner, 1998). According to the 2011 Inventory of U.S. Greenhouse Gas Emissions and Sinks compiled by the U.S. EPA, land converted to cropland was cited as sources of CO₂ (-1.6 Tg C yr⁻¹, 2009) while land continuing in cropland and land converted to grasslands were both considered sinks of atmospheric CO₂ (4.7 and 2.3 Tg C yr⁻¹, respectively, 2009)(USEPA, 2011). In addition to the potential mitigation of climate change, increasing SOC levels has many ancillary benefits including; i) improved soil structure, ii) reduced soil erosion, iii) decreased non-point source pollution, iv) increased water holding capacity, v) improved cation exchange capacity, and vi) increased soil fertility for food production (Lal, 2008). In spite of these benefits, the ability of the soil to serve as a C sink is most likely limited (Six et al., 2002). While the potential sequestration capacity of the soil should be equal to the amount of C that has been lost (55 to 78 Pg), it is thought that the attainable sink capacity of the world's soils is probably only 50 to 60% of this potential; and short-lived if management practices change (Lal, 2004; Lal, 2008; West and Post, 2002).

Agricultural practices impact SOC mineralization and stabilization by directly affecting the soil environment with regards to moisture, temperature, aeration, pH, and nutrient availability. Cultural practices which are often cited as ways to increase SOC or mitigate the loss of SOC include the conversion from conventional to NT farming, cultivation of perennial crops, use of livestock and green manures, increased crop rotation complexity, and the use of synthetic N fertilizers (Huggins et al., 1998; Ogle et al., 2005; West and Post, 2002). Syswerda et al. (2011) in a study of 10 Michigan agroecosystems ranging from annual crop rotations to a mature forest report that SOC increased under NT, organic, successional, and forest systems relative to that of conventionally managed annual grain rotations. West and Post (2002) in a meta-analysis of 67 long-term experiments report that conversion from conventional tillage

(CT) to NT resulted in sequestration rates of $570 \pm 140 \text{ kg C ha}^{-1} \text{ yr}^{-1}$ and that by increasing rotation complexity, $200 \pm 120 \text{ kg C ha}^{-1} \text{ yr}^{-1}$ could be sequestered. These results are consistent with a global meta-analysis of 167 experiments conducted by Ogle et al. (2005) that showed that SOC increased with setting land aside, reducing tillage, and increasing C inputs through cropping practices.

Despite these positive findings however an equally large body of literature has demonstrated the conditionality of C sequestration responses or found net losses in what are considered best management scenarios. In an extensive study comparing soil samples from 1978 to those collected in 2003, Bellamy et al. (2005) report C losses across the UK. These trends were most pronounced in systems with high initial C content but were not related to land management thus suggesting a link to climate change. Grace et al. (2006), using the SOCRATES model, report that if conservation tillage practices were adopted in Wisconsin, 10.8 Tg of SOC could be sequestered by the year 2100 if there was no concomitant change in climate or atmospheric CO_2 levels. When an IPCC climate change prediction scenario was considered in which there was a global annual average increase of 3.9°C and higher atmospheric CO_2 (711ppm vs. 354ppm), losses of SOC ranged from 1 Tg for conservation tillage to 30 Tg for CT during the same time span (Grace et al., 2006). Working in Southern Minnesota on a clay loam soil, Huggins et al. (2007) found that under different management practices for annual crops (including NT), C losses of 1.6 to $3.7 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ occurred over the course of 14 years. They concluded that annual cropping systems had limited potential to restore C levels to those of native sites, and that under the best scenario of continuous corn and NT management, stabilization of initial SOC levels would either require reducing C decomposition rates by over 50% or doubling C inputs. These conclusions are supported by a recent meta-analysis of 69 paired experiments comparing the impacts of CT and NT on SOC sequestration (Luo et al., 2010). Luo et al. (2010) report that cultivation of native systems for more than 5 years results in SOC losses in excess of 20 Mg ha^{-1} in the top 60 cm of the soil profile regardless of cultural practice (CT or NT). When farming practices switch from CT to NT they found that adoption of NT increased SOC accumulation in the surface 30 cm of soil but that when deeper soil depths were considered ($>40 \text{ cm}$) SOC was essentially stable (no significant loss or gain).

These differing conclusions within the scientific literature on the role of NT in restoring SOC levels result in part from experimental designs that may not provide sufficient statistical power to detect changes in a highly variable parameter like SOC, the use of space-for-time studies to make inferences about SOC dynamics, inadequate sampling to depth, lack of accounting for changes in bulk density (BD), and, of course, the large effects that edaphic conditions have in determining the mineralization rates of SOC (Kravchenko and Robertson, 2011; Sanderman and Baldock, 2010; Schmidt et al., 2011; VandenBygaart and Angers, 2006).

In most cases, analysis of SOC in agricultural systems are conducted within a pre-existing experimental design that was optimized for analysis of agronomic parameters [Sandermann et al. 2010 in (Sanderman and Baldock, 2010)]. The large spatial variability of SOC coupled with such designs can often lead to type II statistical errors and the conclusion that loss (or gain) of SOC did not occur because of non-significant differences (VandenBygaart and Allen, 2011). Kravchenko and Roberston (2011) suggest that post-hoc power analysis should be required for all studies that purport to conclude insignificant changes in SOC.

Space-for-time studies are also frequently used to assess the effect of agricultural management on SOC. In such studies the effect of a management strategy on SOC is evaluated based on a control treatment (e.g. a nearby non-cultivated site, or continuous corn) at some point in time following the initiation of the trial. Sanderman and Baldock (2010) indicated that less than 50% of the studies in major reviews of SOC stock changes (including Ogle et al. 2005 above) have actually followed changes in SOC through time. They assert that without adequate baseline SOC data it is impossible to determine whether or not a current measured difference between two treatments has resulted in sequestration of atmospheric CO₂ (Sanderman and Baldock, 2010).

While most of the changes in SOC associated with agricultural management occur within surface soil horizons (Syswerda et al., 2011), a lack of consideration for SOC trends in deeper horizons, coupled with a lack of accounting for changes in BD, can result in significant errors in the estimation of SOC dynamics. In a 25 year study contrasting NT with spring moldboard plowing (MB), Deen and Kataki (2003) working on silt loam soils in Ontario, Canada showed that when C storage in the upper 10 cm of the soil is compared, NT resulted in substantial storage relative to MB (220 kg C ha⁻¹ yr⁻¹, 0-10 cm). If the horizon immediately below 10 cm was considered however the difference between NT and MB was reversed (-118 kg C ha⁻¹ yr⁻¹, 10-20 cm) (Deen and Kataki, 2003). Similar findings are reported by Baker et al. (2007) in which the authors show that the differences between NT and CT are primarily due to differences in SOC distribution, and not the result of SOC accumulation in NT. Furthermore, while it is desirable for C budgeting purposes to report SOC changes on a mass basis (e.g. kg C ha⁻¹ yr⁻¹) such reporting must be done while accounting for changes in soil BD. Lee et al. (2009) evaluated the use of three equivalent soil mass (ESM) correction methods and compared them to the use of a fixed depth method for studying C stock changes. In their study the comparison of mass based SOC changes at a fixed depth (0-15 cm) led to an unrealistic SOC loss of 30% within 6 months following tillage. They suggest that in instances where appropriate soil BD numbers are unavailable the evaluation of SOC concentration dynamics is most appropriate. Of the ESM methods evaluated the “original ESM” method (calculation of equivalent soil mass based on original (t₀) mass) proved the most robust. They concluded that this method was the least confounded and most accurate for detecting soil C changes under all conditions (Lee et al., 2009).

Lack of statistical power, constraints associated with study design, and incomplete accounting efforts can all lead to different conclusions about SOC stability. Nevertheless it is ultimately the interaction of management with climatic and edaphic conditions that drive the stabilization or mineralization of SOC (Schmidt et al., 2011; Six et al., 2002). Historical concepts of SOC stabilization, primarily as a result of chemical recalcitrance brought about by complexation reactions within the soil have been challenged by advances in modern SOC elucidation techniques (Kleber and Johnson, 2010; Schmidt et al., 2011). In many cases the chemical complexity of SOC imparts no added protection from microbial degradation, and long term persistence is just as likely for proteins and saccharides as it is for lignin, n-alkanes, long-chain alkanic acids, and other plant structural tissues (Schmidt et al., 2011). According to this hypothesis, SOC stabilization is tightly coupled to temperature, water regime, the quantity and quality of silt and clay minerals upon which C molecules can adsorb, and physical compartmentalization within the soil that can isolate organic compounds from oxygen and

microbial decomposers (Kleber and Johnson, 2010; Schmidt et al., 2011; Six et al., 2002). Due to the complexity of SOC stabilization, a “one size fits all” approach to SOC managements may not result in the desired ecosystem services of SOC sequestration and greenhouse gas mitigation.

In the present study we compare the impact of six upper Midwestern cropping systems (3 grain and 3 forage) on the fate of SOC over a period of 20 years using archived and current soil samples to a depth of 90 cm. The study is located in southern Wisconsin on what was historically tallgrass prairie. As a result these silt loam soils are deep (>1m), high in native SOC, silt, and clay, with very high crop production potential. The objectives of this study were to evaluate: 1) changes in SOC within each cropping system, and 2) the relative importance of tillage, perenniality, and crop residue inputs on SOC trends. We hypothesize that: 1) SOC will decrease over time as a result of increased tillage frequency, 2) Perennial forage systems with limited tillage, deep rooted crops, and manure inputs will sequester greater amounts of SOC (or lose less) than the annual grain systems, and 3) within enterprise types (grain vs. dairy), systems with greater species diversity will sequester more C (or lose less) than systems with less species diversity.

MATERIALS AND METHODS

Site Characteristics and Experimental Design

The study site is located at the University of Wisconsin’s Agricultural Research Station in Arlington, WI (43°18’N, 89°20’W). The soils at the site are classified as a Plano Silt Loam (fine-silty, mixed, superactive, mesic typic argiudolls). These are deep (>1m), well drained soils with little relief that were formed under tallgrass prairie vegetation in loess deposits over calcareous glacial till. Conversions from prairie vegetation to crop land began in the mid 1800’s primarily for the production of wheat. From the 1860’s until the middle of the 20th century the land was used to produce feed for dairy cattle and from 1960 until the initiation of WICST the predominant crop rotations were of corn (*Zea mays* L.) and alfalfa (*Medicago sativa* L.) with dairy manure serving as the primary source of nutrients (Posner et al., 1995). At the onset of this study the soils at the site (0-15 cm) had an average organic matter content of 47 g kg⁻¹ (loss on ignition), and an average pH (1:1.3 soil/water) of 6.5, with high levels of soil test P and K (Bray-I P =108 mg kg⁻¹ and Exchangeable K=255 mg kg⁻¹)(Posner et al., 2008). The mean annual temperature and precipitation at Arlington are 6.9°C and 869 mm respectively (1981-2010, National Climate Data Center).

The WICST experiment began in 1990 and consists of six cropping systems. Three cash-crop (typical of specialized grain farms) and three forage-crop systems (typical of livestock-crop farms) were selected for study based on crop diversity and level of external inputs (Posner et al., 1995; Posner et al., 2008). Specifically, the cash grain systems are a high-external input, continuous corn system (CS1); a moderate-external input, NT corn-soybean [*Glycine max* (L.) Merr.] system (CS2), and an organic corn-soybean-winter wheat with interseeded red clover (*Trifolium pratense* L.) system (CS3). Forage systems include a high-input corn-alfalfa system (CS4); an organic oats (*Avena sativa* L.)/alfalfa-corn system (CS5), as well as a rotationally grazed pasture (CS6) seeded to a mixture of red clover, timothy (*Phleum pratense* L.), smooth brome grass (*Bromus inermis* L.), and orchardgrass (*Dactylis glomerata* L.) (Table 1).

In 1989 a corn crop was planted on all 24 ha of the WICST trial to improve the uniformity of crop history and to allow baseline measurements to be made. Some of the baseline variables, yield in particular, were used to block the trial into a four-block randomized complete block design with one replication of the 14 total phases in the six cropping systems placed in each block. Instead of starting all crops in all rotations in the first year, a staggered start was used so that each phase of each rotation was replicated in time as well as space (Loughin, 2006; Posner et al., 1995). After the stagger was completed in 1992, every phase was present every year for all the crop rotations, thus meeting a core requirement of a crop rotation trial (Cady, 1991). The 0.3 ha plots are large enough that all field work is done using farm-scale equipment. Additional details on the design and implementation of WICST are provided in Posner et al. (1995) and Posner et al. (2008).

Baseline soil sampling (1989) – T₀

Soil samples were collected in 1989 prior to the layout of the WICST plots as part of the baseline descriptive sampling for the trial. Samples were collected on a 27m x 27m grid that overlaid the 24 ha field. Every other grid point was sampled in 1989, staggering the points in each row. This resulted in even-numbered points being samples in one row and odd-numbered points being sampled in the next (see Fig. 1). Samples were taken at four depths (0-15, 15-30, 30-60, and 60-90 cm). The first two depths were taken using a 3.2 cm diameter probe and the second two deeper depths were collected using a 1.9 cm diameter probe. Four cores were taken at each sampling point and homogenized by depth. Following initial soil analysis (1989) the remaining soils were dried, ground, and archived. In 2009 approximately 1g of each dried homogenized soil from the 1989 archive was picked free of any visible plant material and stored in a desiccation chamber prior to analysis of soil C content.

Contemporary soil samples (2009) – T₂₀

Soil Samples were collected from the WICST plots between 22 April and 17 July of 2009. Samples were collected using a tractor mounted hydraulic soil sampler fitted with a 3.2 cm diameter soil probe. Each plot was divided into three sections [18m x 52m: North (N), Center (Cnt.), South (S)] and three soil cores were taken in the middle of each section. Cores were collected in all plots at 19 cm distances from one another (0, 19, and 38 cm). This was done to insure that samples were collected in-row, between-row and at an intermediate location in all of the corn plots. Samples were then divided into four depth increments (0-15, 15-30, 30-60, and 60-90 cm) and composited by depth within each field section. Field moist samples were sieved to 2 mm in the lab and picked free of all visible plant material. Once cleaned of plant material, samples were place in a 45°C oven until dry. Approximately 1 g of dried homogenized soil was then place in a ball mill and ground to a fine powder. Samples were stored in a desiccation chamber prior to analysis of soil C content.

Soil Carbon Content

Finely ground sub-samples of soil taken from the baseline grid (1989) or from each section (N,Cnt.,S) and depth (0-15, 15-30, 30-60, 60-90) within a WICST plot (2009) were weighed (8-10 mg) and packed into 5 x 9 mm tin capsule. Organic C for each encapsulated sample was then

determined by dry combustion using a Flash EA 1112 CN Automatic Elemental Analyzer (Thermo Finnigan, Milan, Italy).[†]

To match the 2009 data set, C numbers from the 1989 grid were converted to plot data by overlaying the 1990 plot map on the 1989 grid map (Fig. 1). The C data for individual plots was then obtained 1) directly from 1989 number if the grid and plot map lined up correctly (n=36 plots), 2) by attributing neighboring plots the same initial C content if the 27 x 27m grid sampling fell on the plot boundary (n=18), or 3) by averaging the C data from the two neighboring plots if the 1989 grid did not fall on a 1990 plot (n=2). The 1989 sampling was quite extensive, providing three sampling locations (similar to the N, Cnt., and S location in 2009) within a plot, and four depths within a sampling location. If averaging of the 1989 grid numbers was required, it was performed between neighboring samples of corresponding locations (N,Cnt.,S) so that all 1989 plot estimates are balanced.

Bulk Density Measurements

Bulk density cores were collected in June of 1989 at two sampling depths (0-15, 15-30 cm) on the 27 x 27m baseline sampling grid discussed previously using a 7.5 cm diam. hammer core. Bulk densities for individual plots in 1989 were then obtained in the same manner as soil C numbers for that year. Bulk densities were again sampled in 2007 (3.7 cm hammer core) and 2008 (5.4 cm hydraulic core) but to a depth of 90 cm (0-15, 15-30, 30-60, and 60-90 cm). An additional sampling in 2008 was done on a subset of the WICST plots using the same 7.5 mm hammer core used in 1989 to ensure that the two smaller diameter cores produced similar contemporary BD numbers and were comparable to 1989 numbers using the large diameter hammer core (data not shown). Unlike the soil C data, BD numbers are averaged across sample locations within a plot for a total of one data point per depth in each plot. The BD samples collected in 2007 and 2008 were so similar to each other that it was decided to average the sampling times together to provide a more robust mean of current (T_{20}) BD numbers. Furthermore, it was assumed that below 30 cm no significant (or detectable) change in BD was likely to have occurred in the course of the 20 year trial. This is a reasonable assumption given the depth to which BD changes are often reported as well as the soil type and equipment history at WICST (i.e. well-structured grassland soils high in organic matter and relatively light agricultural equipment [$\leq 11 \text{ Mg axle}^{-1}$])(Hamza and Anderson, 2005; Sanford et al., 2008). T_{20} numbers for 30-60 and 60-90 cm horizons were therefore used for both the T_{20} and T_0 sampling times. In cases where data was missing for a depth within a plot, the average BD for that treatment within the block and depth were used. Equivalent mass corrections were conducted based on the original equivalent soil mass method described by Lee et al. (2009).

Statistical Analysis

All statistical analyses were performed using SAS version 9.1.3 (SAS Institute Inc., 2004) within the existing randomized complete block structure of the WICST trial. Linear mixed effects models (PROC MIXED) were used to analyze the variables BD and SOC (g kg^{-1} or Mg ha^{-1}) while all correlations between SOC dynamics and management practices were conducted using the CORR procedure. Due to the high inherent variability in SOC data we assume significance at the $\alpha=0.1$ level but report p-values for most comparisons.

[†] Use of equipment name for information purposes only and not an endorsement for the product.

The response variable SOC (g kg^{-1} or Mg ha^{-1}) was analyzed as a function of time (t_0 or t_{20}), systems (CS1 – CS6), depth (0-15 cm, 15-30 cm, 30-60 cm, 60-90 cm), and their interactions as fixed effects while block (1-4), plot, and location (N,Cnt.,S) within time and plot were considered random effects. The REPEATED statement in PROC MIXED was used to account for spatial correlation between points within a plot location in a given year. The first order autoregressive covariance structure, which assumes equal variance but does not assume equal covariance, was chosen to model this spatial correlation based on its biological significance and low Bayesian Information Criterion (BIC). The full model was significantly better than the simpler alternative of not including the repeated statement based on the residual log likelihood ratio test ($p < 0.0001$). The resulting mixed model is

$$y = \mu + \beta_i + T_j + S_k + T*S_{jk} + \varepsilon_{ijn} + D_l + D*T_{jl} + D*S_{kl} + D*Y*S_{jkl} + \delta_{ijnml}.$$

In this model μ = population mean, β = block, T = time, S = system, and D = depth. The two error terms are for testing the fixed effects of time, system and their interactions (ε) and depth and its interactions with time and system (δ). The subscripts i, j, k, n, l , and m indicate the block, year, system, plot, depth and location, respectively.

The response variable BD (Mg m^{-3}) was analyzed using a simplified version of the full model which did not include the random effect of location within plot.

Carbon input Estimates

As per Jokela et al. (2011), to aid in interpreting cropping system effects on SOC dynamics, we estimated C inputs from each system using the approach and summarized literature values from Bolinder et al. (2007). These included input coefficients for all the grain and forage crops in our study. Aboveground biomass inputs were either measured directly (forage yields, green manure, and residual alfalfa plow-down, wheat grain and straw, and manure applications) or estimated using established harvest indices for corn (0.50) and soybean (0.40) (Bolinder et al., 2007). Below-ground inputs were calculated based on shoot/root ratios and rhizodeposition estimates from Bolinder (2007). We assumed a C concentration of 0.42 g g^{-1} for all plant material and manure, which is in the mid-range of estimated values used by others [(Johnson et al., 2006)(0.40 g g^{-1}); (Allmaras et al., 2004)(0.42 g g^{-1}); and Bolinder et al., 2007 (0.45 g g^{-1})]. In summary, the calculated total C inputs included estimates of the following sources: (i) non harvested aboveground biomass, including stover, stubble, and plant debris, (ii) roots, (iii) material from root turnover and exudates, or “rhizodeposition”, and (iv) manure.

RESULTS

Bulk Density

Change in BD was analyzed for the top two horizons only (0-15 and 15-30 cm) due to a lack of deeper BD numbers in 1989. Overall there was a significant ($p < 0.0001$) increase in soil BD of 62 kg m^{-3} in the 20 years since the start of the WICST trial. This trend was most pronounced in the 0-15 cm horizon compared to the 15-30 cm horizon (100 kg m^{-3} vs. 25 kg m^{-3}) and was also greater in the cash grain systems than in the forage based systems (87 kg m^{-3} vs. 37 kg m^{-3}). Of the cash grain systems, the NT corn and soybeans (CS2) saw the highest increase in BD of 176 kg m^{-3} ($p < 0.0001$) in the upper soil horizon (0-15 cm). While BD in both CS4 and CS5 decreased over time in the 15-30 cm horizon neither change was statistically significant. Bulk density data from 1989 and 2009 are shown in Table 2.

Initial SOC levels

Analysis of initial 1989 SOC concentrations (g C kg^{-1} soil) indicated that there was no detectable difference between system locations prior to the start of the trial ($p=0.2049$), but that there was a significant depth effect as we would expect ($p<0.0001$). There was no system by depth interaction ($p=0.2760$). Variability was high in all horizons with the surface soil the least variable and the 30-60 cm depth the most variable. Initial SOC concentrations averaged 26.3, 20.6, 10.7, and 5.3 g kg^{-1} for the 0-15, 15-30, 30-60, and 60-90 cm horizons respectively with corresponding coefficients of variation (CV's) of 20.3, 34.5, 64.4, and 38.8%. Initial (T_0) SOC concentration and summary statistics are presented in Table 3.

Change in SOC concentration: 1989 to 2009

Results from the analysis of 1989 and 2009 SOC concentration data show a highly significant effect of both time ($p=0.0089$) and system ($p=0.0020$) although their interaction term was not significant ($p=0.7313$) (Table 4). This indicates that on average all systems behaved in a similar manner over the 20 years. As was the case in 1989, the effect of depth was highly significant (<0.0001) with C concentrations decreasing rapidly below 30 cm. When averaged across system and depth there was a loss of 1.6 $\text{g SOC kg soil}^{-1}$ in the course of the 20 year trial ($p=0.0089$). At the system level, the greatest average loss (weighted by horizon depth) was observed in CS1 (-3.3 g kg^{-1} , $p=0.0551$) while rotationally grazed pasture (CS6) showed a non-significant minor loss of -0.3 g kg^{-1} ($p=0.8469$) primarily from gains in the top 30 cm which helped offset losses in deeper horizons. With the exception of CS6 all systems lost SOC throughout the soil profile over the course of the trial. Following CS1 which had the greatest loss of SOC was CS3 the organic grain system (-1.6 g kg^{-1} , $p=0.0703$), with non-significant total losses of -1.4 , -1.2 , and $-0.8 \text{ g SOC kg soil}^{-1}$ for CS2 ($p=0.2227$), CS5 ($p=0.1693$), and CS4 ($p=0.1702$) respectively. While the significant gains in CS6 occurred in the upper 15 cm both CS1 and CS3 had significant losses of SOC extending to a depth of 30 cm. Complete data for each system and depth is presented in Table 5.

The ESTIMATE statement in PROC MIXED was used to further investigate our initial hypotheses with regards to changes in SOC concentration. Averaged over all depths there was no significant difference ($p=0.3088$) between NT (CS2 & CS6) and CT systems (CS1, CS3, CS4, CS5) although there was mathematically smaller losses of SOC in the NT systems. When the most actively managed 0-30 cm soil horizons were compared, however, the NT systems were significantly different than the CT systems ($p=0.0580$). This is primarily due to significant SOC gains in the upper horizon of CS6. As was the case for the comparison of CT versus NT systems, perennial forage systems (CS4, CS5, CS6) lost significantly less SOC than the annual grain systems (CS1, CS2, CS3) in the top 30 cm (3.2 g kg^{-1} , $p=0.0143$) but this difference was not detectable when evaluating the entire soil profile ($p=0.1282$).

One additional approach to evaluate the relative importance of management factors on SOC dynamics across systems was to develop a score for each of four factors that pertained to our original hypotheses. Scores for the influence of tillage, manure, and residue inputs (above and below ground) were developed following the method used by Simonsen et al. (2010). The scores were averaged across phases for each cropping system in order to develop a single value per system. This resulted in indices that were not significantly correlated (not confounded) (Simonsen et al., 2010). Correlation data (Table 6) indicated a small (-0.10) but significant

negative correlation between SOC accumulation and tillage as well as highly significant positive correlations with manure inputs ($p=0.0023$) and estimated below ground C inputs ($p=0.0076$) when evaluating the entire soil profile (0-90 cm). When analyzed by horizon there is a strong depth effect with highly significant correlations in the 0-15 cm soil depth only.

Stock Change is SOC: 1989 to 2009

Analysis of C on an equivalent soil mass basis revealed the same general trends as did analysis of SOC concentration (Table 5). There was an overall loss of C mass between 1989 and 2009 of 4.1 Mg ha^{-1} ($p=0.0062$). Furthermore the effect of system was highly significant ($p=0.0263$) but the interaction of system and time was not significant ($p=0.7360$) indicating that loss of SOC was significant and occurred in all systems (Table 4). Ability to detect system and depth specific changes was limited when analyzing SOC mass compared to the analysis of SOC concentrations. When the entire soil depth is considered (0-90 cm) there was a significant loss of $2.1 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ in the CT continuous corn system (CS1), followed by non-significant losses of 0.86, 0.82, 0.65, 0.55, and $0.02 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ in CS3, CS5, CS2, CS4 and CS6 respectively. Horizon specific changes within system were not significant with the exception of a large loss of -15.1 Mg ha^{-1} in the 30-60 cm horizon of CS1. Both contrasts and correlations with cropping system indices of SOC mass dynamics strongly support our findings associated with changes in C concentration. When considering the 0-30 cm horizon, NT systems (CS2, CS6) performed better (lost less or sequestered C) than CT systems (CS1, CS3, CS4, CS5, $p=0.0580$). The effect of enterprise type was also highly significant between 0-30 cm with forage based systems outperforming (losing less SOC) the cash grain systems ($p=0.0143$).

Correlations with the four cropping systems indices presented in Table 6 were not as strong for SOC mass as they were for SOC concentration. On a whole soil profile basis, only tillage was significantly correlated with SOC dynamics ($p=0.0080$). Estimated below ground C additions were significantly correlated with SOC accumulation in the upper 0-15 cm but there was no significant correlation when the whole soil profile was evaluated. At the modest level of manure additions, and good crop yields, above ground C inputs were not significantly correlated with SOC dynamics overall or at any individual depth.

SOC concentration vs. stocks

There was not substantive difference between the results from analysis of SOC concentration (g kg^{-1}) or mass (Mg ha^{-1}). When considering the entire 90 cm horizon, all of the systems at WICST lost soil C between 1989 and 2009. There was a significant interaction effect between time and depth, but this was limited to the analysis of SOC concentration data ($p=0.0075$). This observation occurred because SOC concentrations changed far less between 1989 and 2009 in deeper soil horizons than they did in surface horizons (e.g. -3.0 v -1.2 g kg^{-1} SOC at 0-15 cm and 60-90 cm respectively). When both the horizon depth (15 cm vs. 30 cm) and soil BD ($>$ with depth) are factored into the calculation as they are using ESM we find no significant interaction between time and depth ($p=0.5691$).

DISCUSSION

Soils at the Arlington Agricultural Research Station are typical of Mollisols which have formed in deep ($>1\text{m}$) loess deposits over calcareous glacial till. Historically (pre 1850) South-

central Wisconsin was dominated by tallgrass prairie and oak savannah communities. These communities preferentially allocated C to below ground fine root biomass which led to the development of a highly SOC enriched mollic epipedon (0 – 30 cm). It is for this historical reason that SOC is highest in the top 30 cm and decreases rapidly at WICST regardless of cropping system. While the WICST systems have not drastically altered this overarching trend of decreasing SOC with depth they have differentially affected both soil BD and SOC relative to their initial levels.

With the exception of the 15-30 cm horizon in the two alfalfa rotations (CS4 & CS5) BD has increased in all remaining treatments and at all depths over the last 20 years. These changes were most pronounced in the 0-15 cm horizon ($+0.1 \text{ Mg m}^{-3}$) and minimal in the 15-30 cm horizon ($+0.03 \text{ Mg m}^{-3}$). Based on results reported in the soil compaction literature under similar conditions we assume that there was no detectable change in BD below 30 cm (Hamza and Anderson, 2005; Sanford et al., 2008). Sanford et al. (2008) showed that on Plano silt loams at the Arlington research station soil compaction was not detectable below 30 cm when applying dairy slurry using equipment with an 11 Mg axle load. Historically, while manure spreading equipment has been the heaviest equipment employed at the site, slurry tankers have only recently been used (2005 onward) and have never exceeded the axle loads reported by Sanford et al. (2008). Furthermore those plots that do receive manure (forage systems CS4 – CS6) have a lower average BD than those that do not receive manure but are more frequently tilled (1.22 Mg m^{-3} forage vs. 1.28 Mg m^{-3} grain). This indicates that increases in soil BD at WICST are less a function of traffic and likely more related to soil consolidation associated with decreased soil aggregation or the well documented phenomenon of surface soil consolidation in NT systems. Data from a recent study of soil quality parameters at WICST supports this theory. Jokela et al. (2011) looking at two different soil depths (0-5 & 5-20 cm) found that the WICST forage systems (CS4-CS6) had a greater concentration of water stable aggregates than did the cash grain systems (CS1-CS3) (820 & 861 vs. 728 & 852 g kg^{-1} for forage and grain systems, 0-5 and 5-20 cm respectively).

The significant interaction of system with depth was by and large the result of the managed pasture system (CS6) which unlike the rest of the systems sequestered C in the top 30 cm of the soil profile. Sequestration of SOC in the upper 30 cm of CS6 was the result not only of the quantity of below ground biomass (4570 kg ha^{-1} , Table 1) but also the morphological characteristics of that biomass. In perennial grass systems like CS6, 80-90% of the below ground biomass is concentrated in the top 30 cm of the soil and is dominated by fine roots (0-2 mm)(Jackson et al., 1996; Rasse et al., 2005). Tufekcioglu et al. (1998) working in central Iowa found that live fine-root biomass in perennial cool season pastures exceeded 6.0 Mg ha^{-1} while in both corn and soybean systems (annual grain) fine root biomass was less than 2.3 Mg ha^{-1} in the top 35 cm of the soil. These fine roots are covered with root hairs that range from 5 to $17\mu\text{m}$ across by 80 to $1500\mu\text{m}$ long depending on the plant species(Rasse et al., 2005). The large surface area associated with fine root biomass [relative to small (2-5 mm) or coarse root ($>5 \text{ mm}$) biomass] increases the interaction of both fine-roots and root hairs with soil micro-pores and micro-aggregates. Penetration of root hairs into such micro-sites, where anoxic condition prevail and which are otherwise inaccessible to microbial decomposers, preferentially stabilizes these stocks of root derived C (Rasse et al., 2005). Such occlusion of root derived C within soil aggregates is thought to play a key role in the long term stabilization of SOC (Schmidt

et al., 2011; Six et al., 2002; Verchot et al., 2011), and helps to explain the observed C sequestration in the 0-30 cm horizon of the managed pasture system (CS6).

The managed pasture (CS6) exerted a large influence over the statistical evaluation of tillage, manure inputs, and the degree of system perenniality (grain vs. forage). When CS6 is removed from these comparisons however we still find that NT practices, inclusion of manure, and increased perenniality (i.e. greater proportion of a rotation in perennial crops) slowed the loss of SOC relative to the more highly tilled or predominantly annual systems at WICST. No-Till practices are thought to favor SOC accumulation (or slow its loss) by limiting the amount of mechanically induced oxidation of plant residues and soil organic matter (Lal, 2008). While some have reported increased SOC associated with the conversion from CT to NT practices (Conant et al., 2007) others have observed no net sequestration or even loss of SOC associated with NT (Baker et al., 2007; Huggins et al., 2007; Luo et al., 2010). It should be noted that crop rotation will influence the observed rate of C turnover in NT systems. A continuous corn system managed as NT may have led to sequestration of C where the NT corn-soybean rotation at WICST did not. Inclusion of soybean in the rotation decreases the total quantity of residue produced (below and above ground), decreases the C/N ratio of residue inputs (making it more favorable for microbial decomposition), and results in a different distribution of the below ground component of that residue (Huggins et al., 2007). The beneficial effects of a perennial system are in part related to the advantages of reduced tillage discussed previously as well as the fact that perennial plants allocate greater C resources to below ground infrastructure than do most annual crops. (Table 1). The influence of below ground biomass on SOC dynamics cannot be understated, playing a greater role in the long term stabilization of soil C than inputs from above ground biomass (Rasse et al., 2005).

While NT production practices, application of manure, and inclusion of perennial crops all served to slow the loss of SOC, none of the practices employed at WICST have favored long-term sequestration of soil C to a depth of 90 cm. These observations are strongly supported by SOC trends observed at the WICST mirror site on a poorly drained prairie soil in Walworth county Wisconsin (data not shown). In this trial all systems lost carbon (NS) over the course of 12 years with the exception of the managed pasture which as was the case in this study sequestered carbon in the 0-30 cm horizon. The lack of sequestration observed over the course of 20 years highlights the importance of knowing what initial SOC concentrations are if one is to make conclusions about the effects of best management practices on C stocks. Had treatment differences at WICST been evaluated based only on the 2009 values with continuous corn as our control (i.e. space for time analysis), we would have correctly concluded that CS2 and CS3 had lost C over time while erroneously concluding that the perennial forage systems (CS4-CS6) had sequestered C. Sanderman and Baldock (2010) clearly demonstrate that a gain of SOC (e.g. +5 Mg C ha⁻¹) following the implementation of an improved agricultural management practice may not be equivalent to sequestering C if soil C at the site being evaluated is not in a state of equilibrium at the time of the study. It is clear from the soil data collected at WICST that SOC at this site has yet to reach such a state.

One major contributing factor to the observed loss of SOC at WICST is that current below ground C inputs are likely far smaller than those realized under the native tallgrass prairie (i.e. input < off take) (DeLuca and Zabinski, 2011). In a review of the relevant literature, DeLuca and Zabinski (2011) report that under tall grass prairie ecosystems, below ground

biomass can range from 8-15 Mg ha⁻¹ yr⁻¹ with an estimated 3-5 Mg ha⁻¹ yr⁻¹ retained in the soil annually. Over the course of 5,000 to 8,000 years this belowground net input led to an estimated 70-130 Mg C ha⁻¹ in the top 30 cm of tallgrass prairie soils (DeLuca and Zabinski, 2011). While aboveground productivity in tallgrass prairies may not differ substantially from that of annual cropping systems, belowground productivity is typically far greater than that of annual systems by as much as 86% (DeLuca and Zabinski, 2011; Guzman and Al-Kaisi, 2010). The transition at Arlington from tallgrass prairie systems to forage crops in the 1850's and later to grain crops (~1960's) has resulted in significant loss of original soil C as well as greatly reducing the contribution of roots biomass to current SOC stocks. Without sufficient C inputs to offset the mineralization of organic matter these soils will continue to lose SOC.

An important and potentially confounding part of the C story at WICST may be a Wisconsin climate that has, for the past 57 years, seen a 1.85°C increase in minimum winter temperatures as well as an increase in growing season precipitation in southern Wisconsin of approximately 50 mm (Kucharik et al., 2010). While the impacts of a warming climate on SOC dynamics are far from being completely understood there is some evidence to suggest that such trends will lead to a preferential loss of older and more stable pools of C (Conant et al., 2008; Conant et al., 2011). That is to say that the organic matter which has contributed to the long term stabilization of SOC in these systems may be the most at risk from a changing climate in southern Wisconsin although no direct connection can be made in the current analysis.

CONCLUSION

Observed changes in SOC at the WICST over the past 20 years highlight the importance of accurate C accounting when drawing conclusions about the sequestration potential of best management practices. While NT management strategies, inclusion of perennial crops, and grass pasture all had beneficial effects on the C stocks at WICST none of the six systems has been able to sequester atmospheric C. These results are consistent with finding at a mirror site in southern WI, as well as with others who have compared initial SOC levels with current levels rather than using space as a surrogate for time (nearby non-cultivated sites or a control treatment). The observed changes at WICST are likely the result of insufficient below ground C inputs to offset loss via SOC oxidation. While a trend in warming night time and winter temperatures as well as an increase in annual precipitation has occurred over the past half century, a connect between regional climate change and SOC dynamics, while potentially important, cannot at this time be clearly established. The trends reported in this study suggest that the potential to sequester C via agricultural best management practices on prairie derived soils in the upper Midwest may not be possible on a practical time scale, or at best may be quite limited.

REFERENCES

- Allmaras, R.R., D.R. Linden, and C.E. Clapp. 2004. Corn-residue transformations into root and soil carbon as related to nitrogen, tillage, and stover management. *Soil Sci. Soc. Am. J.* 68:1366-1375.
- Baker, J.M., T.E. Ochsner, R.T. Venterea, and T.J. Griffis. 2007. Tillage and soil carbon sequestration - What do we really know? *Agric. Ecosyst. Environ.* 118:1-5.
- Batjes, N.H. 1996. Total carbon and nitrogen in the soils of the world. *Eur. J. Soil Sci.* 47:151-163.

- Bellamy, P.H., P.J. Loveland, R.I. Bradley, R.M. Lark, and G.J.D. Kirk. 2005. Carbon losses from all soils across England and Wales 1978-2003. *Nature* 437:245-248.
- Bolinder, M.A., H.H. Janzen, E.G. Gregorich, D.A. Angers, and A.J. VandenBygaart. 2007. An approach for estimating net primary productivity and annual carbon inputs to soil for common agricultural crops in Canada. *Agric. Ecosyst. Environ.* 118:29-42.
- Buyanovsky, G.A., and G.H. Wagner. 1998. Carbon cycling in cultivated land and its global significance. *Global Change Biol.* 4:131-141.
- Cady, F.B. 1991. Experimental-Design and Data Management of Rotation Experiments. *Agron. J.* 83:50-56.
- Collins, H.P., R.L. Blevins, L.G. Bundy, D.R. Christenson, W.A. Dick, D.R. Huggins, and E.A. Paul. 1999. Soil carbon dynamics in corn-based agroecosystems: Results from carbon-13 natural abundance. *Soil Sci. Soc. Am. J.* 63:584-591.
- Conant, R.T., M. Easter, K. Paustian, A. Swan, and S. Williams. 2007. Impacts of periodic tillage on soil C stocks: A synthesis. *Soil Tillage Res.* 95:1-10.
- Conant, R.T., J.M. Steinweg, M.L. Haddix, E.A. Paul, A.F. Plante, and J. Six. 2008. Experimental warming shows that decomposition temperature sensitivity increases with soil organic matter recalcitrance. *Ecology* 89:2384-2391.
- Conant, R.T., M.G. Ryan, G.I. Ågren, H.E. Birge, E.A. Davidson, P.E. Eliasson, S.E. Evans, S.D. Frey, C.P. Giardina, F.M. Hopkins, R. Hyvönen, M.U.F. Kirschbaum, J.M. Lavalley, J. Leifeld, W.J. Parton, J. Megan Steinweg, M.D. Wallenstein, J.Å. Martin Wetterstedt, and M.A. Bradford. 2011. Temperature and soil organic matter decomposition rates – synthesis of current knowledge and a way forward. *Global Change Biol.* 17:3392-3404.
- Deen, W., and P.K. Kataki. 2003. Carbon sequestration in a long-term conventional versus conservation tillage experiment. *Soil Tillage Res.* 74:143-150.
- DeLuca, T.H., and C.A. Zabinski. 2011. Prairie ecosystems and the carbon problem. *Front. Ecol. Environ.* 9:407-413.
- Grace, P.R., M. Colunga-Garcia, S.H. Gage, G.P. Robertson, and G.R. Safir. 2006. The potential impact of agricultural management and climate change on soil organic carbon of the North Central Region of the United States. *Ecosystems*. 9:816-827.
- Guzman, J.G., and M.M. Al-Kaisi. 2010. Soil Carbon Dynamics and Carbon Budget of Newly Reconstructed Tall-grass Prairies in South Central Iowa. *J. Environ. Qual.* 39:136-146.
- Hamza, M.A., and W.K. Anderson. 2005. Soil compaction in cropping systems: A review of the nature, causes and possible solutions. *Soil Tillage Res.* 82:121-145.
- Huggins, D.R., R.R. Allmaras, C.E. Clapp, J.A. Lamb, and G.W. Randall. 2007. Corn-soybean sequence and tillage effects on soil carbon dynamics and storage. *Soil Sci. Soc. Am. J.* 71:145-154.
- Huggins, D.R., G.A. Buyanovsky, G.H. Wagner, J.R. Brown, R.G. Darmody, T.R. Peck, G.W. Lesoing, M.B. Vanotti, and L.G. Bundy. 1998. Soil organic C in the tallgrass prairie-derived region of the corn belt: effects of long-term crop management. *Soil Tillage Res.* 47:219-234.
- Jackson, R.B., J. Canadell, J.R. Ehleringer, H.A. Mooney, O.E. Sala, and E.D. Schulze. 1996. A global analysis of root distributions for terrestrial biomes. *Oecologia* 108:389-411.
- Johnson, J.M.F., R.R. Allmaras, and D.C. Reicosky. 2006. Estimating source carbon from crop residues, roots and rhizodeposits using the national grain-yield database. *Agron. J.* 98:622-636.
- Jokela, W., J. Posner, J. Hedtcke, T. Balser, and H. Read. 2011. Midwest Cropping System Effects on Soil Properties and on a Soil Quality Index. *Agron. J.* 103:1552-1562.
- Kleber, M., and M.G. Johnson. 2010. Advances in Understanding the Molecular Structure of Soil Organic Matter: Implications for Interactions in the Environment, p. 77-142 *Advances in Agronomy*, Vol 106, Vol. 106. Elsevier Academic Press Inc, San Diego.

- Kravchenko, A.N., and G.P. Robertson. 2011. Whole-Profile Soil Carbon Stocks: The Danger of Assuming Too Much from Analyses of Too Little. *Soil Sci. Soc. Am. J.* 75:235-240.
- Kucharik, C.J., S.P. Serbin, S. Vavrus, E.J. Hopkins, and M.M. Motew. 2010. PATTERNS OF CLIMATE CHANGE ACROSS WISCONSIN FROM 1950 TO 2006. *Phys. Geog.* 31:1-28.
- Kucharik, C.J., K.R. Brye, J.M. Norman, J.A. Foley, S.T. Gower, and L.G. Bundy. 2001. Measurements and modeling of carbon and nitrogen cycling in agroecosystems of southern Wisconsin: Potential for SOC sequestration during the next 50 years. *Ecosystems*. 4:237-258.
- Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science* 304:1623-1627.
- Lal, R. 2008. Carbon Sequestration. *Philosophical Transactions of the Royal Society* 363:815-830.
- Lee, J., J.W. Hopmans, D.E. Rolston, S.G. Baer, and J. Six. 2009. Determining soil carbon stock changes: Simple bulk density corrections fail. *Agric. Ecosyst. Environ.* 138:355-355.
- Loughin, T.M. 2006. Improved experimental design and analysis for long-term experiments. *Crop Sci.* 46:2492-2502.
- Luo, Z., E. Wang, and O.J. Sun. 2010. Can no-tillage stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments. *Agric. Ecosyst. Environ.* 139:224-231.
- Ogle, S.M., F.J. Breidt, and K. Paustian. 2005. Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. *Biogeochemistry* 72:87-121.
- Paustian, K., J. Six, E.T. Elliott, and H.W. Hunt. 2000. Management options for reducing CO₂ emissions from agricultural soils. *Biogeochemistry* 48:147-163.
- Posner, J.L., M.D. Casler, and J.O. Baldock. 1995. The Wisconsin integrated cropping systems trial: Combining agroecology with production agronomy. *Am. J. Alternative Agric.* 10:98-107.
- 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.
- Rasse, D.P., C. Rumpel, and M.F. Dignac. 2005. Is soil carbon mostly root carbon? Mechanisms for a specific stabilisation. *Plant Soil* 269:341-356.
- Sanderman, J., and J. Baldock. 2010. Accounting for soil carbon sequestration in national inventories: a soil scientist's perspective. *Environmental Research Letters* 5:6.
- 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 Tillage Res.* 100:42-53.
- Schmidt, M.W., M.S. Torn, S. Abiven, T. Dittmar, G. Guggenberger, I.A. Janssens, M. Kleber, I. Kogel-Knabner, J. Lehmann, D.A.C. Manning, P. Nannipieri, D.P. Rasse, S. Weiner, and S. Trumbore. 2011. Persistence of soil organic matter as an ecosystem property. *Nature* 478:41-56.
- Simonsen, J., J.L. Posner, M. Rosemeyer, and J.O. Baldock. 2010. Endogeic and anecic earthworm abundance in six Midwestern cropping systems. *Applied Soil Ecology* 44:147-155.
- Six, J., R.T. Conant, E.A. Paul, and K. Paustian. 2002. Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. *Plant Soil* 241:155-176.
- Syswerda, S.P., A.T. Corbin, D.L. Mokma, A.N. Kravchenko, and G.P. Robertson. 2011. Agricultural management and soil carbon storage in surface vs. deep layers. *Soil Sci. Soc. Am. J.* 75:92-101.
- Tufekcioglu, A., J.W. Raich, T.M. Isenhardt, and R.C. Schultz. 1998. Fine root dynamics, coarse root biomass, root distribution, and soil respiration in a multispecies riparian buffer in Central Iowa, USA. *Agroforestry Systems* 44:163-174.
- USEPA. 2011. Inventory of US greenhouse gas emissions and sinks: 1990-2009 Executive Summary, *In* USEPA, (ed.).
- VandenBygaart, A.J., and D.A. Angers. 2006. Towards accurate measurements of soil organic carbon stock change in agroecosystems. *Can. J. Soil Sci.* 86:465-471.

- VandenBygaart, A.J., and O.B. Allen. 2011. Experiment design to achieve desired statistical power. *Can. J. Soil Sci.* 91:309-310.
- Verchot, L.V., L. Dutaur, K.D. Shepherd, and A. Albrecht. 2011. Organic matter stabilization in soil aggregates: Understanding the biogeochemical mechanisms that determine the fate of carbon inputs in soils. *Geoderma* 161:12.
- West, T.O., and W.M. Post. 2002. Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. *Soil Sci. Soc. Am. J.* 66:1930-1946.

Table 1. The six cropping systems in the Wisconsin Integrated Cropping Systems Trials conducted at Arlington, Wisconsin: cropping system, crop phase, and average (1990-2009) level of inputs. Bold values are annual means of C input for each cropping system.

Label	Name	Phase	Average Yield ¹ Mg ha ⁻¹	Primary Tillage	Annual N-P-K Input ²		Estimated Annual C Input ³	
					1 st Yr. Available	Source ⁴	Above Ground	Below Ground
----- Cash Grain Systems -----					kg ha ⁻¹		----- kg ha ⁻¹ -----	
CS1	continuous corn	corn	10.7	chisel	142-5-20 ⁵	F	3800	2240
CS2	corn-soybean	soybean	3.5	no till	0-0-0		1970	1040
		corn	11.0	no till	136-4-19 ⁵	L,F	3910	2300
system mean							2940	1670
CS3	organic grain	soybean	3.2	chisel	0-0-0		1750	920
		winter wheat (green manure) ⁶	3.7	field cultivate	0-0-0		1850	850
		corn	8.6	chisel	146-0-0	L	3140	1810
		system mean		2240	1200			
----- Dairy Forage Systems -								
CS4	conventional forage	alfalfa seeding	6.0	chisel	241-23-160	M1	3390	720
		alfalfa	10.7	none	0-0-0		800	2880
		alfalfa	9.2	none	0-0-0		1140	9170
		corn	12.3	chisel	240-24-168	L, F, M1	6890	2560
		system mean		3050	3840			
CS5	organic forage	oat-alfalfa seeding	8.1	chisel	182-17-120	M1	2830	1770
		alfalfa	11.1	none	0-0-0		1280	8150
		corn	10.0	chisel	176-16-117	L, M1	5560	2110
		system mean		3220	4010			
CS6	pasture	mixed pasture ⁷	8.4	none	52-5-31	M2	1590	4570

¹Forage yields reported at 100% DM, corn yields at 84.5% DM, soybean yields at 87% DM, and wheat yields at 86.5% DM.

²First-year legume and manure credits included where applicable based on Univ. of Wisconsin Ext. Bulletin A2809 (Laboski 2006).

³Soil C inputs were estimated based on harvest index and shoot/root ratios from Bolinder et al., 2007; includes C from post-harvest residue, green manure, dairy cow manure, roots and root exudates.

⁴F = commercial fertilizer; L=legume plowdown; M1: Semi-solid manure (155 g kg⁻¹ solids) was applied through fall of 2004 and slurry manure (87 g kg⁻¹ solids) was applied since, following UW recommendations (Laboski, 2006). Manure applied in the fall prior to corn planting and alfalfa seeding. Total N additions 115 kg total N ha⁻¹ yr⁻¹ from solid manure and 140 kg total N ha⁻¹ yr⁻¹ from slurry averaged over the rotation. M2: 65 kg total N ha⁻¹ yr⁻¹ deposited by five grazing heifers on 1.2 ha at 150 days

⁵Nitrogen rates were adjusted according to the pre-plant nitrate test (Bundy et al., 1995).

⁶Red clover frost seeded or drilled into winter wheat in early spring through 2005; berseem clover and oats were planted after wheat harvest for improved weed control post-2005.

⁷Pasture mix: Timothy (*Phleum pratense* L.), brome grass (*Bromus inermis* L.), orchardgrass (*Dactylis glomerata* L.) and red clover (*Trifolium pratense* L.). Red clover was re-seeded every two or three years with a NT drill

Table 2. Bulk density data from WICST: 1989 and 2009¹

		-----Mg m ⁻³ -----			
System	Depth	1989	2009	Δ	pr > t
CS1	0-15 cm	1.15	1.23	0.08	0.1221
	15-30 cm	1.31	1.34	0.03	0.5016
CS2	0-15 cm	1.12	1.30	0.18	<0.0001
	15-30 cm	1.31	1.38	0.07	0.0322
CS3	0-15 cm	1.18	1.30	0.12	<0.0001
	15-30 cm	1.30	1.36	0.06	0.0574
CS4	0-15 cm	1.17	1.22	0.05	0.0240
	15-30 cm	1.30	1.29	-0.01	0.7563
CS5	0-15 cm	1.19	1.25	0.06	0.0283
	15-30 cm	1.35	1.33	-0.02	0.3400
CS6	0-15 cm	1.08	1.20	0.12	0.0139
	15-30 cm	1.25	1.27	0.02	0.6417

¹Bulk density numbers and significance tests were calculated using the ESTIMATE statement within PROC MIXED, SAS v. 9.1.3

Table 3. Initial 1989 (T₀) SOC data from the WICST trial¹

		----- g SOC kg soil ⁻¹ -----					
Source	Depth	N	Average	Range	Std. dev.	Std. Err	CV (%)
Baseline Sampling Grid	0-15 cm	161	26.3	24.35	5.3	0.4	20.3
	15-30 cm	164	20.6	34.3	7.1	0.6	34.5
	30-60 cm	109	10.7	38.1	6.9	0.7	64.4
	60-90 cm	128	5.3	12.3	2.0	0.2	38.8

¹All values were calculated using the MEANS procedure, SAS v. 9.1.3

Table 4. Full model results for SOC concentration (g kg⁻¹) and mass (Mg ha⁻¹)

Type 3 Tests of Fixed Effects		----- g kg ⁻¹ -----		----- Mg ha ⁻¹ -----	
effect	ndf	ddf ¹	pr > F	ddf	pr > F
time	1	103	0.0089	104	0.0062
system	5	102	0.0020	103	0.0263
time*system	5	102	0.7313	103	0.7360
depth	3	904	<0.0001	914	<0.0001
time*depth	3	904	0.0075	914	0.5691
system*depth	15	933	0.0275	958	0.0095
time*system*depth	15	933	0.4176	958	0.9395

¹Kenward-Roger method used to approximate denominator degrees of freedom in PROC MIXED (SAS v.9.1.3)

Table 5. Model estimates and significance tests of initial and final SOC concentrations at WICST¹

System	Depth	g SOC kg soil ⁻¹				Mg SOC ha ⁻¹			
		1989	2009	Δ	pr > t ²	1989	2009	Δ	pr > t
CS1	0-15 cm	28.6	23.5	-5.1	*	50.3	41.5	-8.8	ns
	15-30 cm	21.8	17.0	-4.8	*	42.9	33.9	-9.0	ns
	30-60 cm	11.5	8.2	-3.3	ns	50.5	35.4	-15.1	*
	60-90 cm	5.9	4.3	-1.6	ns	28.3	19.3	-9.0	ns
	weighted sum³			-3.3			sum	-41.9	0.0332
CS2	0-15 cm	24.2	22.7	-1.5	ns	40.9	38.2	-2.7	ns
	15-30 cm	19.7	16.3	-3.4	*	38.6	33.2	-5.4	ns
	30-60 cm	8.6	8.2	-0.4	ns	38.4	37.7	-0.7	ns
	60-90 cm	5.2	3.8	-1.4	ns	22.6	18.5	-4.1	ns
	weighted sum			-1.4			sum	-12.9	0.3479
CS3	0-15 cm	25.8	22.8	-3.0	*	46.4	41.0	-5.4	ns
	15-30 cm	19.8	16.3	-3.5	**	39.1	33.5	-5.6	ns
	30-60 cm	8.1	7.8	-0.3	ns	37.9	36.5	-1.4	ns
	60-90 cm	4.6	3.4	-1.2	ns	20.6	15.9	-4.7	ns
	weighted sum			-1.6			sum	-17.1	0.1263
CS4	0-15 cm	27.6	26.8	-0.8	ns	49.0	47.4	-1.6	ns
	15-30 cm	21.8	19.1	-2.7	*	42.8	38.1	-4.7	ns
	30-60 cm	10.1	10.2	0.1	ns	43.3	41.6	-1.7	ns
	60-90 cm	5.1	4.4	-0.7	ns	22.6	19.6	-3.0	ns
	weighted sum			-0.8			sum	-11.0	0.2502
CS5	0-15 cm	25.6	24.5	-1.1	ns	46.4	44.0	-2.4	ns
	15-30 cm	19.8	17.7	-2.1	ns	40.5	35.8	-4.7	ns
	30-60 cm	9.0	7.8	-1.2	ns	37.7	33.3	-4.4	ns
	60-90 cm	5.3	4.4	-0.9	ns	24.4	19.6	-4.8	ns
	weighted sum			-1.2			sum	-16.3	0.1466
CS6	0-15 cm	26.8	31.1	4.3	†	43.9	51.1	7.2	ns
	15-30 cm	22.9	23.2	0.3	ns	42.8	44.6	1.8	ns
	30-60 cm	13.6	11.8	-1.8	ns	54.0	48.6	-5.4	ns
	60-90 cm	5.8	4.5	-1.3	ns	24.8	20.9	-3.9	ns
	weighted sum			-0.3			sum	-0.3	0.9901

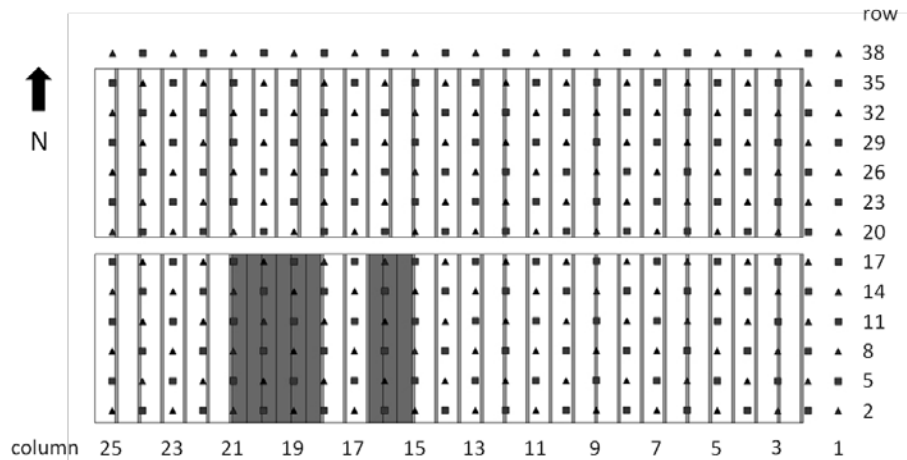
¹ All values and significance tests were calculated using comparison specific ESTIMATE statements within PROC MIXED, SAS v. 9.1.3. Numbers represent modeled estimates and not mathematical means as appear in Table 3.

² Pr > |t|, ns=not significant at the $\alpha=0.1$ level, † p<0.1, * p<0.05, ** p<0.01

³ Weighted Sum = (SOC conc. 0-15 cm x 1/6) + (SOC conc. 15-30 cm x 1/6) + (SOC conc. 30-60 cm x 1/3) + (SOC conc. 60-90 cm x 1/3)

Table 6 A & B. Four cropping system indices (A) and their correlation with change in SOC ($T_{20}-T_0$)

A. Correlation Indices for WICST Cropping Systems				----- Estimated Carbon Inputs ³ -----	
System	Description	Tillage ¹	Manure ²	Above Ground	Below Ground
CS1	Continuous corn	1	0	1	0.49
CS2	NT, C-sb	0	0	0.77	0.37
CS3	Organic grain (C-sb-w/clov)	1	0	0.59	0.26
CS4	Forage (C-a-A-A)	0.5	0.5	0.80	0.84
CS5	Organic Forage (C-o/a-A)	0.67	0.67	0.85	0.88
CS6	Rotational Grazing	0	1	0.42	1
B. Correlation between System Indices and Change in SOC over time					
		Tillage	Manure	C-Above Ground	C-Below Ground
Depth		r			
g SOC kg soil ⁻¹	0-15 cm	-0.19*	0.26***	-0.09	0.24**
	15-30 cm	-0.09	0.12	-0.05	0.10
	30-60 cm	-0.03	0.02	-0.02	0.02
	60-90 cm	-0.08	0.10	-0.04	0.01
	whole profile	-0.10*	0.13**	-0.05	0.11**
Mg SOC ha ⁻¹	0-15 cm	-0.20	0.25	-0.09	0.23**
	15-30 cm	-0.11	0.08	-0.08	0.05
	30-60 cm	-0.09	-0.02	-0.05	-0.03
	60-90 cm	-0.12	0.08	-0.07	0.07
	whole profile	-0.11**	0.07	-0.06	0.05

¹The frequency of tillage over the entire rotation where each tilled phase = 1²The frequency of manure application, each manured phase = 1³Estimated C inputs are taken from Table 1: the correlation index for each system is relative to the system contributing the most total biomass: above ground = CS1, below ground = CS6.*Probability > |r| under H0: $\rho=0$, $p<0.10$ *Probability > |r| under H0: $\rho=0$, $p<0.05$ **Probability > |r| under H0: $\rho=0$, $p<0.01$ ***Probability > |r| under H0: $\rho=0$, $p<0.001$ **Fig. 1: WICST 1989 soil sampling grid overlaid on current plot locations. Squares represent sampling points where deep soil cores were collected in 1989. The WICST Plots (Non-shaded) are 18m wide by 155m long. The shaded area represents a nested trial that is not discussed in the current analysis.**

SOIL ORGANIC CARBON CHANGES IN SIX MIDWESTERN CROPPING SYSTEMS IN SOUTHERN WISCONSIN

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Independent Study 699

INTRODUCTION

Soils form the largest terrestrial pool for carbon (C) and have the potential to sequester C and mitigate greenhouse gas emissions. Practices that increase the photosynthetic input of C to the soil, or slow the emission of CO₂ back to the atmosphere, can increase the potential of soils as a carbon sink. The International Panel on Climate Change (IPCC) estimates soil carbon sequestration to be 89% of the worldwide technical mitigation potential (Smith et al., 2007). As a result, although currently agriculture is estimated to be responsible for up to 14%, or 1.32 Gt of C/yr, of anthropogenic greenhouse gas emissions (Lal, 2009), improved management practices and cropping systems that enhance the potential of soil as a C sink could make agriculture part of the solution to climate change, rather than only part of the problem.

No-till agricultural systems have been identified as a management practice that can lead to increased C sequestration in the soil. In addition, this technique requires less fuel, further reducing C emissions. West and Post (2002) performed a meta-analysis of 67 global, long-term agricultural experiments and found that the conversion from conventional tillage to no-till management on average resulted in C sequestration rates of $48 \pm 13 \text{ g C m}^{-2} \text{ yr}^{-1}$ ($480 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$). These changes were observed in the first 15 cm of depth, whereas no significant change in soil organic carbon (SOC) was found in the 15-35 cm depth. Similarly, in a study performed at six locations in Ohio, Mishra et al. (2010) found higher SOC concentrations in no-till management versus conventional tillage in the 0-10 cm layer ($28.0 \pm 5.7 \text{ g kg}^{-1}$ vs. $11.3 \pm 4.9 \text{ g kg}^{-1}$ respectively), whereas no difference between the tillage treatments was observed at the 10-20 cm depth.

However, these and other tillage studies on C sequestration often fail to take into account the entire soil profile, mostly focusing only on the upper 30 cm. Agricultural practices, including tillage, fertilizer or manure applications, and crop type, have large implications on C distribution and decomposition throughout the soil profile, and should be examined in soil layers beyond the surface plow layer (Six et al., 1999). Luo et al. (2010) performed a meta-analysis of 69 studies examining the effects of tillage on SOC concentrations, selecting only studies that sampled soils deeper than 40 cm. They found that SOC levels decreased in all depths under all cropping systems, regardless of tillage treatment, when compared with adjacent natural systems. Declines were found to be greater in conventionally-tilled treatments than no-till. As with West and Post (2002) and Mishra (2010), Luo (2010) found that the conversion from conventional-till to no-till resulted in increased soil C accumulation in the surface 30 cm of soil; however, when all soil layers (>40 cm) were taken into account, the entire soil profile on average was found to be stable with no increase or loss in soil C. They also found that SOC levels decreased in all depths under all cropping systems, regardless of tillage treatment, when compared with adjacent natural systems, and declines were higher in conventionally-tilled treatments than no-till. Consequently, the potential of no-till systems alone to sequester C has limitations, as C accumulation is limited to the surface soil layers that form a small percentage of the overall soil profile. Furthermore, rates of SOC accumulation following a conversion from conventional-till to no-till are not linear; in fact, the majority of SOC change is believed to occur within the first 10-15 years following

implementation (West and Post, 2002). Linear rates of SOC accrual will not be sustained over time as soils approach their “natural” steady state SOC levels (Kucharik, 2007).

Organic matter additions (usually dictated by the amount or type of biomass production of an agricultural system) also play an important role in SOC dynamics. Increasing organic matter returns to a system by planting more productive crops or by implementing a more complex rotation leads to higher SOC storage, compared to less productive systems (Ogle et al., 2005). For example, increased productivity in corn was shown to increase SOM and SOC soil inputs (Bundy et al., 2011). Organic fertilizers like farmyard manure and slurry have also been shown to increase soil organic matter content of a soil (Haynes and Naidu, 1998). Annual inputs of sheep manure were shown to be similar to the SOM contributions of corn stubble and root residues (Thomsen and Christensen, 2010). In central Iran, Hemmat et al. (2010) found that SOC was significantly affected by the addition of farmyard manure, which increased SOC on average by 2.2 times that of plots not receiving manure amendments. Additionally, in Michigan Thelen et al. (2010) report that manure amendments raise SOC levels enough to overcome the carbon removed from soils during livestock production and C debts associated with manure application. Slurry has been found to increase SOC as well, though not at levels as great as those of farmyard manure. In a study in Italy comparing farmyard manure and slurry in increasing SOC, Bertora et al. (2009) found that high inputs (40 Mg ha⁻¹) of farmyard manure resulted in the highest SOC content. Low farmyard manure inputs (20 Mg ha⁻¹) and slurry applications from 50-100 Mg ha⁻¹ resulted in similar SOC increases; however levels were less than those found in the high-input farmyard manure treatment. Therefore, manure and slurry can serve as tools for agricultural producers to return and retain carbon in their soils, though slurry’s potential to increase C sequestration is less than that of farmyard manure.

Additionally, green manures and crop residues have also been shown to increase SOC content of soils. In paddy soil in China, Li et al. (2010) found that applications of rice straw and green manures both significantly increased SOC, and Majumder et al. (2008) report that SOC was increased in soils with farmyard manure, paddy straw, and green manure treatments, with 67.8, 57.3, and 49.0% respectively of the C applied stabilized in the form of SOC. This shows that while carbon in farmyard manure is more resistant to decomposition than that of residues and green manure, all three can contribute significantly to the SOC pool.

Carbon partitioning in a crop can also play an important role in how much carbon it contributes to a stable SOC pool. Crops that contribute larger amounts of belowground biomass to the soil (i.e., have smaller shoot: root ratios) have the potential to sequester more C than crops that produce more aboveground biomass. Systems typical to the Midwest are comprised of intensively managed corn (*Zea mays* L.) and soybean (*Glycine max* L.), crops with shoot: root ratios averaging 5.6 and 5.2, respectively. In contrast, forages including grasses and legumes were found to have shoot: root ratios ranging from 1-2, much lower than that of annual crops. Forage legumes were found to have shoot: root ratios nearly twice those of grasses. (Bolinder et al., 2007) In comparing alfalfa (*Medicago sativa* L.), a perennial leguminous forage, to grass forages, Syswerda et al. (2011) found that an alfalfa rotation resulted in a significantly lower SOC concentration in the 0-30 cm depth than in no-till native successional communities, whereas levels were similar in the 30-60 cm depth. This suggests that forages contribute a higher percentage of their biomass to the soil in a form that favors C sequestration, compared to annuals, and that forage grasses contribute even more root biomass to the SOC pool than forage legumes. Therefore, cropping systems that include more forage phases (usually accompanied by

less tillage) have higher root biomass production and larger contributions to soil organic C, whereas annuals like corn and soybean contribute less belowground biomass to the soil.

In addition to accumulating a higher proportion of total annual primary productivity in the roots, the forage grasses actually add root biomass when they are grazed. Forages accumulate more C in soils than grain crops due to a higher allocation of photosynthate to root biomass production (Schmidt et al., 2011), which is stimulated and increased by grazing (dos Santos et al., 2011); therefore, grazed cool-season pastures have the potential to be an agricultural system with high C sequestration potential. Grassland ecosystems are currently estimated to contain 306 to 330 Pg C worldwide (Batjes, 1996) and studies have found grazing to increase SOC stocks in grasslands when compared to ungrazed treatments (Liebig et al. 2010, Piñeiro et al. 2010). Because root-derived carbon is retained in soils more efficiently than above-ground OM inputs (Schmidt et al., 2011) and is a more important contributor to SOC (dos Santos et al., 2011), grasses contribute higher amounts of C to the soil than other forages. Jokela et al. (2011), studying the soils at the Arlington site, did find more total organic carbon in an intensively-managed, grazed pasture than other grain- and alfalfa-based cropping systems. Fisher et al. (1994) working in Colombia report belowground C increases of 25-70 t/ha within 5-10 years of establishing grassland pasture. Since perennial grasses are rarely tilled, they also minimize soil erosion and organic matter oxidation, further helping to accumulate SOC.

In addition to management practices, the inherent soil characteristics of a site can play a large role in its ability to serve as a C sink. For example, high soil moisture slows the rate of decomposition of organic matter in the soil (Trumbore and Harden, 1997) and can in semi-arid areas enhance biomass production, contributing to organic matter and residue accrual (Knapp et al., 1993). In a study examining the effect soil moisture exerts on SOC dynamics in prairies in Illinois, O'Brien et al. (2010) found that higher soil moisture was correlated with faster SOC accumulation. They hypothesized that the temporary hydromorphic conditions resulted in lower oxidation rates of the carbon, more effectively preserved in high-moisture conditions than well-drained systems. However, while un-drained to even hypoxic soil conditions may contribute to improved C preservation, anaerobic soil conditions promote the emission of methane (CH₄), a greenhouse gas (GHG), which is often mitigated through aeration by draining. Furthermore, anaerobic-aerobic cycling increases denitrification and the subsequent release of nitrous oxide (N₂O), another potent greenhouse gas (Cai et al., 1997). As a result, poorly drained soils may facilitate both C sequestration and the emission of methane and nitrous oxides.

The purpose of this study is to compare the six cropping systems of WICST over their initial 12 years at the wetter LAC and better-drained ARL sites for their impact on soil carbon concentrations. We hypothesize the following: 1) initial SOC levels will be higher at the wetter site (LAC>ARL); 2) since all the systems are operated following best management practices, and on productive soils, we will see little impact of cropping system on farm level SOC concentrations after only 12 years; 3) however, if we look at specific phases of the systems and different soil depths, we will identify large differences on their annual impact on SOC.

MATERIALS AND METHODS

The soils used in this analysis were collected from the Wisconsin Integrated Cropping Systems Trial (WICST), which was established in 1989 at two locations in southern Wisconsin. The objective of the trial is to compare the productivity, profitability, and environmental impact of six cash-grain and forage systems common in the Midwest that differ primarily in crop

diversity (Posner et al, 1995). The long-term study includes three cash-grain systems: conventional continuous corn (CS1), conventional no-till corn-soybean (CS2), and organic corn-soybean-wheat/red clover (CS3). The three dairy forage systems include conventional corn-alfalfa-alfalfa-alfalfa (CS4), organic corn-oat/alfalfa-alfalfa (CS5), and an intensive rotationally grazed pasture (CS6). The three dairy forage systems receive manure amendments; CS4 and CS5 are amended with 15-20 T/a before and after the corn phase, and in CS6 the manure deposited by the heifers while grazing is left on the field. The trial is laid out in a randomized complete block design, with the four blocks containing 14 plots each, as all phases of the six systems are replicated 4 times each year. Plots were about 0.3 ha in size at both locations.

Soils were sampled at both sites: the Arlington Research Station (ARL) near Madison, WI, and the Lakeland Agricultural Complex (LAC) near Elkhorn, WI. Previously, the ARL site had been in an alfalfa-alfalfa-corn rotation for 10 years and the field had a history of heavy manuring prior to and following the corn phase. The LAC site had been in two-thirds corn production and one-third alfalfa and grass for the previous three years (Posner, 1989-1991). The soil at ARL is a well-drained Plano silt loam (fine-silty, mixed, superactive, mesic Typic Argiudolls) formed from loess on slopes of 0-2%. Soils at LAC are more poorly-drained, and include a Griswold silt loam (fine-loamy, mixed, superactive, mesic Typic Argiudolls, slope 2-4%) and Pella silt loam (fine-silty, mixed, superactive, mesic Typic Endoaquolls, slope 0-2%). To improve the drainage at LAC, drainage tile had been installed prior to the establishment of WICST under the lowest-lying portion of the field, falling under the fourth replication. The LAC site was terminated in 2002, while study of WICST at ARL continues.

Soils were sampled at one place in each plot to the depths of 0-15 cm, 15-30 cm, 30-60 cm, and 60-90 cm in the years 1990 and 2001 at both sites. Soil cores were taken with a 3.2 cm probe while walking diagonally across a plot; with two cores taken in the top third, middle third, and bottom third of each plot. The six subsamples from a plot were composited to form 1 sample/depth/plot, and the four blocks of the trial were sampled to obtain in total 4 soil samples/depth/phase for the year of establishment as well as in 2001 (t=12 years). Due to termination of LAC in 2002, only ARL was sampled in 2007 (t=18 years).

Table 1. Plots Sampled for SOC in the Fall of 1990, 2001 and 2007

System	Crop Phase	ARL 1990, 2001, 2007				LAC 1990, 2001			
		Rep 1	Rep 2	Rep 3	Rep 4	Rep 1	Rep 2	Rep 3	Rep 4
1	Corn	109	204	306	412	101	210	303	401
2	Soybean	101	214	303	401	113	206	311	410
3	Soybean	106	202	307	411	107	205	307	406
4	Alfalfa	111	209	305	409	103	202	310	411
5	Oat/A	110	208	304	413	106	211	312	413
6	Pasture	112	207	302	405	104	213	314	408

Since the WICST trial was established with a staggered start, the plot established in 1990 in each system was selected for sampling. The Arlington Agricultural Research Station (ARL) and the Lakeland Research Complex (LAC) were two sites that contained the WICST trial, and were locations where sampling was performed. The same plots were sampled again in 2001, and the same plots sampled again in 2007 only at ARL.

Samples were then ground and hand-picked to remove all visible organic matter. Approximately 3 mg of each soil was placed in centrifuge tubes and pulverized on a shaker. These pulverized soils were rolled into aluminum tins between 8 and 10 mg in weight, and run through an Electric Corp. Flash EA 1112 Elemental analyzer to measure concentrations of carbon.

Statistical Analysis

To compare the two sites, the MIXED procedure in SAS v 9.1 was used (SAS Institute, 1999). The repeated statement with an autoregressive covariance structure was used to account for spatial autocorrelation between soil samples within a plot from different depths. Site, year, system, and plot were treated as fixed effects, and only the 1990 and 2001 data sets from both sites were included for direct comparison. For the analysis of the full set of data from 1990-2007 (3 sampling years) only at ARL, an ANCOVA method was used in SAS PROC MIXED to evaluate change in C concentration over the course of the 18 years sampled.

RESULTS AND DISCUSSION

Aboveground and belowground C inputs on average were greater in all systems at ARL than at LAC, mostly due to higher yields at ARL. As expected, significant differences in SOC concentrations were found between the two sites ($p = 0.0674$) as well as by depth at the initiation of the trial in 1990. In addition there was a highly significant site x depth interaction ($p < 0.0001$) (Figure 1). The difference between sites is probably due to higher natural levels of carbon at the LAC site, which is most likely caused by greater C preservation in the high-moisture system. Overall, LAC was found to have about 21% more soil organic carbon when averaged across all depths than ARL, prior to the establishment of the trial. The increase in carbon concentration at 60-90 cm at LAC and not ARL is most likely due to the perched water table at the former site. At the better drained Arlington site, concentrations decrease by depth at a steady rate.

For the period 1990-2001 no significant main effect of SOC concentration change by profile ($p = 0.3149$) was found, nor was there a site x year interaction. While arithmetically SOC decreased from 1990 to 2001 at both sites, the losses were not large enough to be significant. Losses in SOC however were larger at LAC than at ARL, supporting the hypothesis that SOC is lost at a higher rate when background carbon levels are higher (Bellamy et al. 2005, Schmidt et al. 2011) and carbon additions lower.

However, some unexpected and expected trends in SOC were observed at some depths within a system. Due to frequent mechanical weed control passes, the organic grain systems (CS3) at both sites experienced a drop in SOC concentration at 0-15 cm and 15-30 cm. At LAC, but not ARL, the two alfalfa-based systems (CS4 & CS5) did show carbon increases at 0-15 cm. Our monitoring indicates that the solid manure from the LAC dairy contained more dry matter than at ARL (on average, 31.5 and 14.9 percent dry matter, respectively). While manure application rates were similar at both sites (10-15 t/a), more dry matter and therefore more carbon was added at LAC than at ARL through the manure source. We had expected to see the greatest increases in surface SOC in the no-till system (CS2) as well as the rotationally grazed paddocks (CS6). However, concentrations of SOC after 8 years of no-till cropping showed no real trend of increase in the surface layers (0-15; 15-30 cm) at either site. It is not perfectly clear why a sharp decrease in SOC concentration was observed in the 15-30 cm range in CS6 at LAC. After the very wet 1996 grazing season, the paddocks at LAC needed to be re-established, and

we hypothesize that the high amounts of tillage performed may have resulted in significant carbon losses from the plow layer (Table 3).

While our results indicate distinct differences in C sequestration in the two sites due to the inherent natural characteristics of each site, overall, no statistically significant change in SOC concentration was observed over the 12-year period of analysis. However, trends show the majority of cropping systems lost carbon, with a few showing gains after 12 years, and the lack of significance is likely due to spatial and temporal sampling restrictions caused by the termination of the LAC site. With a longer time span, it may be possible to more clearly see trends in the way that alternative cropping systems impact SOC.

Overall, the trends observed after 12 years at ARL were maintained through year 18 (2007) (see Figure 2 a-f). Although not every horizon had a significantly negative slope for SOC, there was a downward trend for all three grain rotations (CS1, 2, 3), the two alfalfa-based rotations (CS4 & 5) were relatively flat, and the grazing system (CS6) exhibited a steady increase in SOC levels, mostly in the 0-15 and 15-30 cm depths.

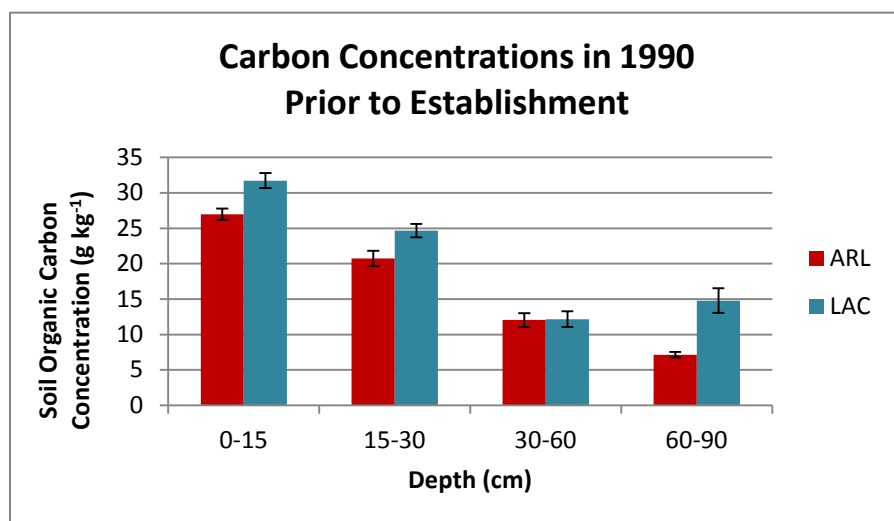
These results indicate an overall downward trend of SOC concentration in agricultural soils, with the exception of the cool-season pasture, which accumulated carbon due to large increases in concentration in the two upper depths despite losses in lower depths. Data sets across large spatial and temporal scales corroborate these findings, showing that long-term carbon losses in soils are occurring despite their potential as a sink for atmospheric C (Bellamy et al., 2005). This could be due to the management practices used on these soils, or to increased rates of loss as an effect of higher global temperatures. While overall significant losses were not found at LAC after 12 years of agricultural production, results at ARL indicate that losses may have been observed in the future, even after just 6 more years. This highlights the need for long-term studies to analyze changes in SOC concentration in agricultural soils on larger decadal time scales to gain a true understanding of how agricultural practices affect C sequestration.

Table 2. Carbon Inputs at ARL and LAC 1992-2002

Cropping System	Phase	ARL							LAC						
		----- kg ha ⁻¹ -----							----- kg ha ⁻¹ -----						
		Avg. Yield	Above-Ground (phase)	Below-Ground (phase)	Total (phase)	Above-Ground (sys)	Below-Ground (sys)	Total (sys)	Avg. Yield	Above-Ground (phase)	Below-Ground (phase)	Total (phase)	Above-Ground (sys)	Below-Ground (sys)	Total (sys)
		Mg ha ⁻¹	Cash Grain Systems						Mg ha ⁻¹	Cash Grain Systems					
1	corn	10.06	3567	2102	5669	3567	2102	5669	6.56	2327	1371	3698	2327	1371	3698
2	corn	10.45	3707	2185	5892	2815	1601	4416	8.08	2864	1688	4552	2379	1344	3723
	soybean	3.51	1923	1017	2941				3.46	1893	1001	2895			
3	corn	8.91	3158	1861	5019				5.99	2124	1252	3376			
	soybean	3.19	1746	923	2669	2254	1214	3468	2.76	1510	798	2308	1713	859	2572
	wheat/rc	3.57	1858	857	2715				2.84	1506	526	2032			
4	corn seeding hay 1 hay 2	Mg DM ha ⁻¹	Dairy Forage Systems						Mg DM ha ⁻¹	Dairy Forage Systems					
		11.61*	6700	2363	9062				8.50*	8902	1744	10646			
		6.53	3174	776	3950	2956	3780	6736	3.28	6298	343	6641	4167	2948	7115
		10.33	765	2761	3526				7.57	561	2024	2585			
		9.16	1185	9221	10406				7.94	907	7681	8589			
5	corn	10.12*	5606	2115	7721				7.38*	7843	1541	9384			
	oat/alf	8.77	2627	1712	4338	3170	4041	7211	6.21	5641	1103	6744	4890	3122	8012
	hay 1	11.34	1276	8296	9573				8.82	1187	6721	7909			
6	pasture	8.60	1588	4475	6063	1588	4475	6063	6.60	3111	3103	6214	3111	3103	6214

Above-ground and below-ground inputs of carbon were calculated for each system from 1990 to 2002 (the duration of the trial at LAC) from biomass, residue, root sampling, and known shoot: root ratios. Inputs are shown for each phase in a system (averaged over the four replications and over the span of 1990-2002), and the inputs for the system as a whole are averages of the phase inputs. Yields were calculated as *ls* means for each phase, from 1990-2002.

* = yield in Mg ha⁻¹

Figure 1. Natural Carbon Levels in WICST—Two Sites

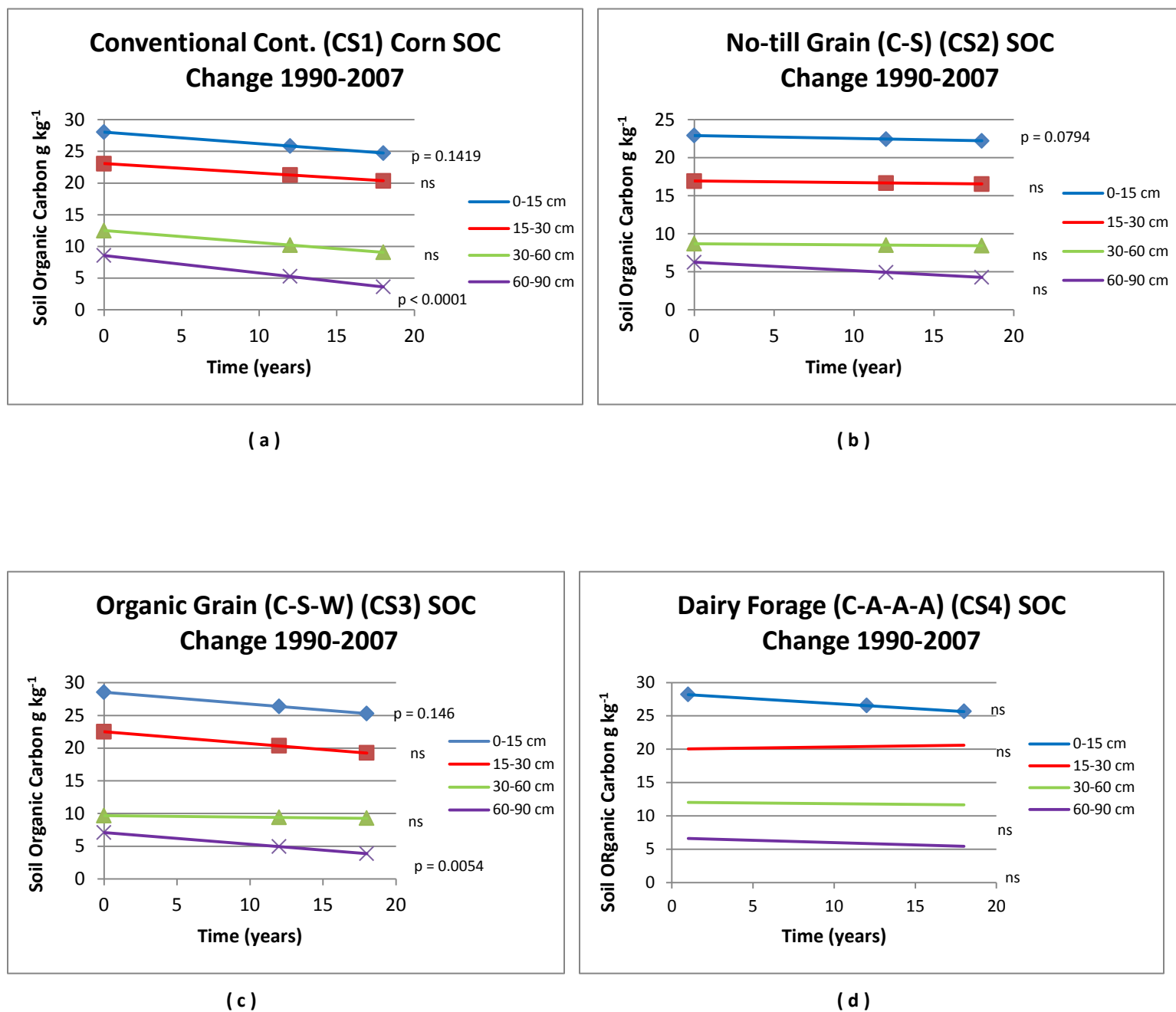
Soil organic carbon concentrations were calculated as least-square means of all plots sampled in a depth at each site. Error bars were calculated as standard error of the mean. Carbon concentrations between sites were found to be significantly different, where $p = 0.07$.

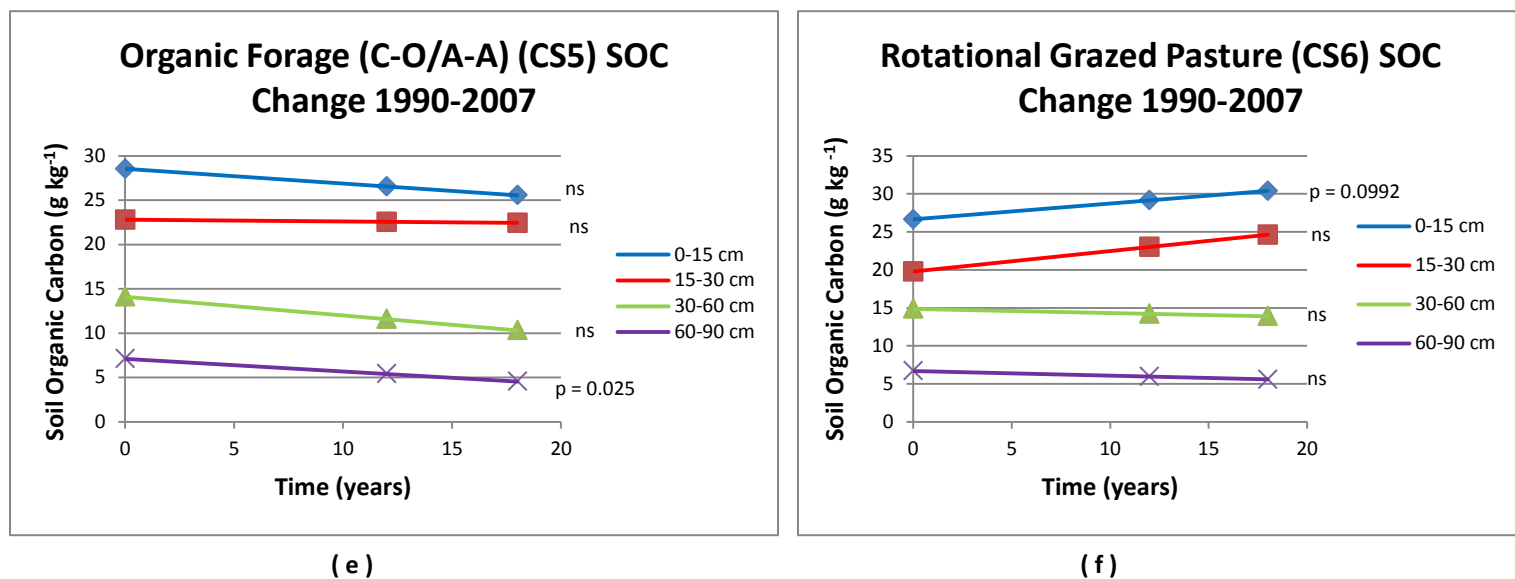
Table 3. SOC Concentration Changes Over 12 Years—Two Sites

ARLINGTON					LAKELAND				
System	Depth	Carbon Concentration (g kg soil ⁻¹)			System	Depth	Carbon Concentration (g kg soil ⁻¹)		
		1990	2001	Δ			1990	2001	Δ
CS1	0-15 cm	27.46	26.97	-0.49	CS1	0-15 cm	28.11	29.00	0.90
	15-30 cm	22.44	22.65	0.21		15-30 cm	22.64	23.35	0.71
	30-60 cm	12.07	10.88	-1.18		30-60 cm	15.81	10.66	-5.14
	60-90 cm	8.63	4.31	-4.31		60-90 cm	15.44	11.72	-3.72
		total =		-1.88			total =		-2.69
CS2	0-15 cm	22.63	23.19	0.56	CS2	0-15 cm	31.11	30.84	-0.27
	15-30 cm	16.42	18.09	1.66		15-30 cm	23.44	25.65	2.22
	30-60 cm	8.60	8.73	0.13		30-60 cm	13.76	8.96	-4.80
	60-90 cm	6.40	4.20	-2.20		60-90 cm	15.80	12.00	-3.81
		total =		-0.32			total =		-2.55
CS3	0-15 cm	28.18	26.85	-1.33	CS3	0-15 cm	30.68	24.75	-5.94
	15-30 cm	22.41	20.08	-2.33		15-30 cm	23.81	20.91	-2.91
	30-60 cm	9.54	9.72	0.18		30-60 cm	8.98	9.83	0.85
	60-90 cm	7.15	4.22	-2.93		60-90 cm	13.87	14.68	0.81
		total =		-1.53			total =		-0.92
CS4	0-15 cm	28.09	26.79	-1.30	CS4	0-15 cm	31.50	34.73	3.23
	15-30 cm	19.83	21.08	1.24		15-30 cm	23.53	17.23	-6.30
	30-60 cm	12.03	11.84	-0.19		30-60 cm	12.18	9.80	-2.38
	60-90 cm	6.85	5.21	-1.64		60-90 cm	11.17	8.52	-2.65
		total =		-0.62			total =		-2.19
CS5	0-15 cm	28.18	27.05	-1.13	CS5	0-15 cm	32.94	39.38	6.44
	15-30 cm	22.58	23.06	0.48		15-30 cm	25.42	23.39	-2.03
	30-60 cm	14.02	11.25	-2.76		30-60 cm	9.39	9.72	0.33
	60-90 cm	7.12	5.02	-2.10		60-90 cm	15.06	13.52	-1.54
		total =		-1.73			total =		0.33
CS6	0-15 cm	26.72	30.28	3.56	CS6	0-15 cm	36.06	37.07	1.00
	15-30 cm	20.19	24.19	4.00		15-30 cm	29.11	18.66	-10.45
	30-60 cm	15.40	13.55	-1.84		30-60 cm	11.47	11.38	-0.10
	60-90 cm	6.80	5.53	-1.27		60-90 cm	17.41	21.81	4.40
		total =		0.22			total =		-0.14

Soil organic carbon concentrations were averaged among the 4 replications to obtain an average C concentration per depth per year. The total change in C is a weighted sum of the C change from 1990 to 2001 over the four depths according to each depth's fraction of the whole profile, where $\text{total } \Delta_{\text{profile}} = (1/6) \cdot \Delta_{0-15} + (1/6) \cdot \Delta_{15-30} + (1/3) \cdot \Delta_{30-60} + (1/3) \cdot \Delta_{60-90}$. This represents the total change in C concentration throughout the entire soil profile.

Figure 2. Soil Organic Carbon Changes Over 18 Years at ARL





The PROC MIXED ANCOVA model was used to generate regression equations for the carbon change in each system over 18 years at ARL. A regression line was calculated and is displayed for each depth sampled in each system. P values displayed indicate depths where change was found to be significant, whereas *ns* indicates no significant change.

REFERENCES

- Abid, M. and R. Lal. 2008. Tillage and drainage impact on soil quality I. aggregate stability, carbon and nitrogen pools. *Soil & Tillage Res.* 100:89-98
- Batjes, N.H. 1996. Total carbon and nitrogen in the soils of the world. *Eur. J. Soil Sci.* 47:151-163
- Bellamy, P.H., Loveland, P.J., Bradley, R.I., Lark, R. M., and G.J.D. Kirk. 2005. Carbon losses from all soils across England and Wales 1978–2003. *Nature* 437: 245-248
- Bertora, C., Zavattaro, L., Sacco, D., Monaco, S., and C. Grignani. 2009. Soil organic matter dynamics and losses in manured maize-based forage systems. *Europ. J. Agronomy* 30: 177-186
- Bolinder, M.A., Janzen, H.H., Gregorich, E.G., Angers, D.A., and A.J. VandenBygaart. 2007. An approach for estimating net primary productivity and annual carbon inputs to soil for common agricultural crops in Canada. *Agric., Ecosys., and Environ.* 118: 29-42
- Bundy, L.G., Andraski, T.W., Ruark, M.D., and A.E. Peterson. 2011. Long-term continuous corn and nitrogen fertilizer effects on productivity and soil properties. *Agron. J.* 103: 1346-1351
- Cai, Z., Xing, G., Yan, X., Xu, H., Tsuruta, H., Yagi, K., and K. Minami. 1997. Methane and nitrous oxide emissions from rice paddy fields as affected by nitrogen fertilisers and water management. *Plant and Soil* 196: 7-14
- David, M.B., McIsaac, G.F., Darmody, R.G., and R.A. Omonode. 2009. Long-term changes in Mollisol organic carbon and nitrogen. *J Environ. Qual.* 38: 200-211
- dos Santos, N.Z., Dieckow, J., Bayer, C., Molin, R., Favaretto, N., Pauletti, V., and J. T. Piva. 2011. Forages, cover crops and related shoot and root additions in no-till rotations to C sequestration in a subtropical Ferralsol. *Soil & Tillage Res.* 111: 208-218
- Fisher, M.J., Sanz, J.I., Thomas, R.J., Vera, R.R., Rao, I.M., Ayarza, M.A., and C.E. Lascano. 1994. Carbon storage by introduced deep rooted grasses in the South American savannas. *Nature* 371: 236-238.
- Haynes, R.J., and R. Naidu. 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. *Nutrient Cycling in Agroecosystems* 51(2): 123-137
- Hemmat, A., Aghilinategh, N., Rezainejad, Y., and M. Sadeghi. 2010. Long-term impacts of municipal solid waste compost, sewage sludge and farmyard manure application on organic carbon, bulk density and consistency limits of a calcareous soil in central Iran. *Soil & Tillage Res.* 108: 43-50
- Jokela, W., Posner, J., Hedtcke, J., Balser, T., and H. Read. 2011. Midwest cropping system effects on soil properties and on a soil quality index. *Agron. J.* 103: 1552-1562
- Kong, A.Y.Y. and J. Six. 2010. Tracing root vs. residue carbon into soils from conventional and alternative cropping systems. *Soil Sci. Soc. Am. J.* 74: 1201-1210.
- Knapp, A.K., Fahnestock, J.T., Hamburg, S.P., Statland, L.B., Seastedt, T.R., and D.S. Schimel. 1993. Landscape patterns in soil-plant water relations and primary production in tallgrass prairie. *Ecology* 74: 549–560.
- Kucharik, C.J. 2007. Impact of prairie age and soil order on carbon and nitrogen sequestration. *Soil Sci. Soc. of Am. J.* 71(2): 430-441
- Lal, R. 2009. Sequestering atmospheric carbon dioxide. *Critical Reviews in Plant Science* 28: 90-96
- Lal, R., Follett, R.F., Kimble, J., and C.V. Cole. 1999. Managing U.S. cropland to sequester

- carbon in soil. *J. of Soil and Water Conserv.* 54(1): 374-381.
- Li, Z., Liu, M., Wu, X., Han, F., and T. Zhang. 2010. Effects of long-term chemical fertilization and organic amendments on dynamics of soil organic C and total N in paddy soil derived from barren land in subtropical China. *Soil & Tillage Res.* 106: 268-274
- Liebig, M.A., Gross, J.R., Kronberg, S.L., Phillips, R.L., and J.D. Hanson. 2010. Grazing Management contributions to net global warming potential: a long-term evaluation in the Northern Great Plains. *J. Environ. Qual.* 39:799-809
- Liu, S., Tan, Z., Li, Z., Zhao, S., and W. Yuan. 2011. Are soils of Iowa USA currently a carbon sink or source? Simulated changes in SOC stock from 1972 to 2007. *Agric., Ecosys., and Environ.* 140: 106-112
- Luo, Z., Wang, E., and O.J. Sun. 2010. Can no-tillage stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments. 139: 224-231
- Majumder, B., Bandyopadhyay, B.M.P.K., Gangopadhyay, A., Kundu, P.K.M.A.L., and D. Mazumdar. 2008. Organic amendments influence soil organic carbon pools and rice–wheat productivity. *Soil Sci. Soc. Am. J.* 72: 775-785
- Mishra, U., Ussiri, D.A.N., and R.Lal. 2010. Tillage effects on soil organic carbon storage and dynamics in Corn Belt of Ohio USA. *Soil & Tillage Res.* 107: 88-96
- O'Brien, S.L., Jastrow, J.D., Grimley, D.A., and M.A. Gonzalez-Meler. 2010. Moisture and vegetation controls on decadal-scale accrual of soil organic carbon and total nitrogen in restored grasslands. *Global Change Biology* 16: 2573-2588
- Ogle, S.M., Breidt, F.J., and K. Paustian. 2005. Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. *Biogeochemistry* 72: 87-121
- Paustian, K., Andrén, O., Janzen, H.H., Lal, R., Smith, P., Tian, G., Tiessen, H., Van Noordwijk, M., and P.L. Woormer. Agricultural soils as a sink to mitigate CO₂ emissions. *Soil Use and Management* 13: 230-244
- Piñeiro, G., Paruelo, J.M., Oesterheld, M., and E.G. Jobágy. 2010. Pathways of grazing effects on soil organic carbon and nitrogen. *Rangeland Ecol. Manage.* 63(1): 109-119
- Posner, J.L. 1989-1991. Wisconsin integrated cropping system trial annual technical reports: 1. Univ. of Wisconsin, Madison.
- Posner, J.L., M.D. Casler, and J.O. Baldock. 1995. The Wisconsin integrated cropping systems trial: Combining agro-ecology with production agronomy. *Am. J. Alternative Agric.* 10: 98–107.
- SAS Institute. 1999. SAS OnlineDoc. Version 8. SAS Institute, Cary, NC.
- Schmidt, M.W.I., Torn, M.S., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I.A., Kleber, M., Kogel-Knabner, I., Lehmann, J., Manning, D.A.C., Nannipieri, P., Rasse, D.P., Weiner, S. and S.E. Trumbore. 2011. Persistence of soil organic matter as an ecosystem property. *Nature* 478: 49-56
- Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko, 2007: Agriculture. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Six, J., Elliott, E.T., and K. Paustian. 1999. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Sci. Soc. of Am. J.* 63(5): 1350-1358

- Syswerda, S.P., Corbin, A.T., Mokma, D.L., Kravchenko, A.N., and G.P. Robertson. 2011. Agricultural management and soil carbon storage in surface vs. deep layers. *Soil Sci. Soc. Am. J.* 75: 92–101
- Thelen, K.D., Fronning, B.E., Kravchenko, A., Min, D.H., and G.P. Robertson. 2010. Integrating livestock manure with a corn–soybean bioenergy cropping system improves short-term carbon sequestration rates and net global warming potential. *Biomass and Bioenergy* 34: 960-966
- Thomsen, I.K., and B.T. Christensen. 2010. Carbon sequestration in soils with annual inputs of maize biomass and maize-derived animal manure: evidence from ^{13}C abundance. *Soil Biol. and Biochem.* 42: 1643-1646
- Trumbore, S.E., Harden, J.W. 1997. Accumulation and turnover of carbon in organic and mineral soils of the BOREAS northern study area. *J. of Geophys. Res.* 102(28): 817–28, 830.
- West, T.O., and W.M. Post. 2002. Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. *Soil Sci. Soc. of Am. J.* 66(6): 1930-1946

Nitrous Oxide Emissions from the Wisconsin Integrated Cropping Systems Trial: 2010

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INTRODUCTION

Nitrous oxide (N_2O) is one of the major greenhouse gas (GHG) contributing to anthropogenic climate change. While atmospheric concentrations of N_2O are much smaller than the other two major GHGs, carbon dioxide (CO_2) and methane (CH_4), the relative global warming potential of a molecule of N_2O is 298 times that of CO_2 and 12 times that of CH_4 over a 100 year time frame. Furthermore, the atmospheric concentration of N_2O is increasing at a rate of $0.26\% \text{ yr}^{-1}$, raising concerns about the future impact of N_2O on climate change (IPCC 2007). Terrestrial ecosystems are a significant source of N_2O as a result of the microbial processes of nitrification and denitrification in soils. Nitrification is the aerobic oxidation of ammonium to nitrate and denitrification is the anaerobic reduction of nitrate to dinitrogen gas. Nitrous oxide is an intermediate in the reaction sequences of both processes which diffuses from microbial cells into the soil matrix and subsequently the atmosphere (Davidson and Schimel 1995). The chief anthropogenic source of N_2O is direct emission from agricultural soils, which is increased by N inputs from inorganic and organic fertilizers and increased biological N-fixation due to cultivation of legumes (Mosier et al 1998). Many environmental factors influence production of N_2O , including soil N and C content, temperature, and soil moisture (Weier et al 1993, Stehfest and Bouwman 2006).

The Intergovernmental Panel on Climate Change (IPCC) has developed a set of equations for estimating GHG emissions, including N_2O , from agricultural systems (IPCC 2007). These equations utilize broad data on a limited set of factors including climate, crop type, and management to generate estimates of nitrogen additions, and assume that 1% of N is emitted as N_2O . However, this emission factor omits important effects of crop, climate, and management on emissions, and thus this simplification of complex cropping systems may cause inaccuracies (Parkin and Kaspar 2006, Lesschen et al 2011). Obviously, attempts to mitigate GHG emissions in agriculture will benefit from more specific information about the impact of cropping systems and management practices on GHGs. Therefore, experimental quantification of the nitrous oxide emissions of cropping systems, and the source of differences, is important when attempting to understand and mitigate impact on climate change.

The north central US, including Wisconsin, contains some of the most productive agricultural land in the world. A high proportion of land in this region is utilized for cropland, and so the greenhouse gas (GHG) emissions due to agriculture in the region are a large percentage of the total for the USA. Model estimates suggest that 34% of the total N_2O emissions from agriculture in the US are due to agriculture in the north central region (Mummey et al. 1998). Therefore, adoption of improved management of agricultural systems of the north central US could help reduce total GHG emissions and thus improve the sustainability of agriculture in this region. However, the relatively few studies of GHG emission from cropland in the central USA suggests a need for more research to better understand the interactions of tillage, crop rotation, and fertilization on global warming impacts of cropping systems (Johnson et al 2005).

In this study we compare N₂O fluxes from the 6 cropping systems at the Wisconsin Integrated Cropping Systems Trial (WICST). The WICST study was established in 1989, so the cropping system treatments have had over 20 years to progress toward new equilibriums. The study is composed of 3 grain and 3 forage cropping systems spanning a spectrum of crop diversity and perenniality, and represents a range of common Wisconsin cropping systems (Posner et al 1995).

Our study contributes insight into N₂O flux from the particular climatic and edaphic context of south central Wisconsin, and will provide insight into the cumulative effect of the multiple factors that differentiate cropping systems on N₂O emissions. As the experimental cropping systems model a wide range of realistic cropping systems that differ in management, crop rotation, and fertilizer regimes, the study may provide estimates for a wider range of currently utilized cropping systems and their relative global warming impacts. We utilize the static chamber methodology of measuring fluxes of trace gases. This methodology has been shown to provide a good basis for relative comparison of treatments and is cost effective (Hutchinson and Livingston 1993).

LITERATURE REVIEW

Nitrous Oxide emissions and farming systems

Previous studies utilizing static chamber methodology have investigated the relationship between climatic, edaphic, and management factors and N₂O emissions. As a biogenic gas resulting from nitrification and denitrification processes, N₂O production is influenced by soil temperature, water-filled pore space, pH, and the supply of C and N compounds (Hutchinson and Davidson 1993). As many of these physical characteristics are influenced by management activities such as tillage, irrigation, and N fertilizer source and timing, crop management practices may hold potential to manipulate N₂O emissions from cropland (Adviento-Borbe et al 2007). A summary of 139 studies of N₂O emissions found that increased N application, high soil organic C content, restricted drainage, and fine soil texture increased N₂O flux. Fertilizer type and crop type were also important factors influencing N₂O emissions (Bouwman et al 2002). In a more recent summary of 1008 measurements of N₂O emissions from agricultural fields, N application rate, crop type, fertilizer type, soil organic C, and soil pH and texture were found to significantly influence N₂O emissions (Stehfest and Bouwman 2006). In a comparison of organic and conventional winter wheat in the Netherlands, annual N₂O emissions from organic and conventional systems (0.54-1.37 kg N₂O-N ha) were not significantly different despite the lower N input in organic rotations. The annual emissions corresponded to 0.5–0.8% of the N applied in manure or mineral fertilizer (Chirinda et al 2010). A study of organic and conventional farms on 5 European sites revealed differences between sites, as conventional rotations had higher N₂O emissions than organic rotations on 4 of the 5 sites (Peterson et al 2006). In Canada, no-tillage and reduced fertilizer during the corn phase of corn-soy-wheat rotations significantly reduced N₂O emissions compared to conventional tillage and fertilization rates. The majority of the reduction was observed during soil thawing events. Insulation by crop residues and snow cover during winter months reduces the duration and intensity of soil freezing, an effect that was significantly correlated with reduced N₂O fluxes during soil thawing periods. This effect may be due to increased microbial activity upon thawing, a response to increased available carbon from freezing lysis of microbial cells and disintegrating soil aggregates (Wagner-Riddle et al 2007).

Much of the research investigating N₂O emissions from cropping systems has focused on N fertilizer source and rates of application. Best management practice for N fertilizer, including calculating N rate based on available soil N and sidedress fertilizer applications during periods of high crop N demand have been shown play a role in significantly reducing N₂O emissions without reducing crop production by matching N supply more closely to N demand, increasing fertilizer uptake efficiency (Adviento-Borbe et al 2007). Furthermore, intensification of crop production to achieve near optimum yields appear to lead to low N₂O emissions per unit of grain produced (Linguist et al 2012). N₂O emissions resulting from crop residue N was found to depend chiefly on the amount of N present, precipitation, and temperature (Novoa and Tejeda 2006).

In Midwestern cropping systems, previous empirical studies have demonstrated an effect of crop rotation on N₂O emissions. Soybeans had lower N₂O emissions than corn fertilized with anhydrous ammonia (AA), but corn following corn and corn following soybeans were not different. Additionally, N fertilization as urea (U) reduced total N₂O emissions when compared to AA (Venterea et al 2010), an effect possibly due to the elevation of soil pH during AA hydrolysis, which could result in the dissolution of organic matter, temporarily increasing carbon availability and thus denitrification activity. A similar study in corn showed an interaction between fertilizer and tillage. AA fertilizer application resulted in greater N₂O emissions than U or urea-ammonia-nitrate (UAN). No-tillage increased emissions compared to conventional tillage following broadcast urea application, but decreased emissions following anhydrous ammonia application. This effect may be attributed to a reduction in microbial activity at depths lower than 10 cm, but increased activity in the soil surface layer under no-till management (Venturera et al 2005). A study comparing tillage treatments in continuous corn systems in Ohio found that no-tillage led to decreased N₂O emissions when compared to chisel plow tillage and moldboard plow tillage (Ussiri et al 2009). Parkin and Kaspar (2006), measuring N₂O emissions in corn-soybean rotations, observed no significant effect of either tillage or of utilization of a rye cover crop following soybean harvest. Again, fluxes from the corn plots were significantly higher than from the soybean plots. In a study of corn-soybean-wheat systems, corn showed greater N₂O emissions than either soybean or wheat phases. N₂O emissions were influenced by both the current crop and the previous crop. Interestingly, a more diverse crop rotation decreased the amount of N₂O emitted from the soil compared with growing the same crops in a monoculture in separate fields (Drury et al 2008). Finally, timing of inorganic fertilizer application (early April v. mid-May) did not impact the cumulative N₂O emissions in corn fields in North Dakota (Phillips et al 2009).

Chamber Flux Methodology

Assumption of linear flux and use of linear regression to calculate flux with static chambers is a commonly practiced method of trace gas flux calculation, due to its simplicity and relative accuracy (e.g. Flessa et al 2006, Hyde et al 2006, Perala et al 2006, Peterson et al 2006, Drury et al 2008, Phillips et al 2009, Alluvione et al 2010, Cardenas et al 2010, Chirinda et al 2010, Pelster et al 2011). Use of 3 time points for calculation of flux rates is common, but the use of 2 points has been shown to be effective (Hyde et al 2006, Dusenbury et al 2008, Alluvione et al 2010, Cardenas et al 2010). However, it has been demonstrated that chamber deployment reduces the concentration gradient at the soil-atmosphere interface, causing a diminishing flux rate over time (Venterea 2010). Linear models of gas flux calculation have thus been shown to underestimate N₂O flux, particularly under conditions of high flux,

with up to 40% underestimation of flux. Previous studies have used alternative nonlinear calculation methods, including quadratic models and stochastic diffusion models. However, while use of nonlinear calculation schemes could improve the absolute accuracy of flux estimates, these schemes can reduce the detection of relative differences in fluxes (Venterea et al 2009). Additional samples at more than two time periods, increased sampling frequency, and shorter duration of chamber deployment may increase the absolute accuracy of flux measurements, but comparative analyses are still likely to be valid (Rochette 2008).

Diurnal patterns in N₂O emission may exist due to variation in soil temperature and moisture. However, expanding the range of times during the day that fluxes are sampled may not improve the accuracy of flux estimates. One study showed that diurnal variations in flux were small, and results from sampling near mid-day were not significantly different from those based on early morning or evening sampling. (Smith and Dobbie 2001).

The length of measurement period and the frequency of flux measurements have been shown to significantly influence N₂O measurements. Longer measurement periods (>300 days) and intermediate frequency of measurements (one every 2-3 days) resulted in the greatest N₂O flux (Bouwman et al 2002). Utilizing simulated flux values, Parkin (2008) demonstrated that static chamber sampling of N₂O flux at 14 day intervals resulted in cumulative estimates that differed by -43% to +64% of the “true” cumulative N₂O emissions. By increasing sampling frequency to once every four days, the probability of estimating emissions within $\pm 10\%$ was increased to >70%.

MATERIALS AND METHODS

Site/Experimental Design

The WICST plots are located in Arlington, WI on a Plano silt loam soil. The trial consists of 6 cropping systems (CS) established in a RCBD with 4 blocks. Three systems are grain based: CS1 is conventionally managed corn-corn with chisel tillage (cc), CS2 is conventionally managed corn-soybean with strip tillage prior to the corn phase (stcsb), and CS3 is organically managed corn-soybean-wheat/berseem clover (csbw/bc). The other three systems are dairy based and include forages and manure application: CS4 is conventional corn-alfalfa-alfalfa-alfalfa (caaa), CS5 is organic corn-oat/alfalfa-alfalfa (co/aa), and CS6 is management intensive rotational dairy heifer grazing (p), for a total of 14 phases (14x4=56 plots total) (Posner et al 1995). Corn in each system was harvested for grain. In order to avoid difficulties managing livestock presence, small enclosures (2.5m x 7m) were created in CS6 pasture plots to simulate a mixed grass-legume hayfield for the 2010 growing season, and were harvested 4 times.

Table 1. Date of relevant field activities in the 14 crop phases for the 2010 growing season.

Crop Phase	Primary Tillage	Secondary Tillage	Planting	Nitrogen Addition	Cultivation	Harvest	Fall Nitrogen Addition	Fall Tillage
CS1 corn	11/23/2009 (chisel plow)	4/28/2010	4/29/2010	4/19/2010 (160 lb/a) 4/29/2010 (5 lb/a)	-	10/5/2010 (206 bu/a)	-	11/8/2010 (chisel plow)
CS2 corn	11/23/2009 (strip till)	-	4/29/2010	4/29/2010 (5 lb/a) 6/7/2010 (135 lb/a)	-	10/5/2010 (215 bu/a)	-	-
CS2 soybean	-	-	5/6/2010	-	-	9/28/2010 (66 bu/a)	-	11/8/2010 (strip till)
CS3 corn	11/23/2009 (chisel plow)	4/28/2010 5/18/2010	5/19/2010	4/16/2010 (1.5t CPM)	6/17/2010 6/29/2010	10/13/2010 (184 bu/a)	-	11/5/2010 (chisel plow)
CS3 soybean	11/23/2009 (chisel plow)	5/18/2010	5/19/2010 (soybean) 9/30/2010 (wheat)	-	6/29/2010	9/28/2010 (62 bu/a)	-	9/29/2010 (disc)
CS3 wheat	10/13/2009 (disc)	7/20/2010 (disc) 8/6/2010 (quack digger)	10/13/2009 (wheat) 8/11/2010 (berseem clover)	-	8/11/2010 (cultivator)	7/13/2010 (60 bu/a) 7/27/2010 (straw 1.1 T DM/a)	-	11/8/2010 (chisel plow)
CS4 corn	11/24/2009 (chisel plow)	4/28/2010	4/29/2010	11/12/2009 (16K gal slurry/a) 4/29/2010 (5 lb/a)	-	10/5/2020 (223 bu/a)	11/2/2010 (11.8K gal slurry/a)	11/5/2010 (chisel)
CS4 seeded alfalfa	11/23/2009 (chisel plow)	3/24/2010	3/30/2010	11/12/2009 (16K gal slurry/a) 4/29/2010 (5 lb/a)	-	6/28/2010 8/5/2010 (2.20 T DM/a)	-	-
CS4 alfalfa I	-	-	-	-	-	5/28/2010 6/30/2010 7/29/2010 9/15/2010 (6.07 T DM/a)	-	-
CS4 alfalfa II	-	-	-	-	-	5/28/2010 6/30/2010 7/29/2010 9/15/2010 (6.19 T DM/a)	11/2/2010 (8K gal slurry/a)	11/5/2010 (chisel)
CS5 corn	11/24/2009 (chisel plow)	5/6/2010 5/18/2010	5/19/2010	11/12/2009 (8K gal slurry/a)	6/17/2010 6/29/2010	10/15/2010 (182 bu/a)	11/2/2010 (11K gal slurry/a)	11/5/2010 (chisel)
CS5 oat/seeded alfalfa	11/23/2009 (chisel plow)	3/24/2010	3/30/2010	11/12/2009 (16K gal slurry/a)	-	6/24/2010 8/5/2010 (3.39 T DM/a)	-	-
CS5 alfalfa I	-	-	-	-	-	5/28/2010 6/30/2010 7/29/2010 9/15/2010 (5.66 T DM/a)	11/2/2010 (11.8K gal slurry/a)	11/8/2010 (chisel)
CS6 pasture	-	-	3/19/2010 white clover	6/17/2010 (60 lb/a) 9/15/2010 (40 lb/a)	-	5/27/2010 7/2/2010 8/6/2010 10/28/2010 (3.05 T DM/a)	-	-

Each plot contained two chambers, at opposite ends of the plots, located approximately 10m from the plot edge. Two corn treatments with mineral N fertilizer application, CS1 corn and CS2 corn, had 4 chambers per plot, two located within the corn row and two located between rows. Fluxes of N_2O , CH_4 , and CO_2 from the soil to the atmosphere were measured bi-weekly from April 12 through November 22, 2010, totaling 17 routine sampling dates. In addition, subsets of the crop phases were sampled on 9 additional dates following special management “events”, i.e. applications of mineral and organic (manure) N fertilizer, and major cultivation events. Subsets were composed of the 5 corn phases, plus various check plots that were monitored in order to be able to isolate the impact of the agronomic event. Table 1 presents the total number of sampling dates for each crop phase.

Table 1. Number of sampling events for the 14 crop phases comprising 6 cropping systems during 2010 season.

Crop Phase	Number of Sampling Events
CS1 corn	26
CS2 corn	26
CS2 soybean	20
CS3 corn	26
CS3 soybean	20
CS3 wheat	21
CS4 corn	26
CS4 seeded alfalfa	17
CS4 alfalfa I	21
CS4 alfalfa II	17
CS5 corn	26
CS5 oat/seeded alfalfa	17
CS5 alfalfa I	18
CS6 pasture	17

Flux measurement

Static chambers were constructed of 10L white HDPE buckets (17cm high X 27cm diameter) with the bottom removed (Letica Corp., Rochester, MI). Chamber lids were 27 cm diameter white HDPE with a butyl rubber gasket along the contact lip of the chamber (Letica Corp., Rochester, MI). The lids included clasp flanges that ensured an airtight seal between lid and chamber. Chambers were equipped with a vent tube (3.2mm diameter, 15cm length) and a butyl rubber septum for syringe insertion.

Chambers were inserted into the soil to a depth of 10cm at least 24h before sampling commenced to allow equilibration of the soil atmosphere. At each chamber three gas samples were taken: one sample at 0 minutes immediately after capping the chamber, and two samples in immediate succession at 45 minutes after capping. Any vegetation present within the flux chamber was folded down into the chamber during measurement to avoid damage to the vegetation. However, in the case of corn, plants within the chambers were unable to develop beyond July due to the limited size of the chambers.

A 30 mL gas sample was removed from the chamber headspace using a 30mL nylon syringe and a 23-gauge needle. 20mL was used to flush the vial, and the remaining 10 mL was injected into 5.9mL glass Exetainer vials (Labco Ltd., Buckinghamshire, England) producing an overpressure. Ambient air and field standards (400 ppm CO₂, 1 ppm N₂O, and 1 ppm CH₄) were also loaded into vials at this time to assess background GHG concentrations and to assess potential storage degradation in the period between sampling and analysis. Fluxes were measured between 9:00 and 16:00 local time. Vials were transported to U.W.-Madison for analysis by gas chromatography with a flame ionization detector for CH₄, a 15 mCi 63Ni electron capture detector for N₂O (Agilent 7890A GC System, Santa Clara, CA, USA), and infra-red gas analyzer for CO₂ (LI-COR LI-820 CO₂ Analyzer, Lincoln, Nebraska, USA). Gas fluxes were calculated from the linear rate of increase or decrease in gas concentration inside the flux chamber over the 45 minutes sampling period, chamber volume, and soil surface area. Gas flux sampling can fail due to a leaking seal between the chamber and the lid (Hutchinson and Livingston 2001) or due to ineffective maintenance of pressure in the vial during transport and storage (Glatzel and Well 2007). Data was checked for quality by comparing the two 45 minute samples, and aberrant samples that showed no accumulation of CO₂ over the 45 minute sample period were discarded. When both 45 minute samples were deemed acceptable, the two sample values were averaged to determine chamber flux. A total of 274 samples were discarded, approximately 3.8% of all samples. 6878 total measurements used in the calculation of N₂O flux. In addition to gas samples, soil temperature at 10 cm depth and VWC at 20 cm depth was measured with a TDR probe (Spectrum Technologies, Plainfield, IL, USA) were measured within 1 m of each chamber.

Analysis

Total growing season N₂O and CH₄ emissions for each treatment were determined by interpolation using trapezoidal integration. It was assumed that daily flux changed linearly between sampling dates. For the two corn plots (CS1 corn, CS2 corn) with in row and alley chamber locations, the two flux values in each subplot were averaged to determine the subplot flux value. CO₂ soil to atmosphere emissions were not calculated using flux data, as chambers often contained growing vegetation which, due to metabolic activities, can mask soil emissions. CO₂ accumulation was used as a check to verify proper functioning of the chambers, vial caps, and gas analyzer.

Statistical analysis was run in SAS 9.2 (SAS Institute, Inc., Cary, NC) using the Mixed procedure to test the main effects due to system and crop, as well as interaction and random effects of blocking. An ANOVA comparing growing season flux of the 6 cropping systems and 14 phases was performed. A separate ANOVA was used to determine the effect of flux chamber row position on the cumulative flux estimate for CS1 corn and CS2 corn. Additional separate ANOVAs were performed to determine the immediate impact of inorganic N fertilizer application, and compared flux values before and after application of anhydrous ammonia in CS1 corn (1 date prior to fertilizer v. 3 days post-fertilization) and 28% urea ammonium nitrate in CS2 corn (2 dates prior v. 2 dates post-fertilization).

RESULTS

The 2010 growing season was exceptionally wet for Arlington WI, with no rain free period longer than 8 days between April and September, and no moisture stress was observed in any crop. Temperatures throughout the season were fairly average. These conditions resulted in above average

crop yields across the cropping systems (see weather graphs in 2010 agronomic report on p. 16 of this volume).

Cumulative growing season fluxes ranged from 1.21 kg N/ha for organic soybeans (CS3) to 3.85 kg N/ha for organic corn following alfalfa (CS5). Flux patterns varied considerably by crop phase and management (Figs 1 and 2). Greatest mean daily flux was $762 \mu\text{g N m}^{-2}\text{h}^{-1}$ and was observed in the organic oat/seeded alfalfa phase. Furthermore, N_2O flux measurements were highly variable within cropping phases, with CVs over the 8 chamber measurements ranging from 16% to 76%.

The ANOVA for effect of system and phase revealed significant effects for both system ($p=0.0056$) and phase ($p=0.0028$). Post-hoc analysis of cropping system effect using Fisher's LSD analysis revealed CS3 had significantly lower growing season emissions than CS1 and CS5 (Fig 3). Analysis of crop phase effect resulted in significant differences between many of the phases (Fig 4).

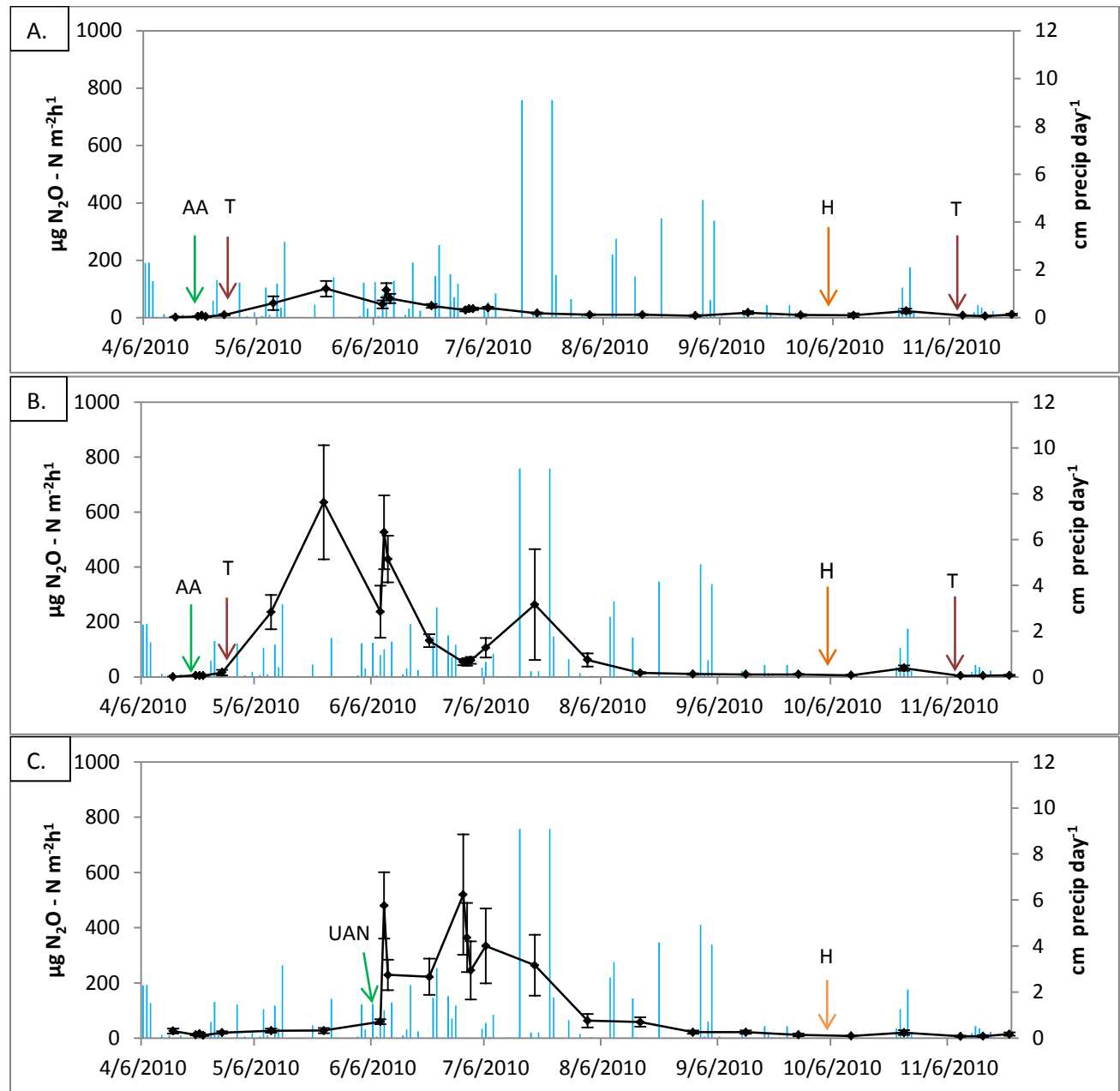
Effect of chamber location in corn plots with mineral N fertilizer was tested with an ANOVA. Growing season N_2O fluxes in corn rows versus in row alleys (i.e. between rows) were tested for CS1 corn and CS2 corn (Fig 5). Chamber location was a significant effect in CS1 ($p=0.006$), but was not significant in CS2 ($p=0.175$).

ANOVA results from analysis of fluxes from dates before and after nitrogen fertilizer application revealed significant effects (Fig 6). Both CS1 corn following AA application ($p=0.0163$) and CS2 corn following UAN ($p<0.001$) had increased N_2O fluxes in the sampling dates immediately following nitrogen fertilizer application. However, the increased flux following UAN application lagged a day, as the peak was not seen until the second day following application. Additionally, the magnitude of the CS2 corn flux increase was much greater (100x) than the increase observed in CS1 over the 3 day period following nitrogen application. In CS2 corn, the flux during the 2 day period following UAN application in early June represented 5% of the total growing season flux, while for CS1, the flux over the same time period following AA application in mid-April represented only 0.2% of the total growing season flux. CS1 emissions did eventually peak at a level similar to CS2, but not until a month after application of AA.

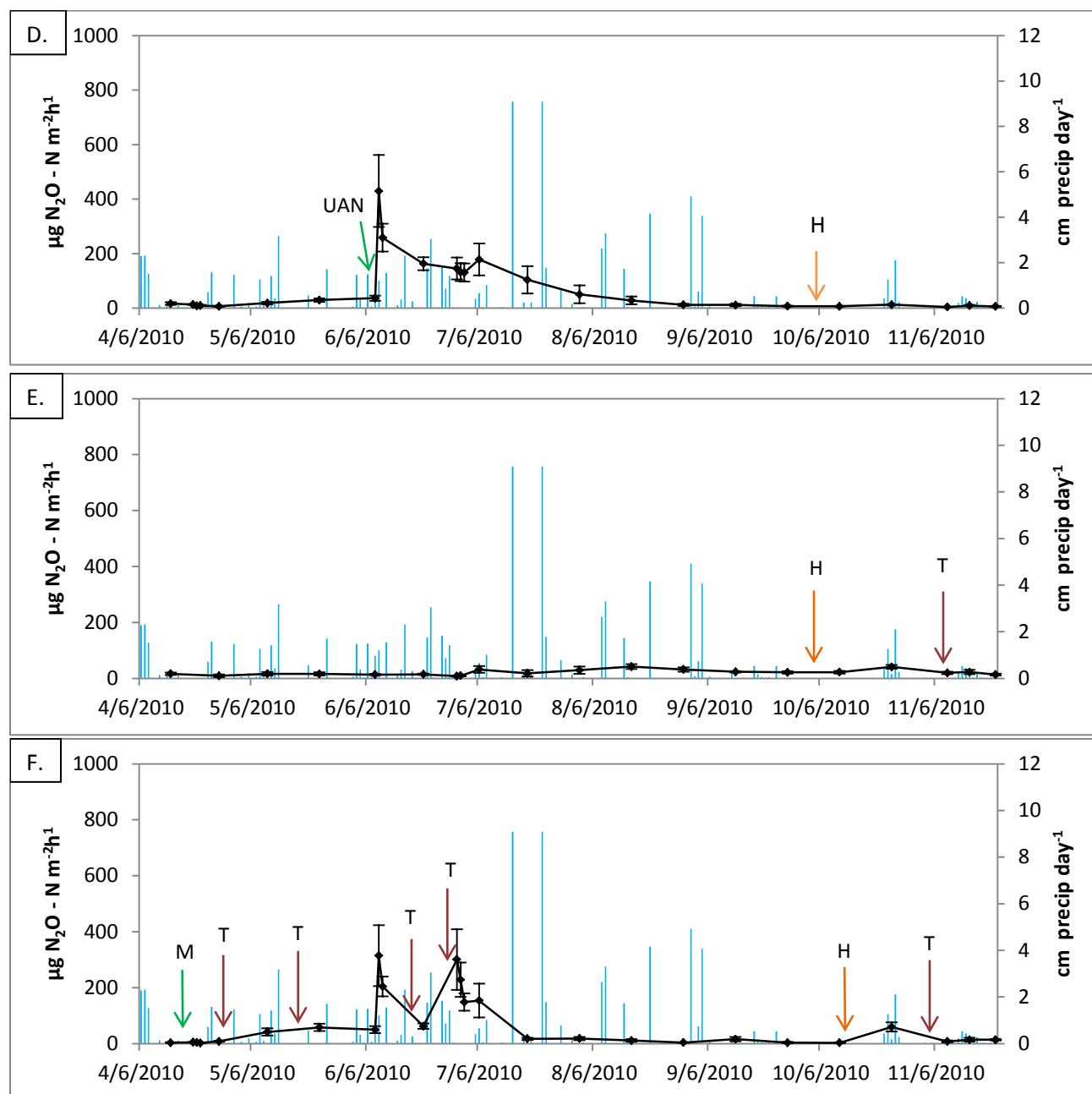
Linear regression of 2660 daily N_2O flux static chamber measurements against volumetric water content (VWC) and temperature showed significant positive correlation between daily flux and both VWC ($p<0.0001$) and temperature ($p<0.0001$). However, predictive power was low for both variables (VWC $R^2=0.01$, Temperature $R^2=0.06$).

Figure 1. N_2O fluxes for the 2010 growing season (mean $\pm$ s.e.) of the grain rotation phases, with cropping system in parentheses. Major agronomic events are denoted: AA is application of anhydrous ammonia, UAN urea ammonium nitrate solution, U urea, M manure slurry, T is tillage (chisel plow, strip till, field cultivator, or row cultivator), and H harvest. Left axis shows magnitude of N_2O flux, and right axis precipitation events.

A. Continuous corn (CS1) between row **B.** Continuous corn (CS1) in row **C.** Strip-till corn (CS2) between row



D. Strip-till corn (CS2) in row E. No-till soybean (CS2) F. Organic corn (CS3)



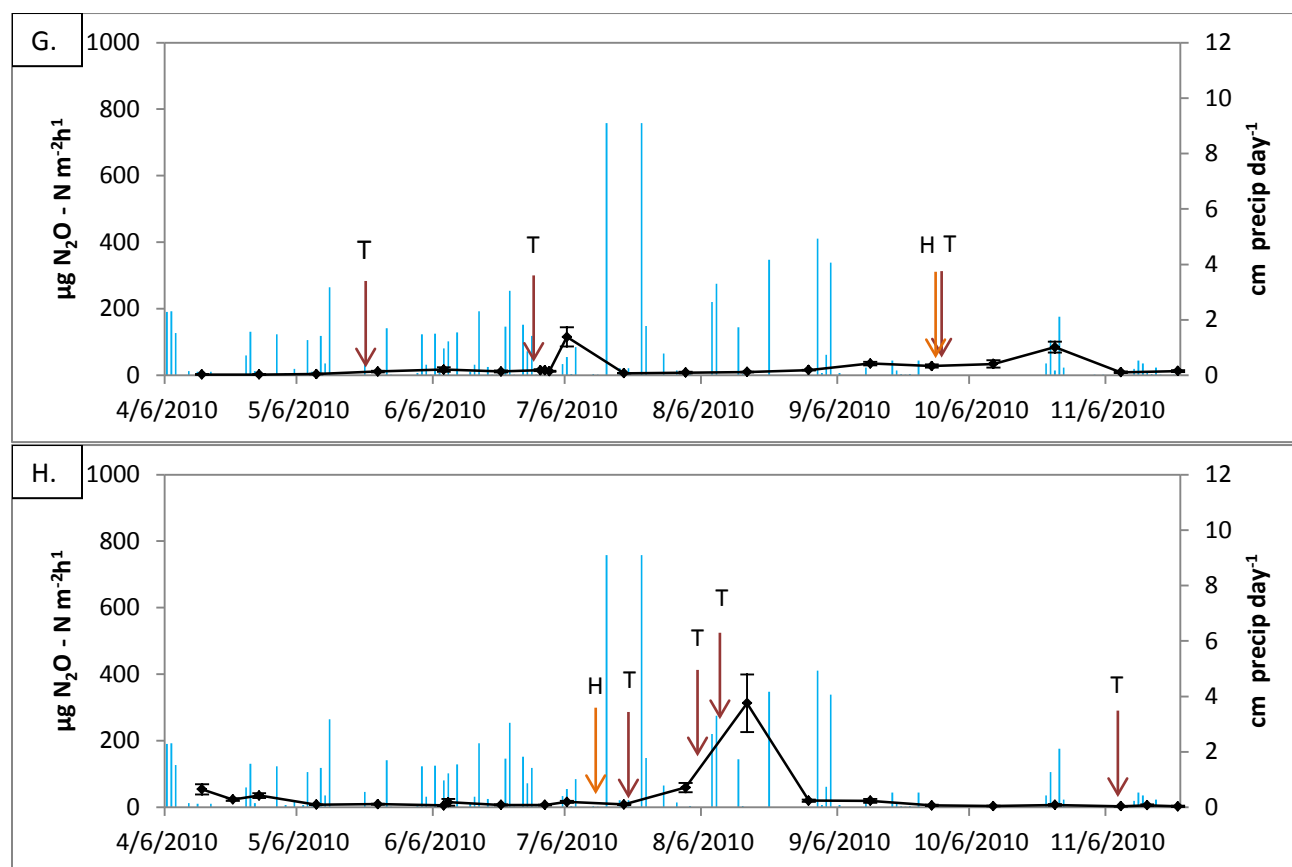
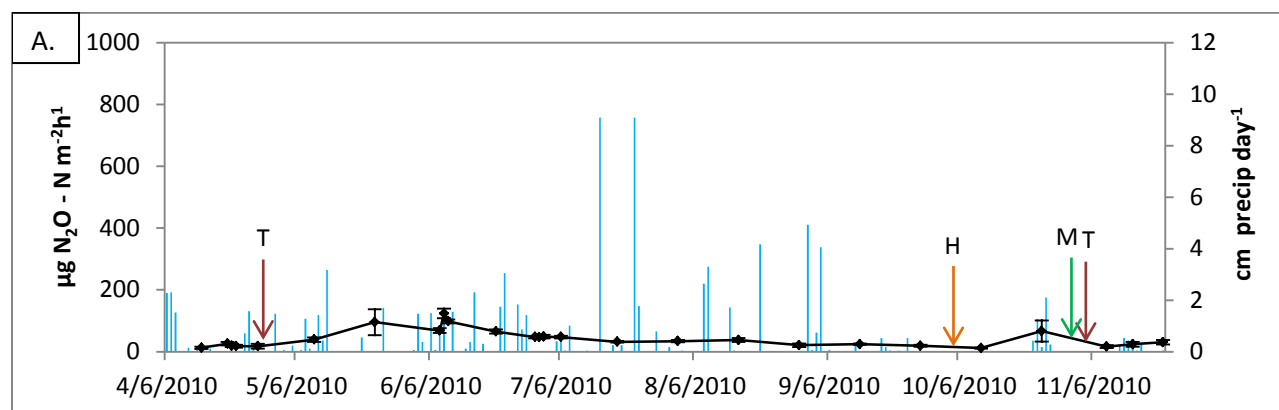
G. Organic soybean (CS3)**H. Organic wheat/berseem clover (CS4)**

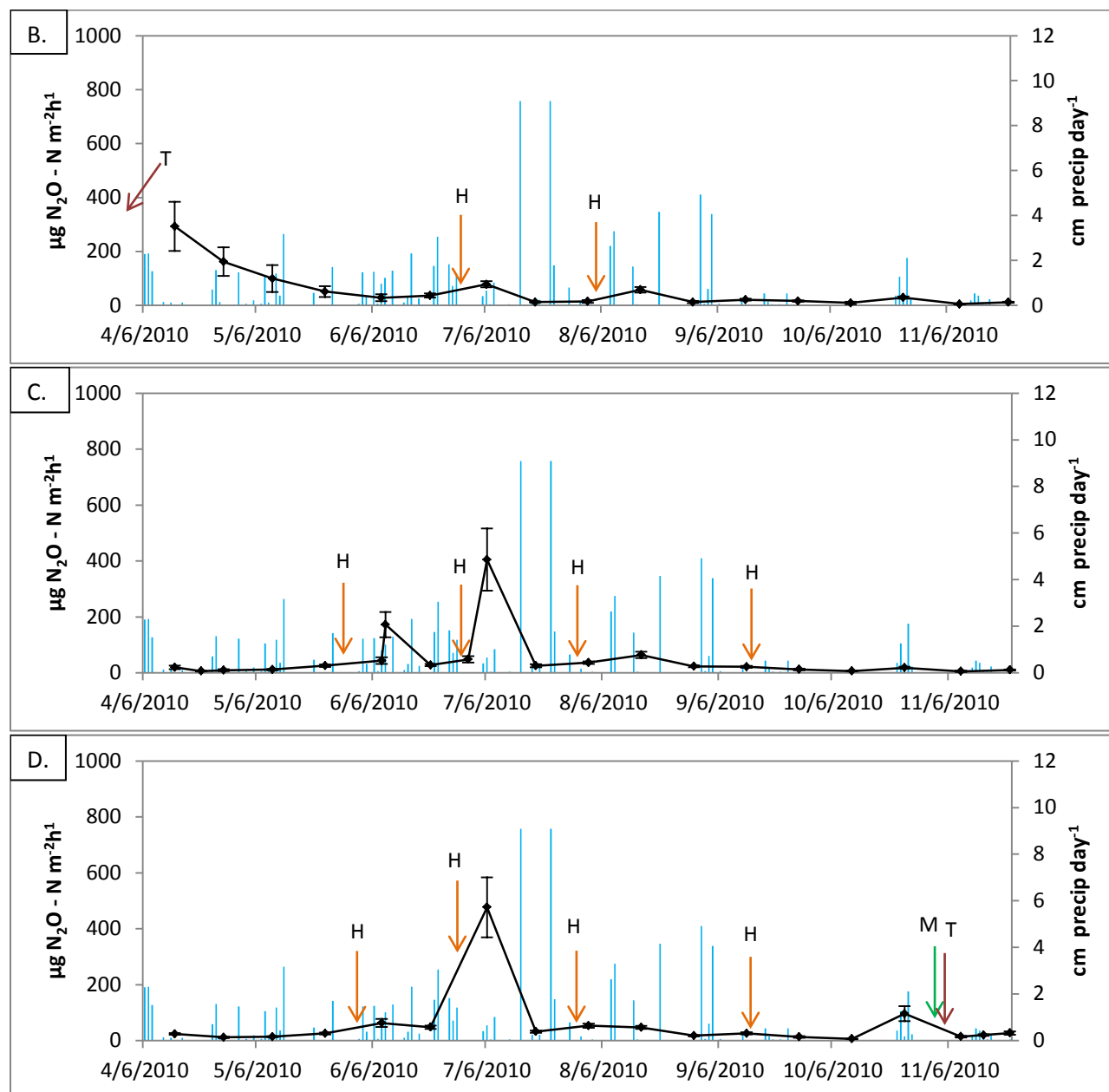
Figure 2. N_2O fluxes for the 2010 growing season (mean $\pm$ s.e.) of the forage rotation phases, with cropping system in parentheses. Major agronomic events are denoted: U is application of urea, M manure slurry, T is tillage (chisel plow, field cultivator, row cultivator, or quack digger), and H harvest. Left axis shows magnitude of N_2O flux, and right axis precipitation events.

A. Conventional corn (CS4)

B. Conventional seeded alfalfa (CS4)
hay II (CS4)

C. Conventional alfalfa hay I (CS4)

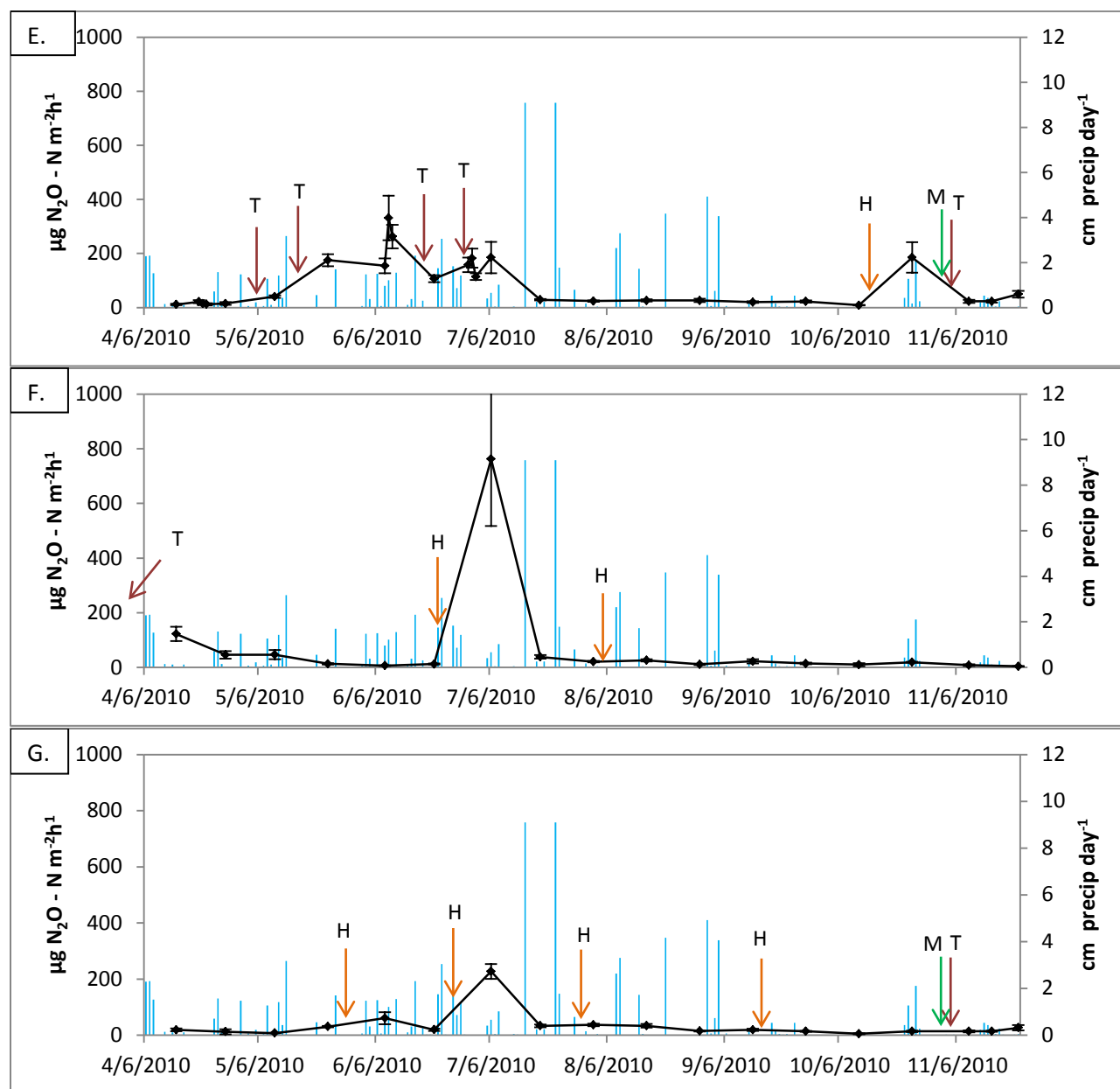
D. Conventional alfalfa



E. Organic corn (CS5)

F. Organic oats/seeded alfalfa (CS5)

G. Organic alfalfa hay I (CS5)



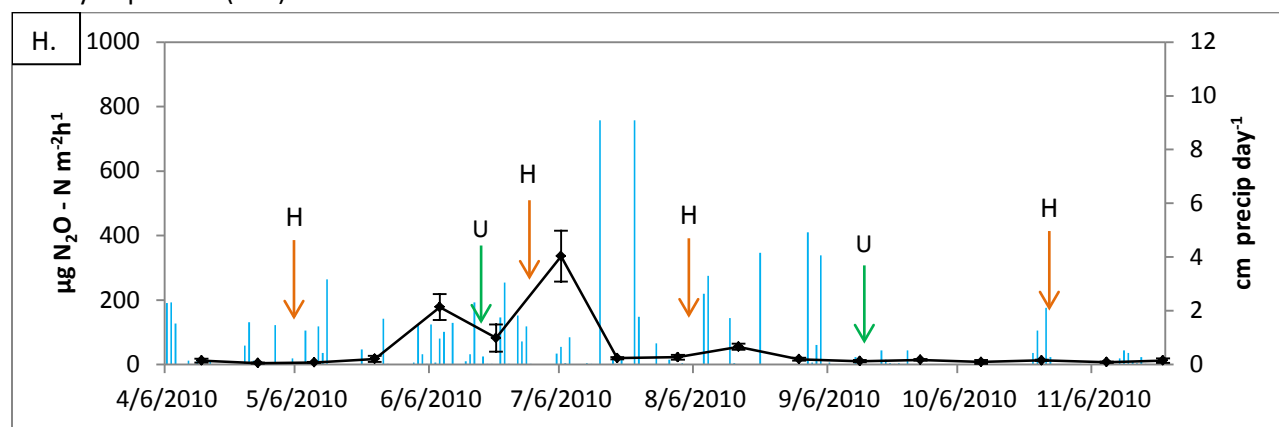
H. Hayed pasture (CS6)

Figure 3. Cumulative N₂O emissions (mean $\pm$ s.e.) from the 6 cropping systems. Cropping systems with the same letter designation are not significantly different ($p < 0.05$, Fisher's LSD).

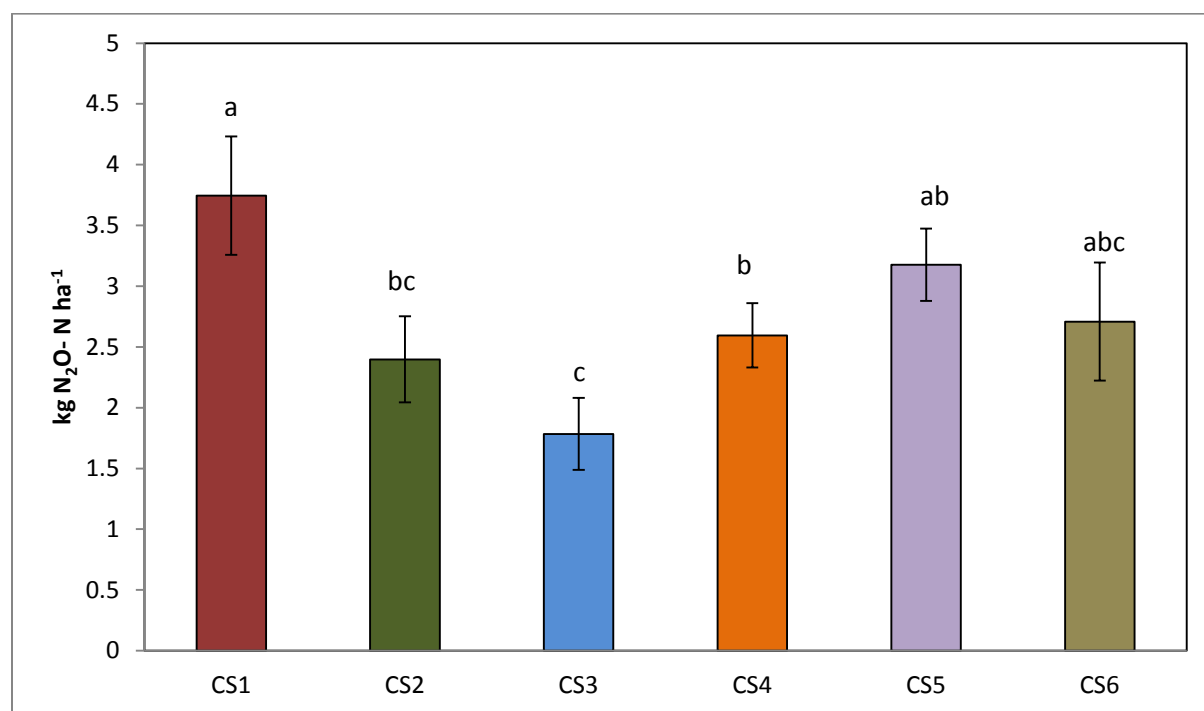


Figure 4. Cumulative N_2O emissions (mean $\pm$ s.e.) from the 14 crop phases. Phases with the same letter designation are not significantly different ($p < 0.05$, Fisher's LSD).

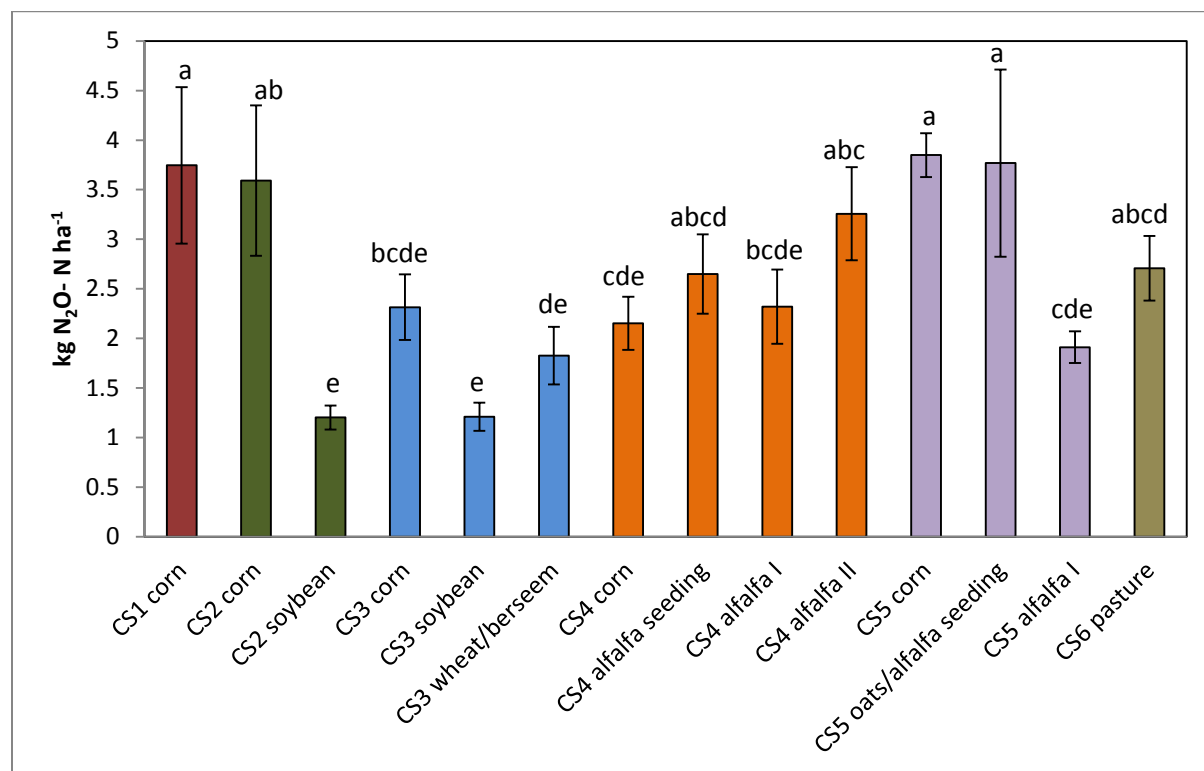


Figure 5. Growing season N_2O flux for CS1 and CS2 corn chamber locations, between row or in row. Chamber location was significant in conventional corn (CS1) ($p=0.006$), but was not significant in strip-till corn (CS2) ($p=0.175$).

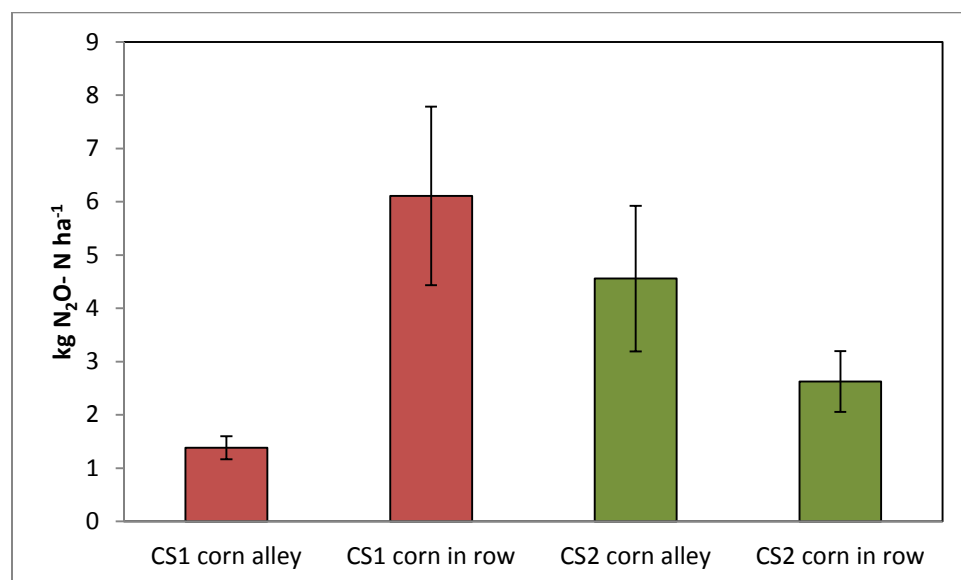
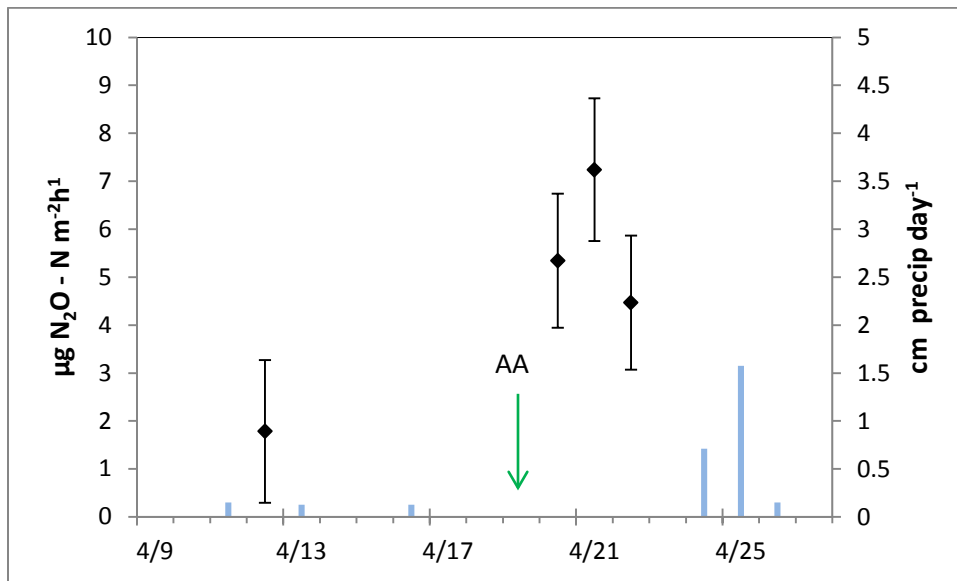
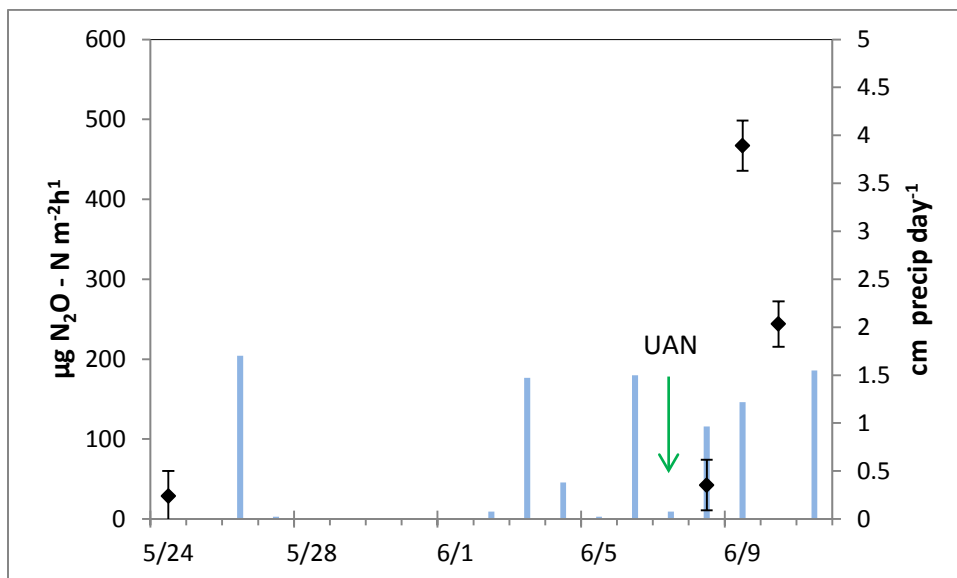


Figure 6. Impact of inorganic fertilizer application on daily N_2O flux (mean $\pm$ s.e.). Graph shows flux on a date before application and fluxes for the three days after application. Scales of flux are two orders of magnitude different for the two graphs. Left axis shows magnitude of N_2O flux, and right axis precipitation events.

- A.** Conventional corn with anhydrous ammonia. The sampling date 6 days before application (4/12) had a lower flux than three days after application ($p=0.0163$). This increased flux following fertilizer application was relatively unimportant in determining total season flux as greatest flux would not be observed until a month later (5/24).



- B.** Strip till corn with UAN. The date 15 days before application (5/24) and the first day following application (6/8) had lower fluxes than 2 and 3 days (6/9 and 6/10) after application ($p<0.001$). Fluxes following fertilizer application were relatively important in determining total season flux.



DISCUSSION

Measured N_2O flux values are comparable with previous studies of annual cropping systems in the upper Midwest. Venterea et al 2005, measuring N_2O emissions from AA or UAN fertilized corn following soybeans on a prairie derived silt loam soil in Minnesota estimated seasonal emissions between 1.1 and 4.2 kg N/ha. On a clay loam in southern Ontario, Drury et al 2007 estimated growing season N_2O emissions from corn following corn, soybean, or wheat to range from 1.34 to 2.62 kg N/ha. On a sandy loam in Quebec, alfalfa was found to emit 0.67-1.45 kg N/ha, and soybean 0.46-3.08 kg N/ha (Rochette et al 2004). The spatial variability observed in this study was not significantly higher than in other N_2O emission studies, as high variability is common in trace gas flux measurement studies and is likely due to microsite characteristics (Parkin 1987).

In spite of the high degree of variability in our data, we observed significant differences between cropping systems in growing season N_2O flux. CS3 emitted less N_2O than CS1, CS4, and CS5. These results suggest that the lower nitrogen inputs in the organic grain system led to lower emissions. In addition, the least diverse cropping system, CS1, had higher emissions than CS2 and CS4, suggesting that more diverse crop rotations than continuous corn result in lower overall system emissions.

Analyzing crop phases within cropping systems can be useful to determine which of the individual crop phases is contributing the greatest emissions to the overall system flux. In the cropping phase analysis, differences were found between phases of different cropping systems as well as phases within cropping systems. In CS2, the corn phase showed a significantly greater N_2O flux than soybeans. In CS3, the three phases did not have significantly different fluxes, perhaps due to the omission of inorganic N inputs in the corn phase. The application of organic nitrogen just prior to corn planting, in the form of 1.5 t/a of pelletized chicken manure, did not lead to significant fluxes of N_2O . In CS4, the corn phase had lower emissions than the second full year of alfalfa, but the other phases were not significantly different. This may be due to high levels of organic N in the system due to manure application following the corn phase combined with biological N fixation by the alfalfa. In CS5 the full year of alfalfa had lower emissions than both the corn phase and alfalfa seeding phase. In this system, both the corn phase and the alfalfa seeding phase were preceded by manure applications the previous fall, which likely contributed to these phases' higher N_2O emissions.

Crop phase comparisons can also be useful in comparing the same crop grown in different cropping systems. Five of the six cropping systems contain corn as a crop. These five corn phases essentially represent different methods of growing corn. Of the 5 corn phases, CS3 corn and CS4 corn had the lowest N_2O fluxes. Soybean phases in CS2 and CS3 had similar fluxes. Alfalfa seeding phases in both CS4 and CS5 did not have significantly different fluxes. Likewise, alfalfa hay phases in CS4 and CS5 did not show significant differences.

Row position of the chamber had a significant effect on N_2O emissions in CS1 corn but not CS2 corn, an inconsistent result similar to a previous study observing fluxes from between row and in row chambers in corn (Venterea et al 2010). The result in the CS1 corn phase may be due to fertilization with bands of anhydrous ammonia prior to corn planting, and then placement of the in row chambers over the fertilized zone. As nitrifying bacteria could be expected to be active in the presence of ammonia, this zone would emit much greater fluxes of N_2O than neighboring unfertilized zones.

N_2O emissions were low early in the growing season, and peaked in May, June, and July, with the exception of the alfalfa seeding phases. This emission pattern was the most common, observed in 12 of 14 cropping systems, and may be due to warmer and wetter soil conditions coupled with greater N availability during the May-July period. In CS1, while fertilization may have induced a small immediate increase in N_2O flux, peak emissions were not observed until a month after AA fertilization. This pattern contrasts with that of CS2 corn, as emissions in this crop phase showed an immediate and dramatic response to UAN fertilization. This difference may be attributed to temporal differences in the two fertilizer applications, as the cooler conditions following AA application in CS1 in early spring may have reduced rates of denitrification and nitrification when compared to the warmer conditions during sidedressing of UAN in CS2. Furthermore, as crop uptake of N is closely coupled with crop growth, available N resulting from fertilization and organic N mineralization is more likely to be taken up by soil microbes early in the growing season, potentially leading to higher denitrification activity and greater N_2O production in the annual crops. In the perennial crops, alfalfa and grass-legume pasture, a slightly later peak in emissions was observed. This may be the result of greater N availability following defoliation by harvest, as suggested by Rochette et al (2004). Alfalfa has been shown to slough off fine roots and increase excretion of N and C compounds following defoliation (Brophy and Heichel 1989), which when combined with warm and wet soil conditions may have caused greater microbial activity and thus greater N_2O production. Alfalfa seeding phases showed a different emission pattern, with greatest flux being observed in early spring and declining through the season. This pattern may be due to a combination of relatively high amounts of available N in the soil due to manure application during the previous fall and early season soil disturbance which may have stimulated soil microbial activity.

Measured soil properties did not have a strong predictive relationship with N_2O flux values. Neither volumetric water content (VWC) nor soil temperature explained a significant amount of variation in daily N_2O fluxes, suggesting that plot characteristics other than soil moisture or temperature determined flux magnitude. Possible alternative important factors include available SOC, available N, and soil aeration.

A large proportion of annual N_2O emissions can result from strong emission pulses (Fuß et al 2011). Freeze-thaw events that occur outside of the growing season can induce large emission pulses of magnitudes comparable to growing season fluxes (Flessa et al 1996, von Bonchove et al 2000, Teepe et al 2001). Dörsch et al (2004) noted that temporal and spatial variation in fluxes during freeze thaw periods can be extremely high due to variable soil conditions, rendering measurement of these fluxes with the chamber methodology highly problematic. Our sampling began in April 14, 2010, after the spring freeze-thaw events. As we did not capture a potentially important emission pulse outside of the growing season, our results are a comparison of growing season flux only, and may not represent the true annual N_2O emissions. However, previous studies have found no consistent patterns in freeze-thaw cycle emissions between fields previously in corn or soybean (Wagner-Riddle et al 2007).

Sampling will continue for the 2011 season on all treatments. Increasing the time period of the study to two growing seasons will strengthen the certainty of our estimates of the relative flux values of the cropping systems.

REFERENCES

- Adviento-Borbe, M., M. Haddix, D. Binder, D. Walters, and A. Dobermann. 2007. Soil greenhouse gas fluxes and global warming potential in four high-yielding maize systems. *Global Change Biology* 13: 1972-1988.
- Alluvione, F., C. Bertora, L. Zavattaro, and C. Grignani. 2010. Nitrous oxide and carbon dioxide emissions following green manure and compost fertilization in corn. *Soil Science of America Journal* 74: 384-395.
- Bouwman, A., L. Boumans, and N. Batjes. 2002. Emissions of N₂O and NO from fertilized fields: Summary of available measurement data. *Global Biogeochemical Cycles* 16: 1058-1071.
- Brophy, L. and G. Heichel. 1989. Nitrogen release from roots of alfalfa and soybean grown in sand culture. *Plant and Soil* 116: 77-84.
- Cardenas, L., R. Thorman, N. Ashlee, M. Butler, D. Chadwick, B. Chambers, S. Cuttle, N. Donovan, H. Kingston, S. Lane, M. Dhanoa, and D. Scholefield. 2010. Quantifying annual N₂O emission fluxes from grazed grassland under a range of inorganic fertiliser nitrogen inputs. *Agriculture, Ecosystems and Environment* 136: 218-226.
- Chirinda, N., M. Carter, K. Albert, P. AMbus, J. Olesen, J. Porter, and S. Petersen. 2010. Emissions of nitrous oxide from arable organic and conventional cropping systems on two soil types. *Agriculture, Ecosystems and Environment* 136: 199–208.
- Davidson, E. and J. Schimel. 1995. Microbial processes of production and consumption of nitric oxide, nitrous oxide, and methane. In: *Methods in Ecology: Trace Gases* (eds P. Matson and R. Harriss), p. 327–357. Blackwell Scientific Publications, London.
- Dörsch, P., A. Palojarvi, and S. Mommertz. 2004. Overwinter greenhouse gas fluxes in two contrasting agricultural habitats. *Nutrient Cycling in Agroecosystems* 70: 117-133.
- Drury, C., X. Yang, W. Reynolds, and N. McLaughlin. 2008. Nitrous oxide and carbon dioxide emissions from monoculture and rotational cropping of corn, soybean, and winter wheat. *Canadian Journal of Soil Science* 88: 163-174.
- Dusenbury, M., R. Engel, and P. Miller. Nitrous oxide emissions from a northern great plains soil as influenced by nitrogen management and cropping systems. *Journal of Environmental Quality* 37: 542-550.
- Eve, M, M. Sperow, K. Howerton, K. Paustian, and R. Follett. 2002. Predicted impact of management changes on soil carbon storage for each cropland region of the conterminous United States (Research). *Journal of Soil and Water Conservation* 57: 196–204.
- Flessa, H., P. Dörsch, and F. Beese. 1996. Seasonal variation of N₂O and CH₄ fluxes in differently managed arable soils in southern Germany. *Journal of Geophysical Research* 100: 23115-23124.
- Fuß, R., B. Ruth, R. Schilling, H. Scherb, and J. Munch. 2011. Pulse emissions of N₂O and CO₂ from an arable field depending on fertilization and tillage practice. *Agriculture, Ecosystems, and Environment* 144: 61-68.

Glatzel, S., and R. Well. 2008. Evaluation of septum-capped vials for storage of gas samples during air transport. *Environmental Monitoring Assessment* 136: 307-311.

Hutchinson, G. and E. Davidson. 1993. Processes for Production and Consumption of Gaseous Nitrogen Oxides in Soil. In L. Harper et al. (eds) *Agricultural Ecosystem Effects on Trace Gases and Global Climate Change*, pp. 79-93. ASA Special Publication 55, ASA, CSSA, SSSA, Madison, WI

Hutchinson, G. and G. Livingston. 1993. Use of chamber systems to measure trace gas fluxes. In L. Harper et al. (eds) *Agricultural Ecosystem Effects on Trace Gases and Global Climate Change*, pp. 63-78. ASA Special Publication 55, ASA, CSSA, SSSA, Madison, WI

Hutchinson, G., and G. Livingston. 2001. Vents and seals in non-steady-state chambers used for measuring gas exchange between soil and the atmosphere. *European Journal of Soil Science* 52: 675-682.

Hyde, B., M. Hawkins, A. Fanning, D. Noonan, M. Ryan, P. O'Toole, and O. Carton. 2006. Nitrous oxide emissions from a fertilized and grazed grassland in the South East of Ireland. *Nutrient Cycling in Agroecosystems* 75: 187-200.

IPCC, 2007. IPCC Fourth Assessment Report: Climate Change 2007. WMO/UNEP, Geneva, Switzerland.

Johnson, J., D. Reicosky, R. Allmaras, and T. Sauer. 2005. Greenhouse gas contributions and mitigation potential of agriculture in the central USA. *Soil & Tillage Research* 83: 73-94.

Linquist, B., K. van Groenigen, M. Adviento-Borbe, C. Pittelkow, C. van Kessel. 2012. An agronomic assessment of greenhouse gas emissions from major cereal crops. *Global Change Biology* 18: 194-209.

Mosier, A., C. Kroeze, C. Nevison, O. Oenema, S. Seitzinger, and O. can Cleemput. 1998. Closing the global N₂O budget: nitrous oxide emissions through the agricultural nitrogen cycle. *Nutrient Cycling in Agroecosystems* 52: 225-248.

Mummey, D., J. Smith, and G. Bluhm. 1998. Assessment of alternative soil management practices on N₂O emissions from US agriculture. *Agriculture, Ecosystems, and Environment* 70: 79-87.

Novoa, R., and H. Tejeda. 2006. Evaluation of the N₂O emissions from N in plant residues as affected by environmental and management factors. *Nutrient Cycling in Agroecosystems* 75: 29-46.

Parkin, T. 1987. Soil Microsites as a Source of Denitrification Variability. *Soil Science Society of America Journal* 51: 1194-1199.

Parkin, T. and T. Kaspar. 2006. Nitrous Oxide Emissions from Corn-Soybean Systems in the Midwest. *Journal of Environmental Quality* 35: 1496-1506.

Parkin, T. 2008. Effect of Sampling Frequency on Estimates of Cumulative Nitrous Oxide Emissions. 2008. *Journal of Environmental Quality* 37: 1390-1395.

Pelster, D., F. Larouche, P. Rochette, M. Chantigny, S. Allaire, and D. Angers. 2011. Nitrogen fertilization but not soil tillage affects nitrous oxide emissions from a clay loam soil under a maize-soybean rotation. *Soil & Tillage Research* 115-116: 16-26.

Perala, P., P. Kapuinen, M. Esala, S. Tyynela, and K. Regina. 2006. Influence of slurry and mineral fertiliser application techniques on N₂O and CH₄ fluxes from a barley field in southern Finland. *Agriculture, Ecosystems, and the Environment* 117: 71-78.

Peterson, S., K. Regina, A. Pollinger, E. Rigler, L. Valli, S. Yamulki, M. Esala, C. Fabbri, E. Syvasalo, and F. Vinther. 2006. Nitrous oxide emissions from organic and conventional crop rotations in five European countries. *Agriculture, Ecosystems, and Environment* 112: 200-206.

Phillips, R., D. Tanaka, D. Archer, and J. Hanson. 2009. Fertilizer Application Timing Influences Greenhouse Gas Fluxes Over a Growing Season. *Journal of Environmental Quality* 38: 1569-1579.

Posner, J., M. Casler, J. Baldock. 1995. The Wisconsin integrated cropping system trial: Combining agro-ecology with production agronomy. *American Journal of Alternative Agriculture* 10: 98-107.

Robertson, G., and P. Grace. 2004. Greenhouse gas fluxes in tropical and temperate agriculture: the need for a full-cost accounting of global warming potentials. *Environment, Development and Sustainability* 6: 51-63.

Rochette, P., D. Angers, G. Belanger, M. Chantigny, D. Prevost, and G. Levesque. 2004. Emissions of N₂O from Alfalfa and Soybean Crops in Eastern Canada. *Soil Science Society of America Journal* 68: 493-506.

Rochette, P. and N. Eriksen-Hamel. 2007. Chamber Measurements of Soil Nitrous Oxide Flux: Are Absolute Values Reliable? *Soil Science of America Journal* 72: 331-342.

SAS Institute. 2006. SAS/STAT user's guide, Version 9.2. SAS Institute, Inc., Cary, NC, USA.

Smith, K., and K. Dobbie. 2001. The impact of sampling frequency and sampling times on chamber-based measurements of N₂O emissions from fertilized soils. *Global Change Biology* 7: 933-945.

Stehfest, E. and L. Bouwman. 2006. N₂O and NO emissions from agricultural fields and soils under natural vegetation: summarizing available measurement data and modeling of global annual emissions. *Nutrient Cycling in Agroecosystems* 74: 207-228.

Taghizadeh-Toosi, A., T. Clough, L. Condon, R. Sherlock, C. Anderson, and R. Craigie. 2011. Biochar Incorporation into Pasture Soils Suppresses in situ Nitrous Oxide Emissions from Ruminant Urine Patches. *Journal of Environmental Quality* 40: 468-476.

Teepe, R., R. Brumme, and F. Beese. 2001. Nitrous oxide emissions from soil during freezing and thawing periods. *Soil Biology & Biochemistry* 33: 1269-1275.

Ussiri, D., R. Lal, and M. Jarecki. 2009. Nitrous oxide and methane emissions from long-term tillage under a continuous corn cropping system in Ohio. *Soil & Tillage Research* 104: 247-255.

Venterea, R. M. Burger, and K. Spokas. 2005. Nitrogen oxide and methane emissions under varying tillage and fertilizer management. *Journal of Environmental Quality* 34: 1467-1477.

Venterea, R., K. Spoka, and J. Baker. 2009. Accuracy and precision analysis of chamber-based nitrous oxide gas flux estimates. *Soil Science Society of America Journal* 73: 1087-1093.

Venterea, R. 2010. Simplified method for quantifying theoretical underestimation of chamber-based trace gas fluxes. *Journal of Environmental Quality* 39: 126-135.

Venterea, R., M. Dolan, and T. Ochsner. 2010. Urea Decreases Nitrous Oxide Emissions Compared with Anhydrous Ammonia in a Minnesota Corn Cropping System. *Soil Sci. Soc. Am. J.* 74: 407–418.

Von Bonchove, E., H. Jones, N. Bertrand, and D. Prevost. 2000. Winter fluxes of greenhouse gases from snow-covered agricultural soil: Intra-annual and interannual variations. *Global Biogeochemical Cycles* 14: 113-125.

Wagner-Riddle, C., A. Furon, N. McLaughlin, I. Lee, J. Barbeau, S. Jayasundara, G. Parkin, P. von Bertoldi, and J. Warland. 2007. Intensive measurement of nitrous oxide emissions from a corn-soybean-wheat rotation under two contrasting management systems over 5 years. *Global Change Biology* 13: 1722-1736.

Weier, K., J. Doran, J. Power, and D. Walters. 1993. Denitrification and the Dinitrogen/Nitrous Oxide Ratio as Affected by Soil Water, Available Carbon, and Nitrate. *Soil Science of American Journal* 57: 66-72.

ANALYSIS OF GREENHOUSE GAS EMISSIONS USING THE LIFE CYCLE INVENTORY DEVELOPMENT 1993-2008

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Greenhouse gases (GHG) of particular interest due to their relatively large contribution to climate change are CO₂ (Carbon dioxide), N₂O (Nitrous oxide), and CH₄ (Methane). Globally, it is estimated that agriculture contributes 10% of total anthropogenic GHG emissions (IPCC 2007), and is the largest emitter of N₂O and the second greatest contributor of CH₄ (EIA 2007). In the United States, 6% of all GHG emissions are due to agriculture, however this calculation is based solely on the emissions occurring in agricultural fields and in animal production facilities, but does not include emissions that occur due to the manufacture and transport of agricultural inputs (U.S. EPA, 2010). Changes in agricultural management could lead to reduction in GHG emissions, and have the potential to mitigate climate change through mechanisms such as carbon sequestration (Johnson et al., 2007).

Life Cycle Inventory Development (LCID) (documenting emissions from ‘cradle to farmgate’), sometimes inaccurately called Life Cycle Assessment (or LCA) (which documents emissions from ‘cradle to grave’), was originally developed for industrial production processes and is a standardized method to account for environmental impacts of a given product or process (Payraudeau and van der Werf, 2005 and Brentrup et al. 2004). LCID of agriculture focuses on the embedded 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, crop residue decomposition). LCID may include evaluations of a few or many “impact categories” to meet the needs of the assessment. Common environmental impact categories include land use, energy use, climate change (GHG emissions), acidification, eutrophication, photo-oxidant formation, terrestrial and aquatic ecotoxicity, and human toxicity (Charles et al. 2006). In this paper, we focus solely on estimating and analyzing GHG emissions.

LCID has been used to study GHG emissions associated with wheat production in Switzerland at varying intensities of nitrogen fertilization, which showed that on a per hectare basis, GHG emissions were higher under high fertility production, however, on a per ton basis, high fertility systems had a lower greenhouse gas impact (Charles et al. 2006). A study of emissions from Dutch crop production, based on national average data on input use and yields, suggested the small grains including wheat and barley have higher emissions per kg of production than potato or various vegetable production (Kramer et al. 1999).

An analysis of emissions of corn-based cropping systems in Eastern Canada found the addition of red clover to a corn-corn-barley-barley rotation reduced emissions to approximately 77% of the original, and that adding wheat to a corn-soybean rotation reduced emissions to about 82% (Meyer-Aurich et al. 2006). Additionally, a change from continuous corn production to a corn-based rotation including two to four species, specifically the inclusion of legumes, had the potential to decrease emissions to 38-77%

compared to continuous production. The methods used to conclude these results are similar to those which will be followed in this report, most prominently the use of equations from the International Panel on Climate Change Inventory (IPCC) Assessment. However, we conduct our study using equations from the 2006 IPCC document which has slight differences from the 1996 document employed by the previous studies.

A study comparing GHG between organic and conventional farms in Germany, which was based on studying 28 commercial farms, concluded that organic cropping systems emitted 30% less than conventional cropping systems on a per product basis, however when investigating only winter wheat, conventional production emitted 28% less than organic winter wheat, on a per product basis (Kustermann et al. 2007). In addition, emissions from biomass cropping systems in the United States have been studied (Adler et al. 2007). In this study, the perennial systems emitted lower GHG per m² per year from agriculture machinery use, lower emissions from total chemical input (excluding reed canary grass treatment), and lower nitrous oxide emissions (excluding reed canary grass treatment) as compared to the annual cropping systems. In addition to crop and biofuel production, the LCID methodology has been used to evaluate dairy (Rotz et al. 2010, Olesen et al. 2006, Thomassen et al. 2008), beef (Pellitier et al. 2010b), hog (Pellitier et al. 2010a), and poultry (Dekker 2011) systems around the world.

The Wisconsin Integrated Cropping System Trial (WICST) is a long-term study that compares six cropping systems common in the upper Midwest at two locations; more details can be found in Posner et al. (1995, 2008). In this study an annual ledger of actual inputs, outputs and field activities are used to make LCID estimations. Currently, there is no study on GHG emissions that is both multi-location and based on annual LCID evaluations on a wide range cropping systems (continuous corn to pasture) common to the Midwest. Based on this data set we have posed the following research questions:

1. How do emissions vary between systems and locations, when they are compared on a per hectare basis
2. Are systems with greater biodiversity and lower synthetic chemical use associated with lower emissions than conventional production systems
3. Within a system, which inputs/field activities are associated with the largest GHG emissions

Based on this cropping systems trial, we hypothesize that per hectare, organic crop systems will emit less greenhouse gas equivalents than conventional systems. We expect systems utilizing perennial crops (alfalfa or pasture) to emit less GHG than those systems composed exclusively of annual row crops. Lastly, we hypothesize that emissions will be higher per hectare in crop production on wetter soils, due to lower yields on poorer soils, and to more anaerobic conditions which are conducive to N denitrification.

MATERIALS AND METHODS:

Data Collection – Field Experiment

The scope of the LCID is the 6 systems of the WICST plots (Table 1), at two sites in SW Wisconsin, over the course of 16 years at the first site and 10 years at the second site. The trial is ongoing at Arlington Research Station (ARS), though the trial at the Lakeland Ag Complex in Elkhorn, WI (LAC) was discontinued in 2002. Annual ledgers were used

to collect raw data on inputs and yields from each system. Though the experimental design was a randomized complete block, data was collected using the average inputs and yields from the four replications of each treatment each year. In the WICST project, we used a staggered start approach so that by 1993 each phase of each system is present each year; therefore 14 plots of land each year are considered over the 6 systems.

All items that come from outside the plot boundary are considered *inputs*, and plant products or biomass removed from the plot boundary are considered *outputs*. Emissions were not calculated for the manufacture or maintenance of machinery used in each system. However, fuel emissions were documented for general field operations. Manure hauling was based on the assumption that the manure facility is located 0.5 mile from the field (1 mile round trip) at a travel speed of 15mph to haul each load of manure multiplied by the number of loads to spread each acre. Through 2005, solid manure was hauled with a 170 hp tractor and spread at 15 to 20 tons/a. Assuming each spreader held 8 tons, it would take 1.9 or 2.5 trips/acre to apply these rates. Since 2006 (ARS site only), a 6500 gal tanker was used to apply slurry in 2 trips/a using a 250 hp tractor. Fuel use was estimated with conversion factors from Lazarus (2009). Though cropping systems in this study were designed to be integrated with livestock, enteric emissions associated with livestock are accounted for only in conjunction with manure production, which will be described in greater detail later.

The rotationally grazed plots have livestock present during a portion of the year; however, the system will be compared on the basis of dry matter crop production, not animal weight gain. Ruminant-related emissions (manure and enteric) associated with grazing cattle are addressed in the same manner as in the alfalfa-based systems (more detail follows).

CO₂ Equivalents

Each GHG compound has a different ‘Global Warming Potential’. According to IPCC Fourth Assessment Report, total CO₂ is multiplied by 1 kg CO₂ eq. per kg CO₂, total N₂O is multiplied by 298 kg CO₂ eq. per kg N₂O, and total CH₄ is multiplied by 25 kg CO₂ eq. per kg CH₄ (Forster et al 2007). All results are added together and reported as the CO₂ eq. per functional unit. Throughout this report, references to GHG emissions are in kg of CO₂ equivalents /ha.

Estimating Embedded GHG Emissions

Embedded emissions, which are the emissions that occur during production of inputs, were calculated using GaBi 4, a LCID modeling program which utilizes a database of inputs with documented information regarding the emissions for a given input (GaBi 4, 2008, PE International). When exact input emission data was not available in Gabi’s proprietary Production databases, we used second party developed databases EcoInvent (for seed, herbicides and P and K fertilizers), US LCI (for anhydrous ammonia), and Energy Conversion for fuel (diesel, propane). Not all products were available from manufacturing data in the United States, in which case data from other countries was utilized. From the database we retrieved conversion factors on CO₂, CH₄, and N₂O emissions for all inputs used on WICST.

From our annual field records, a spreadsheet was developed with separate worksheets for calculation of emissions from machinery (sum of emissions from diesel production and combustion), fertilizer inputs, pesticide inputs, manure, grain drying (sum of emissions from propane production and combustion), seed, and supplement feed given to grazing heifers. These were then totaled as CO₂ equivalents.

Estimating In-field GHG Emissions

In-field emissions, which are those emissions due to agricultural production practices in the field, were determined using 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Paustian et al., 2006). These are primarily N₂O emissions generated from 1) N from crop residue, 2) N from nutrient addition as commercial fertilizer and manure (including dung/urine from grazing animals), 3) indirect emissions from N leaching and volatilization, as well as 4) CO₂ from urea. A fifth category of in-field emissions include CO₂ from measured changes in soil carbon stocks in the plow layer (0-90cm) at WICST. For the continuing site at ARS, this change in carbon was measured after 20 yrs (see Sanford report in this volume) and at the LAC site, after 11 yrs before the study was terminated there (see Tautges report in this volume). Robertson et al (2000) looking at systems similar to WICST also included change in soil carbon as an emission source but only to a depth of 7.5cm.

Calculating Total GHG Emissions

The embedded and in-field emissions are summed in order to calculate the total greenhouse gas emissions of a cropping system. The total is compared between systems in terms of the functional unit. In our study, the emissions were compared by the functional unit land area (ha⁻¹), similar to Meyers-Aurich (2006) and Kramer et al (1999).

Allocating GHG Emissions from Manure and Enteric Fermentation

Allocation is a method utilized when emissions for a given input or process are relevant to two or more products. In this study, a fraction of the emissions generated by manure production were allocated to the manure itself, and a fraction was allocated to livestock production, as the emissions from manure can be attributed to two valuable processes: livestock production and fertilization of crop production systems. Various strategies for allocation can be used in LCID, including allocation based on mass balance, nutrient balance, or economic value allocation.

We have selected to use a version of economic allocation to properly allocate a portion of the emissions from dairy manure to the cropping systems that utilized the manure as a nutrient source. In addition to manure, other products that are direct products of the farm are milk and meat animals (male calves and cull cows) in the case of dairy or eggs in the case of poultry manure. Rotz et al, using the DairyGHG model estimated GHG emissions associated with a 100 cow (@ 9000 kg milk/cow (plus replacements)) herd in Pennsylvania, in a free-stall dairy (Rotz et al, 2010). The model includes an economic allocation of the GHG to milk production (92%) as well as meat animals (8%). In addition to estimating GHG emissions the model estimates nutrient flows and manure production. In the WICST experiment, field application of manure to the 2 alfalfa-based

dairy systems, averaged over the rotation, was 10 t/a/yr as a semi-solid from 1990 through 2005 and 4-5,000 gals of slurry/a/yr from 2006-2008. These application rates are equivalent to 115-140 kg of total N/ha/yr. The calculated rates of N-application were used to estimate the number of dairy cows (and replacements) needed to manure the plots. Although changes in efficiencies have occurred (see Clapper comparing 1944 and 2007) we assumed for the period of this study (1993-2008) that the production of manure and GHG emissions per animal stayed reasonably constant. For each year of the study we estimated the available N, P, and K in the applied manure and used annual prices for fertilizer value from our field records, as well as annual state statistics for the production and price of milk (NASS, 1993-2009). According to UW extension recommendations, 3-year nutrient availability is considered as 0.45 for manure N, 0.75 for manure P, and 0.95 for manure K (Laboski et al 2006). Therefore, manure nutrient analyses were adjusted to provide a 3-year availability fertilizer value for the allocation. Finally, the ratio of the annual fertilizer replacement value of the manure and the value of the milk plus calves and cull animals produced by the cows supplying the manure was used to allocate the GHG emissions between milk and manure for each year of the study period. Eight percent of the dairy emissions were allocated to the production of calves and cull animals, according to Rotz et al 2010. Based on a farm with 100 moderate-sized Holstein cows plus replacements housed in free stall barns, the total emissions from production of milk were 0.6 kg CO₂ equivalents per kg of Energy Corrected Milk (ECM), the form which farmers are paid is in milk constituents, primarily fat and protein. Thus 0.6 was used to calculate the emissions from manure. $ECM = 0.327 + 0.1295 (\%fat) + 0.072 (\%protein)$. Thus if milk is 3.5% fat and 3.1% protein the energy correction will be 1. According to Ag Source 2009, mean Holstein milk was 3.8% fat and 3.1% protein, so the correction factor for that year =1.04.

Starting in 2008, chicken manure pellets were applied to the CS3 corn phase to maintain soil test P and K as well as provide some N. The fraction of GHG from poultry production that was attributed to the poultry manure was calculated as a percentage of the total GHG embedded in the production of eggs as shown in Dekker (2011). Egg production data from Wisconsin Ag Stats Service and Ritz (2009) associated production of one egg with 0.9 kg of manure. The allocation of GHG to manure was based on an economic value ratio generated by comparing the value of the eggs to the fertilizer replacement value of the manure.

Methane emissions from enteric fermentation for the systems that included manure inputs were also calculated. The CH₄ in the alfalfa-based systems was assumed to be 53 kg CH₄ per head per year (IPCC 2006 Chapter 10, Table 10.11 'North America, other cattle'). Methane emissions from manure production by the grazing heifers in the pasture system were partially allocated to fertilization of the pasture assuming 60 lbs N/a were dropped as dung each year. This value was based on pounds of 25 lbs available N from manure/yr/hd (from UW-Extension bulletin A3601) times average of 150 days on pasture times the average stocking density of 5 (500lb) heifers/season. This source of N was then converted to CO₂ equivalents.

Statistical Analysis

A necessary feature of analyzing data from a long-term trial is to look for trends over time. Inherent in trend analyses is repeatedly sampling from the same plots, which may cause the data to be correlated and thus may violate the assumption of independent errors (Cady, 1991; Loughin, 2006). An investigation of this issue found little-to-no correlation of errors within each plot using the Durbin-Watson test. The time series-autoregression routine in SAS determined there were no linear or quadratic trends for any system. Therefore, LSMEANS were computed and year and replicate were used as random factors and cropping system and site were considered fixed effects.

RESULTS

Total GHG emissions.

In the combined-site analysis, GHG emissions were higher at the LAC site ($p < 0.001$) as expected because of the wetter, less productive soils there. By far, the largest driver of the overall emissions was loss in soil organic carbon (SOC) over the 1m profile in all systems over 20 years at ARS and 11 years at LAC. At ARS, emissions from SOC loss were highest in continuous corn and lowest in pasture with the other systems intermediate but relatively much lower compared to continuous corn (Fig 1a). At LAC however, all the conventional crop systems (CS1, CS2, and CS4) were higher than the pasture and the organic systems. The only system sequestering carbon in the 90-cm profile was the organic forage system at LAC but the cause of this gain is unclear. The impact of crop diversity on lowering emissions was more profound at LAC. Between infield and embedded fractions, infield emissions were nearly 50% for the grain system, but in the forage systems the infield fraction was about 70% of the total, mostly due to the manure input.

Embedded GHG

Embedded emissions partitioned among various sources are shown in Figs. 2a and 2b. There was no site effect on total embedded emissions but there was a significant system and site x system interaction (both $p < 0.001$). At both sites, the continuous corn had the highest emissions mostly due the annual chemical fertilizer input and corn grain drying. However, the two forage systems with alfalfa had the next highest emissions at LAC while the NT corn-soy and the three forage systems were equally high at ARS. Manure inputs and fuel from multiple harvests were the largest sources of emissions on the alfalfa systems at each site. The richer nutrient concentration of the manure pack at LAC, coupled with lower yields at that site, were likely the causes in differences between sites among the forage systems. Pesticides were a minor contributor overall. The lowest emissions were in the pasture and in the 3-yr organic grain system due their low input management. The difference between sites for the pasture system was due to the manure application and tillage at LAC for renovation in 1996 after plots were destroyed by grazing on saturated soils. Supplemental feed for the pastured animals was also a significant source of emissions. Though emissions in the organic grain system were significantly lower than the other 2 grain systems at both sites, the organic forage system was as high or higher than the conventional forage system.

Linear contrasts showed that the corn phase was higher than any other phase within most systems, with the exception of the alfalfa seedlings which were similar to the corn phase.

The alfalfa seeding phase was higher than the established forage phase in both systems ($p < 0.001$).

In-field GHG Emissions

Partitioning of the in-field N_2O into sources is shown in Figs. 3a and 3b (CO_2 emission from urea was ignored in these graphs but is included in Figs 1a and 1b). There was no meaningful site effect or site $\times$ system effect. The dairy systems, with pasture being the highest, had the largest N_2O emissions primarily from the manure component but the indirect and residue portions were also much higher in the dairy systems than the grain systems. Within the grain systems, N_2O emissions were highest for continuous corn and lowest for the 3-yr organic grain system, with the biggest difference in the nutrient addition fraction.

As found with the embedded GHGs, linear contrasts showed the corn phase emitted higher amounts of N_2O (mostly due to residue and applied N nutrients) vs. the non-corn phases. One exception was that the seeding phase of the forage system was not different than corn in the conventional system but was higher than corn in the organic system. More frequent manure application in the organic system rotation (3-yr) versus the conventional system rotation (4-yr) contributed to the higher emissions in the organic system.

CONCLUSION

Largest emissions sources were due to the loss in soil carbon stocks that we measured over one and two decades at LAC and ARS, respectively. Of the total modeled emissions, the infield fraction was higher than the embedded fraction in the forage systems. The system with the highest total emissions was continuous corn. Increased crop diversity led to a large reduction in emissions. System biodiversity was more important at LAC where more diverse systems (and therefore ones with lower inputs) had lower embedded emissions and less loss in SOC. However, the infield losses were not different between the forage systems where manure was the largest contributor to infield emissions.

Our use of the current IPCC methodology for estimating in-field GHGs emissions may oversimplify cropping system impacts on this important component of overall GHGs. Measurements of in-field N_2O and CH_4 emissions on the WICST plots have been made for the 2010 and 2011 growing seasons (see Osterholz report in this volume), and incorporation of this data into our LCI framework could improve the accuracy and specificity of the overall GHG budgets of these cropping systems.

The next step is to take the LCID developed from WICST to the farm level and determine how emissions vary from field to field under different management, topography, and soil type.

REFERENCES

- Brentrup, F., Küsters, J., Lammel, J., Kuhlmann, H., 2004. Environmental impact assessment of agricultural production systems using the life cycle assessment (LCA) methodology. I. Theoretical concept of a LCA method tailored to crop production. *Eur. J. Agronomy*. 20:247-264.
- Cady, Foster B. 1991. Experimental design and data management of rotation experiments. *Agron. J.* 83:50-56.
- Charles, R., O. Jolliet, G. Gaillard, and D. Pellet. 2006. Environmental analysis of intensity level in wheat crop production using life cycle assessment. *Ag, Ecosystems and Environment* 113: 216-225.
- Dekker, S.E.M, I.J.M de Boer, I. Vermeij, A.J.A. Aarnick, and P.W.G Groot Koerkamp. 2011. Ecological and economic evaluation of Dutch egg production systems. *Livestock Science*. 139:109-121.
- Dyer, J.A. and R.L. Desjardins. 2005. Analysis of Trends in CO₂ Emissions from Fossil Fuel Use
for Farm Fieldwork Related to Harvesting Annual Crops and Hay, Changing Tillage Practices and Reduced Summerfallow in Canada. *J of Sust Ag* 25 (3): 141-155
- Energy Information Administration (EIA). 2007. Washington DC.
<http://www.eia.doe.gov/oiaf/1605/ggrpt/index.html>
- Erosion Productivity Impact Calculator Model. 2009. <http://epicapex.brc.tamus.edu/>
Verified 27 March, 2012.
- Flessa, H., R. Ruser, P. Dorsch, T. Kamp, M.A. Jimenez, J.C. Munch, and F. Beese. 2002. Integrated evaluation of greenhouse gas emissions (CO₂, CH₄, N₂O) from two farming systems in southern Germany. *Ag, Ecosystems, and Environment* 91: 175–189.
- Fornara, D.A. and D. Tilman. 2008. Plant functional composition influences rates of soil carbon and nitrogen accumulation. *Journal of Ecology* 96: 314–322.
- GABI 4 Software. <<http://www.gabi-software.com/index.php?id=1159>>. Verified 27 March, 2012.
- Gasol, C.M., X. Gabarrell, A. Anton, M. Rigola, J. Carrasco, P. Ciria, M.L. Solano, and J. Rieradevall. 2007. Life cycle assessment of a *Brassica carinata* bioenergy cropping system in southern Europe. *Biomass and Bioenergy* 31: 543-555.
- Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. <http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf>. Verified 22 March 2012.

- Intergovernmental Panel on Climate Change (IPCC). 2007. Contribution of the Working Group III to the fourth assessment report of the IPCC. Geneva.
<http://www.ipcc.ch/ipccreports/ar4-wg3.htm> > Verified 27 March, 2012.
- Intergovernmental Panel on Climate Change (IPCC). 2006. IPCC Guidelines for National Greenhouse Gas Inventories. <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html> Verified 28 March, 2012.
- Intergovernmental Panel on Climate Change (IPCC). 2006. IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 4: Agriculture, forestry and other land use. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf
- International Organization for Standardization. 2001. ISO14042. Geneva, Switzerland.
- Johnson, J.M.F., A.J. Franzluebbers, S. Lachnicht Weyers, and D.C. Reicosky. 2007. Agricultural opportunities to mitigate greenhouse gas emissions. *Environmental Pollution* 150: 107-124.
- Johnson, J.M.F., D.C. Reicosky, R.R. Allmaras, T.J. Sauer, R.T. Venterea, and C.J. Dell. 2005. Greenhouse gas contributions and mitigation potential of agriculture in the central USA. *Soil and Tillage Res.* 83: 73-94.
- Kramer, K.J., H.C.Moll, and S. Nonhebel. 1999. Total greenhouse gas emissions related to the Dutch crop production system. *Agriculture Ecosystems and Environment.* 72:9-16.
- Kustermann, B. et al. 2007. Modeling carbon cycles and estimation of greenhouse gas emissions from organic and conventional farming systems. *Renewable Agriculture and Food Systems*: 23(1); 38–52.
- Laboski, C. A. M., J. B. Peters, and L. G. Bundy. 2006. Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin. Univ. of Wisconsin Cooperative Extension Publications, Univ. of Wisconsin-Madison, Madison, WI.
- Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science* 304: 1623-1626.
- Lal, R., R.F. Follett, B.A. Stewart, and J.M. Kimble. 2007. Soil Carbon Sequestration to Mitigate Climate Change and Advance Food Security. *Soil Science* 172 (12): 943-956.
- Lazarus, W. F. 2009. Machinery cost estimates. University of Minnesota Extension. <http://www.extension.umn.edu/distribution/businessmanagement/df6696.pdf>. Verified 14 February 2012
- Lehmann, J., J. Gaunt, and M. Rondon. 2006. Bio-char sequestration in terrestrial ecosystems – a review. *Mitigation and Adaptation Strategies for Global Change* 11: 403–427.
- Livesley, S. J., R. Kiese, J. Graham, C.J. Weston, K. Butterbach-Bahl, and S.K. Arndt. 2008. Trace gas flux and the influence of short-term soil water and temperature dynamics in Australian sheep grazed pastures of differing productivity *Plant and Soil* 309: 89-103.

- Loughin, T.M. 2006. Improved experimental design and analysis for long-term experiments. *Crop Sci.* 46:2492-2502.
- Meyer-Aurich, A., A. Weersink, K. Janovicek, and B. Deen. 2006. Cost efficient rotation and tillage options to sequester carbon and mitigate GHG emissions from agriculture in Eastern Canada. *Agriculture, Ecosystems and Environment* 117: 119-127.
- National Propane Gas Association (NPGA). 2001. Facts about propane. NPGA Bulletin 3026. http://www.npga.org/files/public/Facts_About_Propane.pdf. Verified 25 February 2012
- Olesen, J.E., K. Schelde, A. Weiske, M.R. Weisbjerg, W.A.H. Asman, and J. Djurhuus. 2006. Modelling greenhouse gas emissions from European conventional and organic dairy farms. *Agric. Ecosyst. Environ.*, 112:207–220.
- Pelletier, N., P. Lammers, D. Stender, and R. Pirog. 2010a. Life cycle assessment of high- and low-profitability commodity and deep-bedded niche swine production systems in the Upper Midwestern United States. *Agricultural Systems*. 103:599-608.
- Pelletier, N., R. Pirog, and R. Rasmussen. 2010b. Comparative life cycle impacts of three beef production strategies in the Upper Midwestern United States. *Agricultural Systems*, 103:380–389.
- 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(2): 253-260.
- Posner, J.L., M.D. Casler, and J.O. Baldock. 1995. Wisconsin integrated cropping system trial: combining agro-ecology with production agronomy. *J. Alternative Agric.* 10:98-107.
- Payraudeau, S. and H.M.G. van der Werf. 2005. Environmental impact assessment for a farming region: A review of methods. *Agriculture Ecosystems and Environment*. 107:1-19.
- Ritz, C.W., and W. C. Merka. 2009. Maximizing poultry manure use through nutrient management planning. University of Georgia Cooperative Extension Bulletin 1245.
- Robertson, G. P., D.C. Coleman, C.S. Bledsoe, and P. Sollins (eds). 1999. Standard soil methods for long-term ecological research. Oxford University Press, New York.
- Rochette, P., D.A. Angers, M.H. Chantigny, B. Gagnon, and N. Bertrand. 2008. N₂O fluxes in soils of contrasting textures fertilized with liquid and solid dairy cattle manures. *Canadian Journal of Soil Science* 88: 175-187.
- Rotz C.A., F. Montes, and D.S. Chianese. 2010. The carbon footprint of dairy production systems through partial life cycle assessment. *J. Dairy Sci.* 93:1266-1282.
- SAS Institute. 2006 SAS/STAT user's guide, Version 9.1.3. SAS Institute, Inc., Cary, NC, USA.

- SimaPro Life Cycle Strategies. <http://www.pre-sustainability.com/content/simapro-lca-software> Verified 28 March, 2012.
- Thomassen, M.A., K.J. van Calster, M.C.J. Smits, G.L. Iepema, and I.J.M. de Boer. 2008. Life cycle assessment of conventional and organic milk production in the Netherlands. *Agricultural Systems* 96: 95-107.
- University of Wisconsin-Extension. How much fertilizer do your animals produce? Bulletin A3601. <http://learningstore.uwex.edu/assets/pdfs/a3601.pdf>. Verified 14 February 2012.
- USDA. National Agricultural Statistics Service, Statistics by State: Wisconsin. 1993-2008. Milk, All, Prices Received by Farmers, Wisconsin. http://www.nass.usda.gov/Statistics_by_State/Wisconsin/Publications/Dairy/mkalpri.pdf Verified 28 March, 2012.
- USDA. National Agricultural Statistics Service Statistics by State: Wisconsin. 1993-2008. Milk Production per Cow, Wisconsin. http://www.nass.usda.gov/Statistics_by_State/Wisconsin/Publications/Dairy/mkpercow.pdf Verified 28 March, 2012.
- U.S. Environmental Protection Agency. 2010. Inventory of U.S. greenhouse gas emissions and sinks: 1990 – 2008 <http://epa.gov/climatechange/emissions/usinventoryreport.html> Verified 28 March, 2011.
- U.S. Environmental Protection Agency. Inventory of U.S. greenhouse gas emissions. <http://epa.gov/climatechange/emissions/index.html>
- Wisconsin Agricultural Statistics Bulletin 2011. Poultry. Pp. 61. http://www.nass.usda.gov/Statistics_by_State/Wisconsin/Publications/Annual_Statistical_Bulletin/page61.pdf Verified 28 March, 2012.

Table 1. The six cropping systems in the Wisconsin Integrated Cropping Systems Trials conducted at Arlington and Elkhorn, WI: crop rotation, management philosophy, and specific inputs.

Management philosophy				Specific inputs for management philosophy and crop					
Code	Enterprises	External input level	Crop rotation	Primary tillage	Estimated annual N-P-K input†			Pest control methods	
					Arlington	Elkhorn	Source‡	Weeds	Insects
					kg ha ⁻¹				
CS1	cash grain	high	continuous corn	chisel	142–5–20§	141–4–15§	F	herbicides	insecticide¶
CS2	cash grain	medium	soybean	NT#	0–0–0	0–0–0		herbicides	none
			corn	NT	136–4–19§	136–5–21§	L, F	herbicides	none
CS3	cash grain	low (organic)	soybean††	chisel	0–0–0	0–0–0		mechanical	none
			winter wheat (red clover)‡‡	field cultivate	0–0–0	0–0–0		none	none
			corn	chisel	146–0–0	93–0–0	L	mechanical	none
CS4	livestock & crop	high	alfalfa§§	chisel	241–23–160	337–41–296	M1	herbicides	insecticide
			alfalfa	none	0–0–0	0–0–0		herbicides	insecticide
			alfalfa	none	0–0–0	0–0–0		herbicides	insecticide
			corn	chisel	240–24–168	393–44–300	L, F, M1	herbicides	none
CS5	livestock & crop	low (organic)	oat (alfalfa)§§	chisel	182–17–120	253–29–222	M2	none	none
			alfalfa	none	0–0–0	0–0–0		none	none
			corn	chisel	176–16–117	270–29–236	L, M2	mechanical	none
CS6	livestock & crop	low	mixed pasture	none	52–5–31	117–9–75	M3	none	none

† Legume credits (L) and manure credits included where applicable.

‡ F = commercial fertilizer; M1 = 44.8 Mg manure ha⁻¹ and M2 = 33.6 Mg manure ha⁻¹; M3 = 12.9 Mg manure ha⁻¹ deposited by five grazing heifers on 1.2 ha at 150 d (University of Wisconsin Extension, 1996–2006).

§ Nitrogen rates were adjusted according to soil nitrate N tests.

¶ Only soil insecticides were used.

Before 1995, conventional tillage and drilling were used to plant soybean; thereafter the system was no-till drilling of seed (NT).

†† Soybeans were planted in 76-cm rows with a row-crop planter.

‡‡ The red clover was frost seeded or drilled into the winter wheat in early spring.

§§ The alfalfa in Phase I of CS4 was sole seeded; the alfalfa in Phase I of CS5 was companion seeded with the oat-pea mix.

Fig 1a. Total emissions on WICST at ARS (1993-2008) using 0-90cm profile for changes in soil organic carbon (SOC).

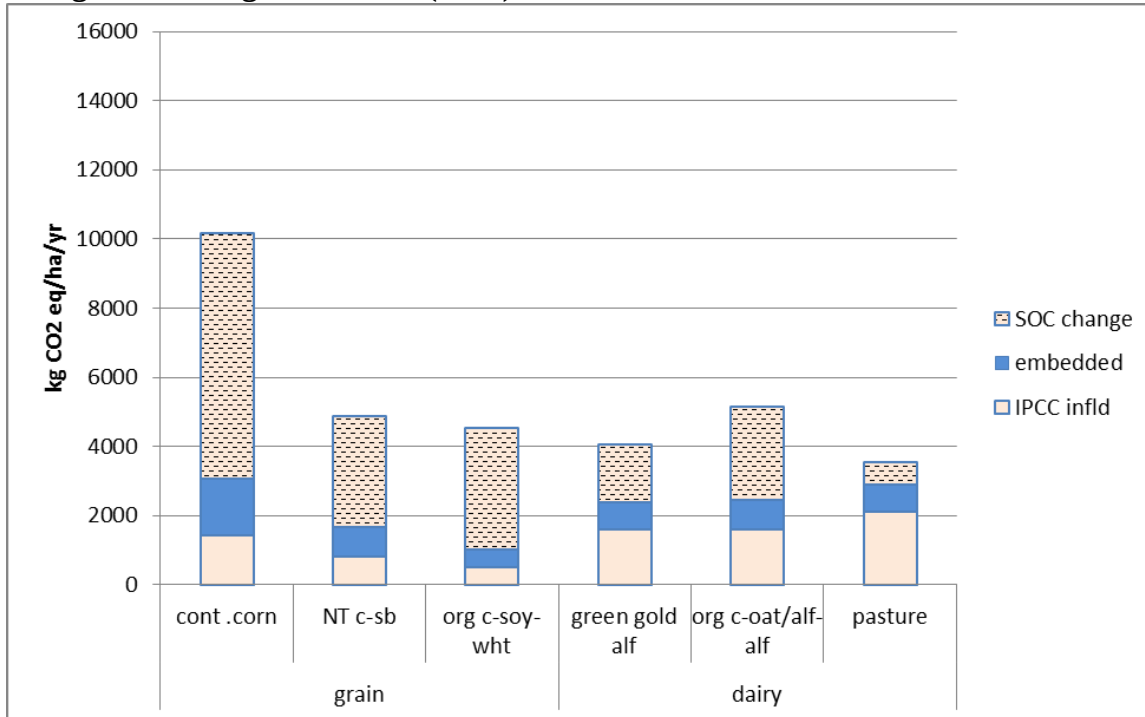


Fig 1b. Total emissions on WICST at LAC (1993-2002) using 0-90cm profile for changes in soil organic carbon (SOC).

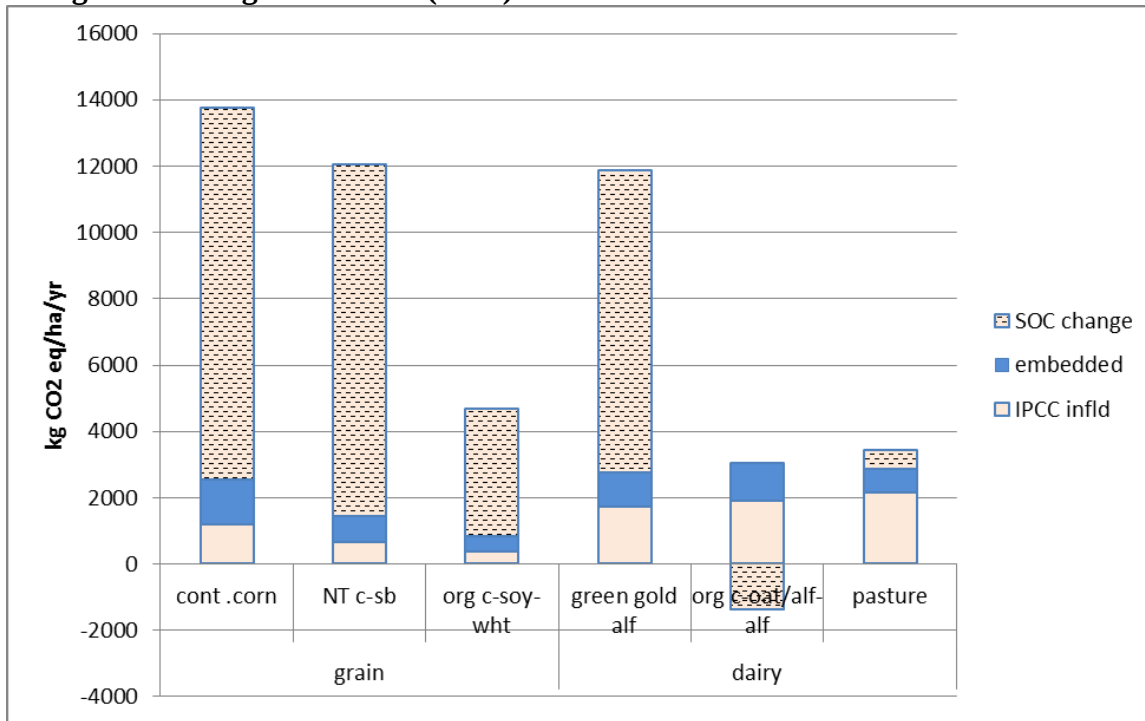


Fig 2a. Partitioning of total embedded GHG emissions from WICST at ARS (1993-2008). Misc = seed, supplemental grain and hay; pestic = herbicide, insecticide; manure = dairy solid or slurry or poultry pellets; fert = commercial N or K fertilizer; graindry=propane production and consumption for corn grain drying; diesel = fuel production and combustion for field work.

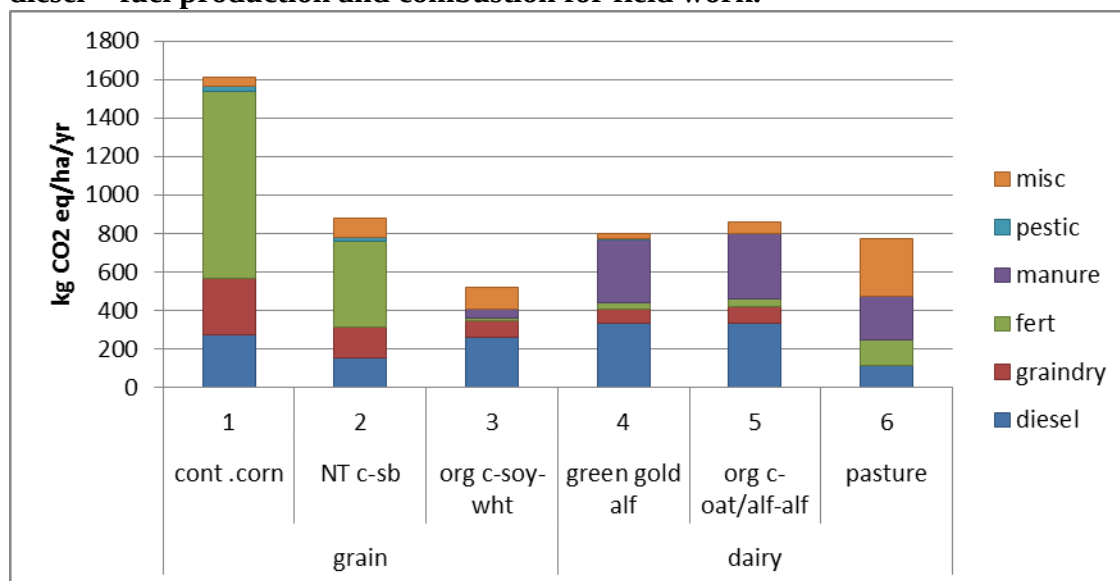


Fig 2b. Partitioning of total embedded GHG emissions from WICST at LAC (1993-2002). Misc = seed, supplemental grain and hay; pestic = herbicide, insecticide; manure = dairy solid or slurry; fert = commercial N or K fertilizer; graindry=propane production and consumption for corn grain drying; diesel = fuel production and combustion for field work.

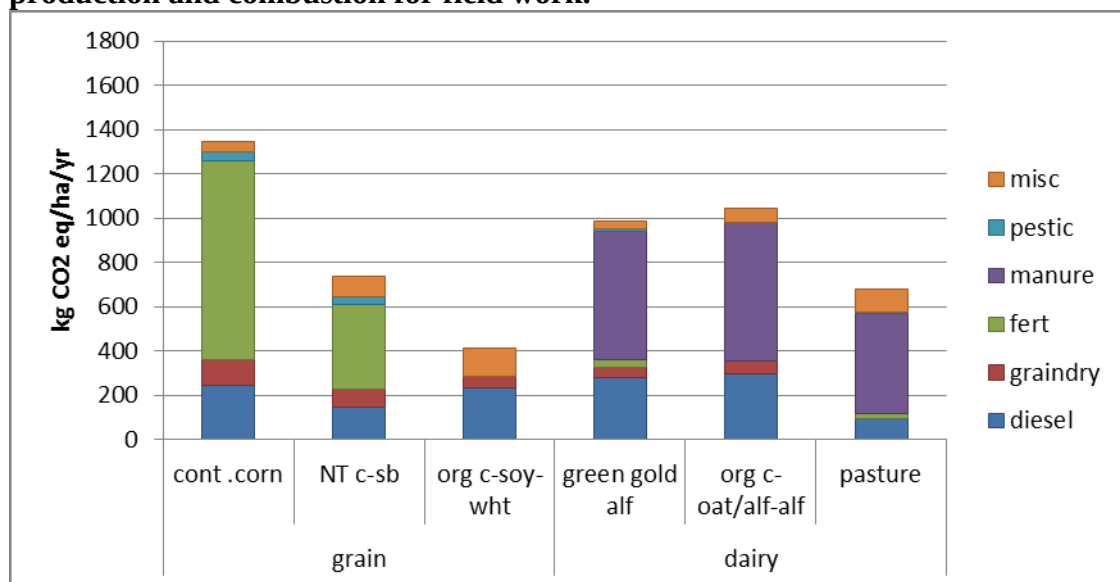


Fig 3a. –IPCC modeled infield GHG emissions (less the CO₂ from urea) on WICST at ARS (1993-2008). Indirect = N loss via leaching/volatilization; nutrts = N in fertilizer, applied manure and grazing manure (cow pies); residue = N in crop residue and cover crop residue.

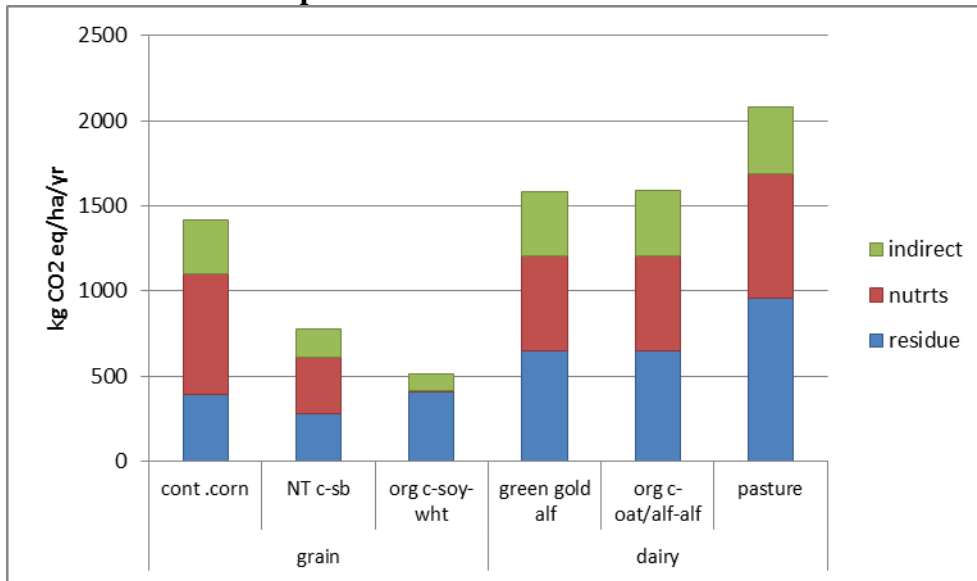
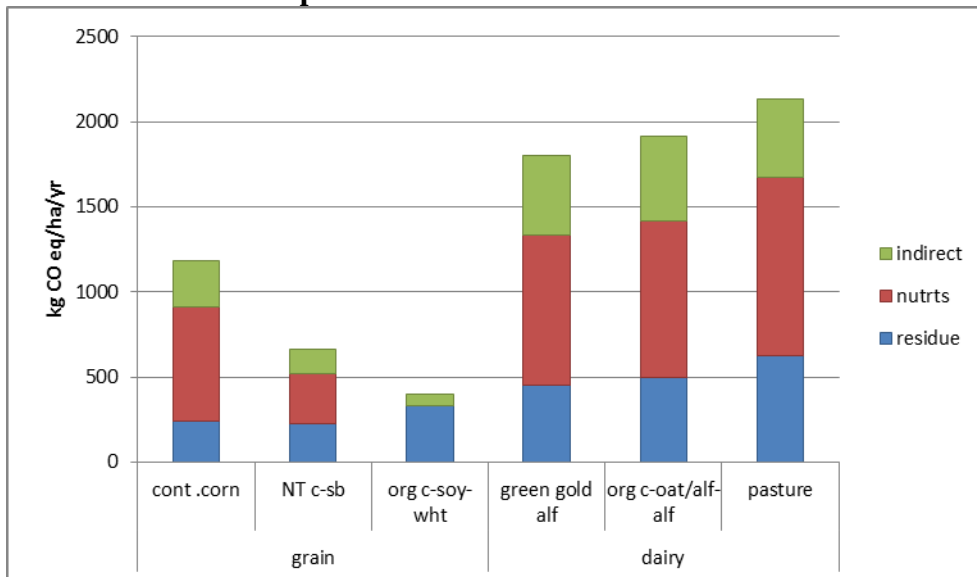


Fig. 3b. IPCC modeled infield GHG emissions (less the CO₂ from urea) on WICST at LAC (1993-2002). Indirect = N loss via leaching/volatilization; nutrts = N in fertilizer, applied manure and grazing manure (dung patches); residue = N in crop residue and cover crop residue.



SOIL EROSION, SOIL CONDITIONING INDEX, SOIL TILLAGE INTENSITY RATING AND FALL SOIL NITRATES SUMMARY FROM WICST DATASET

Janet Hedtcke¹, Josh Posner², and Nicole Tautges³

INTRODUCTION

Maintaining and increasing crop production requires maintaining soil quality. Jokela et al (2011) summarized the 18-year impact of the WICST cropping systems on a suite of soil quality factors (e.g., aggregate size, bulk density, microbial biomass, total organic carbon, potentially mineralizable N) that were subsequently integrated into a Soil Quality Index (SQI). The highest ranking and only significantly different system was the pasture (CS6); the other five systems were not different (in the 0-5 cm depth). However, arithmetically the 3-yr organic grain system (CS3) had the lowest SQI value. In the following article, we complement Jokela's soil quality study that focused on the legacy of these systems on the soil (at 0-5 cm and 5-20 cm depths), and additionally examine several other indicators of sustainability. The Natural Resources Conservation Service (NRCS) use these scores to alter payments to farmers in the Conservation Security Program as they move up management tiers (Hansen 2007). Specifically, the impact of management on soil physical and organic matter (OM) trends was modeled via the Revised Universal Soil Loss Equation 2 (RUSLE2), and those results, as well as, measured fall soil nitrate data are reported here. These additional measures of soil quality will help gain better knowledge of the effects of various farming practices on sustainability.

The RUSLE2 model (http://fargo.nserl.purdue.edu/rusle2_dataweb/) makes daily calculations over the years of a rotation and provides a wealth of information; however, the most widely-used output from the program is soil erosion. In addition to predicting erosion, RUSLE2 provides other useful metrics such as a Soil Conditioning Index (SCI) rating and the Soil Tillage Intensity Rating (STIR) which can serve to inform crop producers on the impact of their crop production practices.

- Soil erosion (in tons/a/yr) has been defined by an equation $E = f(K \cdot R \cdot L \cdot S \cdot C \cdot P)$ or in words, Erosion, E, is a function of K: soil erodibility (texture); R: rainfall kinetic energy (amount and number of heavy storms including snow melt); C: crop productivity and ground cover; S: slope steepness; L: slope length; and P: conservation practices (e.g., terraces, grass waterways, strip cropping) as shown in Renard et al. (1997). NRCS has developed the coefficients by county for most of the variables (Table 1), and then the user adds the details of the cropping rotation (crops, field operations, fertility inputs, yields, etc.) and the characteristics of the specific field (soil type, slope, length, and conservation practices).
- Soil Conditioning Index (SCI): This tool can help base management decisions towards improving soil structure and C sequestration and is comprised of three components: 1) OM returned to the soil, which is a function of yield, cover crops, and manure additions; 2) field operations which stimulate OM mineralization like tillage type, speed, and

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number of passes, planting, and N application, and 3) surface erosion which removes surface soil material via wind or water erosion. The SCI is on a scale of -2 to +2 with negative values implying loss of soil OM and positive values implying a gain of soil OM, while values near 0 show OM is being maintained (NRCS SCI Factsheet, June 2005 <http://www.wi.nrcs.usda.gov/technical/consplan/rusle.html>).

- Soil Tillage Intensity Rating (STIR). This index varies from 0 to 200, with the objective of drawing the producer's attention to the number and aggressiveness of the annual machinery passes in a cropping system that can oxidize soil OM as well as destroy soil structure, increase compaction, and in turn, increase the potential for erosion. Values < 30 are required for no-till, and low numbers in general are ideal (NRCS STIR Factsheet September 2005 <http://www.wi.nrcs.usda.gov/technical/consplan/rusle.html>)

Unlike the RUSLE2 data which was modeled using county-level climate data, we have measured fall soil nitrates since the beginning of the trial. Fall soil nitrate-N levels are an indirect metric of the synchrony between nitrogen availability during the growing season and crop nitrogen uptake in agricultural fields. Bundy (1994) has created a test to measure preplant soil nitrate levels as a BMP for economical N fertilizer rates. Also, between late fall and the following spring these nitrates can leach below the rooting zone and be lost to the agricultural system. Fall nitrate levels can thus serve as an indicator of nutrient management, and monitoring fall soil nitrates is one measure of potential environmental impact of the various production systems.

MATERIALS AND METHODS

Detailed description of WICST is reported in Posner et al (2008, 1995). The trial was initiated in 1990 at two sites in southern Wisconsin: The Arlington Ag Research Station (ARS) in Columbia County and at the Lakeland Ag Complex (LAC) in Walworth Co. both on silt loam soils developed under prairie vegetation. Other than a 70-mile distance between sites, the main difference between the sites was soil drainage, with ARS being well-drained and LAC being poorly-drained. The trial compares three cash-grain systems (continuous corn, NT corn-soybean, and organic corn-soybean-wheat/clover) and three forage (+manure) based systems [a 4-yr 'green gold' alfalfa (i.e. 3 yrs of alfalfa, 1 year of corn), organic corn-oat/alfalfa-alfalfa, and pasture under managed grazing with dairy heifers]. Plots are about 0.75 acres in size, all phases of each system are present every year and each phase is replicated four times at each location. The RUSLE2 analysis begins with 1992 at both sites. In 2002, the LAC site was terminated, resulting in an 11 yr data set for that site. The trial continues at the ARS site, so the data set is for 18 years in this paper.

Annual data on crop production and records of field operations based on the 4-rep average from both sites of WICST (Arlington 1992-2009; Lakeland 1992-2002) was used to estimate soil erosion and the SCI and STIR indices. The model uses soil type, slope, field length, and climate data by county. In this study, we set the model at a 4% slope steepness and 150 ft slope length in order to see if the systems were sustainable on more marginal lands than the relatively flat LAC and ARS sites.

The results presented in the following figures are based on assuming each model farm was equally divided among the phases of the rotation, and the resulting erosion is the farm-wide average. The RUSLE2 model was run each year on each system using the field records from

each site-year. The pasture which was seeded in 1990 at each site was relabeled as 1992, the first year in the analysis in order to include a seeding phase. The 1-phase systems (continuous corn and pasture) were each defined as a 3-yr rotation (i.e. corn-corn-corn for continuous corn) to simulate a rotation over time. Tolerable soil loss ('T') is defined as the maximum rate of soil erosion that can occur and still permit sustained productivity. The term 'tolerable soil loss' considers loss of soil productivity due to erosion, the rate of new soil formation from weathering and mineralization of parent material, processes of topsoil formation, loss of nutrients and the cost to replace them, erosion rate at which gully erosion might be expected, as well as practices a producer can implement to control erosion (Renard et al. 1997). Values for 'T' were derived by scientists using soil type-specific factors such as soil depth, physical properties affecting root development, gully prevention, on-field sediment problems, seeding losses, loss in soil organic matter, and loss of plant nutrients (Johnson 1997 and Schmidt et al 1982). For each site, 'T' was 5 tons/a/yr.

To collect the fall nitrate data, all plots were sampled in late October/early November (post-harvest, before any manure application or tillage) each year. Each sample consisted of six cores that were taken as 3-paired samples across the plot and bulked at 0-12 in., 13 to 24 in., and 25-36 in. depths. Initially (1990-1996) sampling was done by hand with a 1-in. diameter probe and subsequently (1997-2009) with a truck or tractor mounted 1.25-in. diameter hydraulic probe. Each year samples were also taken from adjacent unfarmed land (fence line or natural area) to serve as checks (i.e. background biological N) which Bundy (1994) reports to be close to 50 lbs NO_3^- -N/a. Since 2000, we have used the 3 reps of the high- diversity prairie treatment at ARS as our check and that value has been closer to 30 lbs NO_3^- -N/a. Nitrate-N was extracted from the top 3 feet of soil using a 2M KCl extractant and analyzed with a Lachat Flow Injection Analyzer.

Data analysis was done with SAS using PROC MIXED. For the RUSLE2 output, year was used as the random replication factor and site and system were fixed effects, with the alpha level set at 0.05. For the fall nitrate data, year and block (i.e. replicate) were the random factors while site and system were fixed. Levene's test showed evidence of heterogeneous variance between systems for the nitrate data so the GROUP=System statement was used and the compound symmetry covariance structure was used to account for autocorrelation on plots over time. Because the fall nitrate data was measured and therefore more variable, alpha was set at 0.10 for this discussion. Because there was a strong site x system interaction and due to the different time span at each site, nitrate data was analyzed by site. The pasture data point at LAC in 1997 was omitted as it was unusually high due to manure application during that pasture renovation year.

RESULTS & DISCUSSION

RUSLE2 output

Preliminary analysis with the RUSLE2 data using the 'common years' data set (1992-2002) vs. 'all site-years' data set (ARS 1992-2009; LAC 1992-2002) showed no differences in main effects or interactions. Furthermore, weed control in the organic systems has become more intense and manure management has changed in recent years at ARS. For example, summer tillage in the 3-yr organic grain system was added in the mid-2000's when we switched from an inter-seeded red clover cover crop to a sequentially-seeded berseem clover/oats cover crop to improve weed control. Further, since the fall of 2005, slurry, not semi-solid, manure has been applied to the alfalfa systems based on the nutrient management standards of the 590 rule (i.e.

not building soil test P or over-applying N). For these reasons, we used the full, ‘all site-years’ data set for this report.

Soil Erosion. When averaged over rotation phases, the ranking of the systems for soil erosion were nearly the same at both locations and there was no notable site x system interaction. And, although LAC had lower K and R factors than ARS (Table 1a), the C-factors were higher for every system at LAC (Table 1b). As a result, the LAC site had higher erosion than the ARS site ($p < 0.001$). As part of the C factor, the lower yields (and residues returned to the soil) realized at LAC (Table 2) had a big impact on erosion. System was also strongly significant ($p < 0.001$). The 3-yr annual organic grain system (CS3) had the highest levels of predicted soil loss, followed by the 3-yr organic forage system, while the managed grazing system (CS6) had the lowest predicted soil loss (Fig. 1a). When looking at the median values, managed grazing soil loss is much closer to zero (median 0.07 and 0.20 tons/a/yr at ARS and LAC, respectively) as the seeding year becomes less an influence over time. The average soil loss for CS3 was 3.8 tons/a/yr (median=3.5) but it was above ‘T’ (average of 6.1 tons/a/yr) in 2 of 18 yrs at ARS, once in 2004 when corn had to be replanted and again in 2005 when yields were quite low. No other system at ARS ever exceeded ‘T’. Most systems at LAC, except the no-till grain (CS2) and the pasture, had 1 yr out of 11 where soil loss was above ‘T’ but in different years for different reasons (delayed or replanting, poor yields).

Looking at specific phases of each system, it’s apparent that the corn phase, particularly in the organic systems is where most of the ‘above T’ violations of non-compliance exist (Fig 1b). For example, at both sites, the corn phase in the organic grain system (CS3) has over half the values above T (9 of 18 yrs at ARS; 9 of 11 yrs at LAC). Luckily, the soybean and wheat phases in that system help pull the overall rotation below T (Fig 1b). One exception was the seeding year in CS4 was higher than the corn phase at both sites ($p < 0.038$ at LAC and $p < 0.086$ at ARS). Also of note is that the seeding phase of each dairy rotation at LAC also had a high frequency of years above T (3 of 11 yrs in CS4 and 4 of 11 yrs in CS5). Experience showed that establishing forages, particularly alfalfa, on these poorly drained soils was difficult in wet years like 1993, 1996 and 1998. Table 2 shows the average yields and C inputs returned to the soil in the form of crop residue, manure inputs, and root biomass. In most cases, yields and C inputs were lower at LAC than ARS across systems with the exception of the manured corn and the pasture at LAC. The solid manure was drier at LAC which resulted in higher manure C inputs in the dairy systems at LAC. Manure was applied to pasture in 1993, and during pasture renovation in 1996 and 1998 at LAC at 20 tons/a in each case.

SCI. Similar to soil loss analysis, site and system were highly significant (both $p < 0.002$). Arlington had an SCI more than twice that of LAC (0.44 vs. 0.19) mostly because the pasture system at ARS was very high. Across sites, the managed grazing system far outperformed the other systems with an SCI score of +1.2 (Fig. 2) with it being above +2 on two occasions at ARS. Gaining OM at a reduced rate were the no-till corn-soy and the 4-yr green gold alfalfa system. Increased productivity and manure additions have been shown to increase soil OM in other studies as well (Bundy et al., 2011; Haynes and Naidu, 1998; Thelen et al 2010). The 3-yr annual organic grain system was the only system losing OM in every year according to RUSLE2. The site x system interaction ($p < 0.001$) was due to CS1 and CS5 modestly gaining OM at ARS (SCI=+0.22) vs. holding steady at LAC (SCI=0) (Fig. 2). Soil conditioning index data were not

available on a phase level. However, the higher SCI at ARS was mostly driven by the OM subfactor of the SCI, which was almost three times higher than at LAC, as well as a better ER (erosion) subfactor at ARS.

STIR. Soil tillage intensity rating is an index of soil disturbance and levels above 200 are considered very intensive and levels below 30 are ideal. The ARS site had a higher STIR value than LAC in the common-years (1992-2002) analysis ($p < 0.089$) and the site effect was strengthened using the full site-years (1992-2009 at ARS and 1992-2002 at LAC) data set ($p < 0.042$). This was mostly due to more passes to prepare seedbed at ARS than at LAC. Furthermore, with better drained soils at ARS, there was usually more opportunity to use the row cultivator for weed management in the organic grain system (Fig. 3). Across sites, the no-till grain and pasture systems were both below 30 (Fig. 3) with an occasional high value during the establishment year (or renovation at LAC after wet season of 1996) of the pasture. The alfalfa systems were intermediate in their STIR values while continuous corn (with annual tillage) and the tillage-intense 3-yr organic grain system being highest.

Examining the data at the phase level provides more insight than the overall system means. All corn phases of each system (except the no-till corn) had STIR ratings above 120 each year (data not shown). Likewise, the organic soybeans and both alfalfa seedings had annual STIR values above 120. The established phases of the alfalfa systems were close to 0 thus pulling down the overall STIR on these rotations. Hence rotations that include perennial crops (and therefore have infrequent tillage) or are completely no-till are a good way to keep a system's STIR value modest but some fields at the beginning of the rotation are susceptible to erosion and organic matter loss.

Fuel use. Relative fuel use is a measure of energy efficiency. Site, system and site x system were highly significant. Arlington had slightly higher fuel use than LAC ($p < 0.001$) which may be due to the slightly different set of equipment available at each site or more tillage passes for weed control. The systems that were highest in fuel use were the alfalfa systems due to multiple harvests per year and biennial manure applications. These dairy systems had 2.5x the fuel use as the grain systems (linear contrast $p < 0.001$). Within the grain systems, the 3-yr annual organic system was similar to continuous corn and both were 2x higher in fuel use as the no-till grain system. The pasture and the no-till grain systems had similarly low fuel use rates. The site x system interaction ($p < 0.001$) was due to the 'green gold' alfalfa system at ARS using about 25% more fuel than the same rotation at LAC while all other systems were similar between sites perhaps related to higher forage yields at ARS (Fig. 4). The pasture system was higher at ARS than LAC from more post-graze clipping and haying supplemental forage.

Like SCI, fuel use data were not available on a phase level; however, fuel data presented and discussed above is prorated on an annual basis.

Fall nitrates

We've previously summarized fall nitrates in a report in the WICST 10th Technical report but since then, some changes have been made at ARS in regard to manure type. Generally, LAC had higher mean nitrates with more variability around each mean (i.e. wider confidence limits). This

may be due to the more nutrient dense manure used there or to the lower yields obtained there vs. those at ARS.

Using confidence limits, all six cropping systems at both sites had nitrate-N levels that were significantly above the standard background level in Wisconsin of 50 lbs NO_3^- -N/3 ft a (Bundy, 1994). Compared to our neighboring prairie check treatment (30 lbs NO_3^- -N/3ft a), all systems had more than 2 to 3x the fall nitrates (Fig 5). The 3-yr annual organic grain system (CS3) and the managed grazing (CS6) were among the lowest at ARS and not significantly different from each other. Less system differences were evident at LAC, with most hovering around 100 lbs NO_3^- -N/3ft a. The pasture at LAC was highly variable with CVs ranging from 5 to 115 over the years, with a 10-yr average CV of 50, whereas most other systems had average CVs of 20 to 30. However, the pasture treatment at ARS had CVs similar to the other systems there.

Though we still follow the pre-plant nitrate test recommendations and operate under Best Management Practices for the conventional corn, there is still a lot of N (2-3x higher than that of the check) left in the systems post-harvest, which are then prone to being lost via leaching. Somewhat surprisingly, continuous corn (CS1) and the no-till corn soybean system (CS2) were very similar in fall nitrates to the two dairy rotations amended with manure (CS4 and CS5). As shown in the phase analysis in Figs. 6 and 7, the corn phase is the 'hot' part of the rotation as N is coming from both plowdown legume and manure inputs. Luckily, the forage phases in the dairy systems pull the overall system average down. It is interesting to note that the soybean phase is just as 'hot' as the corn phase in both grain systems at both sites. It is interesting to see that only the wheat phase at ARS has nitrates not higher than the check. Similar results were seen at LAC but Fig. 7 shows the higher variability at that site by the wider confidence intervals.

CONCLUSIONS

The RUSLE2 model shows how different systems can impact soil structure and can be used as a tool for 1) realizing the effect of different cropping systems and their associated operations and 2) modifying current systems for improved performance such as adding perennial crops or reducing tillage.

This work suggests that all the agricultural systems studied did have significantly higher levels of fall nitrates than the non-agricultural levels. Also, both the forage-based and grain-based systems resulted, on average, in equally high levels of fall nitrate-N. The most benign systems were 3-yr organic grain (CS3) and managed grazing (CS6) systems. The highest fall soil nitrate-N levels were associated with corn production, especially when corn received both legume-N and manure-N as in the alfalfa systems.

CITATIONS

- Bolinder, M.A., Janzen, H.H., Gregorich, E.G., Angers, D.A., and A.J. VandenBygaart. 2007. An approach for estimating net primary productivity and annual carbon inputs to soil for common agricultural crops in Canada. *Agric., Ecosys., and Environ.* 118: 29-42.
- Bundy, L. 1994. Soil nitrate test for Wisconsin cropping systems. UW Extension Bulletin A3624. University of Wisconsin Madison, WI

- Bundy, L.G., Andraski, T.W., Ruark, M.D., and A.E. Peterson. 2011. Long-term continuous corn and nitrogen fertilizer effects on productivity and soil properties. *Agron. J.* 103: 1346-1351.
- Hansen, L. 2007. "Conservation Reserve Program: Environmental Benefits Update," Agriculture and Resource Economics Review. 36(2):267-280.
- Haynes, R.J., and R. Naidu. 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. *Nutrient Cycling in Agroecosystems* 51(2): 123-137.
- Johnson, L.C. 1987. Soil loss tolerance: Fact or myth? *J. Soil and Water Conserv.* 42:155-160.
- Jokela, William, J.L. Posner, J. Hedtcke, T. Balser, and H. Reed. 2011. Midwest Cropping Systems Effects on Soil Properties and on a Soil Quality Index. *Agronomy Journal* 103:5:1552-62.
- Posner, J.L., M.D. Casler, and J.O. Baldock. 1995. The Wisconsin integrated cropping system trial: Combining agro-ecology with production agronomy. *Am. J. Alt Agric.* 10:98-107.
- Posner, J.L., J.O. Baldock, and J.L. Hedtcke. 2008. Organic and conventional production systems in the Wisconsin Integrated Cropping Systems Trial: I. Productivity 1990-2002. *Agron. J.* 100:253-60.
- Renard, K.G., G.R. Foster, G.A. Weesies, K.K. McCool, and D.C. Yoder. 1997. Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation (RUSLE). U.S.D.A. Agricultural Handbook No. 703, 404 pp.
- Schmidt, B.L., R.R. Allmaras, J.V. Mannering, and R.I. Papendick (eds). 1982. Determinants of soil loss tolerance. *Am. Soc. Agron. Spec. Publ.* No. 45. Madison, WI.
- Thelen, K.D., Fronning, B.E., Kravchenko, A., Min, D.H., and G.P. Robertson. 2010. Integrating livestock manure with a corn–soybean bioenergy cropping system improves short-term carbon equestration rates and net global warming potential. *Biomass and Bioenergy* 34: 960-966.
- <http://www.ia.nrcs.usda.gov/news/factsheets/SCI.html> (verified 13 Jan, 2012)
- http://soils.usda.gov/sqi/concepts/soil_organic_matter/som_sci.html (verified 13 Jan, 2012)

Table 1a. Coefficients and general site information from RUSLE2

	Arlington	Lakeland
Soil type	Plano silt loam, 2-6% slope	Griswold silt loam, 2-6%
K, erodibility	0.30	0.23
R, rainfall kinetic energy	190	150
L, slope length (ft)	150	150
S, slope steepness (%)	4	4
C, crop productivity, variable by year and system	See Table 1b	See Table 1b
P, conservation practices	Default of 1 (rows up and down slope)	Default of 1 (rows up and down slope)

Lower coefficients preferred—lead to less erosion

$$E = f(K \cdot R \cdot L \cdot S \cdot C \cdot P)$$

Table 1b. Rotation C-Factors averaged over years

	Arlington (1992-2009)			Lakeland (1992-2002)		
	Mean	Min	Max	Mean	Min	Max
CS1	0.101	0.045	0.580	0.177	0.078	0.430
CS2	0.067	0.014	0.330	0.090	0.055	0.120
CS3	0.163	0.110	0.270	0.234	0.160	0.350
CS4	0.099	0.077	0.140	0.180	0.089	0.320
CS5	0.128	0.068	0.190	0.185	0.120	0.250
CS6	0.015	0.001	0.170	0.020	0.001	0.220

Lower coefficients preferred— lead to less erosion

Table 2. Yield¹ and carbon inputs² on WICST at the Arlington Research Station and the Lakeland Ag Complex.

Cropping System	Phase	ARS (1992-2009)							LAC (1992-2002)						
		----- lbs C a ⁻¹ -----							----- lbs C a ⁻¹ -----						
		Avg. Yield	Above-Ground	Below-Ground	Total	Above-Ground	Below-Ground	Total	Avg. Yield	Above-Ground	Below-Ground	Total	Above-Ground	Below-Ground	Total
		Phase			system			Phase				system			
		<i>bu a⁻¹</i> <i>Cash Grain Systems</i>							<i>bu a⁻¹</i> <i>Cash Grain Systems</i>						
1	corn	170.6	3391	1998	5390	3391	1998	5390	104.5	2077	1224	3301	2077	1224	3301
2	corn	175.8	3495	2059	5554	2601	1481	4081	128.7	2557	1507	4064	2124	1200	3324
	soybean	51.9	1707	902	2609				51.4	1690	894	2584			
3	corn	137.6	2849	1611	4460	1985	1053	3038	95.4	1897	1118	3015	1530	767	2297
	soybean	47.0	1545	817	2362				41.0	1348	713	2061			
	wheat/clover ³	55.4	1561	730	2291				42.2	1344	470	1814			
		<i>bu a⁻¹ or T DM a⁻¹</i> <i>Dairy Forage Systems</i>							<i>bu a⁻¹ or T DM a⁻¹</i> <i>Dairy Forage Systems</i>						
4	corn	195.4	5972	2214	8186	2661	3414	6075	135.4	7948	1557	9505	3721	2632	6353
	seeding	2.69	2926	640	3566				1.47	5623	306	5930			
	hay 1	4.77	707	2555	3262				3.38	501	1808	2308			
	hay 2	4.12	1037	8248	9285				3.54	810	6858	7668			
5	corn	160.0	4891	1874	6766	2825	3551	6377	117.5	7003	1376	8379	4366	2787	7154
	oat/alf	3.62	2434	1472	3906				2.77	5037	985	6021			
	hay 1	4.96	1151	7308	8459				3.93	1060	6001	7061			
6	Pasture ⁴	3.77	1422	3958	5380	1422	3958	5380	2.95	1568	2771	4339	2778	2771	5548

¹Forage yields reported at 100% DM, corn yields at 84.5% DM, and soybean and wheat grain yields at 87% DM. Average straw yields in CS3 = 1.01 and 1.07 tons dm/a at ARS and LAC, respectively

²Soil C inputs were estimated based on harvest index and shoot: root ratios from Bolinder et al., 2007; includes C from post-harvest residue, green manure, dairy cow manure, roots and root exudates.

³Red clover frost seeded or drilled into winter wheat in early spring through 2005; berseem clover and oats were planted after wheat harvest for improved weed control post-2005.

⁴Pasture mix: Timothy (*Phleum pratense* L.), brome grass (*Bromus inermis* L.), orchardgrass (*Dactylis glomerata* L.) and red clover (*Trifolium pratense* L.). Red clover was re-seeded every two or three years with a no-till drill

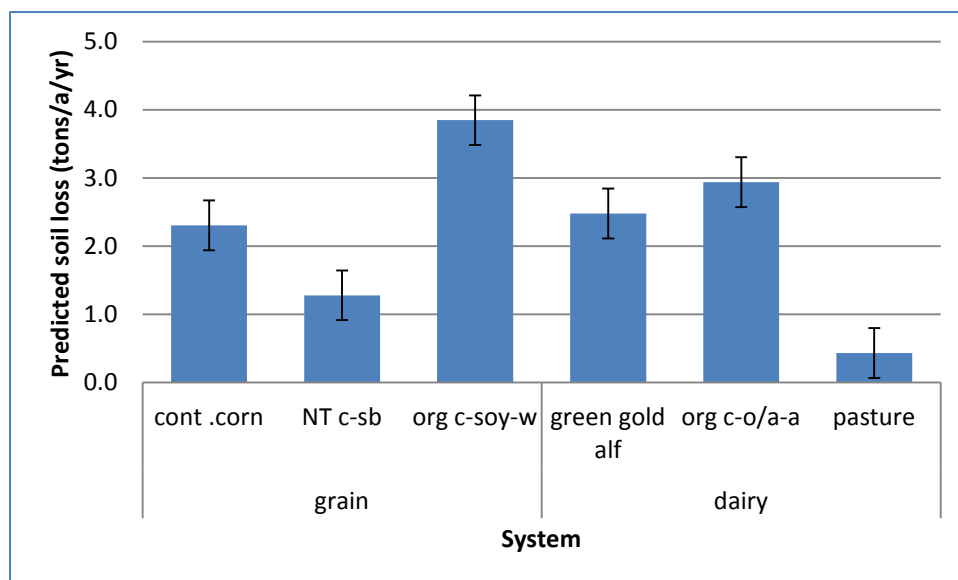


Fig. 1a. Mean soil loss (tons/a/yr) predicted from RUSLE2 at WICST across years and sites (1992-2009 at Arlington and 1992-2002 at Lakeland) with 95% confidence limit shown as vertical lines.

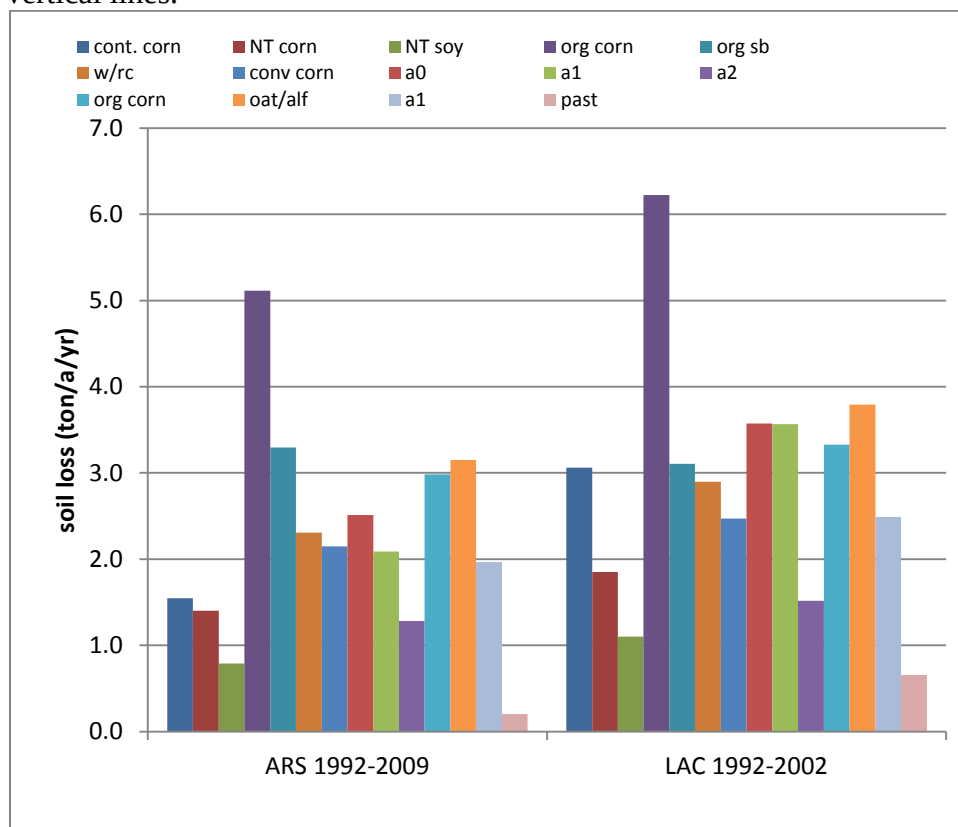


Fig 1b. Soil loss by crop phase of each system.

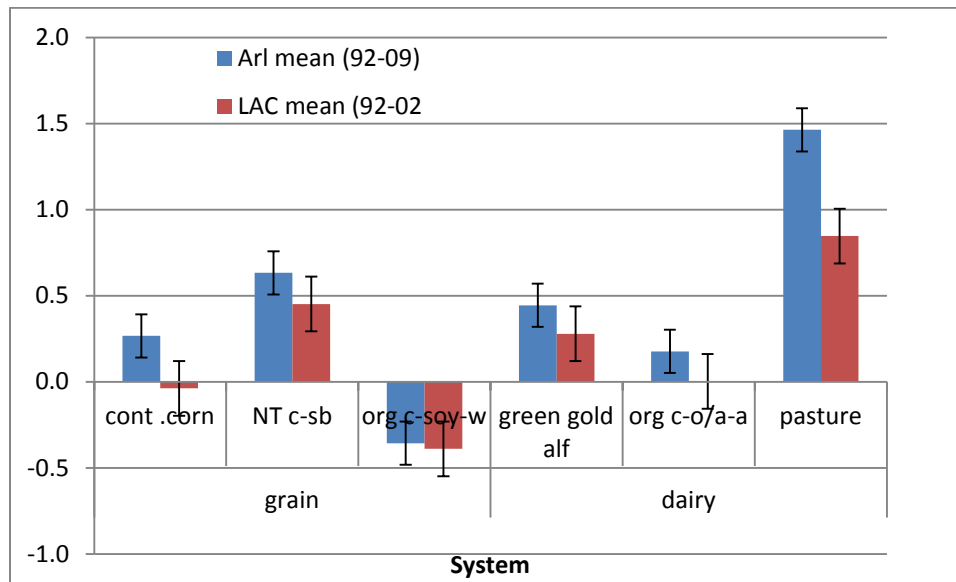


Fig. 2. The mean Soil Conditioning Index predicted from RUSLE2 at WICST across years and sites with 95% confidence limit shown as vertical lines. Values below zero are losing organic matter, values above zero are gaining organic matter.

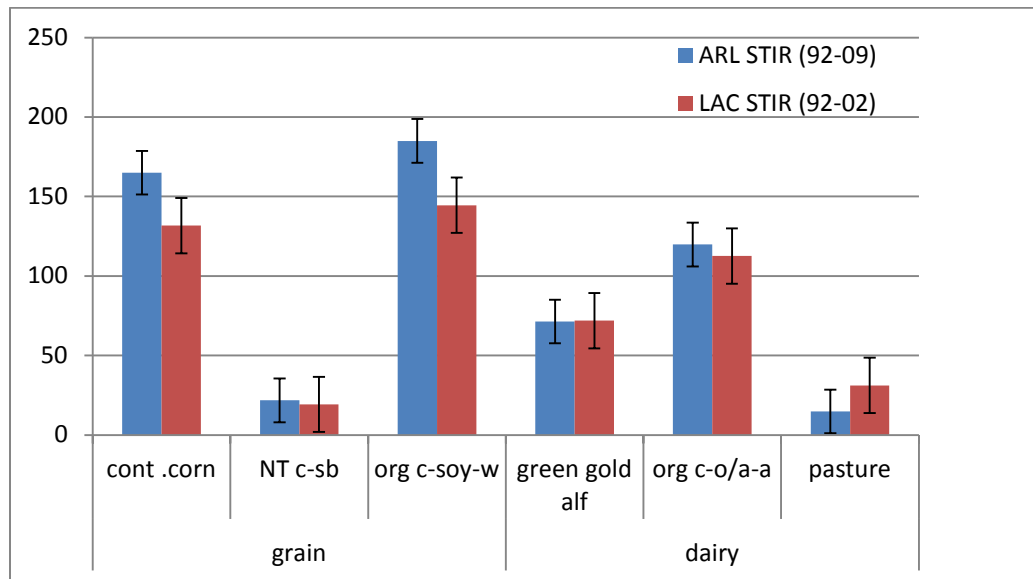


Fig. 3. The mean Soil Tillage Intensity Rating predicted from RUSLE2 at WICST across years and sites with 95% confidence limit shown as vertical lines.

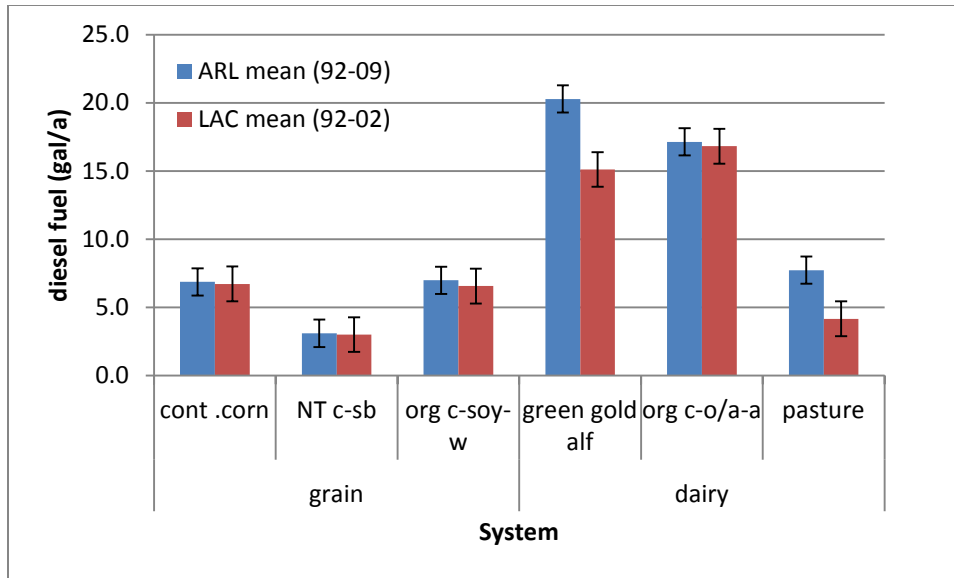


Fig. 4. Average annual fuel use (gal/a) by system at each site.

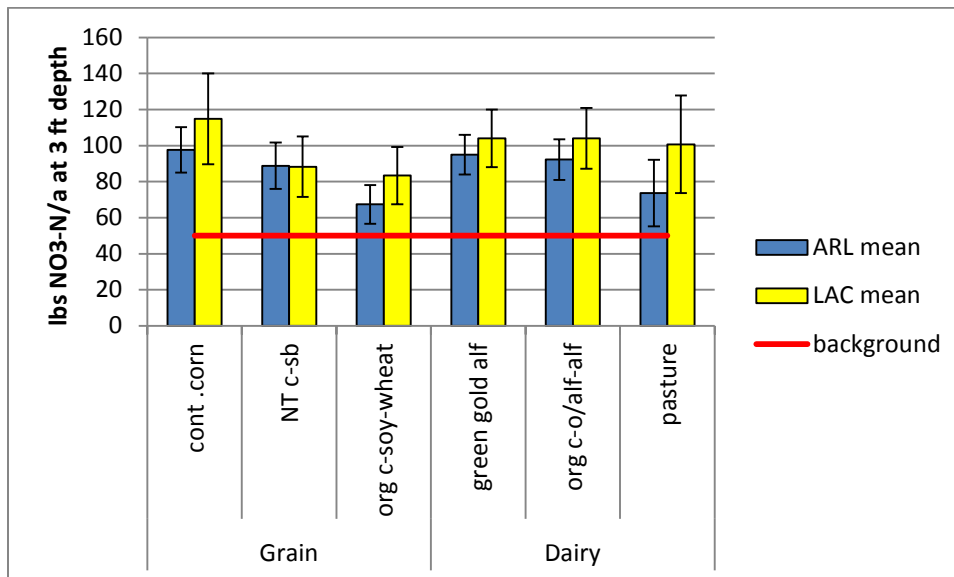


Fig. 5. Mean soil nitrates at Arlington (1993-2010) and Lakeland (1993-2002) with 90% confidence limit shown as vertical lines.

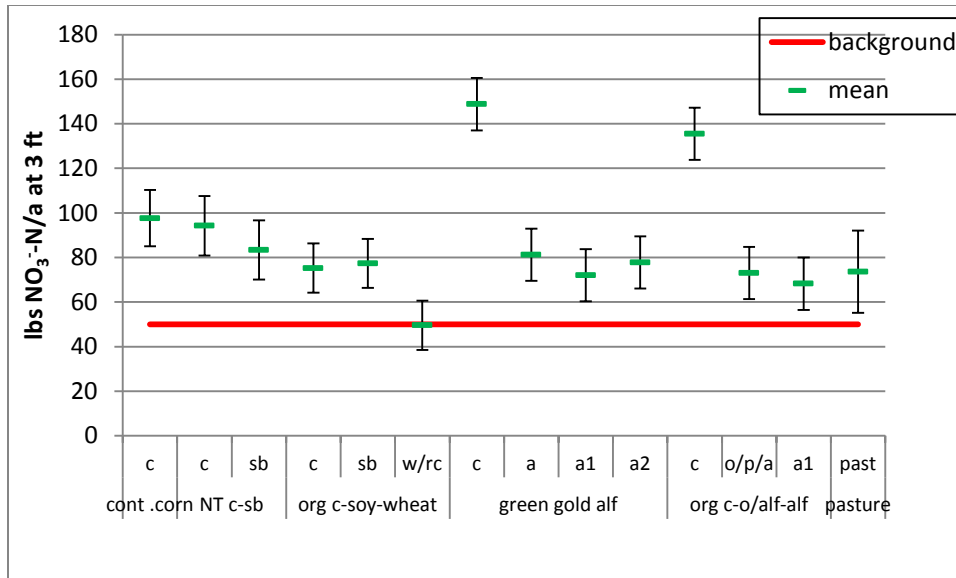


Fig. 6. Mean fall soil nitrates by phase of each system at Arlington with 90% confidence interval (1993-2010).

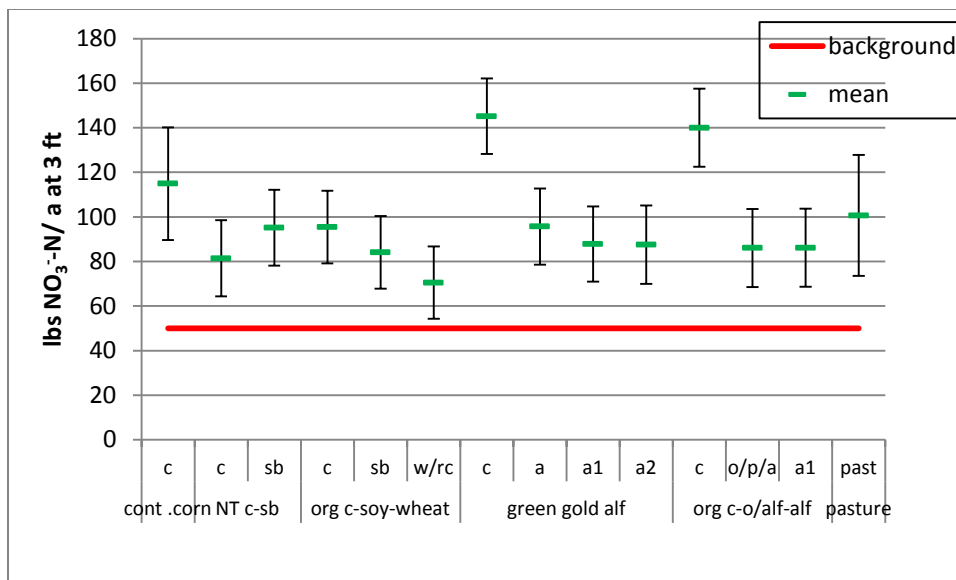


Fig. 7. Mean fall soil nitrates by phase of each system at Lakeland Ag Complex with 90% confidence interval (1993-2002).

SUMMARY OF PASTURE BIOMASS ESTIMATES ON THE ROTATIONAL GRAZING (CS6) SYSTEM 1990-2010

Janet Hedtcke and Joshua Posner

INTRODUCTION

Pasture swards are complex systems of growing grasses and forbs, that are grazed during the growing season and occasionally cut for hay. As a result, it is difficult to characterize their productivity and this can be confounded by heifer management. Briefly, in 1990 we seeded cool-season grasses (timothy, smooth brome grass) and red clover at both Arlington and Lakeland and for the first 2 years hayed the plots with field machinery until fencing and water systems were installed. Animals began grazing in 1992 at Lakeland and in 1993 at Arlington and at both sites the heifers were supplemented with a modest amount of grain. In the late 1980's and early 1990's, managed grazing on the Wisconsin landscape was still a very young movement and there wasn't a lot of resources available for guidance. Thus management of the grazing plots varied over the 20 years, beginning with two heifers per paddock (1992-1995), to a put-and-take system of starting with 12 and once the spring flush was finished, dropping to six heifers (1996-1999) to the current system where the four or five heifers are treated as a cohort and move from paddock to paddock as a group (2000-present). In the 11th Technical Report (2007 pg 20-31) we reported more completely on the productivity, weight gain and profitability of the grazing system at the Arlington site. In this report, we summarize the three different approaches used to develop pasture biomass estimates as it becomes more and more important as we compare primary productivity, carbon cycling and economic productivity among the WICST systems.

Total Forage Availability Approach

Forage availability (FA) is a metric useful to ecologists for measuring above-ground primary productivity (APP) and by definition, it represents all the standing forage as it is clipped to soil level by hand sampling from small quadrats (0.25-0.50 m² in our case). However, FA overestimates economic yield and APP for two reasons. First, it is clipped lower than either machinery harvest or by managed grazing, both which have a target residual height (usually 3-4") that is necessary for adequate regrowth and sward persistence. Secondly, in a pasture situation, forage is clipped just prior to grazing so the hand sampling method may capture some refused forage (not new growth) that was either trampled or defoliated upon in the previous grazing cycle(s). Likewise, because it includes more stems and older and/or senesced leaves in the sample, FA underestimates forage quality. From 1993-2003, pastures yields was measured as FA. Based on research conducted by Cosgrove and Undersander (2001) and Gerrish (2002) it was decided to reduce FA data by 25% to make it more equivalent to our other mechanically harvested forage systems.

Exclosure and Hay Yield Approach

Starting in 2004, grazing exclosures were established in each rep of the pasture to simulate a hay harvest using a self-propelled sickle-bar mower. The exclosures were hayed approximately 4 times per season, while the paddocks, during this period, were grazed, on average, 5 times/season. While this too may over-estimate actual animal consumption, treating a strip of the paddock as a hay field does allow for more accurate comparisons with the hayed alfalfa fields. In a given season the strips were not accessible to the heifers so they were not manured that year

and instead 40 lbs N/a of fertilizer was added after 1st cut. The exclosures were then relocated each year to capture the grazing activity of the previous year.

Table 1 is a summary of the various methods used to estimate yield over the course of the trial.

Table 1. Record of pasture biomass sampling technique		
Year	Arlington	Lakeland
1990	Hayed at 3”cutting height with tractor-pulled haybine	none
1991		Hayed at 3”cutting height with tractor-pulled haybine
1992		Hand sampled w/quadrat to soil surface
1993		
1994		
1995		
1996		
1997		
1998		
1999		
2000		
2001		
2002	Sickle bar mower at 3” cutting height inside grazing exclosure	n/a
2003		
2004		
2005		
2006		
2007		
2008		
2009		
2010		
n/a = not applicable (LAC site discontinued at end of 2002).		

Dry Matter Intake Approach

Although both hand sampling and mechanically harvesting pasture provide useful estimates of pasture production, as stated earlier, both overestimate what the animal actually consumes as dry matter intake (DMI). Actual forage consumption is difficult to determine for grazing studies without using invasive techniques such as surgically implanted fistulas. Therefore, we used animal energy consumption formulas, tables of feed composition, and animal nutrient requirements to estimate dry matter consumed by the grazing animals. Daily net energy for maintenance (NE_M) and net energy for growth (NE_G) requirements for the animals were determined by the standard formulas from the 2001 NRC Publication on Nutrient Requirements for Dairy Cattle (shown below) using average weight of each animal during the grazing period and their average rate of gain.

$$NE_M \text{ (in Mcal/day)} = .086 * (LW)^{.75}$$

and

$$NE_G \text{ (in Mcal/day)} = .035 * (LW)^{.75} * (LWG/1000)^{1.119} + 1.0 * LWG/1000$$

where LW is live weight in kg and LWG is live weight gain in g/day.

The pasture NE_M and NE_G (in Mcal/kg DM) used for ARL were an average of the following three values taken from the NRC feed energy tables:

- 1) $NE_M = 1.52$ and $NE_G = 0.93$ for avg. of early and medium bloom red clover
 - 2) $NE_M = 1.69$ and $NE_G = 1.08$ for young orchardgrass
 - 3) $NE_M = 1.48$ and $NE_G = 0.89$ for avg. of early and medium maturity bromegrass
- Avg $NE_M = 1.56$ and $NE_G = 0.97$ for grass/clover mix pasture**

Energy value of supplemented grain mix at Arlington is

$NE_M = 1.96$ and $NE_G = 1.30$

For Lakeland, the formulas are

$NE_M = 1.31$ and $NE_G = 0.74$ for reed canarygrass

$NE_M = 2.06$ and $NE_G = 1.40$ for barley supplement

Daily DMI was calculated using the following equation:

$DMI \text{ (kg/d)} = (\text{daily } NE_M \text{ requirement} / NE_M \text{ per kg ration}) + (\text{daily } NE_G \text{ requirement} / NE_G \text{ per kg ration})$

The actual NE_M and NE_G of the complete ration were calculated after determining the percent of daily DMI from the grain. Forage consumption was then determined by subtracting off the grain from the daily DMI. Then, we multiplied the number of days the animals were on pasture by the daily DMI per animal. Total DMI per acre was determined by multiplying forage consumption per animal by the total number of animals.

Table 2. Comparison of pasture productivity over the course of the trial at Lakeland and Arlington.				
Site	Year	Forage Availability with 25% adjustment	Hay (whole plot or exclosure)	Dry Matter Intake
		Tons DM/acre		
Lakeland	1990	n/a	n/a	n/a
	1991	n/a	3.38 (whole plot)	n/a
	1992	4.00		3.35
	1993	3.22		2.46
	1994	2.81		3.24
	1995	0.94		2.54
	1996	missing		1.47
	1997	missing		n/a
	1998	missing		0.76
	1999	4.28		1.55
	2000	missing		1.50
	2001	1.97		1.86
	2002	missing		1.77
Mean		2.87	3.38	2.05
Arlington	1990	n/a	4.03 (whole plot)	n/a
	1991	n/a	4.71 (whole plot)	n/a
	1992	n/a	2.81 (whole plot)	n/a
	1993	3.10		2.16
	1994	3.02		3.86
	1995*	1.41		1.89
	1996	missing		1.59
	1997	3.26		2.06
	1998	5.42		1.75
	1999	3.88		1.60
	2000	5.49		2.08
	2001	4.75		1.88
	2002	4.18		2.10
	2003	2.16		1.68
	2004	7.75	5.48 (exclosure)	2.45
	2005	6.03	2.61 (exclosure)	2.06
	2006	4.46	5.80 (exclosure)	3.10
	2007	4.70	3.37 (exclosure)	3.23
	2008	6.37	3.23 (exclosure)	3.07
	2009	3.47	2.87 (exclosure)	2.31
	2010	n/a	3.05 (exclosure)	2.89
Mean		4.34	3.88	2.29
n/a =not applicable; missing due to lack of or incomplete sampling during season				
* Combination of some hand sampling in June and July (0.42 tons DM/a) and one hay harvest in Oct across all plots (0.99 tons DM/a)				

DISCUSSION

As shown in Table 2, the different pasture productivity estimation methods show considerable variability. The limited data at the Lakeland site showed that the pasture plots yielded an average of 2.9 tons DM/a using the adjusted FA. At the Arlington site, with a longer history, average pasture productivity was 4.3 tons DM/a. This is in agreement with the other crops consistently having greater yields at the well-drained Arlington site. The corrected FA was nevertheless often higher than the exclosure method suggesting that perhaps a correction greater than 25% is necessary to estimate a 3" cutting height. The DMI approach results in the lowest off-take estimates. This is not surprising since in years of abundant rainfall, although forage production was up, heifer numbers were not increased so intake was probably a lower percentage of production than in drier years. Our plan is to continue a few more years with FA estimates and exclosure estimates as the best two ways to estimate primary productivity and economic productivity.

REFERENCES

- Gerrish, J. 2002. Is perennial ryegrass a viable forage in Northern Missouri?
<http://aes.missouri.edu/fsrc/news/archives/nl02v11n1a.stm>. University of Missouri Food Systems Research Center. Forage Systems Update. Vol 11(1).
- Cosgrove, D., and D. Undersander. 2001. Evaluation of a simple method for measuring pasture yield. <http://www.uwex.edu/ces/forage/wfc/COSGROVE.html>

MANAGED GRAZING WITH DAIRY HEIFERS: INTEGRATING COOL- AND WARM-SEASON GRASSES FOR IMPROVED SEASONAL PRODUCTIVITY

Janet Hedtcke and Joshua Posner

INTRODUCTION

Managed grazing in Wisconsin has been a growing fraction of the dairy industry for nearly 20 years. A recent survey by Wis-DATCP (Paine and Gildersleeve, 2011) revealed that 22% of all dairy farms now practice some managed grazing, highest in the Southwest (28%) and in each of North central and West central regions (23%), with lower adoption in the East central and Southeast regions at 11-12%. That same survey indicated an average of 93 acres in pasture per farm with grazing and an average grazing season of 7 months.

A common topic of discussion among graziers is how to overcome the ‘summer slump’, a period of low production for cool-season grasses due to warm and often dry weather of summer (Fig. 1; Casler et al., 1998; Paine et al., 1999). While some farmers may plant summer annuals such as sudangrass, sorghum, and even soybeans for forage, these typically involve tillage and can mean obtaining equipment they don’t own. Another option that is being considered is integrating native warm-season grasses into a cool-season system for more uniform seasonal production (Fig. 1).

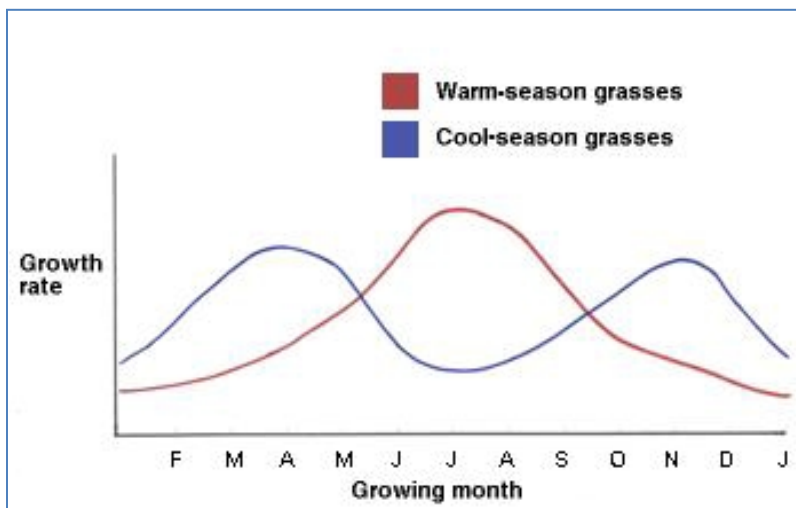


Fig. 1. General seasonal growth pattern of cool-season (C3) and warm-season (C4) grasses. Cool-season curve is bimodal; warm-season curve is unimodal. Combined, there is a more-even seasonal forage availability vs. either alone. (graphic borrowed from google)

Although, it has been a tradition in the West to graze beef cattle on native warm season grasses on rangeland, this is a fairly new idea in Wisconsin and researchers and producers are just beginning to evaluate it. Due to the more efficient carbon fixation pathways and different cell wall structure of warm-season grasses, they are inherently lower in digestibility and N content (Barbehenn et al., 2004) than the introduced cool-season grasses. Nonetheless, when grazed at the proper stage, warm-season grasses can offer a high plane of nutrition for grazing livestock. Animal feeding trials have shown similar performance from cattle on cool and warm-season grasses (Moore et al., 2004; Smart et al., 1995). Doll’s PhD thesis (UW-Madison, 2008)

reported that 35% of graziers surveyed were interested in using warm-season native grasses in their pasture rotation but most were unsure of how to do it. The WICST and SARE (PI, R. Jackson and M.S. candidate C. Maier) projects allowed us to integrate warm-season grass-based prairies into the cool-season grass/legume pasture cycle on WICST. This report summarizes the 2009 and 2010 season when we integrated the native plots into the grazing rotation.

BACKGROUND

In 1999, 3 replicates of 3 treatments (two prairie treatments and a continuous corn treatment) were seeded on an old water way on WICST on a continuum of plant diversity. One prairie treatment was a high diversity (HD) blend of 25 species (3 grasses, 4 legumes, 18 forbs), while the other prairie treatment was a low diversity (LD) blend with 6 species (2 grasses, 2 legumes, and 2 forbs). While corn served as the monoculture from 1999 to 2007, it was replaced with switchgrass in 2007 so that in this old waterway, there were three native perennial treatments. Species composition in the WICST prairies was analyzed with 0.5m² quadrat sampling in August 2008 (N. Budd, WICST 12th Technical Report, p.79): Nearly ten years after establishment, the prairies contain several introduced (i.e. non-native) cool-season grasses such as kentucky bluegrass, smooth brome grass (in >50% of quadrats), timothy or quackgrass (in about 25% of quadrats). The four most prevalent native species were sawtooth sunflower (highly unpalatable), indiangrass, big bluestem, cananda wild rye (very palatable in vegetative stage). With funding from SARE (Jackson and Maier 2009-10) a study was initiated to characterize effect of mowing or grazing on establishing native legumes in existing prairies and switchgrass (collectively referred to here after as the native plots). In the fall of 2008, the native plots were fenced with 3-strand high-tensile electric wire and starting in 2009, the dairy heifers were put onto the native plots as part of the CS6 rotation.

METHODS

In both study years when the native plots were >10" tall (early to mid-June), the heifers were put on the plots for roughly 15 hrs/plot or until they had grazed to about 6" stubble height. In 2009, the plots were grazed 2x and in the wetter 2010 season, they were grazed 3x. Six heifers, about 500 lb each (1 animal unit = 1000 lbs) were grazed on the 0.1 acre plots resulting in a stocking density of 30 AU/a-- comparable to that of cool-season grass pastures. At each sampling event on the native plots, five samples were collected in 2009 and 2 samples were collected in 2010. Samples were clipped from 0.5 m² quadrats to soil level to estimate total forage availability (FA). No attempt was made to separate palatable from non palatable species so forage quality (FQ) is underestimated compared to what the animals would have selected. Likewise, cutting height to estimate forage availability is much lower than how the animals graze under moderate grazing intensity, and therefore FA overestimates economic productivity. This report summarizes the grazing season in 2 parts: Part 1 compares FA and FQ between cool-season to warm-season grasses. Part 2 is an more in-depth analysis within the 3 repetitions of the 3 native treatments showing FA and FQ comparisons between switchgrass, low-diversity, and high-diversity prairie, sampled once a month in early summer.

Statistics. Due to the small sample set, some variables were transformed to adhere to the assumptions of normality and homogeneity of errors. For example, the 2010 FA data was transformed using the log10 function when comparing the warm-season native plots to the cool-

season pastures as well as when comparing FA among the treatments in the 3 reps of the native plots.

RESULTS

Part I.

Integrating Cool-season and Warm-season Swards

By incorporating the native plots into the grazing cycle in 2009 & 2010, it was possible to increase stocking rates while holding steady on average daily gain and days on pastures (Table 1). Days on pasture however, is most affected by seasonal moisture and was only 155 days in 2009 when we experienced a very dry August and September and saw little regrowth on the pastures. In 2010, frequent rainfall all summer long maintained pasture vigor for nearly 30 days longer (182d).

Comparison of animal productivity in 2009 & 2010 (with native plots) with previous decade means (without access to the native plots)		
	2009-10 (range)	2000-08 mean (range)
# head/season	6 (6)	4.7 (4-5)
# Days on pasture/season	169 (155-182)	165 (140-176)
ADG (lbs/hd/d)	2.04 (1.99-2.09)	1.95 (1.38-2.36)

Historical seasonal FA from 2000-2008 from the CS6 (cool-season grasses) is presented Fig 2. As shown, FA peaks in early June which reflects the stem elongation and seed head growth stage of the cool-season grasses. The plots are clipped post-grazing after this phase to promote a more uniform sward height, to increase the light quality to the base of the plants, which encourages new growth from the crown, and to improve FQ and palatability by removing the undesirable stiff stems, seed heads, or old forage. After peak biomass in early June, FA dips and remains somewhat stable through the rest of the season at about 1.2 tons DM/a on offer as available forage. However, there is also a noticeable decline in FA at the end of the season. This is due to the growing animals consuming more biomass on the same acreage combined with the shorter day lengths reducing regrowth.

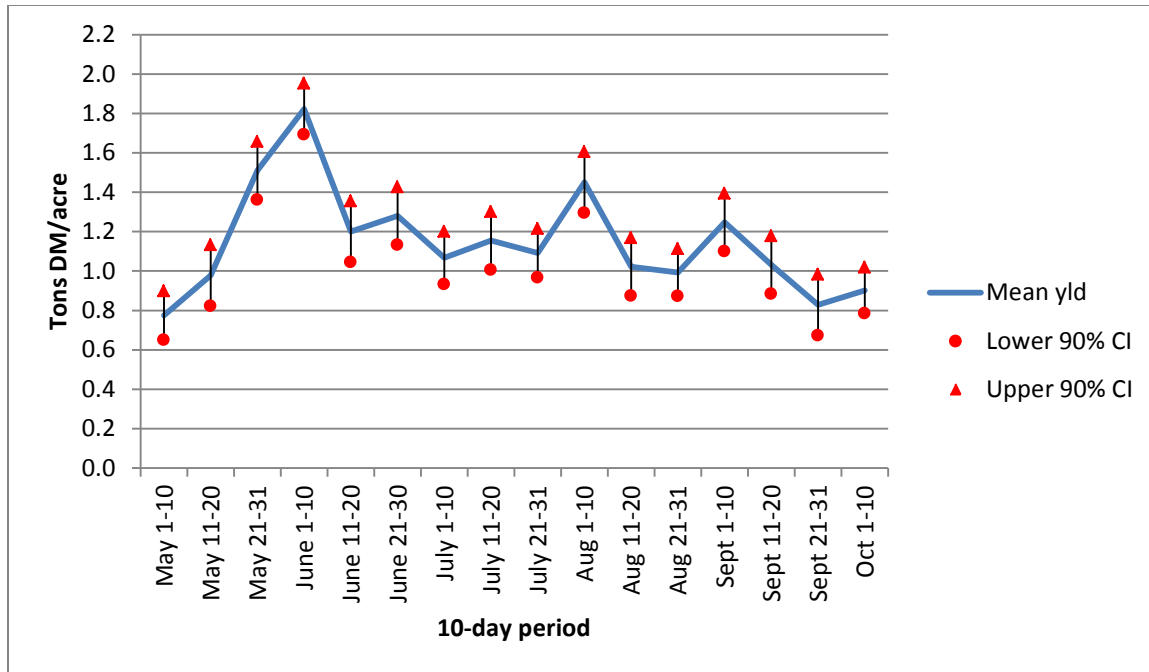


Fig. 2. Seasonal forage availability from 2000-2008 at the Arlington WICST pastures. Each period is a mean of at least 36 observations.

In 2009, heifers were moved off the cool-season pastures in mid-June and mid-July and onto the native plots and in 2010 they grazed the native plots three times. As shown in Fig.3, FA of the warm-season grasses added substantially to the total FA at a time when the cool-season grass production was slumping.

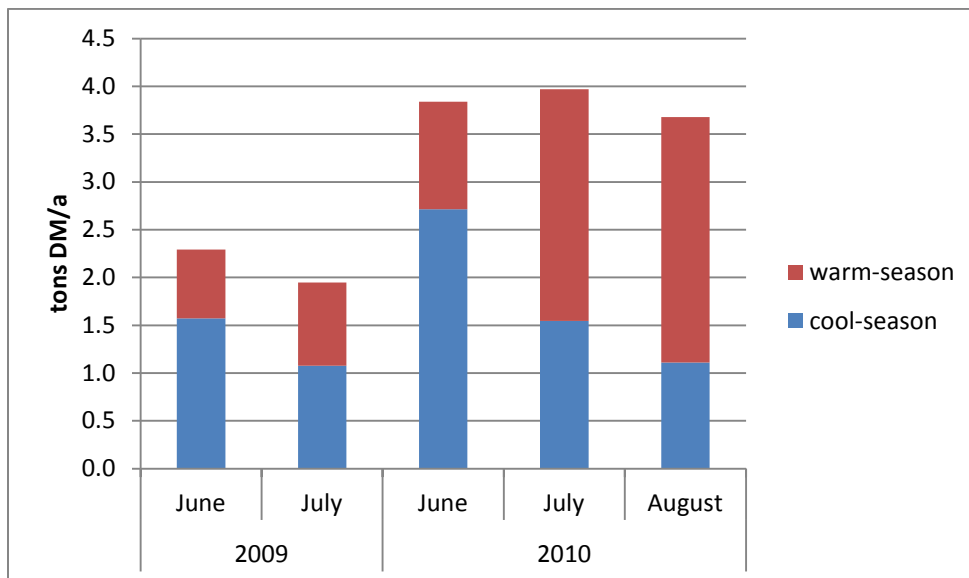


Fig 3. Forage availability from cool-season (i.e. pasture) and warm-season (native grass and prairie) plots in early summer of 2009 and 2010.

Seasonal FQ of the cool-season pastures since 2000 is presented in the 11th WICST Technical Report (p. 26) and isn't shown here. Both crude protein (CP) and Relative Feed Quality (RFQ) remain fairly high throughout the season, but the lowest point is in June when cool-season grasses are stemmy and headed out. This is a good time to transition the heifers to the warm-season native plots where the warm-season grasses are quite lush and vegetative while allowing more recovery time of the cool-season grasses. However, as Figures 4-7 show, FQ does decline rapidly on the native plots, averaged across the 3 treatments (labeled 'warm-seasons' in the figures) in July and August.

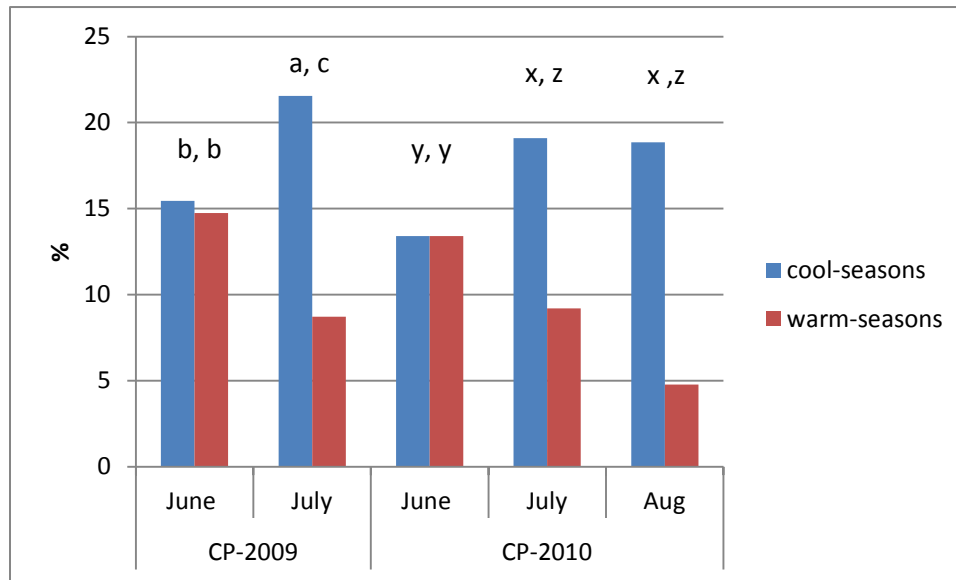


Fig 4. Crude protein (CP) concentration of cool-season (pasture) vs. warm-season (native) plots in early summer of 2009 and 2010. Different letters show significant differences within years at $p < 0.10$.

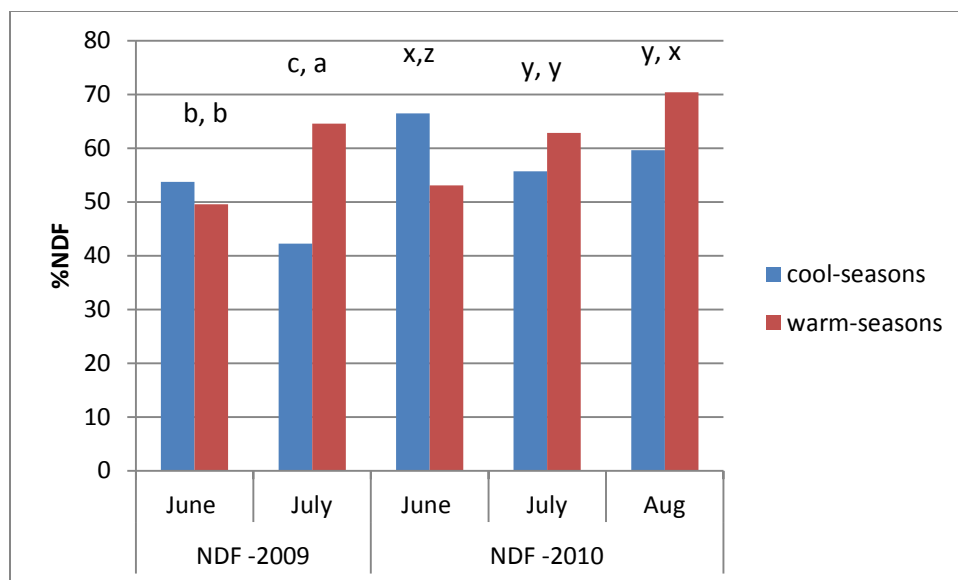


Fig. 5. Neutral detergent fiber (NDF) concentration of cool-season (pasture) vs. warm-season (native) plots in early summer in 2009 and 2010. Different letters show significant differences within years at $p < 0.10$.

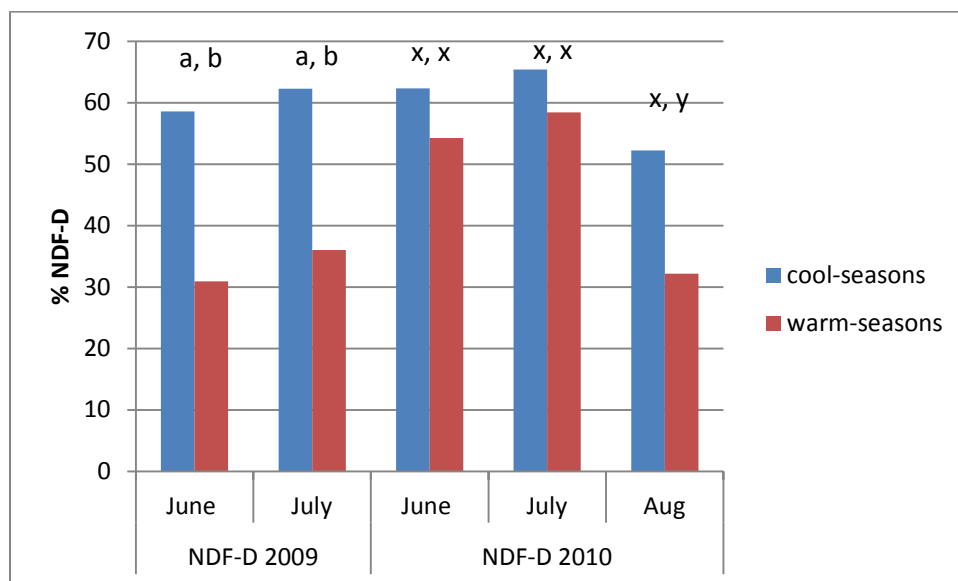


Fig. 6 Neutral detergent fiber digestibility (NDFD, 48-hr) of cool-season (pasture) vs. warm-season (native) plots in early summer in 2009 and 2010. Different letters show significant differences within years at $p < 0.10$.

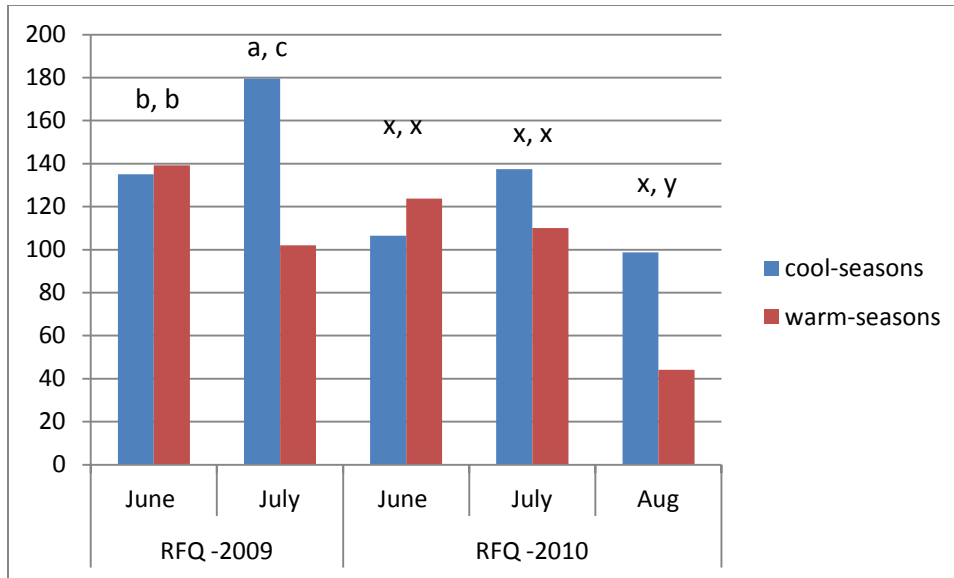


Fig 7. Relative Forage Quality (RFQ) of cool-season (pasture) vs. warm-season (native) plots in early summer in 2009 and 2010. Different letters show significant differences within years at $p<0.10$.

Part 2.

Warm-season Grass Comparison

Among the 3 reps and 3 treatments of native plots, FA and FQ comparisons were made while grazing occurred in early summer (June 11 and July 7, 2009; June 1, June 28, and August 23, 2010). As shown in Figs. 9 and 10, in both years, the three systems were similar in mid-June, but by July and August the biomass of the switchgrass plots had significantly greater FA than the prairie plots.

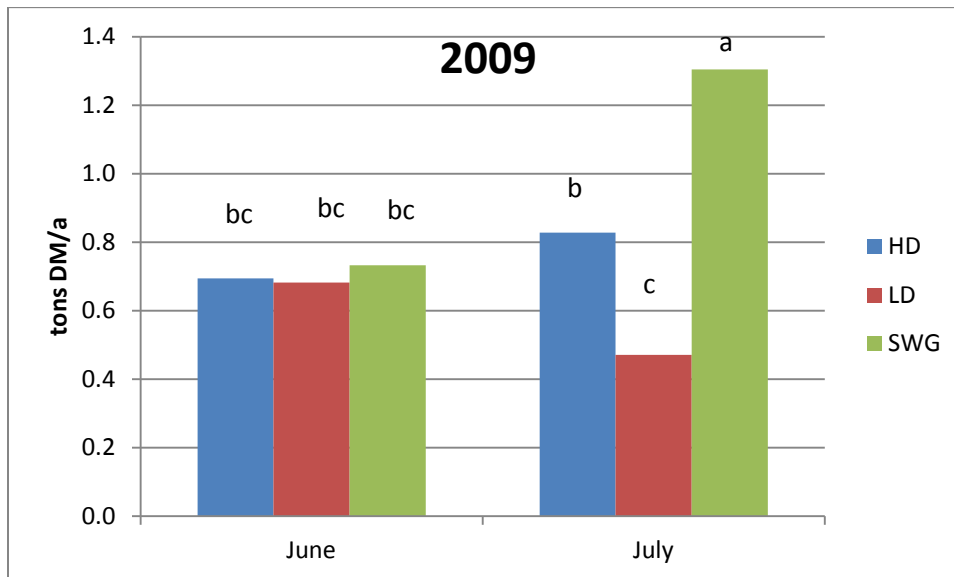


Fig. 9. Forage availability among native plots in 2009. Different letters show significant differences at $p<0.10$.

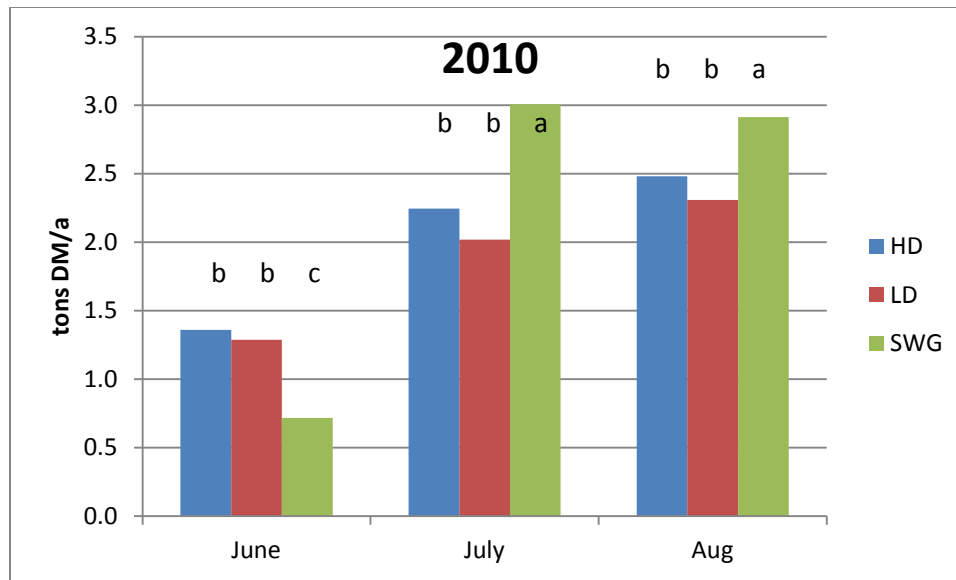


Fig. 10. Forage availability among native plots in 2010. Different letters show significant differences at $p < 0.10$.

Crude protein concentrations are impressive and adequate for growing heifers in June. The switchgrass treatment was especially striking at 14.6 to 17.4% each year (data not shown as there was no treatment or treatment x month effects; see Fig. 4 for warm-season grasses in general). Likewise, there was no treatment or treatment x month effects within the native plots for NDF levels (see Fig. 5). There was an interesting treatment x month interaction for NDF-D in 2009 (Fig. 11) where switchgrass was highest in NDF-D in June but lowest in July, reflecting a more rapid change in maturity than the other warm-season grasses. And though there was no significant interaction in 2010, switchgrass ranked highest in NDF-D in June and July but lowest in August. It's unclear why 2009 was so much lower in NDF-D than in 2010 when the other variables (CP and NDF) were similar between years.

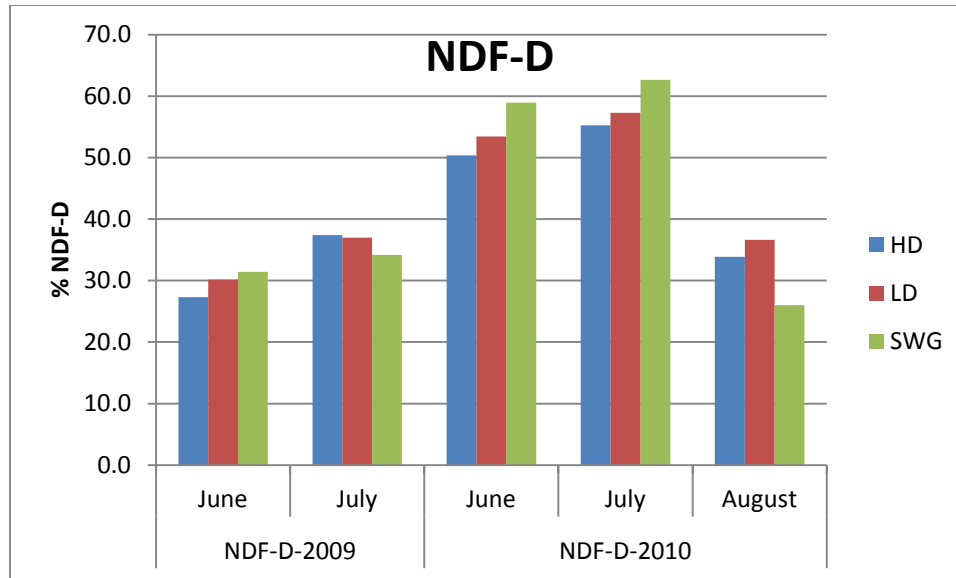


Fig. 11. Forage NDF-D (48-hrs) of native plots. In 2009, there was an interaction between trt and month ($p<0.0015$) and just a main effect of month in 2010 ($p<0.0001$).

SUMMARY

Integrating warm-season grasses into cool-season pastures seems to work best if done in June before the warm-season grasses get too mature. This is an important time to give the cool-season pastures adequate rest and recover and avoids having to graze stemmy grasses in the cool-season pastures. The warm-season component adds a significant contribution to the overall available forage and though FQ declines progressively beyond June, the animals could select a higher quality diet if stocked at a moderate density.

LITERATURE CITED

- Barbehenn, R.W., Z. Chen, D. N. Karowe, and A. Spickard. 2004. C3 grasses have higher nutritional quality than C4 grasses under ambient and elevated atmospheric CO₂. *Global Change Biology* 10:1565-1575.
- Casler, M. D., D. J. Undersander, C. Fredericks, D. K. Combs, and J. D. Reed. 1998. An on-farm test of perennial forage grass varieties under management intensive grazing. *Journal of Production Agriculture* 11 (1):92-99
- Moore, K. J., T. A. White, R. L. Hintz, P. K. Patrick, and E. C. Brummer. 2004. Forages and pasture management - sequential grazing of cool- and warm-season pastures. *Agronomy Journal* 96 (4):1103-1111.
- Paine, L.K., and R. Gildersleeve. 2011. A summary of dairy grazing practices in Wisconsin. WI-DATCP and UW-Extension survey.
- Paine, L. K., D. Undersander, and M. D. Casler. 1999. Pasture growth, production, and quality under rotational and continuous grazing management. *Journal of Production Agriculture* 12 (4):569-577.

Smart, A. J., D. J. Undersander, and J. R. Keir. 1995. Forage growth and steer performance on Kentucky bluegrass vs. sequentially grazed Kentucky bluegrass-switchgrass. *Journal of Production Agriculture* 8 (1):97-101.

MANAGED GRAZING IN WICST PRAIRIES: TRADEOFFS BETWEEN PLANT FUNCTIONAL DIVERSITY, FORAGE AVAILABILITY, AND RESISTANCE TO WEED INVASION

Craig M. Maier, Daniel J. Undersander, Randall D. Jackson, Janet Hedtke, Josh Posner

INTRODUCTION

The potential benefits and tradeoffs of high biodiversity in grazing lands have been explored for cool-season grass-legume pastures of the temperate United States (Sanderson et al., 2004), but it is unknown if positive the positive relationship between diversity and productivity in tallgrass prairies in the North Central U.S. (Fargione et al., 2007) is maintained when herbivores are added to the system.

In humid to sub-humid environments, cool-season (C3) grasses are very productive, but season-long carrying capacity can be reduced when peak growth occurs by mid-June (Riesterer et al., 2000; Moore et al., 2004). An important component of this region's natural history is the tallgrass prairie ecosystem, a mid-continent grassland in which warm-season (C4) grasses produce the majority of above- and belowground biomass. Dominant species include *Andropogon gerardii* Vitman (big bluestem), *Panicum virgatum* L. (switchgrass), and *Sorghastrum nutans* (L.) Nash (Indiangrass). C4 grasses utilize the C4 photosynthetic pathway, generally resulting in inherently lower forage quality due to low digestibility of leaf structure and reduced levels of nitrogen-rich photosynthetic enzymes compared to the C3 pathway used by cool-season grasses (Barbahenn et al., 2004).

The advantages of C3 and C4 grasses can be captured when managers plan to graze non-native and native pastures in sequence: at the beginning of the grazing season, animals are stocked on C3 pastures; then, in early summer, animals are stocked on pastures dominated by C4 grasses to utilize rapid vegetative growth (allowing C3 pastures longer rest periods), and, finally, animals remain on C3 pastures from late summer through fall after C4 grass productivity and quality have declined. In the North Central U.S., sequential grazing with C3 and C4 pastures has previously been evaluated in Iowa, central Wisconsin, and southwestern Michigan. In comparing steer weight gains in C3-only and sequential grazing systems, researchers found no difference when comparing a C3 monoculture (*Poa pratensis* L. [Kentucky bluegrass]) to a switchgrass monoculture in central Wisconsin (Smart et al., 1995), but in southern Iowa, cattle that grazed in sequential systems gained less than those that remained on C3 pastures throughout the season (Moore et al., 2004). In the Wisconsin study, summer weather conditions favored C3 grass growth during the length of the trial. In the Iowa study, C4 grass grazing was initiated fairly late in the growing season (early July) when forage production was high but crude protein (CP) concentrations were low (6 percent), which may have affected animal performance.

To explore the relationships between plant functional diversity, forage production, and forage quality in native grasslands managed for sequential grazing, managed grazing was employed across a diversity gradient in reconstructed tallgrass prairie communities. A well-established switchgrass monoculture was compared to reconstructed (planted) prairies that had been seeded with varying levels of native plant functional diversity (including native C4 grasses, native C3 grasses, native forbs, and native legumes, and which were invaded over time by non-native C3 grasses and non-native legumes). Native legumes were interseeded across all diversity levels to test if this functional group can be successfully established in existing native grasslands and how increased legume cover affects forage production and quality. We hypothesized that:

- * increased functional diversity would be correlated to increased forage production; and
- * across diversity treatments, native legume interseeding would result in greater increases in forage quality and production in C4 monocultures than in diverse prairies.

METHODS

Location

Native grassland reconstruction at WICST began in 1999 (Simonsen et al., 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. The species sown in these treatments are native species found in mesic tallgrass prairie communities and represent several functional groups (Table 1). The prairie seed was hand broadcast and cultipacked in June 1999, and subsequent management included periodic clipping for weed control from 1999-2002 (Simonsen et al., 2002). The CC treatment concluded in 2006; in June 2007 the CC plots were planted with switchgrass (cultivar: Forestburg) to include a native C4 monoculture (SW) treatment. The grasslands were burned in 2003, 2005, and 2008. During this study, the grasslands were burned again in 2009 and 2010. Canada thistle has been treated with spot application of herbicide during the growing season.

Experimental design

Plant community diversity, management, and legume interseeding treatments were applied in a hierarchical split-split plot design. Diversity treatments served as whole plots in the nomenclature of split plot design. Each whole plot was split into three subplots to apply management treatments: grazing, mowing, and control. Due to requirements of the grazing treatment (fencing and supplying water), this split was applied at the block level, with control subplots located in the southern position, and grazing and mowing subplots randomly assigned to the northern or central positions. To account for this spatial arrangement, we also included these management blocks as a random factor in statistical analyses. Management treatments subplots were split into sub-subplots for native legume interseeding. Sub-subplots were randomly assigned interseeding or no interseeding treatments. 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 55 ft by 45 ft m, covering approximately 0.1 acre. All experimental units were burned annually in the spring from 2008-2010.

Rotational Grazing

Six Holstein heifers were used in the managed grazing treatment. In June, each animal weighed approximately 500 pounds, and the animal unit equivalents (AUE) for the herd were estimated at 3.0 and 3.6 for June and July grazing periods, respectively. Area of individual paddocks was 0.1 acres. Animals were moved to a new paddock when herd managers observed that the majority of C4 grasses were grazed to a residual height of approximately 6 inches, and we recorded time spent on each paddock (Table 1).

Legume recruitment

Interseeding occurred on June 26, 2009, following completion of the June grazing and mowing treatments. Five native legume species were incorporated into a mixture and seeded at a rate of 100 seeds per square meter (20 seeds per species). Prior to planting, each species was inoculated with appropriate *Rhizobium* bacteria to promote healthy growth of legume seedlings. Interseeding was accomplished using a Great Plains no-till drill, an implement designed for interseeding in grasslands with minimal soil disturbance.

Legume recruitment

Native legume recruitment was estimated in August–September 2009, June 2010, and August 2010 using seedling counts. Five 0.5 m² quadrats were located in each experimental unit. The 1 m by 0.5 m frame was wider than five rows of the no-till interseeding implement. In each quadrat, native legume seedlings rooted inside the quadrat were identified to species and species counts were recorded. In June 2010, quadrats were again randomly located, and the northwest corner of each quadrat was marked with a large plastic stake. The same quadrat locations were revisited in August 2010. The Central Region Seedling Identification Guide for Native Prairie Plants (2005) provided adequate information to identify native legume seedlings used in this study to species.

Standing biomass and forage

Vegetation was harvested to estimate standing biomass and available forage quantity and quality. In June 2009, we estimated standing biomass and available forage using five 0.1 m² quadrats randomly located in each experimental unit. Within each quadrat biomass was clipped to ground level. Spring prescribed fire removed the previous year's standing stems and litter. Biomass was sorted into palatable and unpalatable fractions, based on observations of which species cattle were selecting while grazing in switchgrass and prairie stands in the acclimation paddocks. Forage yield and quality were estimated using the palatable fraction of subsamples.

In 2009, we found that high dispersion of unpalatable species caused cattle to avoid selecting sparse, short-statured palatable plants located within stands of tall-statured native forbs. For 2010, biomass and forage sampling methods were altered to reflect cattle behavior. Forage availability and quality was estimated using clippings obtained from feeding stations (Bailey et al., 1998), which are patches of palatable vegetation which cattle selected for grazing from the heterogeneous sward.

Forage yield at the paddock-level scale was estimated for each experimental unit by multiplying the mean forage yield at the feeding station scale by the mean frequency of feeding stations. The frequency of feeding stations in each experimental unit was estimated using stratified random sampling. Five subsamples were located approximately 2 meters apart along 5 transects spaced 3 meters apart (25 subsamples per experimental unit). At each subsample location, a 0.25 m² quadrat was placed at canopy level and the cover of palatable species was visually estimated. Each subsample with greater than 50 percent cover of palatable species was counted as a feeding station. Frequency was calculated by dividing the number of feeding stations counted in each experimental unit by the total number of samples taken.

All biomass was dried at 60°C to constant weight. Forage samples were ground in a mill until dry matter passed through a 2 mm screen. Samples were analyzed for forage quality by near infrared reflectance spectroscopy (NIRS). Crude protein (CP), neutral detergent fiber (NDF), and relative forage quality (RFQ) were estimated using the mixed grass equation from the NIRS Forage and Feed Testing Consortium and WinISI II Version 1.50 software (Infrasoft International, LLC, Port Matilda, PA).

Statistical analysis

Standing biomass, available forage yield, forage quality, and frequency of feeding stations in the grazing treatment were analyzed using linear mixed effects modeling. All mixed effects models were fit with block as a random factor. Models were evaluated using Akaike's Information Criteria (AIC). For June 2009 data, model selection followed Crawley (2002). Likelihood ratio tests were used to compare the full model (with all levels of diversity) with the simpler models comparing switchgrass and prairies. The more parsimonious model was chosen unless models were significantly different ($p \leq 0.05$). The model with the lower AIC was chosen when $p \leq 0.05$.

For 2010 data, likelihood ratio tests were used to compare the full model (diversity X month) with simpler models. Tukey's Honestly Significant Difference (HSD) was used to evaluate pair-wise comparisons of factor levels in the final models.

All mixed effects models were analyzed using R version 2.13.2 R (R Development Core Team, 2011). The package lme4 was used for linear mixed effects modeling; p-values for fixed effects were estimated using the LMERConvenienceFunctions and LanguageR packages. The package sciplots was used to graph means and standard errors in barchart formats.

RESULTS

Legume recruitment

Differences in recruitment to seedling stage were not ecologically significant because few seedlings were observed surviving to maturity. Mean recruitment to the seedling stage was highly variable among species (Table 3).

Forage quality and quantity

Due to the lack of native legume seedling recruitment, data from paired interseeded and not-interseeded plots was combined and averaged.

In June 2009, CP in switchgrass was significantly higher than in diverse prairies ($p = 0.019$), but diversity level did not have a significant effect on NDF ($p = 0.126$) or RFQ ($p = 0.16$) (Fig. 2). Available forage yields were similar across all diversity levels (0.187), but standing biomass was higher in diverse prairies ($p = 0.049$).

In 2010, CP levels were lower for switchgrass than diverse prairies in both June and July ($p = 0.05$) (Fig. 4), reflecting more advanced development in switchgrass in 2010; the model was improved by removing the diversity X month interaction term. NDF was higher in switchgrass than prairies across both months ($p = 0.002$). For RFQ, the effect of month was highly significant ($p < 0.001$); we found a highly significant effect of diversity treatment ($p = 0.005$), and a weakly significant diversity X month interaction ($p = 0.081$). Pairwise comparisons indicated that RFQ was similar across diversity treatments in June ($p = 0.66$) and dropped for both prairies and switchgrass in July. RFQ was significantly lower in switchgrass than prairies in July ($p < 0.001$), reflecting minimal switchgrass defoliation by June grazing and advanced developmental stage in mid-summer.

Diversity had a strong effect on frequency of feeding stations ($p < 0.001$) (Fig. 5). For June, pairwise comparisons found that frequency was higher in switchgrass than in low diversity treatments ($p < 0.038$) and high diversity treatments ($p < 0.001$). Model selection indicated that low and high diversity treatments were different; however, the more conservative Tukey comparison did not find a significant difference in mean frequency between prairies ($p = 0.308$). The pattern was the same for July. Within treatments, frequency did not change significantly from June to July. July frequency in low diversity prairies was similar to June frequency observed in high diversity prairies ($p = 0.475$).

Feeding-station-scale available forage yield was significantly higher in switchgrass than diverse prairies ($p < 0.001$); a month X diversity interaction was weakly significant ($p = 0.066$), but the more conservative Tukey pairwise comparisons did not find significant differences within diversity levels between June and July. Results were similar for paddock-scale available forage; available forage yield was significantly higher in switchgrass than diverse prairies ($p < 0.001$); there was a weakly significant month X diversity interaction ($p = 0.078$), but the more conservative Tukey pairwise comparisons did not find significant differences within diversity levels between June and July.

Mean standing biomass was not significantly different across diversity levels and increased across all levels from June to July ($p < 0.001$).

DISCUSSION

We found a negative tradeoff between forage yield and increased plant species diversity in reconstructed grasslands. Our results indicate that high abundance of unpalatable forb species can significantly limit forage availability in prairies compared to a C4 monoculture, even when standing biomass is similar across diversity levels. Forage quality was not significantly different across diversity treatment levels, so the diversity trade off primarily impacts the amount of land that must be used for pasture to achieve forage availability goals. Across diversity and management treatments, native legume interseeding did not result in ecologically- or agronomically-significant recruitment to mature plants.

CP concentration was higher across all diversity levels in June 2009 than June 2010, and NDF levels were lower, reflecting the earlier date of the first grazing period in 2009; switchgrass monocultures had also accumulated greater forage yield in 2010 than 2009, reflecting the common relationship between increased yield and decreased quality as grasses mature. Low digestibility limited forage intake in switchgrass monocultures in June 2010, resulting in much lower forage quality in July 2010 as the grasses continued to mature.

Forage quality was similar to mixed C4 grasses grazed under a similar schedule during the same time period in southern Wisconsin (Chamberlain, 2011), but available forage was greater in the mixed C4 grasses in July than switchgrass monocultures and diverse prairies. NDF and CP concentrations reported by Smart et al. (1995) were intermediate between 2009 and 2010 levels reported here.

In 2010, forage yield at feeding stations was greater in switchgrass stands and prairies, but because we sampled forage yield at feeding stations where the biomass of unpalatable vegetation was up to half of the total standing biomass, this result alone does not provide strong evidence that switchgrass plants were more productive than Indiangrass or big bluestem plants in the diverse prairies. Lower forage yield in prairie feeding stations may also be due to high dispersion of unpalatable species, such as native forbs (reflected in the low ratio of palatable:unpalatable species standing biomass found by the sampling method in 2009), as well as high dispersion of exotic palatable species such as Kentucky bluegrass, smooth brome and white clover which invaded the prairies prior to the beginning of this study. We observed that these C3 forage species did not yield as high in the prairies as in conventionally-managed C3 pastures in the region, potentially due to lower yield in naturalized populations compared to cultivars. Environmental limitations or plant-plant competition in the prairies (such as effects of annual burning or competition with taller-statured native species for limited resources) may also limit productivity of non-native cool season grasses and legumes growing in reconstructed prairies.

Available forage yield and quality was comparable to summer values for C3 mixtures in southern Wisconsin managed with rotational grazing by beef cow-calf pairs (Oates et al., 2011). The available forage yields of the prairie were higher than yields reported by Smart et al. (1995) for switchgrass grown on sandier soils in central Wisconsin, but yields were low in comparison to the WICST switchgrass monocultures and a vigorous stand of mixed C4 grasses evaluated by Chamberlain (2011). Mowing greatly reduced the stature of unpalatable native forbs in the diverse prairie treatments, and defoliated plants may exhibit higher leaf:stem ratios and thus lower C:N ratios than undefoliated plants. In a grazing and clipping management regime, the changes in structure and quality induced by mid-summer mowing could make these species much more attractive to cattle in the re-growth stage. Increasing palatability and selection of these species could result in competitive release of grasses and smaller statured legumes, causing a significant change in plant community. This could positively influence the frequency of feeding stations and forage yield at both the feeding station and paddock scales.

CONCLUSION

By incorporating sequential grazing of C4 grasses into a grazing operation, farmers can reduce the risk of over-taxing C3 grasses during potential episodes of midsummer stress induced by drought or

high temperatures. Depending on soils, plant community composition, and management, C4 grass stands can provide similar or improved yield and quality as C3 grasslands during summer months, or may result in reduced forage quality and intake. Despite potential negative impacts at the paddock scale, incorporating C4 grasslands could benefit farmers at the farm scale in a number of ways. Having a low to moderate proportion of pasture land devoted to C4 grasses (10-25 percent) could make it easier to manage the “spring flush” of C3 community growth that typically precedes the onset of rapid growth in C4 communities: given less acreage in C3 pasture, stocking rates must increase, which could facilitate increased utilization of rapid early growth rates and reduce the need for mechanical forage management such as haying or post-graze clipping. Overall, sequential grazing may improve animal performance and farm profitability by providing opportunities to decrease the intensity of summer defoliation on C3 stands, increase rest periods, and ultimately support higher vigor of the C3 stands.

WORKS CITED

- Bailey, D. W., B. Dumont, and M. F. Wallisdevries 1998. Utilization of Heterogeneous Grasslands by Domestic Herbivores: Theory to Management. *Annals of Zootechnie* **47**:321-333.
- Barbahenn, R. V., Z. Chen, N. Karowe, and A. Spickard 2004. C3 Grasses Have Higher Nutritional Quality Than C4 Grasses under Ambient and Elevated Atmospheric Co₂. *Global Change Biology* **10**:1565-1575.
- Chamberlain, S. K. 2011. Persistence and Productivity of Native Warm-Season Grass Ecotypes and Cultivars under Managed Grazing in Southern Wisconsin. M.S. University of Wisconsin-Madison, Madison, WI.
- Fargione, J., D. Tilman, R. Dybzinski, J. H. R. Lambers, C. Clark, W. S. Harpole, J. M. H. Knops, P. B. Reich, and M. Loreau 2007. From Selection to Complementarity: Shifts in the Causes of Biodiversity-Productivity Relationships in a Long-Term Biodiversity Experiment. *Proceedings of the Royal Society B: Biological Sciences* **274**:871-876.
- Moore, K. J., T. A. White, R. L. Hintz, P. K. Patrick, and E. C. Brummer 2004. Forages and Pasture Management - Sequential Grazing of Cool- and Warm-Season Pastures. *Agronomy Journal* **96**:1103-1111.
- Oates, L., G., D. Undersander, J., C. Gratton, M. Bell, M., and R. Jackson, D. 2011. Management-Intensive Rotational Grazing Enhances Forage Production and Quality of Subhumid Cool-Season Pastures **51**:892-901.
- R Development Core Team 2011. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
- Riesterer, J. L., M. D. Casler, D. J. Undersander, and D. K. Combs 2000. Seasonal Yield Distribution of Cool-Season Grasses Following Winter Defoliation. *Agron. J.* **92**:974-980.
- Sanderson, M. A., R. H. Skinner, D. J. Barker, G. R. Edwards, B. F. Tracy, and D. A. Wedin 2004. Plant Species Diversity and Management of Temperate Forage and Grazing Land Ecosystems. *Crop Sci.* **44**:1132-1144.
- Simonsen, K., E. Howell, and J. Posner 2002. Prairie Establishment in Agricultural Soils. Pages 136-144. Wisconsin Integrated Cropping System Trial 9th Technical Report. University of Wisconsin-Madison, Madison, WI.
- Smart, A. J., D. J. Undersander, and J. R. Keir 1995. Forage Growth and Steer Performance on Kentucky Bluegrass Vs Sequentially Grazed Kentucky Bluegrass Switchgrass **8**:97-101.

Appendix 1. Tables and Figures

Table 1. Diversity Treatments in Reconstructed Native Grasslands at WICST

Diversity Treatment	No. of Species Planted	Functional Groups Planted			
		C4	C3	Leg. ^a	Forb.
Switchgrass Monoculture (SW)	1	X			
Low Diversity Prairie (LD)	6	X	X	X	X
High Diversity Prairie (HD)	26	X	X	X	X

a Prior to native legume interseeding trial.

Table 2. Timing of Grazing, Duration and Instantaneous Stocking Rate.

Grazing Period	Diversity	Dates	Duration ^a	Rate ^b
June 2009	SW	6/5 – 6/10	5.0	6.3
	LD	6/5 – 6/11	22.8	28.5
	HD	6/4 – 6/10	22.0	27.5
July 2009	SW	7/10 – 7/13	14.4	21.6
	LD	7/8 – 7/13	10.0	15.0
	HD	7/9 – 7/14	9.8	14.8
June 2010	SW	6/17 – 6/21	24.3	30.4
	LD	6/18 – 6/23	12.7	15.8
	HD	6/17 – 6/22	14.8	18.5
July 2010	SW	7/20 – 7/23	18.8	28.3
	LD	7/21 – 7/23	8.2	12.3
	HD	7/21 – 7/24	4.5	6.8

a Duration reported as mean hours paddock-1

b Instantaneous stocking rate reported as mean animal units acre-1 day-1.

Table 3. Proportion of native legume seed recruited to seedling stage at three sampling periods.*a. Desmodium canadense*

Diversity	Fall 2009			June 2010			Fall 2010		
	Cont.	Graze	Mow	Cont.	Graze	Mow	Cont.	Graze	Mow
SW	0.04	0.19	0.08	0.00	0.08	0.12	0.05	0.02	0.02
LD	0.07	0.08	0.14	0.07	0.24	0.13	0.02	0.01	0.02
HD	0.04	0.12	0.13	0.28	0.26	0.07	0.02	0.07	0.05

b. Desmanthus illinoensis

Diversity	Fall 2009			June 2010			Fall 2010		
	Cont.	Graze	Mow	Cont.	Graze	Mow	Cont.	Graze	Mow
SW	0.02	0.04	0.03	0.07	0.07	0.07	0.00	0.01	0.01
LD	0.04	0.04	0.04	0.03	0.13	0.07	0.01	0.00	0.00
HD	0.02	0.08	0.11	0.03	0.10	0.15	0.00	0.01	0.01

c. Dalea purpurea

Diversity	Fall 2009			June 2010			Fall 2010		
	Cont.	Graze	Mow	Cont.	Graze	Mow	Cont.	Graze	Mow
SW	0.01	0.06	0.02	0.00	0.03	0.03	0.00	0.00	0.00
LD	0.00	0.03	0.05	0.00	0.00	0.00	0.00	0.00	0.00
HD	0.01	0.06	0.04	0.00	0.00	0.00	0.00	0.00	0.00

d. Lespedeza capitata

Diversity	Fall 2009			June 2010			Fall 2010		
	Cont.	Graze	Mow	Cont.	Graze	Mow	Cont.	Graze	Mow
SW	0.01	0.12	0.05	0.00	0.03	0.00	0.00	0.00	0.00
LD	0.04	0.09	0.05	0.00	0.00	0.00	0.00	0.00	0.00
HD	0.01	0.14	0.08	0.00	0.00	0.00	0.00	0.00	0.00

e. Amorpha canescens

Diversity	Fall 2009			June 2010			Fall 2010		
	Cont.	Graze	Mow	Cont.	Graze	Mow	Cont.	Graze	Mow
SW	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
LD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HD	0.00	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.00

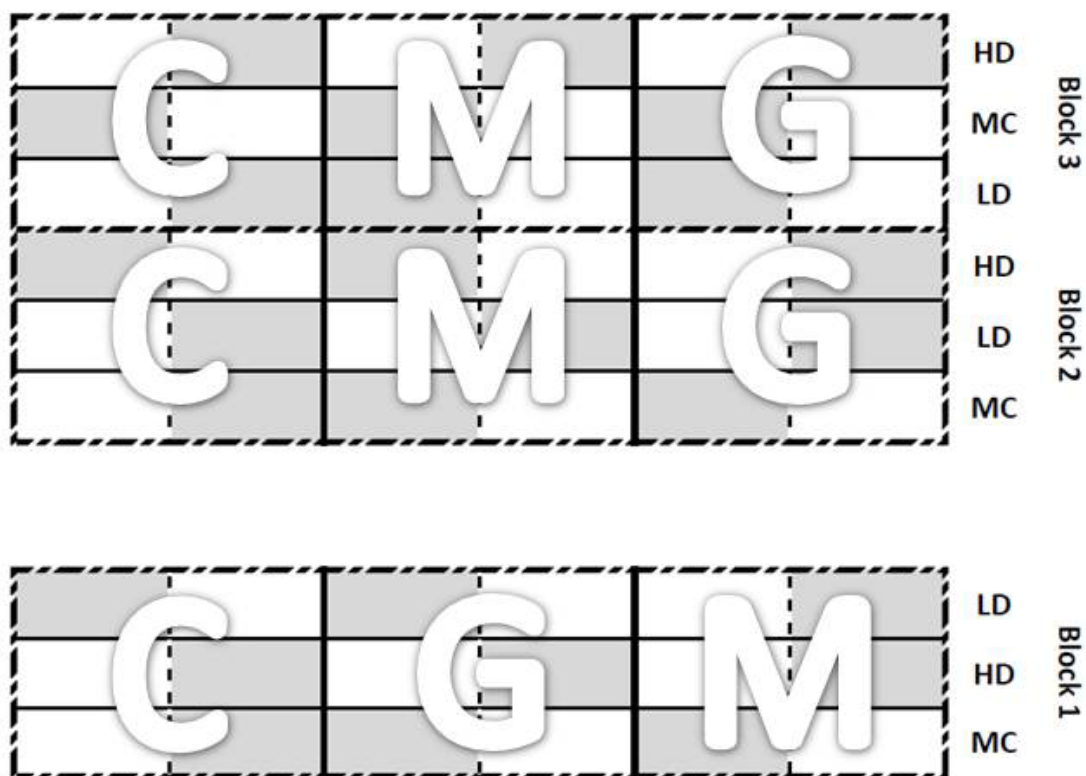


Figure 1. Experimental design at WICST. Original diversity treatments (HD – high diversity prairie; LD – low diversity prairie; MC – switchgrass monoculture) are 105 m by 13 m and were established in a randomized complete block design. Management treatments (C – control; M – mow; G – graze) are legume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

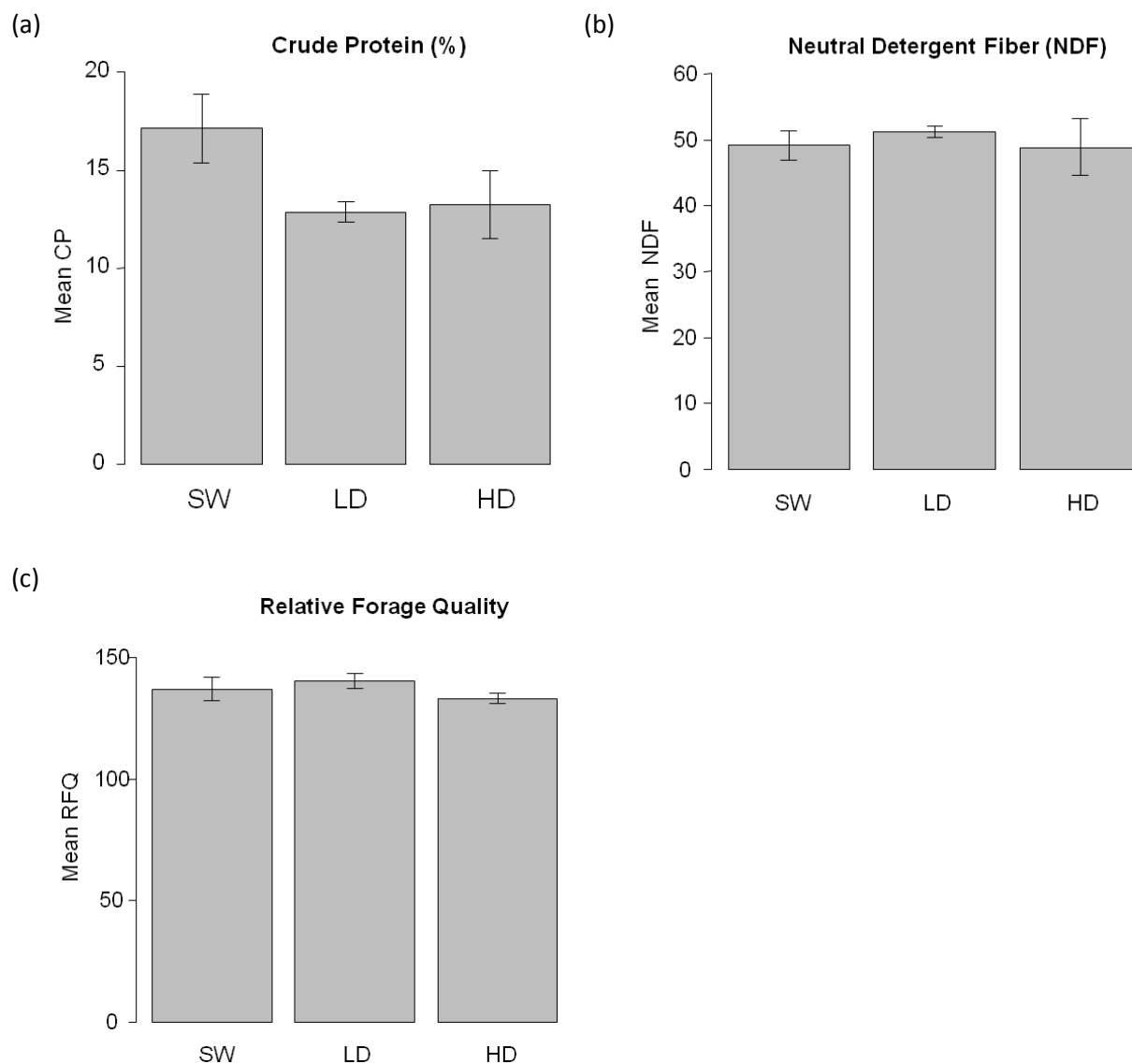


Figure 2. Comparison of several forage quality parameters across diversity treatments sampled in June 2009. Values are means $\pm$ 1 SE of the mean. Crude protein in switchgrass is significantly higher than prairies ($p = 0.019$). Means are not significantly different for neutral detergent fiber or relative forage quality.

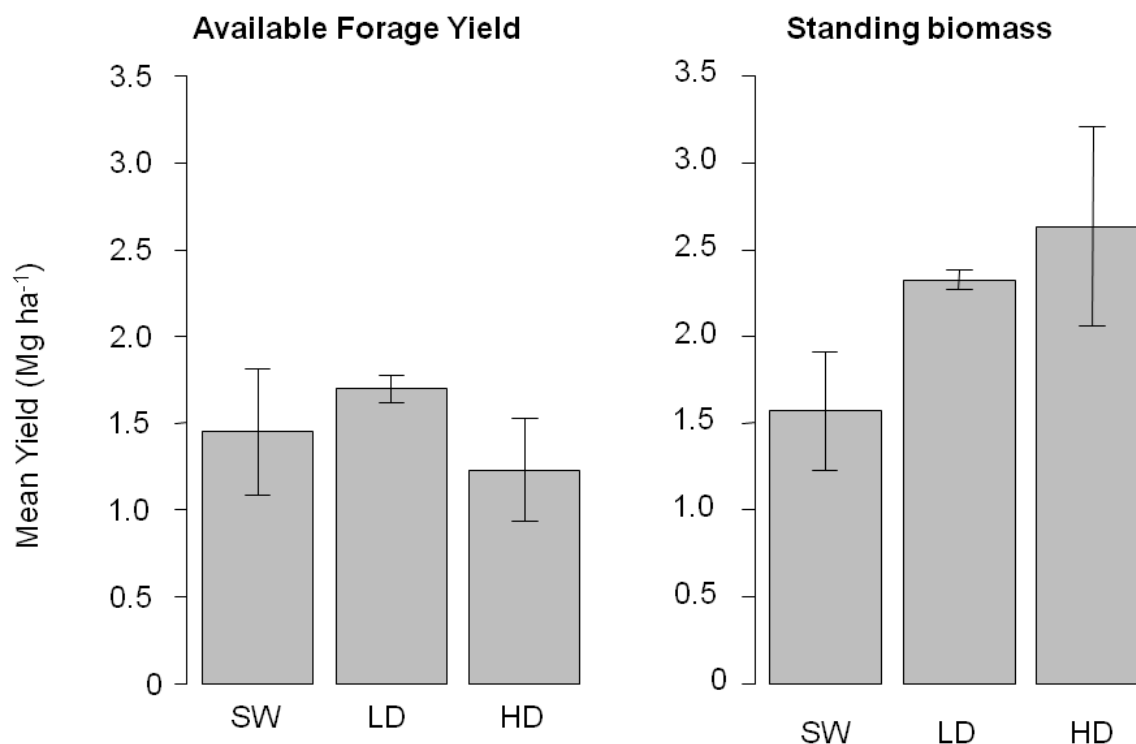


Figure 3. Comparison of available forage and standing biomass across diversity treatments in June 2009. Values are means $\pm$ 1 SE of the mean. Available forage means are not significantly different; mean switchgrass standing biomass is significantly lower than diverse prairies ($p = 0.049$), but differences between low and high diversity prairies were not significant.

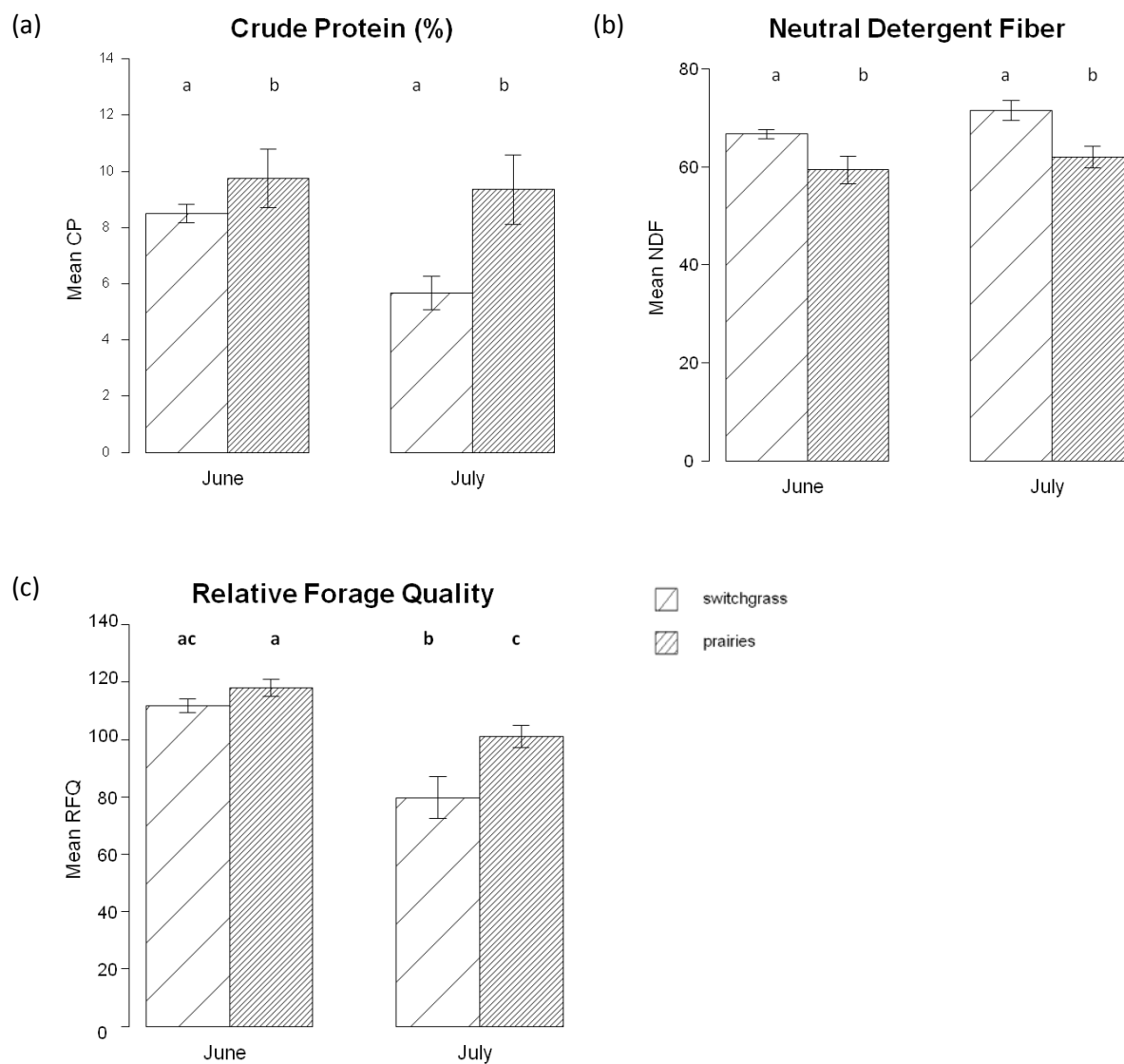


Figure 4. Comparisons of several forage quality parameters in switchgrass and prairie diversity treatments sampled in June and July 2010. Bars show means; error bars show ± 1 SE of the mean. Letters indicate which means are significantly different ($\alpha \leq 0.05$) across diversity treatments and month.

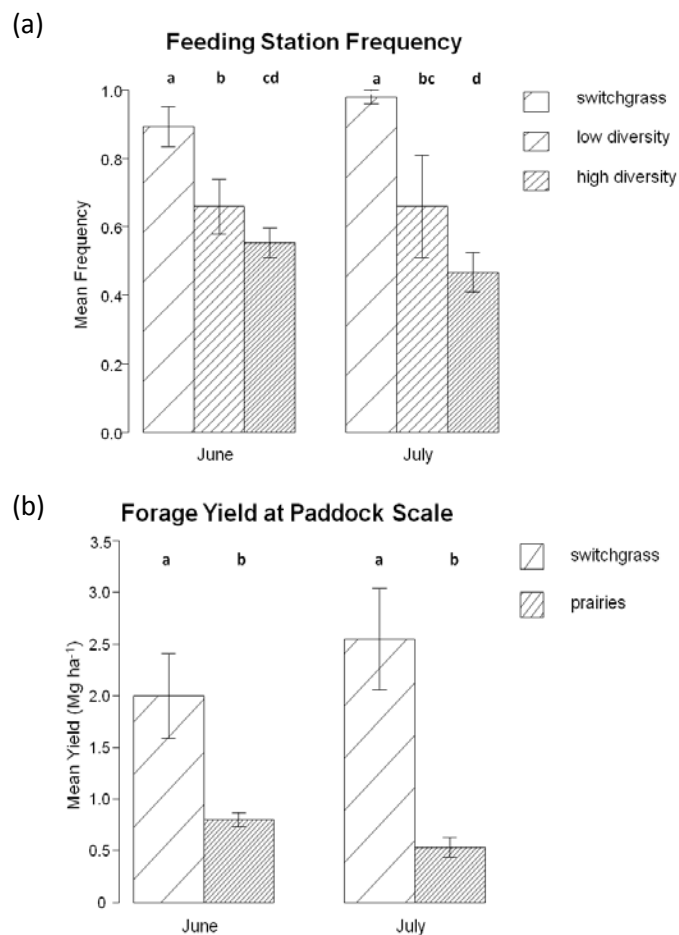


Figure 5. Summer 2010 feeding station frequency and forage yields across diversity treatments. Due to significant differences between the frequency of feeding stations across diversity levels (a), differences between forage yield at the feeding station scale (0.25 m^2) (b) are magnified at the paddock scale (c). Values are means $\pm$ 1 SE of the mean. Letters indicate which means are significantly different ($\alpha \leq 0.05$) across diversity treatments and month.

EFFECT OF N-FERTILIZER AND HARVEST TIMING ON BIOMASS YIELDS AND QUALITY IN *PANICUM VIRGATUM* L. AND RESTORED PRAIRIE IN THE UPPER MIDWEST

L. C. Smith

BACKGROUND

Native warm-season grasses of the tallgrass prairie are anticipated to be a significant source of cellulosic biofuel feedstocks for renewable energy, as well as deliver additional ecosystem services, such as mitigate nitrogen (N) losses to the environment. Whether additional services are realized, however will depend largely on how these perennial bioenergy crops are managed. Balancing the trade-offs of maximizing yields while minimizing N removal at harvest and conserving N in the plant-soil system to limit N-losses, remains a major challenge in growing bioenergy crops. One way to increase agricultural production, while simultaneously increasing N conservation and reducing N runoff, is to use cropping systems that are inherently N-use efficient (Robertson and Vitousek, 2009; McSwiney *et al.*, 2010). Perennial grass cropping systems, such as a *Panicum virgatum* (switchgrass) monoculture or Tallgrass prairie, are two such systems currently being considered for cellulosic feedstock production. Although perennial grass cropping systems provide an optimistic alternative to other forms of energy (Donner and Kucharik, 2008), there still may not be enough reductions in N losses to maintain or restore ecosystem functions such as nutrient retention.

Altering nutrient management and carbon inputs in agroecosystems has a great potential to alter the system's N balance and N cycling (McSwiney *et al.*, 2010). In biomass production, N losses will include N removed in a harvest, as well as losses through volatilization, denitrification, runoff, and leaching. To make up for system losses, managers may apply N fertilizer at rates that replaces the N removed during the previous biomass harvest, or at higher rates to reduce risk by striving for maximum production (Anex *et al.*, 2007). Studies have demonstrated however that warm-season grasses may depend significantly on endogenous N sources, which means significant amounts of fertilizer-N applied may not be retained in the agroecosystem, or is at least unaccounted for in the production of the biomass. This is illustrated through the large ranges of reported biomass yield responses to nitrogen fertilizer addition (Table 1) (Parrish and Fike, 2005). Numerous studies have evaluated biomass production of switchgrass based on nitrogen and harvest management, but the results have been mixed with some finding a positive yield response to fertilization (Lemus *et al.*, 2008a; Heggenstaller *et al.*, 2009), while others found no response (Thomason *et al.*, 2004; Mulkey *et al.*, 2008). This lack of response to N fertilization has been attributed to uncharacterized microbial processes and the inherent N conservation strategies of the plants (Parrish and Fike, 2005).

There are ecological and economic incentives to reduce the amount of N taken off the field in biomass, such as less N fertilizer required for the subsequent growing season and less N being subjected to possible loss pathways. The N removed by harvest is significantly affected by N fertilization rate and harvest timing. Vogel *et al.* (2002) found that biomass N concentrations increased with N fertilization rates but decreased with later harvests, which was attributed to the diminishing N contents in biomass during senescence. High N concentrations in biomass also decrease feedstock quality for the conversion process: a suggested upper-limit threshold of biomass N concentration for feedstocks is 0.6% N (Kauter *et al.*, 2003). Although current

management recommendations suggest that harvesting biomass should be delayed until after complete senescence, no clear approach has emerged to balance the trade-offs between maximizing biomass production and quality, while minimizing nutrient removal and maintaining high N-retention for ecosystem function.

Research Objectives:

The purpose of this research was to understand how perennial grass cropping systems respond to different harvest timings and N fertilizer rates. Maintaining high yields while minimizing N removal with harvest and retaining N in the plant-soil system is essential to help meet the goals of sustainable biofuel production. We used two perennial grass systems of differing diversity levels to 1) Determine the yield and biomass N concentration response to N additions at different harvest dates, 2) Quantify the N removal at different N fertilizer levels and different harvest dates, and 3) Evaluate yield NUE metrics at different N rates and harvest dates. Inorganic soil N pools and mineralization rates were also measured to help characterize inorganic N pools before fertilizer additions.

METHODS

Study site and experimental design

This work was conducted at the Arlington Agricultural Research Station in Arlington, Wisconsin (43°18' N, 89°21' W). Experimental units were positioned on the existing WICST switchgrass and high-diversity prairie plots. Switchgrass plots were seeded in August 2007 with the cultivar “*Forestburg*” at a rate of 10lb PLS/ac. The prairie plots were seeded in 1999 with 25 different species native to the Tallgrass prairie, including C4 grasses, legumes and forbs. Weeds were managed with herbicide as needed (Table S1).

Management treatments applied to the prairie and switchgrass plots included three N fertilizer rates (0, 50, and 150 kg N ha⁻¹) and three harvest timings (summer, fall and the following spring). Fertilizer was hand-applied in June of 2009 and 2010 as ammonium-nitrate (see Table S1 for dates of plot management). The summer harvest timing was at the post-anthesis phase of the dominant species within each perennial grass system; the fall harvest was two weeks after a killing frost (temperature reach $\leq -2.2^{\circ}\text{C}$ for a minimum of 4hrs); and the spring harvest was as soon as possible after snow-melt when field conditions permitted. A control check plot that was never harvested and never fertilized was also included in the design. This was a RCBD, with two levels of blocking – the first level the WICST plot, with a second sub-block nested within each WICST block. Every management treatment was replicated six times with a control plot in every block, creating 120 total experimental units with a plot size of 4m². A 1-meter alley between all plots allowed for some buffer between treatments in case of fertilizer-N runoff and to reduce edge-effects.

Yield, N concentration and N content data collection

Biomass was harvested using a self-propelled sickle-bar mower in 2009; in 2010 we transitioned to a gas-powered hedge-trimmer (Echo HC-150 hedge trimmer, 20” blade) to improve precision and accuracy of cutting. Cutting height was approximately 15cm – similar to that of farm-scale equipment. Field weights of biomass were recorded immediately after harvest. Biomass was then chopped (TroyBilt CS4325 Chipper Shredder) to coarsely-homogenize biomass before a subsample was taken for obtaining moisture contents by drying biomass at 65°C for over 48 hours. After subtracting moisture weight, dry matter weights were extrapolated from plot yield to Mg ha⁻¹. Biomass samples were finely ground using a Wiley Mill to pass a

<1mm screen, then pulverized using stainless steel balls in 2ml micro-centrifuge tubes to further homogenize. N concentrations were determined by combustion on a Carlo-Erba elemental analyzer (CE Elantech EA1112, Lakewood, N.J.). N content of biomass was calculated by multiplying yield by N concentration.

Soil inorganic N pools and mineralization rates

Soil N measurements were collected in 2009 and 2010 in order to characterize the soil N-status before and after treatments were implemented. Inorganic soil N pools (nitrate and ammonium) and inorganic N mineralization rates (mineralized nitrate and ammonium) were assessed in plots in June 2009 before any management treatments were implemented and again in June 2010, immediately before the 2010 fertilizer application. Soil samples consisted of three composited soil cores (2.5 cm x 15cm) in each plot. Samples were transported on ice and stored at 4°C until processed, which was within 48 hours of field collection. Soils were homogenized and organic matter and rocks removed using a 2mm sieve, followed by a 2M KCl extraction (Robertson *et al.*, 1999). Extracts were then filtered using Whatman A/E 0.2 µm glass fiber filters and frozen (-20°C) until analysis. Nitrate concentrations were determined by reduction with Devarda's alloy (Sims *et al.*, 1995) and ammonium concentrations by the Berthelot method (Rhine *et al.*, 1998). Samples were read on a Labsystems Multiskan EX microplate reader (Thermo Fischer Scientific, Waltham, MA) at 650 nm absorbance.

Statistical analyses

Yields, N concentrations, N contents and soil N data were analyzed separately for each year (2009, 2010). We used linear-mixed effects models (TIBCO Spotfire S+ v.8.1.1, TIBCO Software, Inc., Palo Alto, CA) to evaluate treatment effects. Fixed effects were the N fertilizer rates (used as a factor) and harvest treatments. Random effects were always sub-blocks nested within blocks. If needed, response variables were transformed for analysis using log₁₀ to meet assumptions of normality and equal variance, although figures use untransformed data to report agronomically-meaningful values. Analysis of variance evaluated fixed effects of models, where significance was determined at $\alpha = 0.05$.

To evaluate differences between treatment means, model simplification described by Crawley (2002) was used, where the Akaike Information Criterion (AIC) and the restricted maximum likelihood algorithm (REML) determined the most parsimonious model. This was done by dropping factors from the initial model to create a more simplified model, then comparing the more complex to the simplified model. If the models were significantly different (at $p < 0.05$), the model with the lower AIC was chosen.

RESULTS

Biomass Yields

Yields varied by crop, N fertilizer rate and harvest timing within each year (Table 2, Table 3). Switchgrass out-yielded the prairie in 2009, but 2010 proved prairie to be an equal competitor in harvestable yield. Switchgrass response to fertilizer was apparent in 2009 for the summer and fall harvests, while no response was evident the following spring. There was no switchgrass yield response to fertilizer additions in 2010, except for the 2010 spring harvest, when fertilized plots actually produced significantly less biomass (Figure 1). Prairie yields had the opposite outcome where N response was not apparent in 2009, but 2010 yields showed significant yield increases when fertilized across all harvest timings (Figure 1). Across cropping systems, the

summer harvest treatment generally produced the greatest yields, followed by the fall, and the least yield in spring. This however was not the case in 2010 prairie yields where harvest timing had no effect on yields (Table 1 and Figure 1).

Biomass N Concentration

N concentrations of the harvested biomass were more responsive to management treatments of N fertilizer additions and harvest timing. N concentrations did not differ between cropping systems in 2009 but prairie N concentration was significantly higher in 2010 (Table 3). Switchgrass N concentration was responsive to fertilizer additions while the prairie was only responsive to fertilizer additions in 2009 (Figure 2). Across both years and cropping systems, harvest timing had a very strong impact on N concentrations. Most of the decrease occurred between the summer and fall harvests, with a smaller or non-significant change from fall to the spring harvest, such as in the prairie 2010 biomass. N rate had no effect within each year of the prairie spring harvest, whereas the fertilizer effect remained very apparent through all switchgrass harvest timings (Figure 2). The unfertilized plots tended to have approximately the same N concentrations as the high N-rate plots in the fall and spring, although this trend was not sustained in the 2010 prairie biomass. The 2009-2010 switchgrass and 2009 prairie had relatively similar patterns in regard to treatment effects on N concentrations whereas the 2010 prairie N concentrations were unique in regard to treatment effects (Figure 2).

Biomass N Content

N content, driven by both the yield and N concentration, indicates the amount of N in the harvested biomass, which is synonymous with N removed from the system at harvest. The summer harvest also represents a measure of total N uptake. The cropping systems differed in their N removal rates by year: switchgrass removed more N in 2009 whereas the prairie removed more N in 2010. Switchgrass averaged 37 kg N ha⁻¹ and 38 kg N ha⁻¹ in 2009 and 2010, respectively, averaged across N and harvest treatments. Prairie N content varied considerably between years, with only 21 kg N ha⁻¹ in 2009 and 44 kg N ha⁻¹ in 2010, averaged across harvest and N treatments. N rate and harvest timing were significant treatment effects in both years (Table 3), with N removal patterns often following the yield and N concentration patterns (Figures 1 and 2). Although the 2010 prairie biomass had no fertilizer treatment effects on N concentrations, the biomass N content followed roughly the same pattern of the yield response to N rates (Figure 1, Figure 3). Increasing fertilizer rates generally increased N removal rates, with the magnitude of the effect decreasing with later harvest times (Figure 3). N uptake averaged 31 kg N ha⁻¹ in the 2009 prairie summer harvest and 42 kg N ha⁻¹ in the 2010 summer harvest. N uptake in switchgrass summer harvests were 40 kg N ha⁻¹ and 49 kg N ha⁻¹ in 2009 and 2010, respectively.

In 2010, prairie yields were not affected by harvest timing ($p=0.09$), but responded to N rate ($p<0.0001$) (Figure 1), while the N concentration was affected by harvest timing ($p=0.0002$) and not N rate ($p=0.4$). This instance where biomass yield increases with N rate, but N concentrations do not, is the preferred situation for biomass production systems because the plants are using nitrogen more efficiently and adding more units of carbon per unit of added fertilizer-N. Although N removal increases with increasing N rate, it is driven by the increase in yield rather than increasing N concentrations.

Inorganic soil N status and mineralization rates

The 2009 soil data revealed that there were no differences in inorganic soil levels between plots before the fertilizer and harvest treatments were implemented (Table 4). In June

of 2010, one year after the initial fertilization, soil N levels were generally higher across all management treatments. The only significant treatment effect was seen in the unfertilized switchgrass plots, which had lower inorganic N levels compared to the fertilized switchgrass plots ($p=0.008$). Although there were no treatment effects in mineralization rates, it is interesting to note that mineralization rates were negative in 2009, suggesting that inorganic N was being immobilized rather than mineralized. In 2010, mineralization rates were positive and were not affected by legacy of the management treatments implemented in 2009.

DISCUSSION

Responses to N fertilizer additions were not consistent between cropping system, year or harvest timing. While the prairie had no yield response to N additions in 2009, switchgrass had modest yield increases with fertilization, whereas the 2010 growing season brought the opposite trends. Why was there not a fertilizer response in all situations? Weak fertilizer responses could indicate no N-limitation. However, inorganic soil N data in 2009 showed negative N-mineralization rates, suggesting that these systems were in fact N-limited and plants may have been out-competed for resources by microbes. In 2010, when N mineralization rates were positive, there was more soil N available, however the switchgrass yields still had no fertilizer N response. The 2010 growing season apparently had better growing conditions irrespective of N availability since all yields were greater than 2009 yields even in the unfertilized plots. This study is an indication that yield response to fertilization is extremely variable even within a field.

Yield trends by harvest timing were more predictable where later harvest-timings often produced smaller yields in switchgrass. Waiting for a fall harvest resulted in an average 30% loss in yield and delaying harvest the following spring caused about another 30% loss in biomass, or approximately 53% loss from the summer harvest. Adler et al. (2006) found 40% losses by over-wintering biomass in the field with the reductions attributed to harvest inefficiencies and a drop in individual tiller weights. The prairie seemed to be more resilient to biomass losses from fall to spring but did show yield reductions only in the 2009 growing season from summer to fall.

Plant tissue N concentrations tended to increase with fertilization, as others have found (Madakadze *et al.*, 1999; Heggenstaller *et al.*, 2009; Garten *et al.*, 2011). The one exception to this trend was in the 2010 prairie harvest, where N fertilizer rate had no effect on biomass N concentrations, which has also been an observed trend in other studies (Lemus *et al.*, 2008b; Waramit *et al.*, 2011). In addition to high N concentrations contributing to higher N removal rates, the biomass N concentrations often did not fall below the recommended threshold for feedstocks of 0.6% N (Kauter *et al.*, 2003). Only some of the fall or spring-harvested biomass in the 0-N or 50-N treatments would meet this biomass-quality parameter.

Unfertilized plots removed a cumulative of 74 kg N ha⁻¹ in prairie and 90 kg N ha⁻¹ in switchgrass over two growing seasons without any fertilizer inputs. It is remarkable that N removal in 2010 exceeded N removal in 2009 despite biomass removal for the second-consecutive seasons with zero inputs, although this is not uncommon for switchgrass, as many other studies have demonstrated unfertilized switchgrass removing high N amounts despite continuous years of no added N inputs (Parrish and Fike, 2005; Lemus *et al.*, 2008b). Fertilized switchgrass can also exhibit high levels of N removal that exceeds the initial fertilizer application (Lemus *et al.*, 2009), but was the case in this study only for the 50-N treatment in switchgrass and the 50-N treatment in 2010 for prairie.

CONCLUSIONS AND IMPLICATIONS

This study reveals the responses to N fertilizer and harvest timings on yields, biomass N concentrations and N removed with harvest. Given that this experiment was conducted on high-productivity soils, a comparison of management treatments on more marginal soils may have revealed different trends. Subsequent years of management may show more drastic effects of management treatments as harvesting begins to deplete soil resources or plant reserves, but after two years of management, it appears that fertilizing these systems for biomass production realizes relatively small increments of additional yield at the expense of lower biomass quality and unaccounted for fertilizer-N that will be subject to N-loss pathways and likely contribute to air and water pollution. This was evidenced by (1) yields had a very limited response to fertilizer application in switchgrass, although the prairie response varied by year (2) fertilizing switchgrass increased N concentrations, while the prairie N concentration response again varied by year (3) delaying harvest until fall minimizes the amount of N removed from the field; it is not necessary to wait until the following spring to harvest to reduce N removal and sacrifice biomass.

While perennial warm-season grass cropping systems show great potential for a sustainable feedstock, assumptions are often overlooked regarding their benefits because of management effects. Our results suggest that fertilizer responses are often weak, or at least variable, and therefore excess applied fertilizer-N is prone to loss pathways. Goals of increasing land devoted to biomass production and simultaneously reducing N exports to the air and waterways may be conflicting if the expected perennial cropping systems are unable to retain added nitrogen inputs and N-recycling strategies. Future managers and policy-makers should consider the trade-offs in yields with biomass quality, N-removal and NUE in biomass production to ensure that land devoted to biomass production will not contribute to, but rather mitigate agroecosystem N losses.

LITERATURE CITED

- Anex, R.P., Lynd, L.R., Laser, M.S., Heggenstaller, A.H., Liebman, M., 2007. Potential for enhanced nutrient cycling through coupling of agricultural and bioenergy systems. 47, 1327-1335.
- Donner, S.D., Kucharik, C.J., 2008. Corn-based ethanol production compromises goal of reducing nitrogen export by the Mississippi River. *Proceedings of the National Academy of Sciences of the United States of America* 105, 4513-4518.
- Garten, C.T., Brice, D.J., Castro, H.F., Graham, R.L., Mayes, M.A., Phillips, J.R., Post, W.M., Schadt, C.W., Wullschlegel, S.D., Tyler, D.D., Jardine, P.M., Jastrow, J.D., Matamala, R., Miller, R.M., Moran, K.K., Vugteveen, T.W., Izaurralde, R.C., Thomson, A.M., West, T.O., Amonette, J.E., Bailey, V.L., Metting, F.B., Smith, J.L., 2011. Response of "Alamo" switchgrass tissue chemistry and biomass to nitrogen fertilization in West Tennessee, USA. *Agriculture Ecosystems & Environment* 140, 289-297.
- Heggenstaller, A.H., Moore, K.J., Liebman, M., Anex, R.P., 2009. Nitrogen Influences Biomass and Nutrient Partitioning by Perennial, Warm-Season Grasses. *Agronomy Journal* 101, 1363-1371.

- Kauter, D., Lewandowski, I., Claupein, W., 2003. Quantity and quality of harvestable biomass from *Populus* short rotation coppice for solid fuel use - a review of the physiological basis and management influences. *Biomass & Bioenergy* 24, 411-427.
- Lemus, R., Brummer, E.C., Burras, C.L., Moore, K.J., Barker, M.F., Molstad, N.E., 2008a. Effects of nitrogen fertilization on biomass yield and quality in large fields of established switchgrass in southern Iowa, USA. *Biomass & Bioenergy* 32, 1187-1194.
- Lemus, R., Parrish, D.J., Abaye, O., 2008b. Nitrogen-Use Dynamics in Switchgrass Grown for Biomass. *Bioenergy Research* 1, 153-162.
- Lemus, R., Parrish, D.J., Wolf, D.D., 2009. Nutrient Uptake by 'Alamo' Switchgrass Used as an Energy Crop. *Bioenergy Research* 2, 37-50.
- Madakadze, I.C., Stewart, K.A., Peterson, P.R., Coulman, B.E., Smith, D.L., 1999. Cutting frequency and nitrogen fertilization effects on yield and nitrogen concentration of switchgrass in a short season area. *Crop Science* 39, 552-557.
- McSwiney, C.P., Snapp, S.S., Gentry, L.E., 2010. Use of N immobilization to tighten the N cycle in conventional agroecosystems. *Ecological Applications* 20, 648-662.
- Mulkey, V.R., Owens, V.N., Lee, D.K., 2008. Management of warm-season grass mixtures for biomass production in South Dakota USA. *Bioresource Technology* 99, 609-617.
- Parrish, D.J., Fike, J.H., 2005. The biology and agronomy of switchgrass for biofuels. 24, 423-459.
- Rhine, E.D., Sims, G.K., Mulvaney, R.L., Pratt, E.J., 1998. Improving the Berthelot reaction for determining ammonium in soil extracts and water. *Soil Science Society of America Journal* 62, 473-480.
- Robertson, G.P., Coleman, D.C., Bledsoe, C.S., Sollins, P., 1999. *Standard Soil Methods for Long-Term Ecological Research* Oxford University Press, Inc., New York.
- Robertson, G.P., Vitousek, P.M., 2009. Nitrogen in Agriculture: Balancing the Cost of an Essential Resource. *Annual Review of Environment and Resources*. Annual Reviews, Palo Alto, pp. 97-125.
- Sims, G.K., Ellsworth, T.R., Mulvaney, R.L., 1995. Microscale determination of inorganic nitrogen in water and soil extracts. *Communications in Soil Science and Plant Analysis* 26, 303-316.
- Thomason, W.E., Raun, W.R., Johnson, G.V., Taliaferro, C.M., Freeman, K.W., Wynn, K.J., Mullen, R.W., 2004. Switchgrass response to harvest frequency and time and rate of applied nitrogen. *Journal of Plant Nutrition* 27, 1199-1226.
- Waramit, N., Moore, K.J., Heggenstaller, A.H., 2011. Composition of Native Warm-Season Grasses for Bioenergy Production in Response to Nitrogen Fertilization Rate and Harvest Date. *Agronomy Journal* 103, 655-662.

TABLES and FIGURES

Table 1. Studies that cover a range of sites and N fertilizer rates show both positive and no response to N fertilizer additions. Adapted from Parrish and Fike, 2005.

Site	range of N rates (kg ha ⁻¹)	Yield response to N additions	Reference
Montreal, QB	0 - 150	positive	Madakadze <i>et al.</i> (1999)
IA, USA	0 - 220	positive	Heggenstaller <i>et al.</i> (2009)
IA, USA	0 - 224	positive	Lemus <i>et al.</i> (2008)
TX	0 - 268	positive	Suplick <i>et al.</i> (2002)
IA, NE	0 - 300	positive	Vogel <i>et al.</i> (2002)
Rothamsted, UK	0 - 60	no	Christian <i>et al.</i> (2001)
VA, USA	0 - 110	no	Parrish and Wolf (1992)
Trisaia, Italy	0 - 150	no	Piscioneri <i>et al.</i> (2001)
SD, USA	0 - 224	no	Mulkey <i>et al.</i> (2008)
OK, USA	0 - 896	no	Thomason <i>et al.</i> (2004)

Table 2. Mean biomass yields (Mg ha⁻¹) and mean standard error (SE) for prairie and switchgrass at three harvest timings (*Summer, Fall and Spring*) by N fertilizer rate in 2009 and 2010 (n = 5 or 6).

N fertilizer rate (kg ha ⁻¹)		0		50		150	
		Mean	SE	Mean	SE	Mean	SE
2009	Prairie						
	<i>Summer</i>	3.79	0.69	4.61	1.01	3.82	0.73
	<i>Fall</i>	2.05	0.38	2.50	0.68	2.62	0.44
	<i>Spring</i>	1.61	0.25	1.30	0.32	2.38	0.33
	Switch						
	<i>Summer</i>	5.53	0.62	6.34	0.39	6.94	0.64
	<i>Fall</i>	3.24	0.26	4.79	0.11	5.15	0.55
	<i>Spring</i>	3.50	0.35	2.86	0.44	2.88	0.36
2010	Prairie						
	<i>Summer</i>	3.71	0.39	5.95	0.48	6.59	0.66
	<i>Fall</i>	3.79	0.31	4.29	0.78	5.51	0.78
	<i>Spring</i>	3.99	0.24	3.85	0.47	6.12	0.84
	Switch						
	<i>Summer</i>	6.62	0.35	6.86	0.24	7.17	0.56
	<i>Fall</i>	4.30	0.18	5.17	0.34	4.80	0.33
	<i>Spring</i>	3.78	0.18	2.48	0.26	3.06	0.30

Table 3. Analysis of variance for linear mixed-effects models predicting plot yield (Mg ha^{-1}), N concentration of the harvested biomass ([N]) and the N content of the harvested biomass in 2009 and 2010. Fixed effects are: cropping system (*crop*), N fertilizer rate (*N rate*) and harvest timing (*harvest*) ($n = 5$ or 6 , $\alpha = 0.05$).

Fixed Effects	Df	F statistic	p-value	F statistic	p-value
<i>Yield</i>					
		2009		2010	
crop	1	61.47	<0.0001	0.19	0.67
N rate	2	2.85	0.06	10.85	0.0001
harvest	2	47.18	<0.0001	40.24	<0.0001
crop x N rate	2	0.30	0.74	8.34	0.0005
crop x harvest	2	1.29	0.28	18.14	<0.0001
N rate x harvest	4	1.46	0.22	2.44	0.05
crop x N rate x harvest	4	1.53	0.20	1.05	0.39
<i>[N] (%)</i>					
crop	1	0.59	0.44	21.86	<0.0001
N rate	2	23.24	<0.0001	5.54	0.0056
harvest	2	35.52	<0.0001	26.25	<0.0001
crop x N rate	2	0.13	0.88	0.68	0.51
crop x harvest	2	0.10	0.90	0.46	0.63
N rate x harvest	4	4.06	0.0047	2.23	0.07
crop x N rate x harvest	4	1.02	0.40	0.90	0.47
<i>N Content (kg N ha^{-1})</i>					
crop	1	76.83	<0.0001	19.55	<0.0001
N rate	2	25.53	<0.0001	24.28	<0.0001
harvest	2	130.3	<0.0001	123.3	<0.0001
crop x N rate	2	0.03	0.98	1.22	0.30
crop x harvest	2	1.01	0.37	14.90	<0.0001
N rate x harvest	4	1.89	0.12	1.24	0.30
crop x N rate x harvest	4	1.11	0.36	0.72	0.58

Table 4. Mean inorganic soil N (nitrate + ammonium) and mean inorganic N mineralized (nitrate and ammonium) in the top 15cm of soil in early June before fertilizer additions in 2009 and 2010, by management treatments of N fertilizer rates (kg ha⁻¹) and harvest timing (*summer, fall and spring*). Note that 2009 data is pre-treatment, meaning the fertilizer and harvest treatments were not yet implemented. (*) indicates significance across all management treatments within each cropping system and year ($\alpha = 0.05$).

N fertilizer rate	Inorganic N (kg ha ⁻¹)			Inorganic N mineralized (kg ha ⁻¹ day ⁻¹)		
	0	50	150	0	50	150
June 2009, pre-treatment						
prairie						
<i>summer</i>	5.34	4.20	3.84	-0.21	-0.28	-0.38
<i>fall</i>	3.64	3.27	3.69	-0.29	-0.67	-0.22
<i>spring</i>	5.97	4.44	2.97	-0.16	-0.25	-0.30
switchgrass						
<i>summer</i>	4.51	4.58	3.56	-0.49	-0.24	-0.25
<i>fall</i>	4.93	3.81	3.46	-0.36	-0.54	-0.33
<i>spring</i>	2.87	3.93	3.47	-0.33	-0.43	-0.22
June 2010, pre-fertilizer						
prairie						
<i>summer</i>	8.39	7.98	9.15	0.90	0.90	0.93
<i>fall</i>	9.05	8.82	8.05	0.90	0.96	0.88
<i>spring</i>	8.83	10.72	8.45	0.99	0.81	1.11
switchgrass						
<i>summer</i>	6.95*	7.59	9.91	1.49	1.46	1.36
<i>fall</i>	7.11*	7.90	7.94	1.32	1.23	1.65
<i>spring</i>	7.43*	8.32	8.63	1.09	1.18	1.26

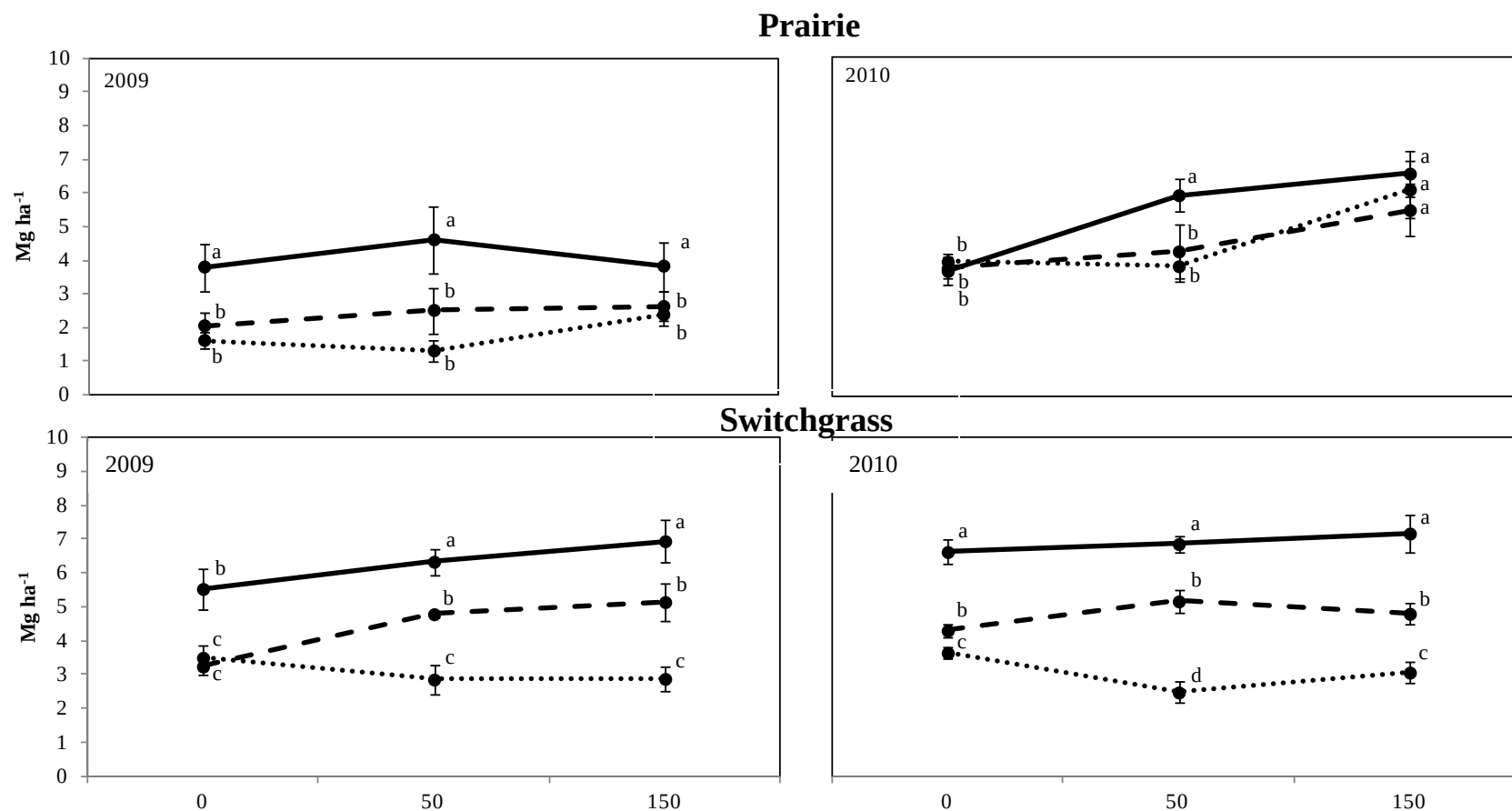


Figure 1. Interaction plots of yields for prairie and switchgrass in 2009 and 2010 by N fertilizer rate. Solid lines are the *summer harvest* treatment, dashed lines are the *fall harvest* and dotted lines are the *spring harvest*. Error bars are ± 1 S.E., where $n = 5$ or 6 . Letters represent significance at $\alpha = 0.05$ across all fertilizer and harvest treatments within that year and cropping system.

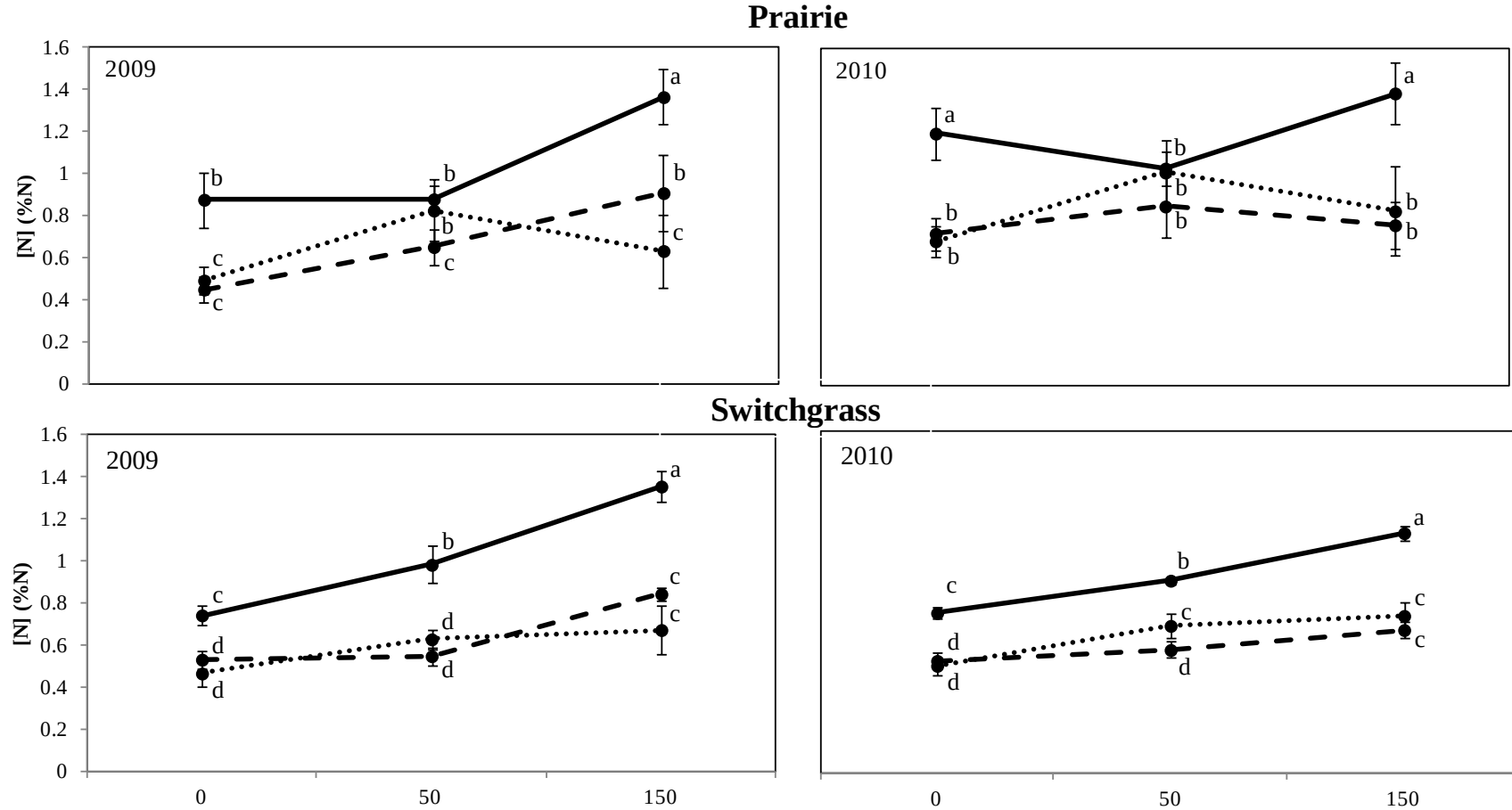


Figure 2. Interaction plots of N concentration for prairie and switchgrass harvested biomass in 2009 and 2010 by N fertilizer rate. Solid lines are the *summer harvest* treatment, dashed lines are the *fall harvest* and dotted lines are the *spring harvest*. Error bars are ± 1 s.e., where $n = 5$ or 6 . Letters represent significance at $\alpha = 0.05$ across all fertilizer and harvest treatments within that year and cropping system.

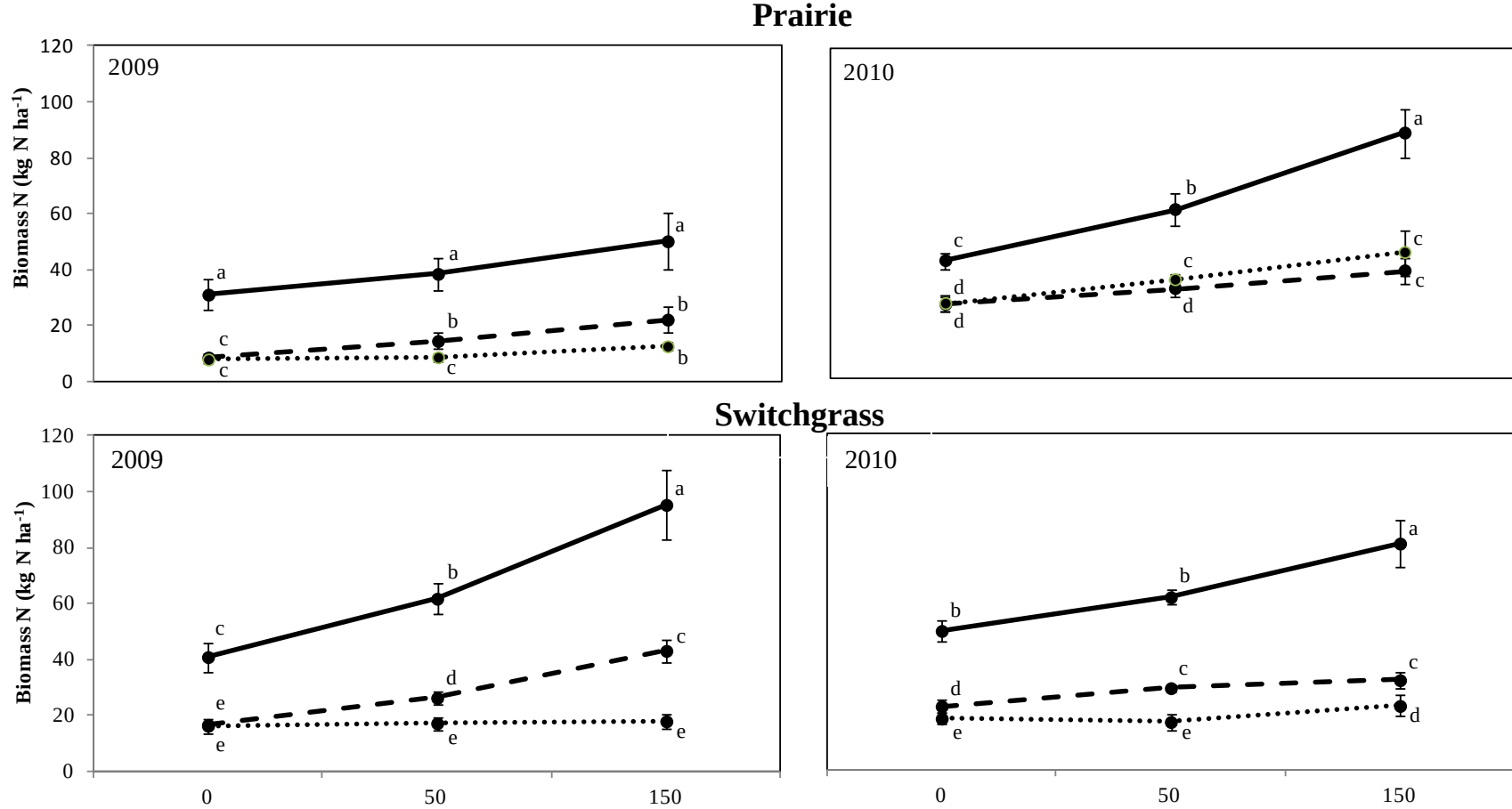


Figure 3. Interaction plots of biomass-N removed at harvest for prairie and switchgrass in 2009 and 2010 by N fertilizer rate. Solid lines are the *summer harvest* treatment, dashed lines are the *fall harvest* and dotted lines are the *spring harvest*. Error bars are ± 1 s.e., where $n = 5$ or 6 . Letters represent significance at $\alpha = 0.05$ across all fertilizer and harvest treatments within that year and cropping system.

Appendix.**Table S1.** Timing of field operations and treatment implementation on the prairie and switchgrass cropping systems.

Year	Field operation	Prairie	Switchgrass
2009	herbicide sprayed - glyphosate (24 oz/ac)	na	29-Apr
	spot sprayed thistles with aminopyralid @ 0.35 oz/gal	29-Apr	29-Apr
	fertilizer treatments applied	24-Jun	24-Jun
	summer harvest	31-Aug	28-Aug
	fall harvest	28-Oct	28-Oct
2010	spring harvest (over-wintered 2009 biomass)	18-Mar	18-Mar
	herbicide sprayed - glyphosate (22 oz/ac)	na	12-Apr
	herbicide sprayed - 2,4-D (1pt/ac)	na	10-May
	spot sprayed thistles with aminopyralid @ 0.35 oz/gal	17-Jun	17-Jun
	fertilizer treatments applied	3-Jun	3-Jun
	summer harvest	26-Aug	18-Aug
	fall harvest	8-Nov	8-Nov
2011	spring harvest (over-wintered 2010 biomass)	7-Apr	7-Apr

EFFECT OF PREVIOUS CROP ON SWITCHGRASS PRODUCTION IN SOUTHERN WISCONSIN

Janet Hedtcke, Nicole Tautges

INTRODUCTION

Switchgrass (*Panicum virgatum*) was identified as a potential bioenergy production decades ago and more recently has been plugged by former President G.W. Bush in his 2006 State of the Union Address. As a result, in 2007 the US DoE funded a \$125 million project at the UW CALS known as the Great Lakes Bioenergy Research Center (GLBRC) to overcome bottlenecks in the conversion of cellulose to ethanol. Switchgrass is attractive as a biofuel crop because of its adaptability and suitability on marginal, highly erodible, and droughty soils; it has potential for sequestering large amounts of atmospheric carbon; and it provides nesting habitats for many species of wildlife. Switchgrass, a native perennial warm-season bunch grass adaptable from Canada to Texas, needs approximately two years in order to be sufficiently established to permit harvesting (Vogel et al. 2002), however may not reach full yield potential until the third year in colder climates such as Wisconsin. As the technology, demand, and markets grow for bioenergy production, more producers may become interested in establishing switchgrass on their farm. However, they 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 profitably, economically feasible systems for the establishment period need to be designed. The purpose of this study is to look at two dual cropping options with small grains that will allow farmers to realize economic gains during the establishment phase of switchgrass, but also without reducing switchgrass productivity. The objectives for this research are twofold:

1. Develop agronomic systems (i.e. small grain systems) which allow for economic gain during switchgrass establishment period. Important components include keeping weeds in check during establishment and measuring switchgrass frequency and yields in the seeding year and 1st production year.
2. Manage established switchgrass as a dual-use crop which creates another income source through livestock feed harvested in June and biomass feedstock harvested in October.

In this article, the focus will be on the first objective, the seeding year of switchgrass and the effect of the previous crop on income and switchgrass establishment success. Preliminary data from the 1st production year will also be shown but one more year of data will be collected to complete the analysis of yields in the established year of switchgrass and its potential use as a dual crop.

METHODS

Experimental Design and Site Description

Three switchgrass establishment treatments were evaluated. Switchgrass was planted 1) in early June into fallow ground (control treatment); 2) in early June following a winter rye crop harvested for forage; and 3) in early August following wheat harvested for grain and straw (Table 1). The fallow vs. the winter rye comparison, being planted at the same time, will show if the rye had any negative effect on switchgrass establishment that may

be due to allelopathy, water stress, or seedbed condition. The winter wheat treatment will test the efficacy of a delayed planting date on switchgrass establishment and persistence.

The study is designed as a randomized complete block, with four replications at each of the three selected sites. The research trial was established in September 2009 and again in Sept 2010 at all three sites. This resulted in testing these systems in 6 environments (3 sites, 2 starting dates). One field study site is at the Arlington Research Station (ARS) in conjunction with the GLBRC (i.e. biofuel research) plots, on well-drained Plano silt loam (0-2%). Two other sites have been established on-farm: One is in Rio, Wisconsin (RIO) on Wyocena sandy loam and Plainfield loamy fine sand (2-6%) and the other is in Sugar Creek, Wisconsin (SC) on Miami silt loam (2-6%). Basic site characteristics can be viewed in Table 2.

ARS and RIO were managed as no-till while SC used tillage for seedbed preparation. Luckily, none of the sites had major issues with perennial weeds such as Canada thistle or quackgrass and so all had good potential for establishing switchgrass. RIO was characterized as having relatively low weed pressure while SC had very high weed pressure and ARS was in between. Weed community varied by site but annual weeds such as pigweed, lambsquarter, and barnyard grass were common at ARS, while crabgrass and a few lambsquarter were present at RIO. The SC site was in an organic forage rotation with regular manure inputs and was managed with tillage, all factors which ranked this site as a high-weed pressure environment, particularly with foxtail, crabgrass, pigweed, lambsquarter, and horseweed.

Previous Crop Management

Using best management practices, winter rye and winter wheat were planted on the same day within a site and in October across all environments using a no-till drill at ARS and RIO or a grain drill at SC. Plots were 30' wide by about 150 ft long. During the winter rye phase, no herbicide was necessary because the rye smothered out most weeds and it was cut for forage in mid-May (boot stage). The winter wheat was sprayed with 1 pt/a of 2,4-D as the wheat began to joint (late April/early May) to control broadleaf weeds at ARS and RIO. No herbicide was used on the wheat treatment at the SC site. The fallow treatment was not sprayed or tilled during the small grain phase. At ARS and RIO, N was applied to the wheat and rye treatments in early spring at 60 lbs N/a as urea. Manure (at a rate of about 60 lbs N/a) was applied prior to planting the small grains at SC.

Switchgrass Establishment

After the cereal crops were harvested, as well as in the fallow treatment, weeds were burned down with a full rate of glyphosate at ARL and RIO or tilled under at SC.

'Cave-in-Rock' switchgrass was seeded with a no-till drill (ARS and RIO) and with a regular grain drill (SC) at 20 lbs seed/a in late June into the fallow and previous rye treatments and in mid- August after wheat. This rate was at least twice as high as the recommended rate because this lot of seed had very poor germination (12%) and a lot of hard seed (78%). When it reached the 3-4 leaf stage (late July/early Aug), 1-2 pt/a of 2,4-D was used at ARS and RIO to control broadleaf weeds. The on-farm site at SC managed

its plots organically by clipping with a rotary mower to suppress weeds. No nitrogen was applied to switchgrass to discourage weeds (per Renz and Undersander, 2009). In the 1st production year of switchgrass, before it broke dormancy, a spring burndown treatment of glyphosate was applied at ARS and RIO to reduce weed pressure from winter annuals and cool-season grasses. A broadleaf herbicide (1-2 pt/a 2,4-D) was later applied at ARS and RIO about a month later.

Sampling Methods

Seeding year switchgrass was randomly sampled from the center area of the plot with 3 subsamples/plot using hand shears and a 0.50m² quadrat with stubble cut to about 6". Harvest timing was targeted for peak biomass in late September or early October. Weeds were sorted out and only switchgrass yields are reported for this report. Weed component will be evaluated once the stand has been fully established. First year production biomass was randomly hand sampled using a 0.25m² quadrat with stubble height at 6" about 1-2 weeks after the killing frost. Biomass was dried at 60°C in a forced air oven until constant mass was achieved, and then weighed.

Volumetric moisture content (VMC, %) status of the soil was measured with a TDR (time domain reflectometer) probe on all treatments at two depths (4.7" and 8") within 1 week after seeding (i.e. June and August) in four sub-samples per plot. Data from ARS and RIO was used to compare soil type and effect of treatments on VMC in the two seasons.

Switchgrass frequency was evaluated using the grid method (a grid of 25 cells of 0.15cm² each) developed by Vogel and Masters (2001). Frequency counts were taken in the year after seeding to determine if overwintered stands were above the 40% threshold level, which qualifies as a successful establishment, as determined by others (Schmar et al, 2006). Two measurements were taken from each treatment in July when switchgrass was actively growing, but before it got too tall to get the grid down into the canopy.

RESULTS

Small Grain Income

Across sites, the silt loam sites (ARS, SC) produced higher income off the small grain treatments than at the less productive sandy soils at RIO (Table 3). Furthermore, no straw was harvested at RIO because the producer wanted to build soil organic matter and offset the need to buy potassium fertilizer. Across sites, winter wheat produced significantly more crop income than the winter rye forage because of the two sources of income from the wheat (grain and straw), both for which prices have been very high in recent years. However, the wheat treatment produced no switchgrass (August establishment was NOT successful) in any environment tested, so that treatment is moot. Further income could be realized by taking one cut of the switchgrass in the seeding year if it was exceptional, like RIO 2010 which yielded 1.5 tons DM/a (Table 4), but in general, it is not cost effective to harvest switchgrass in the seeding year.

Switchgrass yields in seeding year

Of the 3 sites, RIO had the most switchgrass production in the seeding year (Table 4). Season also had a large effect on tonnage at all sites. The 2010 weather was great for forage production with frequent rains throughout the summer (10" above average) and above average GDD (by about 300 units); however, 2011 was quite different, having a cold delayed spring and a super dry summer. Rainfall pattern in 2011 was typical early on but then there was essentially no rain from mid-June to mid-September resulting in a 5" shortfall for the season compared to the norm. Frequent rainfall coupled with sandy soils that warm quickly allowed the switchgrass to establish superbly at RIO in 2010 as noted above with exceptional yields. Averaged over the two years of establishment, switchgrass height was 25" at RIO, 20" at ARS but only 10" at SC at the end of the seeding year (Table 4). No real difference in height was found between the fallow and the winter rye treatments. There was an environment effect where switchgrass heights were much taller in 2010 at RIO and SC but not different between years at ARS. The lack of response at ARS was probably due to better water holding capacity of these higher organic matter soils which buffered against the dry 2011 season.

Weed control is an important aspect of switchgrass establishment, and it can have a major impact on switchgrass yields in succeeding years. It is an area of active research and products labeled for switchgrass are being developed by herbicide companies. In the meantime, Renz and Undersander (2009) have provided some guidelines which we followed at 2 of the 3 sites (SC site was managed without herbicides). Among the six environments, as visually noted, weed control in the seeding year was excellent at RIO, very good at ARS, and very poor at SC. If present, warm season annuals (foxtail spp., crabgrass spp.) are difficult to manage in the seeding year of switchgrass even with herbicide as a management tool because there is no mode of action that targets them separately from the switchgrass itself. Weeds, particularly grass weeds, can also serve as a vector for disease organisms such as rust and fusarium. Clipping (as done at SC) was not always effective as weeds, in response to changes in day length, would set seed at very low heights—often below that of the mower. As can be seen from Table 4, there was essentially no measureable yield from SC in 2011 due to severe weed competition in that tough cropping year.

Effect of treatment. Establishing switchgrass after winter wheat was a complete failure at all six environments. It was observed to germinate, emerge, and grow to about 5-8 inches tall across environments before the end of the growing season but it didn't survive the winter. Frost damage was evident in 2011 at RIO and ARS and it was very hard to find any switchgrass at all under the volunteer wheat cover at SC. Volunteer wheat pressure was also very high at ARS and RIO where the wheat regrowth had been sprayed with glyphosate before seeding the switchgrass no-till. This competition of the volunteer wheat with the seedling switchgrass and the lack of late summer rain and heat units to get switchgrass well established before frost was a fatal flaw with this treatment.

Anecdotally, the only August seeding that was successful in our program over the years was that seeded into a clean, low weed pressure seedbed next to the WICST prairie plots. This planting coincided with record rainfall in the summer of 2007.

Excluding the wheat treatment from the analysis, there was no main effect of treatment (rye vs. fallow) on seeding year switchgrass biomass (data not shown) and environment was highly significant ($p < 0.001$). There was a moderate environment $\times$ treatment effect ($p < 0.062$) where in most cases the fallow plot had higher switchgrass yields than the winter rye treatment. The one exception was at RIO in 2011 where switchgrass established after winter rye yielded more than in the fallow plot. On sandy soils in a water limited year, rye can have a positive effect on switchgrass establishment, as discussed in the following paragraphs.

Frequency. From the one established phase in place thus far, the switchgrass planted after winter wheat had a frequency range of 0 at SC, 11% at RIO and 25% at ARS, but all sites were significantly below the 40% threshold to qualify as a successful establishment. Removing the wheat/August seeding treatment from the analysis, frequency analysis showed that switchgrass established in June after winter rye was significantly higher than that in the fallow treatment (88 vs. 82%, $p < 0.047$). Of the three sites, SC was a little lower than the other two sites but well above the 40% level (Table 4). Rye may have helped shade the soil to reduce surface evaporation, improved water holding capacity of the soil with its decaying roots, created a more uniform, mellow seedbed than the fallow treatment, or all of the above.

Volumetric Moisture Content

Surface Moisture. In 2010, VMC was adequate (above permanent wilting point) and similar across all treatments and sampling times for each soil type (Fig 1). Striking differences were evident between years at RIO when 2011 had much lower soil moisture than 2010 with only the rye treatment being just above the permanent wilting point of 10% (Fig. 1 and Table 5). Perhaps the rye was able to pull moisture from deeper in the profile and make it available at a shallower depth. Or, the shading effect of the rye may have helped reduced evaporation from the upper profile of the soil. The actively growing wheat treatment in the relatively dry season of 2011 had lower VMC than the other treatments across soils and seasons which may have been a factor in the failed switchgrass establishment that year.

Deeper Moisture. At the 8" depth, VMC had a similar pattern as the 4.7" depth with the exception that the rye treatment at RIO was lower than the other treatments in the Summer period (Fig. 2). As noted above, the rye may have moved the water from below up towards the surface during its growth and transpiration process. Table 5 shows the summary of statistics for Figs. 1 and 2.

Switchgrass yields 1 year after establishment

By the end of the 2nd growing season on the three environments measured to date, switchgrass harvested after the killing frost yielded most at ARS and least at SC (Table 4). The late-season stand at SC was only about half the height of the other 2 sites and can be related back to the tough growing environment in the seeding year. Plots were 99% weed-free at the end of the 2nd growing season (i.e. first production year) at ARS and RIO but up to 20% of total biomass was weeds at SC. There was no legacy of treatment (rye vs. fallow) on the production year.

A Note on Yield Estimates: Mechanical Harvest vs. Hand Sampling with Quadrats

We had the opportunity to compare harvest methods of established switchgrass at ARS in the fall of 2011. Subsamples of biomass from each plot were cut with hand shears and a 0.25m² quadrat (as described in the Methods section) or it was measured using a 11.5' wide swather machine (farm scale machinery) from a large plot area (excluding borders). The target stubble height for both harvest methods was 6". As reported earlier, the quadrat method yield was 4.59 tons DM/a while the swather method yield was about half that at 2.53 tons DM/a. It's worth noting that the machine cutting height can vary if the terrain is rough while the quadrat method may overestimate yields. Also of interest is as discussed previously, the quadrat method showed no treatment differences between rye and fallow. Doubling the sample size and thus reducing the standard error in the swather vs. quadrat dataset, the rye treatment yielded lower than the fallow treatment (4.18 vs 5.01 tons DM/a, respectively; $p < 0.031$) at this one environment tested.

CONCLUSION

Though growing wheat produced more crop income than winter rye, it was not a viable option for sequentially establishing switchgrass. Switchgrass was established successfully at all environments following winter rye, and in some cases winter rye helped its establishment. This suggests that a small grain forage crop such as winter rye in the year of switchgrass establishment can increase the profitability of the system as a whole for the producer, while having the potential to benefit the switchgrass yield as well. Site and related management was the biggest factor affecting switchgrass production and it is not recommended to establish it without herbicide.

REFERENCES

- Parrish, D.J. and J.H.Fike. 2005. The biology and agronomy of switchgrass for biofuels. *Critical Reviews in Plant Sciences*. 24:423-59
- Renz, M. and D. Undersander. 2009 Establishing and managing switchgrass. University of Wisconsin Extension. <
<http://www.uwex.edu/ces/forage/pubs/switchgrass.pdf>>.
- Schmar, M.R., K.P. Vogel, R.B. Mitchell, L.E. Moser, K.M. Eskridge, and R.K. Perrin. 2006. Establishment stand thresholds for switchgrass grown as a bioenergy crop. *Crop Sci*. 46:157-161.
- Vogel, K.P., Brejda, J.J., Walters, D.T., and D.R. Buxton. 2002. Switchgrass biomass production in the Midwest USA: Harvest and nitrogen management. *Agron. J.* 94: 413-420.
- Vogel, K.P. and R.A. Masters. 2001. Frequency grid-a simple tool for measuring grassland establishment. *J. Range Management*. 54(6):653-655.

Table 1. Description of treatments in seeding and established phases

Year 1 – Seeding phase of switchgrass					
No Prior Crop June switchgrass planting		Winter Rye June switchgrass planting		Winter Wheat August switchgrass planting	
Year 2 – Established phase of switchgrass					
1 cut system	2 cut system	1 cut system	2 cut system	1 cut system	2 cut system
harvest for biofuel after killing frost	harvest for hay in June and for biofuel after killing frost	harvest for biofuels after killing frost	harvest for hay in June and for biofuel after killing frost	harvest for biofuels after killing frost	harvest for hay in June and for biofuel after killing frost
Tmt 1	Tmt 2	Tmt 3	Tmt 4	Tmt 5	Tmt 6

Table 2. Site characteristics for three trial locations in southern Wisconsin.

	Arlington	Rio	Sugar Creek
Organic Matter, %	4.0	1.5	2.4
pH	6.9	6.6	7.3
STP, ppm	98	37	59
STK, ppm	179	127	132
Soil Texture	Silt loam	Sandy loam	Silt loam
Production practices	no-till/herbicide	no-till/herbicide	tillage/clipping
Location type	research station	on-farm	on-farm

Table 3. Crop income (\$/ac) from small grain treatments + switchgrass (2 year average).

	Arlington	Rio	Sugar Creek
	\$/ac		
Winter rye forage + seeding year switchgrass	246+77=310	162+134=285	325+41=332
Winter wheat –grain&straw + seeding year switchgrass	578+0	353+0	420+0
LSD			

Footnote:

wheat \$/bu

Straw (or swg) \$/ton
DM

ryelage \$/ton DM

2010

\$5.32

\$118.34

\$98

2011

\$6.43

\$120

\$150

Table 4. Switchgrass yields and height in seeding year and 1st production year yields and frequency. Averaged over 2 treatments (rye and fallow) and 4 reps/site

	Arlington	Rio	Sugar Creek
Seeding year yield	Tons DM/ac		
2010	0.47d	1.50a	0.65c
2011	0.81b	0.76bc	0.05e
Switchgrass Height	inches		
2010	21.0x	32.0w	13.5y
2011	19.3x	19.7x	6.5z
Year 1 yield	Tons DM/ac		
2011	4.59A	3.98B	1.22C
Year 1 frequency	%		
2011	89.9p	87.7p	77.0q

Different sized or set of letters show significant differences at $p < 0.10$ within category

Table 5. Corresponding statistics to the LSMEANS in Figs. 1 and 2

	Env	Treatment	Env x Treatment
	-----P > F-----		
4.7" VMC			
Spring	0.001	0.001	0.001
Summer	0.001	0.001	0.001
8.0" VMC			
Spring	0.001	0.001	0.001
Summer	0.001	0.003	0.002

Fig. 1. LSMEAN volumetric moisture content at 4.7" depth in Spring and Summer at 2 sites in southern Wisconsin.

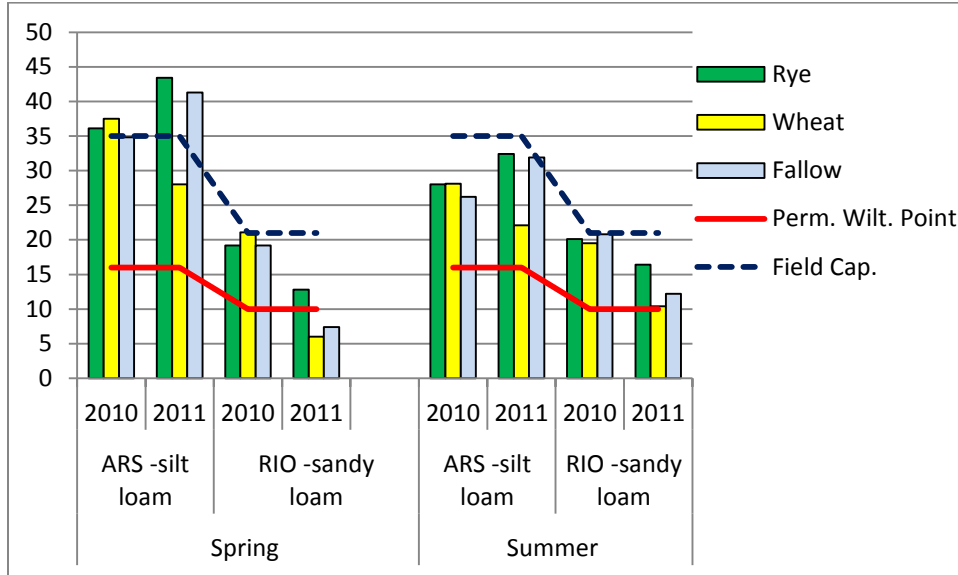
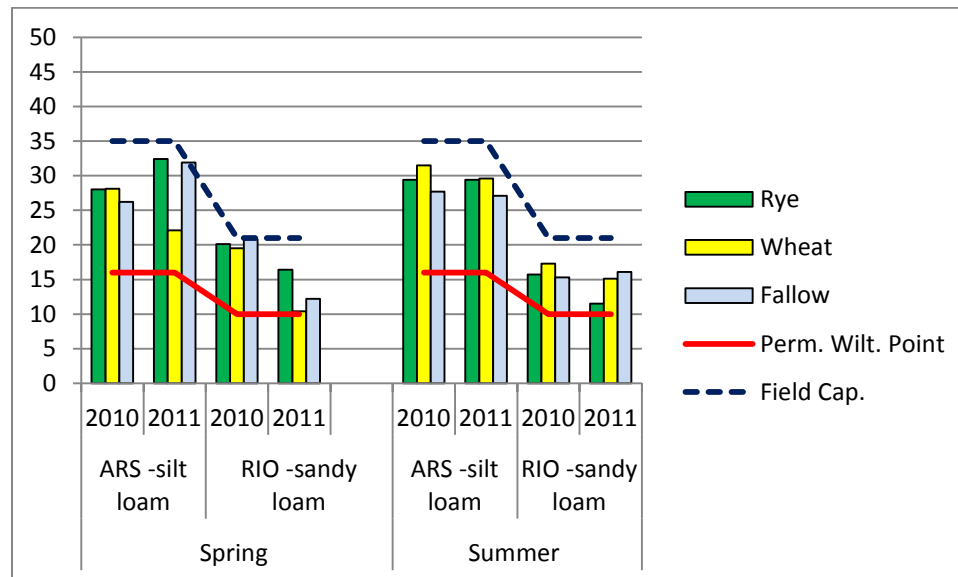


Fig. 2. LSMEAN volumetric moisture content at 8.0" depth in Spring and Summer at 2 sites in southern Wisconsin.



TARTARY BUCKWHEAT LESS EFFECTIVE THAN COMMON BUCKWHEAT AS A SUMMER COVER CROP IN SOUTHERN WISCONSIN

Mary Saunders

INTRODUCTION

Systematic assessment of novel crops and management techniques are practical objectives of agricultural field research. This study sought to expand the cover cropping toolkit available to WI farmers with a series of on-station experiments using buckwheat (*Fagopyrum* spp.).

Cover crops provide many benefits to farms and the environment, including improving soil quality and fertility, weed suppression, beneficial insect habitat, and erosion prevention (Clark ed., 2007). Summer cover crops have not been widely studied in Wisconsin because a relatively short growing season tends to limit their use on commercial grain farms. However, many organic vegetable growers use summer cover crops as part of complex, diverse rotations. In a survey conducted in 2006 of 70 Wisconsin and Illinois vegetable growers, 78% reported using common buckwheat (*F. esculentum*) cover crops, with over a third of respondents using it every year (John Hendrickson, unpublished data).

Common buckwheat (CBW) is known for its ease of establishment, thick canopy, profuse flowers and rapid decomposition. Previous research has detailed the positive effects of buckwheat cover crops on soil tilth in Quebec (N'Dayegamiye and Tran, 2001), weed suppression in New England (Schonbeck, 1991), phosphorus availability in Australia (Zhu et al., 2002), and promoting beneficial insect populations in New Zealand (Araj et al., 2009). WI vegetable growers value these benefits to varying degrees, and are open to more research and information that would improve the efficacy of buckwheat cover cropping.

Tartary buckwheat, a novel cover crop

Our study evaluated the cover cropping potential in southern WI of tartary buckwheat (*F. tataricum*), a related species to CBW. Tartary buckwheat (TBW) is primarily grown as a subsistence grain at high altitudes in the Himalayas, and its unique nutritional profile has spurred development as a functional food. It is self-pollinating, relatively frost tolerant, and has a similar growth habit and phenology to common buckwheat. TBW has been reported to grow more vigorously than CBW in cold climates (Senthilkumaran et al., 2008), which may fill a unique niche for vegetable farmers in the upper Midwest. Tartary buckwheat also contains high levels of potentially allelopathic phytochemicals in the vegetation (Fabjan et al. 2003) and seeds (Briggs et al. 2004; Fabjan et al., 2003).

Weed suppression

TBW and CBW were compared for effectiveness in weed suppression both during the cover cropping phase and after cover crop termination. This study takes a detailed look at weed emergence and growth in an early-sown buckwheat cover

crop, and tracks the season-long effects of buckwheat on weeds and yield of a cabbage test crop (*Brassica oleracea*).

Reduced tillage

Development of reduced tillage systems is an active area of cover crop research (Vollmer et al., 2010), (Teasdale, 2007). Tillage reduction using cover crop mulches in agricultural systems can improve soil conservation, suppress weeds, and provide habitat for beneficial organisms (Masiunas et al., 1997). Tillage tends to stimulate weed seed germination, which can increase weed pressure in crop fields. Tillage is also associated with greater costs in terms of labor, equipment, and soil quality (Bernstein et al., 2011). This study includes a test of a reduced-tillage management system using buckwheat cover crops.

METHODS

Sites and experimental design

Experiments were conducted on-station at West Madison (WM) in 2010 and 2011 and Arlington (AR) in 2011 (see Table 1).

Table 1. Experiment site comparison

	latitude	longitude	OM (%)	STP (ppm)	STK (ppm)	pH	soil type
West Madison	43.065800°	-89.534875°	2.9	33	95	7.1	Kegonsa silt loam
Arlington	43.314456°	-89.335969°	4.0	93	214	7.3	Saybrook/Plano silt loam

Plots were laid out in an expanded factorial design with a fallow check, in four replications per site-year. In 2010 we established five treatments: CBW/mowed, CBW/tilled, TBW/mowed, TBW/tilled, and a fallow control. In 2011 the no-till (NT) treatments were expanded to include two alternatives: a roller-crimper and a sickle-bar mower. Plots at WM 2010 measured 8' x 50'. The inclusion of new equipment in 2011 necessitated widening the plots, which measured 14' x 40' at WM and 20' x 30' at AR that year.

Cover crops were drilled on June 3, 2010, and May 31, 2011 at WM and June 1, 2011 at AR. Seeding rate was 80 lbs/acre for CBW and 65 lbs/acre for TBW, which due to seed size differences resulted in approximately equal population densities. This rate is consistent with recommendations in the literature (Bjorkman and Shall, 2010). However, because of low populations in 2010 the TBW drill setting was increased to 80 lbs/a for 2011.

Cover crop and weed emergence and biomass accumulation

One permanent quadrat (1m x 1m) was established in each treatment plot for repeat counts of buckwheat and weed emergence. Counts were made twice weekly in the first three weeks following planting, and then once weekly until the end of the six week cover cropping period. Weeds were identified to the genus level, and all plants were marked with colored toothpicks to prevent their being counted twice.

In addition to permanent quadrats, weekly destructive samples (0.25m x 0.25m) were randomly harvested from each treatment beginning week 2 after planting. Aboveground biomass was cut and partitioned into cover crop and weed components. Weeds were identified to genus level, counted, and weighed fresh. Cover crop plants were also counted and weighed fresh. After cover crop killing in mid-July, weed biomass samples were collected from plots at three week intervals. Fresh samples were placed in drying ovens in the Seeds Building on UW-Madison campus and re-weighed as dry biomass one week later.

Soil measurements

Soil samples were taken from each plot immediately after cover crop termination. Four soil cores per plot were extracted at 6" depth using a ¾" diameter probe, and samples were combined for one analyzed sample per plot. Samples were assessed for NO₃-N. Penetrometer and soil moisture readings were taken in late July 2011.

Organic cabbage yield

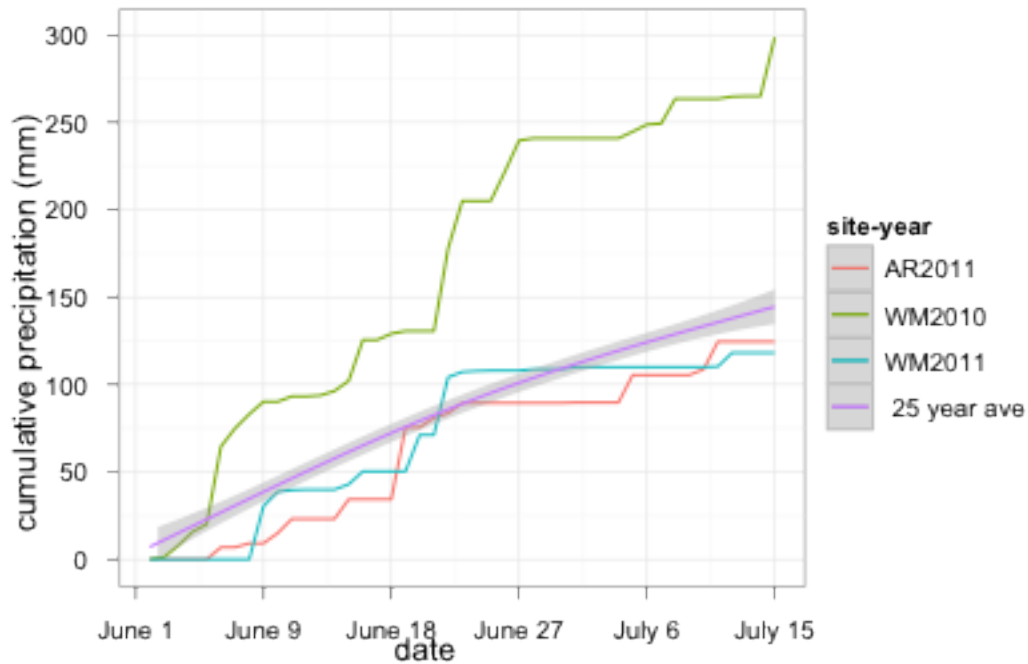
Copenhagen, a 65-75 day cabbage variety, was hand transplanted in experimental plots within one day of cover crop termination. Most cabbages were left unweeded, but a section of each plot containing 15-16 cabbages was hand-weeded twice during the course of the growing season to provide an estimate of the effects of weed pressure on cabbage yield. In 2010, no cabbages were harvested due to crop failure. In 2011, cabbages were harvested on Oct 11 and 12 and WM and AR respectively. Harvested cabbages were evaluated for head weight and diameter.

RESULTS

Precipitation

In 2010, rainfall during the buckwheat growing period was high, about twice the 25 year average. Rainfall in 2011 was just below the 25 year average (Fig 1).

Figure 1 Cumulative precipitation by date and site-year, with 25 year average



Cover crop emergence and growth

Tartary buckwheat emerged slightly later than CBW in all sites and years. The overall emergence of the two cover crops varied. CBW populations were similar (100 seedling/m²) between years at WM. A higher drill setting for TBW in 2011 increased populations to the level of CBW at WM. The Arlington site had higher innate fertility and better water holding capacity than at WM, which probably contributed to stronger emergence of both cover crops (Figs. 1-3).

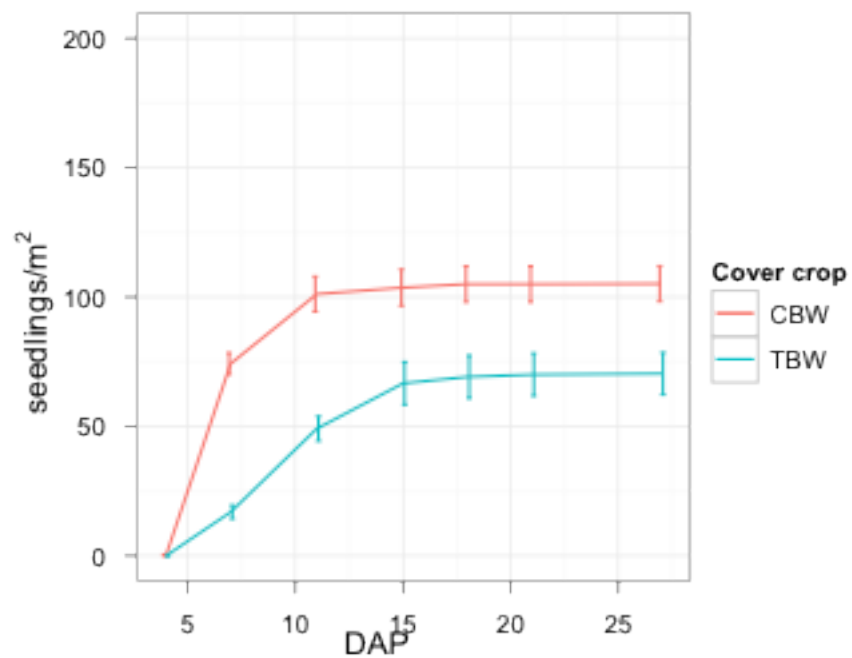
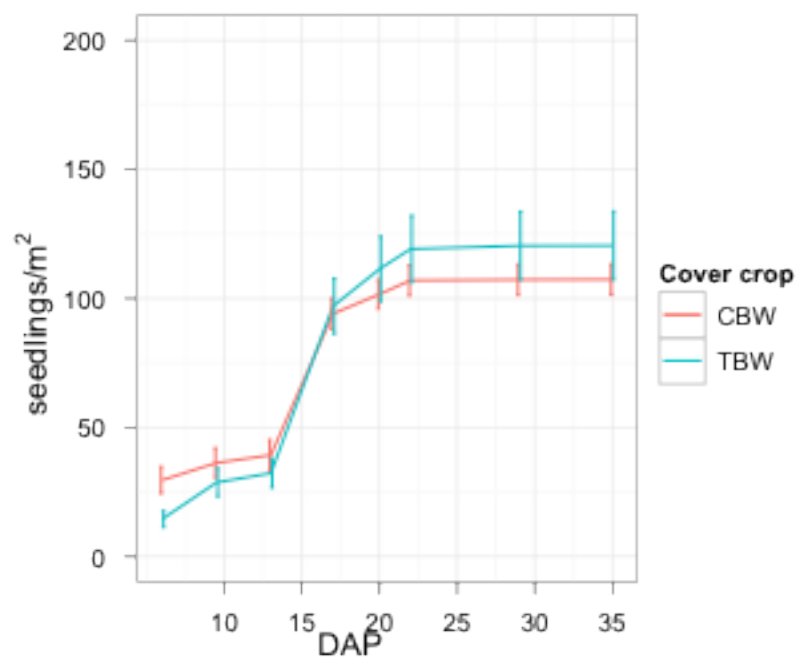
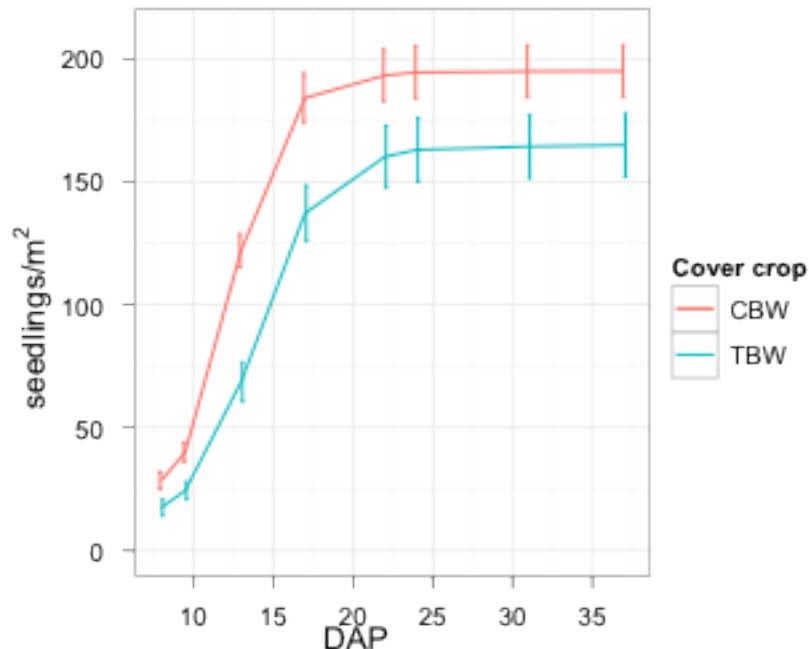
Figure 1 Cover crop emergence – West Madison 2010 Bars are standard error of the mean.**Figure 2 Cover Crop emergence – West Madison 2011.** Bars are standard error of the mean.

Figure 3.. Cover crop emergence - Arlington 2011. Bars are standard error of the mean.



Cover crop and weed biomass

At WM, CBW accumulated more biomass over the course of the season than TBW both years. Biomass was not statistically different between cover crops at AR. Site, year, and cover crop treatment all influenced weed biomass. WM plots were weedier overall than AR plots.

The growing season of 2010 produced CBW biomass averaging 3.8 Mg/ha and TBW biomass of 1.9Mg/ha. Weed biomass was greater than cover crop biomass in the TBW plots, comparable to weed biomass in fallow plots. In contrast, weeds in the CBW plots had much less biomass (Fig. 4).

At WM in 2011, cover crop biomass averaged 1.5 Mg/ha for CBW and 1.1 Mg/ha for TBW. Weeds grew vigorously, and weed biomass in the fallow plots reached 3.8 tons/ha. No significant differences were found between weed biomass in TBW and CBW plots, with growth equal to TBW growth at about 1.1tons/ha (Fig. 5).

No significant differences in cover crop biomass was observed in AR in 2011, although CBW produced nominally more, with 3.1 Mg/ha compared to 2.5 Mg/ha for TBW. The last sampling date saw a rise of weed biomass in TBW plots relative to weeds in CBW. Fallow plots saw peak weed biomass of 1.5 tons/ha (Fig. 6).

Figure 4.. Cover crop and weed biomass at West Madison, 2010. Bars are standard error of the mean.

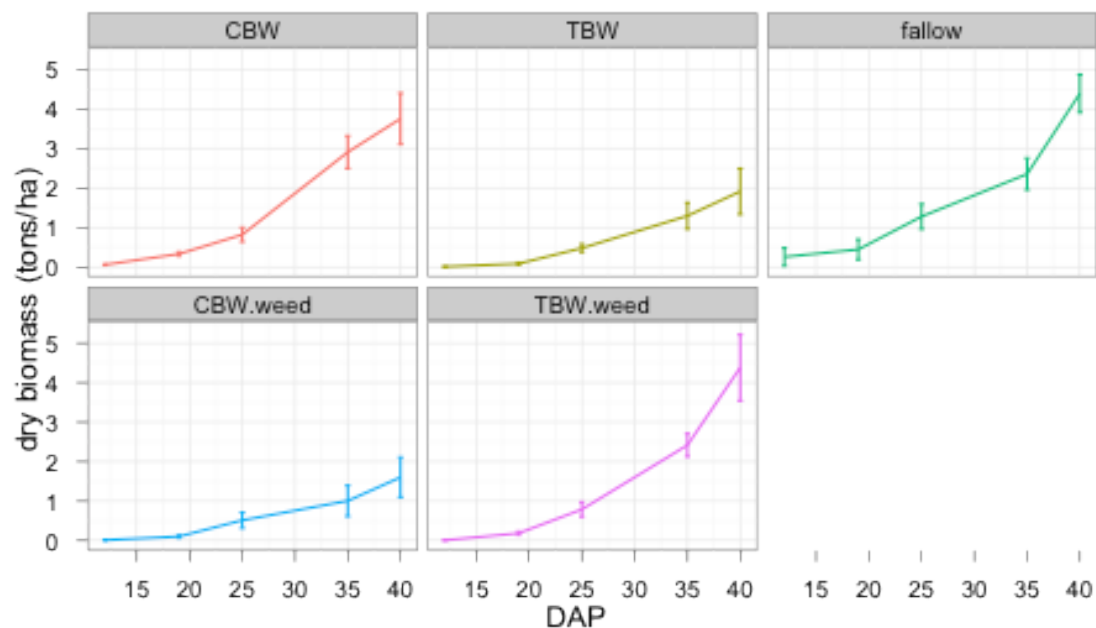


Figure 5 Cover Crop and weed biomass – West Madison 2011. Bars are standard error of the mean.

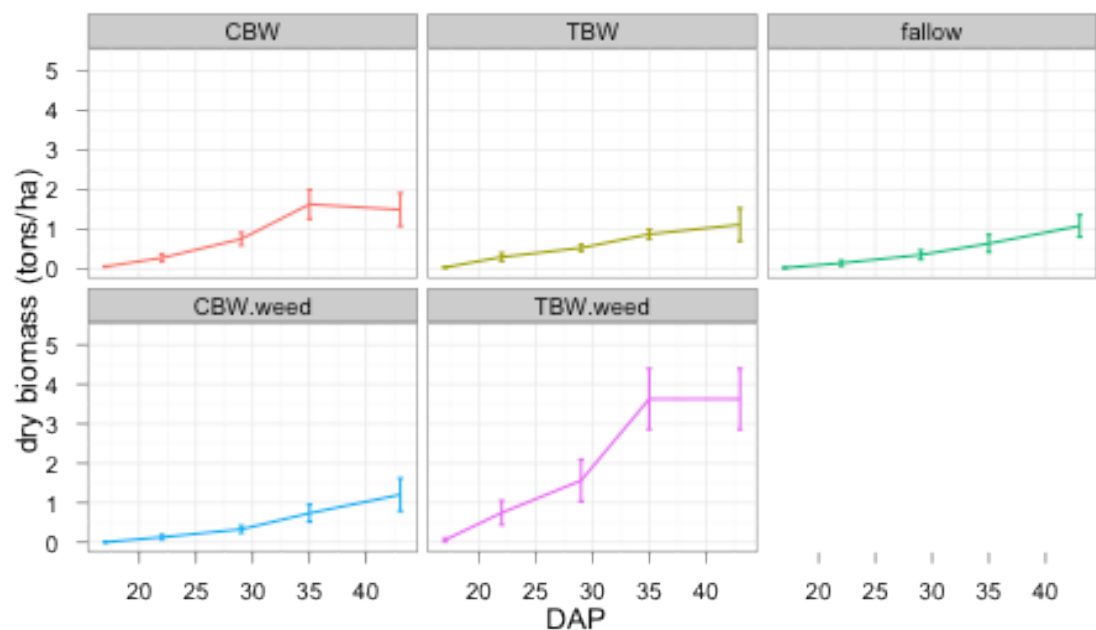
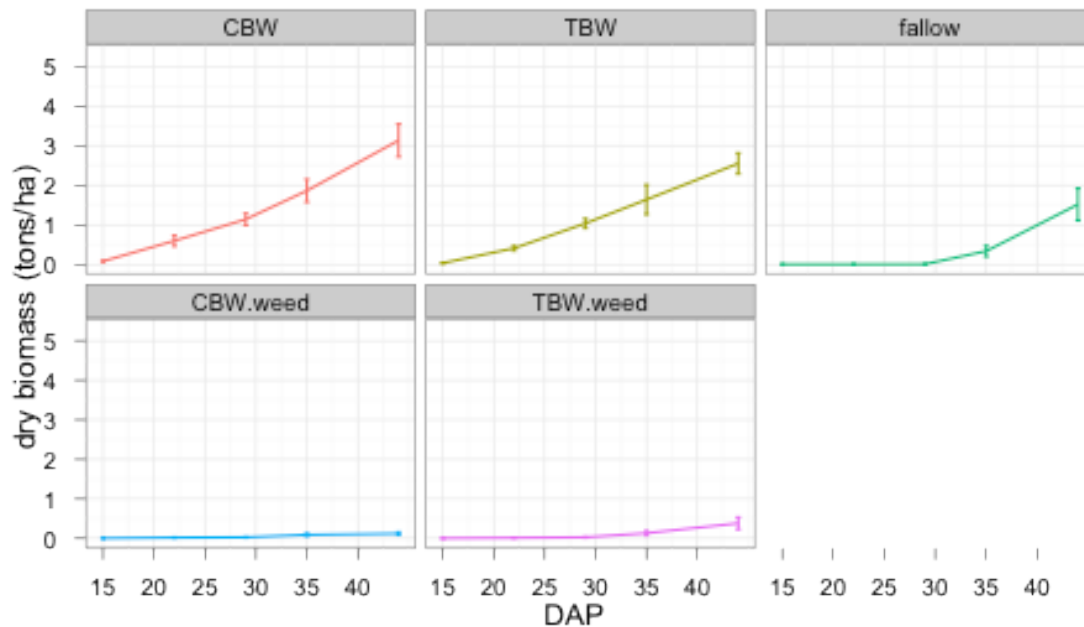


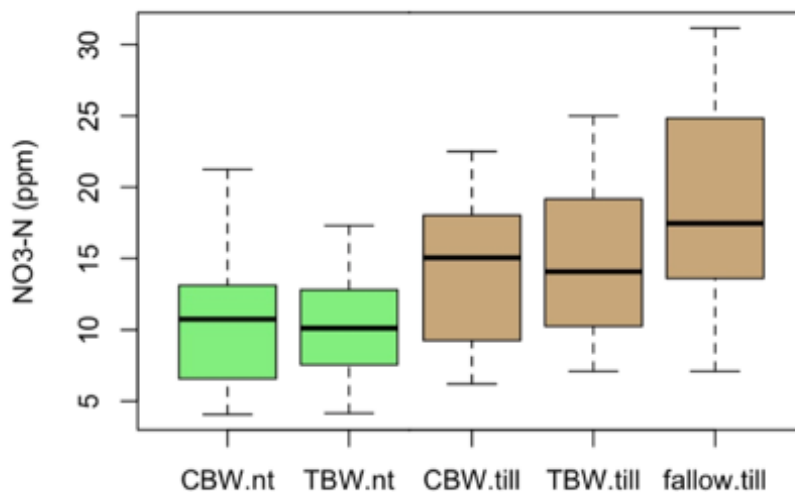
Figure 6 CoverCrop and weed biomass Arlington 2011. Bars are standard error of the mean.



Soil compaction, nitrate availability, and soil moisture

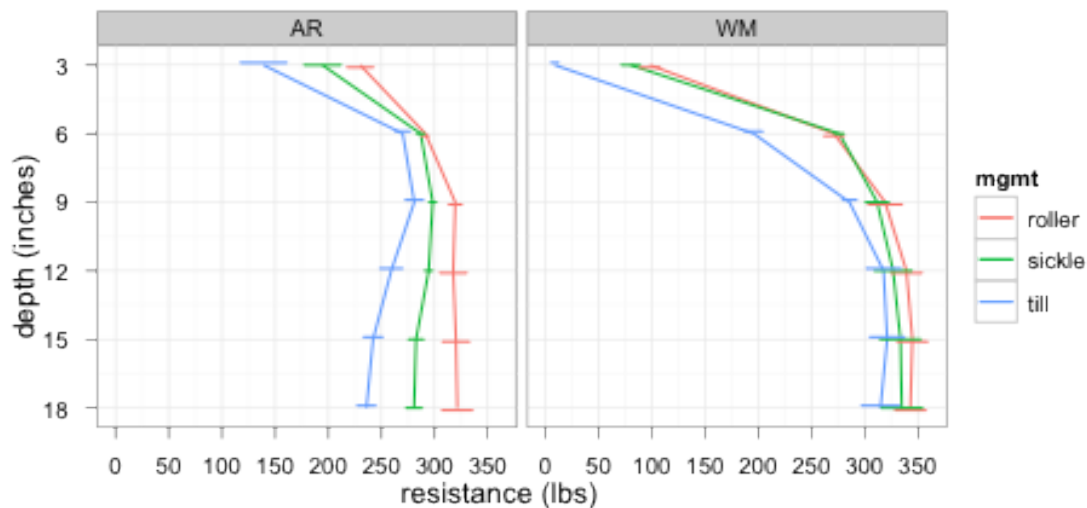
Nitrate availability was heavily influenced by tillage, and cover crop was found to be a significant factor. A mixed model was fit using `lmer()` in the [lme4] package in R. The best model included site and year as random effects and cover crop treatment and tillage as fixed effects. There were no significant differences between the two buckwheat cover crops, but both produced less nitrates than the fallow plot (Fig. 7).

Figure 7 NO₃-N - pooled sites and years



Penetrometer readings showed differences between sites and tillage treatments. At WM, both no-till treatments showed a similar resistance pattern, exhibiting greater resistance than the tilled treatment up to a depth of 12 inches. At AR, the tilled treatment showed less compaction for the entire measured depth of the soil profile. This site showed evidence of a plowpan at 6 inches. The sickle bar treatment also showed significantly less compaction than the rolled plots through most of the profile (Fig. 8).

Figure 8 Penetrometer resistance. Error bars are standard error of the mean.

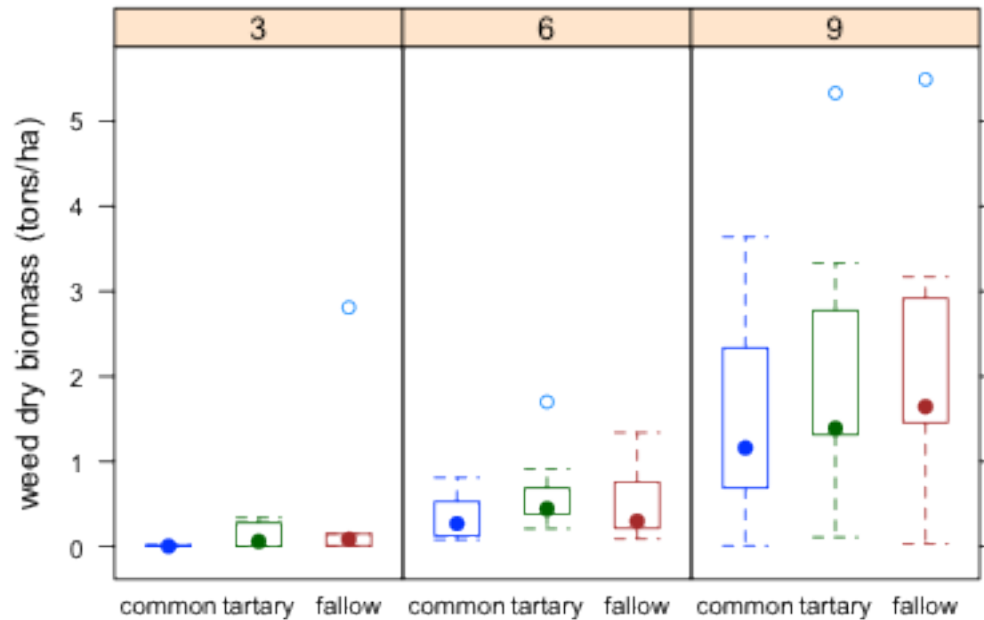


Soil moisture at WM displayed a wider range than at AR, but did not show any significant relationship with management, cover crop, or cabbage yield.

Late season weed growth

In the NT treatments, weeds were a major problem. Weed biomass showed similar patterns within NT treatments, but overall weed biomass was higher in the rolled plots than the sickle bar plots, and much higher than in the tilled plots. Site differences were important earlier, but the two sites were not statistically different in the late season. Cover crop treatment did not affect weed biomass Fig. 10.

Figure 9 Weed biomass in tilled plots at 3,6, and 9 weeks – pooled sites



Cabbage yield

Tillage and weeding played an important role in cabbage yield outcomes. Unweeded NT treatments produced no harvestable cabbages. In weeded plots, cabbage yield was higher in the tilled treatments than NT treatments. In the weeded treatments at WM, both the sickle bar and rolled treatment performed equally poorly. At AR, yields were slightly higher in the sickle bar plots (Fig. 11). This is probably due to the greater cover crop biomass at AR, weed community differences between the sites, and the better observed efficacy of the sickle bar in bringing down the cover crop. AR was characterized by many more broadleaf weeds, while WM had a proliferation of grass weeds that were not killed by rolling or mowing (data not shown). These established weeds probably competed with the cabbage crop before they were pulled. Within the tilled plots, cover crop had no effect on cabbage yield, producing comparable yields with fallow plots (Fig. 12). Site effects in tilled plots were not significant.

Figure 10 Weight of weeded cabbages by management

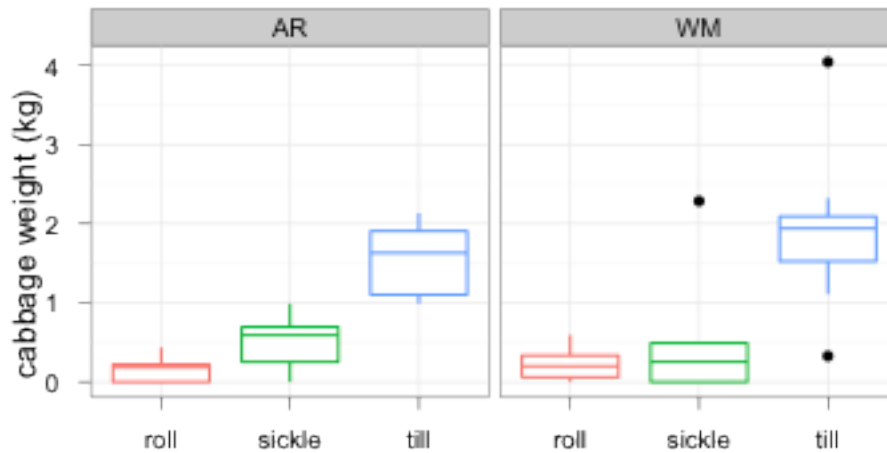
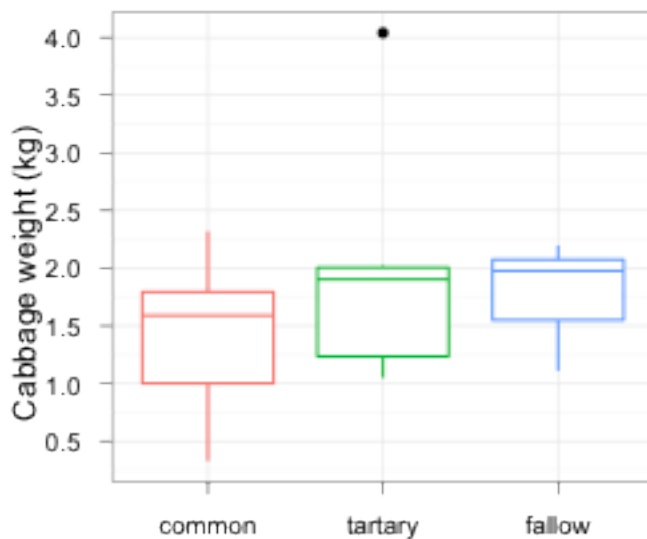


Figure 12 Weight of tilled cabbages by cover crop – pooled sites



DISCUSSION

As a cover crop for southern Wisconsin, TBW did not impress. It performed the same or worse than CBW in all measured parameters, including speed of emergence, biomass accumulation, weed suppression, and subsequent crop yield. Both cover crops effectively suppressed weeds in 2011, though neither improved cabbage yield in comparison with the fallow check. Wisconsin growers expect yields of about 2kg/head for late cabbage (Delahaut and Newenhouse, 1997); cabbages from the tilled treatments averaged slightly less than that at 1.7 kg/head, and cabbages in the NT treatments averaged just 0.3 kg/head. A high incidence of cabbage loopers at

both sites reduced yield compared to that of a typical grower who would probably use numerous applications of pesticide.

Regarding nutrient dynamics, buckwheat biomass may release nutrients more slowly than weed residues, indicated by the differences in NO₃-N between fallow and cover cropped tilled plots. This discrepancy did not immediately appear in differing cabbage yields in this study. Perhaps over a longer time frame buckwheat cover crops add stable organic material to the soil.

The management regime for reduced tillage proved ineffective in this study. Some cover crop regrowth occurred in the NT plots, particularly in the TBW/rolled treatment, where the erstwhile cover crop became a weedy competitor with cabbage. In general, after cover crop termination weeds living underneath took over the plots quickly.

Weed suppression by organic mulch is a complex phenomenon with multiple proposed and possibly interacting mechanisms, including physical barriers, effects on nutrient dynamics, and allelopathy (Creamer and Baldwin, 2000; Altieri et al., 2011). Perhaps the most important attribute of an effective mulch is high biomass production. Teasdale and Mohler (2000) estimated 75% weed suppression is possible only at biomass production above 8Mg/ha. In contrast, buckwheat in our experiment produced an average of just 2.8 Mg/ha for CBW and 1.9 Mg/ha for TBW.

CONCLUSION

Common buckwheat is planted by many Wisconsin farmers for its multiple benefits of weed suppression, beneficial insect habitat, soil improvement, ease of management, and erosion protection. For these qualities it is likely to remain a valued cover cropping tool. Our results indicate no reason for farmers to choose tartary buckwheat over common buckwheat in the situations we tested. It is also possible that in southern WI, neither buckwheat species is a good candidate for no-till mulch systems compared with more vigorous grasses or mixtures. Toward these questions, some progress has been made in developing novel systems, and more is sure to follow.

REFERENCE LIST

- Altieri, M.A., M.A. Lana, H.V. Bittencourt, A.S. Kieling, J.J. Comin, and P.E. Lovato. 2011. Enhancing Crop Productivity via Weed Suppression in Organic No-Till Cropping Systems in Santa Catarina, Brazil. *Journal of Sustainable Agriculture* 35(8): 855-869.
- Araj, S.-E., S. Wratten, A. Lister, and H. Buckley. 2009. Adding floral nectar resources to improve biological control: Potential pitfalls of the fourth trophic level. *Basic and Applied Ecology* 10(6): 554-562.

- Bernstein, E.R., J.L. Posner, D.E. Stoltenberg, and J.L. Hedtcke. 2011. Organically Managed No-Tillage Rye–Soybean Systems: Agronomic, Economic, and Environmental Assessment. *Agronomy Journal* 103(4): 1169.
- Bjorkman, T., and J.W. Shall. 2010. Cornell cover crop guide for buckwheat. Ithaca, N.Y.
- Briggs, C., P. Campbell, Clayton, G. Pierce, and P. Jiang. 2004. Bioflavonoid analysis and antioxidant properties of tartary buckwheat accessions. *In* International Buckwheat Research Association, Prague.
- Clark ed., A. 2007. Managing Cover Crops Profitably. 3rd ed. Sustainable Agriculture Research and Education Program, Beltsville, MD.
- Creamer, N.G., and K.R. Baldwin. 2000. An Evaluation of Summer Cover Crops for Use in Vegetable Production Systems in North Carolina. *HortScience* 35(4): 600-603.
- Delahaut, K.A., and A.C. Newenhouse. 1997. Growing broccoli , cauliflower , cabbage , and other cole crops in Wisconsin: A guide for fresh market growers (A3684). Madison, WI.
- Fabjan, N., J. Rode, I.J. Kosir, Z. Wang, Z. Zhang, and I. Kreft. 2003. Tartary Buckwheat (*Fagopyrum tataricum* Gaertn.) as a Source of Dietary Rutin and Quercitrin. *Journal of Agricultural and Food Chemistry* 51(22).
- Masiunas, J.B., D.M. Eastburn, V.N. Mwaja, and C.E. Eastman. 1997. The Impact of Living and Cover Crop Mulch Systems on Pests and Yields of Snap Beans and Cabbage. *Journal of Sustainable Agriculture* 9(2): 61.
- N'Dayegamiye, A., and T.S. Tran. 2001. Effects of green manures on soil organic matter and wheat yields and N nutrition. *Canadian Journal of Soil Science* 81(4): 371-382.
- Schonbeck, M. 1991. Comparison of weed biomass and flora in 4 cover crops and a subsequent lettuce crop on 3 New England organic farms. *Biological Agriculture and Horticulture* 8: 123-143.
- Senthilkumaran, R., I.S. Bisht, K.V. Bhat, and J.C. Rana. 2008. Diversity in buckwheat (*Fagopyrum* spp.) landrace populations from north-western Indian Himalayas. *Genetic Resources and Crop Evolution* 55(2): 287-302.
- Teasdale, J. 2007. Sustainable Production of Fresh-Market Tomatoes and Other Vegetables With Cover Crop Mulches. Beltsville, MD.
- Vollmer, E.R., N. Creamer, C. Reberg-Horton, and G. Hoyt. 2010. Evaluating Cover Crop Mulches for No-till Organic Production of Onions. *HortScience* 45(1): 61-70.
- Zhu, Y.-G.G., Y.-Q.Q. He, S.E. Smith, and F.A. Smith. 2002. Buckwheat (*Fagopyrum esculentum* Moench) has high capacity to take up phosphorus (P) from a calcium (Ca)-bound Source. *Plant and Soil* 239(1): 1-8.

Orchardgrass Ley for Improved Manure Management in Wisconsin: I. Forage Yield, Environmental Impact, and Production Costs

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4. Richard P. Walgenbach and
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Published in Agronomy Journal 2010. 102:956-963

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 (GL) does open several windows for manure spreading. The effects of such a strategy were examined in a 3-yr, 2 by 2 factorial trial comparing orchardgrass (*Dactylis glomerata* L.) and corn silage (CS) with either manure or fertilizer at two locations in Wisconsin. In the fourth year a test crop of CS was grown following both crops. During the first 3 yr, the manured corn plots out-produced the manured grass plots (16.0 vs. 8.6 Mg DM ha⁻¹ yr⁻¹) but in the fourth 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 (STP) values climbed 2 to 4 mg kg⁻¹ yr⁻¹ and soil test potassium (STK) 14 to 20 mg kg⁻¹ yr⁻¹ under the manured systems. Variable costs per metric ton of forage dry matter (DM) were significantly higher in the manured GL compared to manured continuous CS 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 GL may be an ecologically and economically sound strategy where summer manure spreading is required.

Orchardgrass Ley for Improved Manure Management in Wisconsin: II. Nutritive Value and Voluntary Intake by Dairy Heifers

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6. Jill Davidson

Published in Agronomy Journal. 2011. 103:1106-1114

Abstract

Confinement dairy feeding operations in the Upper Midwest could benefit from using a wider range of forages than alfalfa (*Medicago sativa* L.) and corn silage (*Zea mays* L.). A short-term ley of orchardgrass (*Dactylis glomerata* L.) (OG) frequently treated with manure, was compared with corn silage (CS) in a 2×2 factorial trial conducted across 3 yr at two locations in Wisconsin. Nutrients were applied as either manure (M) or fertilizer (F) to meet crop N needs. Weighted on the basis each cut contributed to the total annual yield of OG, concentrations of crude protein (163 g kg^{-1}) and 48-h neutral detergent fiber (NDF) digestibility (657 g kg^{-1} NDF) were suitable for incorporation into the diets of dairy cows (*Bos taurus*) and replacement heifers. Tissue concentrations of P and K were 3.7 and 32.0 g kg^{-1} , respectively. High tissue concentrations of P can help with soil-test P drawdown, and reduce purchases of supplemental dietary P. Although heavy manuring resulted in high tissue K, especially in late-season cuts, K concentrations were not significantly greater in the hay-production years relative to the seeding year in either M or F. Based on results with $483 \pm 37.6 \text{ kg}$ Holstein heifers, there were no differences in voluntary intake by heifers offered commercially fertilized compared to manured OG hays. These results indicate that an OG ley system could be part of a larger alfalfa–corn silage rotation, providing confinement dairies with an alternative forage option, and additional manuring opportunities during summer months.

Organically Managed No-Tillage Rye–Soybean Systems: Agronomic, Economic, and Environmental Assessment

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Published in Agronomy Journal 2011. 103:1169-1179

Abstract

A major challenge that organic grain crop growers face is weed management. The use of a rye (*Secale cereale* L.) cover crop to facilitate no-tillage (NT) organic soybean [*Glycine max* (L.) Merr.] production may improve weed suppression and increase profitability. We conducted research in 2008 and 2009 to determine the effect of rye management (tilling, crimping, and mowing), soybean planting date (mid-May or early June), and soybean row width (76 or 19 cm), on soybean establishment, soil moisture, weed suppression, soybean yield, and profitability. Soybean establishment did not differ between tilled and NT treatments; and soil moisture measurements showed minimal risk of a drier soil profile in NT rye treatments. Rye mulch treatments effectively suppressed weeds, with 75% less weed biomass than in the tilled treatment by mid-July. However, by this time, NT soybean competed with rye regrowth, were deficient in Cu, and accumulated 22% as much dry matter (DM) and 28% as much N compared to the tilled treatment. Soybean row width and planting date within NT treatments impacted soybean productivity but not profitability, with few differences between mowed and crimped rye. Soybean yield was 24% less in the NT treatments than the tilled treatment, and profitability per hectare was 27% less. However, with fewer labor inputs, profitability per hour in NT rye treatments was 25% greater than in tilled soybean; in addition, predicted soil erosion was nearly 90% less. Although soybean yields were less in NT rye mulch systems, they represent economically viable alternatives for organic producers in the Upper Midwest.

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Nutrient and alkalinity removal by corn grain, stover and cob harvest in Upper Midwest USA

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ABSTRACT

In the USA, most corn stover currently remains in fields as crop residue that provides soil erosion control and maintains soil organic carbon levels. This stover is a potential biofuel feedstock for direct combustion, pyrolysis, and ethanol fermentation. At a research site in south central Wisconsin, the northern edge of the US Corn Belt, corn grain harvest averaged $9.8 \text{ Mg ha}^{-1} \text{ DM}$ over a 6-year period, 1997 to 2002. Removal of all stover could recover an additional $7.2 \text{ Mg ha}^{-1} \text{ y}^{-1} \text{ DM}$ and, in the process, remove an additional 47, 6, 81 and $197 \text{ kg ha}^{-1} \text{ y}^{-1}$ of N, P, K and calcium carbonate equivalent, respectively. The fertilizer replacement cost for stover removal is $32 \$ \text{ Mg}^{-1} \text{ DM}$, which is 95% of the fertilizer value of the grain. However, most of the N, P, K and alkalinity of the stover is found in the leaves, stalk, and husks, not in the cob. At our study site, complete stover removal would export $235 \$ \text{ ha}^{-1} \text{ y}^{-1}$ of fertilizer and limestone, mainly as K, while cob export would be worth $20 \$ \text{ ha}^{-1} \text{ y}^{-1}$ in nutrient equivalents. Based on this research, removal of cobs only is equivalent to 16.6% of total stover removal but with a greatly reduced fertilizer replacement cost of $17 \$ \text{ Mg}^{-1} \text{ DM}$ and the same energy density.

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1. Introduction

The production of corn (*Zea mays* L.) produces stover—the non-grain portion of the corn plant, i.e., leaves, stalks, husks, and cobs—roughly equal to the amount of grain harvested [1]. Although various uses have been traditionally found for stover, among them silage and animal bedding, the amount of stover available far exceeds on-farm needs [2] and only five percent of stover is currently harvested in the USA [3]. Leaving stover on fields has been found to be an effective practice for erosion control, and secondarily for carbon sequestration, maintenance of soil organic matter, and nutrient cycling. However, in this era of increased interest in biofuels, corn stover, estimated at 130 Mt annually across North America [4], has been viewed as a candidate for utilization as either

feedstock for cellulosic ethanol production, direct combustion or gasification. This interest in corn stover has been tempered by the objective of maintaining good soil cover by leaving behind some stover to meet soil erosion standards. Using the Universal Soil Loss Equation (USLE), it has been estimated that 52 Mt of corn stover could be removed in 9 US Corn Belt states [5] while later calculations using the Revised Universal Soil Loss Equation (RUSLE) estimated that 35–47 Mt of corn stover could be removed annually from 37 US states, including all of the Corn Belt [6]. A life cycle assessment of corn stover harvest [2] used values of 50% stover removal, or less, for the sites they analyzed while others [7] have concluded that under current rotation and tillage practices, erosion and soil moisture concerns would limit corn stover collection to ~30% of total production. Even these reductions in stover removal to meet

Abbreviations: CCE, calcium carbonate equivalent; DM, dry matter; ICP-OES, Inductively Coupled Plasma Optical Emission Spectrometry; NI, Neutralizing index; WICST, Wisconsin Integrated Cropping System Trials.

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Midwest Cropping System Effects on Soil Properties and on a Soil Quality Index

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Abstract

Cropping systems may improve or decrease soil quality depending on the specific crop rotation, nutrient amendments, and tillage practices employed. We conducted this study to determine the effect of six cropping systems in the Wisconsin Integrated Cropping Systems Trial on soil properties after 18 yr of continuous treatments. We sampled soils (0–5 cm and 5–20 cm depths) following the corn (*Zea mays* L.) year of three grain-based systems (continuous corn and two grain rotations), after both corn and alfalfa (*Medicago sativa* L.) in two forage-based systems (organic and conventional), and in grass–legume pasture. Extractable P and K, pH, total organic carbon (TOC), total N, active soil C, potentially mineralizable nitrogen (PMN), water-stable aggregates (WSA), bulk density (BD), penetrometer resistance, and total microbial biomass (TMB) were measured, and the Soil Management Assessment Framework (SMAF) soil quality index (SQI) was determined. The pasture (0–5 cm) was significantly better than all other systems in almost all soil quality indicators and had the highest SQI (96 vs. mean of 87 for others). The alfalfa-based systems had more total N, TOC, active C, PMN, and WSA and higher BD in one or both depths than did the grain-based systems but SQIs were not different. Among the grain systems, there was less variation and few significant differences were observed. While there were significant differences among systems for most soil properties, a SQI based on a composite of seven soil properties, showed few differences on this well managed, productive, prairie-derived soil.

NEW RESEARCH

ESTIMATED ON-FARM GREENHOUSE GAS EMISSIONS AND ENERGY USE IN SOUTH CENTRAL WISCONSIN

Richard Gaillard and Joshua Posner

INTRODUCTION

Concerns over anthropogenically induced climate change and national energy security have resulted in a flurry of research and publications that attempt to quantify the magnitude and various sources of greenhouse gas (GHG) emissions and energy use. The ultimate aim of many of these investigations into is to quantify national or regional contributions. One direct way to accomplish this is to evaluate national or regional data to characterize farm practices and to then attach GHG or energy values to the available statistics. Energy use in corn ethanol systems, especially, has been evaluated at the national level several times and often with conflicting results (Shapouri 2004, Pimentel 2003). The Environmental Protection Agency (EPA) is also becoming increasingly interested in the sources of GHG emissions. Agriculture is the 4th largest emitter of GHGs (EPA 2012) by national sector, and understanding the mechanics and variation in emission sources is vitally important to a national GHG reduction portfolio.

These national evaluations are important for estimating total GHG and energy use values, but they do little to help us understand the dynamics present on individual farms. Each farm is managed differently and is subject to the limitations or advantages of both management and the geographic region it occupies. Some studies have evaluated research station trials (see Posner et al in this report) as a way to examine GHG emissions and energy use for a single location. These studies have been helpful in understanding what factors may affect processes in a single location. However, the appropriateness of using research station trials as more accurate estimators of farm GHG emissions and energy use has not been thoroughly investigated.

This study will seek to provide much needed understanding of how farm management impacts GHG emissions and energy use at the farm level. By examining many different farms in similar cropping systems, we will be able to evaluate the variation within systems and the sources of that variation. It is understanding these key components of agricultural GHG emissions and energy use, that will provide researchers and policy makers with the information necessary to make assertions and decisions regarding these new evaluation metrics.

Thus far, few studies have estimated GHG, and energy use, modeled by life cycle inventory development (LCID) tools to the individual farm level. The Wisconsin Integrated Cropping System Trial (WICST), an on-station experiment, has provided a unique opportunity to perform LCID's on cropping systems over a 16 year period and that effort is reported in a sister article in this volume (Posner et al). We propose that the next step is to evaluate on- farm situations to assess system variability from farm to farm and compare the results with the WICST project. In a recent, long-term trial in Eastern Canada, a study of the effects of tillage intensity and crop rotation on GHG emissions ($\text{kg CO}_2 \text{ eq ha}^{-1}$) (Meyer-Aurich 2006) found that crop rotation, specifically the inclusion of legumes into corn-based cropping systems, significantly reduced GHG emissions. For example, the introduction of wheat, underseeded with red clover, into a corn-soybean system reduced GHG emissions by 595-700 $\text{kg CO}_2 \text{ eq ha}^{-1} \text{ yr}^{-1}$. Chisel plow systems had generally fewer GHG emissions than moldboard plow systems, however the reductions were minor when compared to the effect of crop rotation. Other studies have examined the impacts of different farming systems on energy use (MJ ha^{-1}) (Cruse 2010). In a comparison of 2,3 and 4 year crop

rotations over 6 years, the longer rotations of 3 (corn-soybean-wheat) and 4 years (corn-soybean-alfalfa-alfalfa) used generally less energy (MJ ha^{-1}) and were more energy efficient (US \$ return per GJ ha^{-1} fossil fuel energy) than a conventional 2 year corn-soybean rotation. The emergence of these new metrics for evaluating farm performance and their potential role in farm payments, necessitates a closer look at how well a single site, following Best Management Practices (BMPs) is able to describe cropping systems across multiple sites.

One study of 28 farms in Germany compared estimated energy use (GJ ha^{-1}) and GHG emissions ($\text{kg CO}_2 \text{ eq ha}^{-1}$) across several organic (18) and conventional (10) farming systems (Kustermann 2007) and showed a range of +50% above and below the median value for GHG emissions. However, the actual cropping systems among the farms were highly variable ranging from rotational grazing to intensive wheat/turnip/canola systems. In order to address the variation within specific crop rotations and cropping systems, it is necessary to generate a significant sample size for each system under examination. Our proposal is to collect samples of 10-15 farms for cropping systems that are representative of farming practices of the upper Midwest. Issues concerning GHG emissions and energy use in agriculture cannot be adequately addressed until a good sense of the range of these values and their sources are gathered from a range of production farms.

METHODS

Our GHG LCID tool is built with two major components, embedded and infield emissions ($\text{kg CO}_2 \text{ eq ha}^{-1}$). The embedded emissions relate to farm inputs, and describe the GHG emissions associated with the manufacture of each input. The individual input categories are 'Machinery Use' (GHG emissions are calculated from the diesel used to run the machinery), 'Fertilizer', 'Pesticide', 'Grain Drying' (GHG emissions are calculated from propane used to dry corn grain), and 'Seed'. In the case of 'Machinery Use' and 'Grain Drying', the values used in the LCID included the emissions from the burning of the fossil fuel as well as the values associated with the production of diesel and propane. The GaBi software libraries were used to determine embedded values for each of the input categories. GaBi is a Life Cycle Assessment (LCA) modeling tool used to perform LCA's on various processes and product streams. The values for embedded inputs were drawn from the GaBi program and incorporated into our LCID tool.

The category 'Infield Emissions' calculates GHG emissions from the farm field, as a function of management. Infield emissions are calculated using the IPCC equations for 'N₂O emissions from managed soils and CO₂ emissions from lime and urea application' (IPCC 2006). There are three major categories for indirect emissions in the IPCC equation used in this LCID. The first category is 'Direct N₂O Emissions from N inputs and crop (& cover crop) residue', which refers to emissions directly from the soil in the agricultural field. Direct emissions are a function of soil available N and subsequent nitrification and denitrification resulting in the production of N₂O. The second, 'Indirect N₂O emissions from leaching and volatilization', refers first to the leaching of N from the agricultural field into water pathways and the resulting nitrification and denitrification in those pathways. 'Indirect Emissions' also include the volatilization of N as NH₃ and NO_x as a result of N deposition on the field. The third category, 'CO₂ emissions from Urea' reflect that the CO₂ captured from the atmosphere in the urea production process is lost as bicarbonate (a product of urea evolution in the field) evolves into CO₂ and H₂O. The primary areas that affect the infield emissions in the IPCC equation are level of synthetic and organic N fertilization and crop residue removal.

The evaluation of energy use, on-farm, is similar to the GHG LCID, but has no infield component. Infield energy use could be characterized as the burning of diesel by field machinery, but was not included as a second category. The energy embodied in diesel is the sum of both the energy content of the diesel

itself (MJ liter⁻¹) and the energy it took to produce the diesel. Energy values for the categories were taken from various sources, to our knowledge there is no comprehensive review of farm input related energy use. Production energy for diesel was taken from a joint study between the USDA and USDE (Sheehan et al 1998) where the embedded energy is 83% of diesel energy content (Sheehan et al 1998). Energy values associated with seed production were taken from a comprehensive review of energy use in agriculture (Pimentel 1983). The paper is outdated, but it was determined that, for one category, a single source using consistent evaluation metrics was preferable, for purposes of system comparison, to an amalgamation of several sources. Energy use in grain drying was a combination of the energy in both the propane (NPGA 2001) and electricity (Graboski 2002) used in the process. Values for fertilizer, based on N, P and K, (Gelfand 2010) and pesticide (Shapouri 2004) were assessed on the quantity of the product not specific formulations or products.

To conduct the on-farm LCID, we constructed a survey to document and characterize the cropping systems of individual farms. As farmers generally manage several fields, we limited our survey to the characterization of two reference fields. These fields are determined, with the farmer, to be representative of the farm's general crop rotation, or rotations, and indicative of the farmer's own management style. Data is collected on each field for the most recent 3 years for which complete data is available. In the event that a farmer has a rotation longer than 3 years, two fields are chosen that represent all stages of the rotation and information for additional years is collected if the rotation is longer than 6 years.

For the characterization of farm inputs for the on-farm LCID tool, we collect production inputs (seed rate, yield, moisture) for the main crop, as well as for any cover crops or secondary crops planted. Data for pesticide and fertilizer/manure inputs consist of product, rate and application method (for future confirmation with machinery use). Machinery use covers the rest of the farm practices. Machinery is broken into categories according to use (tillage, planting, cultivation, fertilizer/pesticide application, harvest, and post-harvest). Implement used, tractor horsepower and number of passes/field provide the information to determine diesel usage (Lazarus 2009).

Once all the information has been gathered, it is entered into the LCID spreadsheet that was developed to determine GHG emissions (kg CO₂ eq ha⁻¹) and energy use for WICST (MJ ha⁻¹). The test farms are compared on two levels: One comparison is made with the Arlington WICST system most similar to the test farm; and the other comparison is made between similar test farms. The WICST corn-soybean system is a no-till 2-yr rotation. The WICST corn-soybean-wheat ('WICST csw') rotation included in the figures and text is taken from the 'Chemlite' plots at WICST(1995-2008). The reduced input Chemlite plots were the best WICST comparison for the surveyed farms as the organic grain system in WICST (also corn-soybean-wheat) is organic and therefore confounded. However, as with the organic grain system, the Chemlite plots also used a green manure red clover crop to provide a significant portion of the N for the subsequent corn crop.

PRELIMINARY RESULTS

Embedded Emissions

When the survey farms that included a corn-soybean (cs) and corn-soybean-wheat (csw) rotation and the two systems from WICST were compared, the introduction of wheat into the rotation lowered overall GHG emissions in all instances (Fig. 1). This is consistent with the findings from Meyer-Aurich 2006, where diversified rotations resulted in lower GHG emissions. In the conventional surveyed system, the reduction was due primarily to a large reduction in the use of propane for corn grain drying. This reduction can be attributed to the fact that, in the corn-soybean system, corn grain was dried every

other year as opposed to every three years in the corn-soybean-wheat rotation. However, the on-farm no-till systems seem to contradict this conclusion (fig. 1). The lower rate of emissions from propane in this case was due to a very low moisture content in the corn at time of harvest. The values for grain drying on WICST are averaged over 16 seasons, whereas the surveyed systems will not have the advantage of reducing inter-annual variability for moisture at harvest. The reduction in the WICST corn-soybean-wheat system was a result of both grain drying and lower fertilization rates, which we would expect to see as the WICST csw system was intentionally 'low-input'.

However, in the on-farm no-till system, the reduction was due mostly to pesticide use. This was due to the use of a particular herbicide, Acumen, which had a very high embedded GHG factor. Acumen was applied at the suggested rate of ~ 4 pints acre⁻¹, which is much higher than many herbicides and results in higher associated embedded emissions. This is an interesting result, as it suggests that product choice can be an influential factor in the overall GHG emissions of a farming system. The variation in sources for the reduction of embedded GHG emissions in the comparison of just a few systems seems to validate the necessity for further study. When examined at the level of crop rotational diversity, GHG emission reduction seems to be correlated with increased diversity. However, when we examine reduction sources, we see that input choices may also play a key role in determining overall GHG emissions.

Infield Emissions

We evaluated the infield flux of N₂O and CO₂ for all of the cropping systems according to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Fig. 2). This allows us to evaluate the total GHG contribution of the farm field. Preliminary results show that the infield emissions for WICST were significantly lower than the surveyed on-farm corn-soybean rotations. This appears to be due to higher average rates of synthetic N fertilization in the surveyed system (WICST 140 kg N ha⁻¹ yr⁻¹; on-farm 203 kg N ha⁻¹ yr⁻¹) during the corn phase. The addition of wheat into a corn-soybean rotation seemed to reduce infield emissions in the WICST project, but did not have a similar effect in the surveyed farms. This is most likely due to the fact that the Chemlite system was characterized by a reduction in chemical inputs and the subsequent reduction in synthetic N fertilizer by the use of the red clover green manure crop. The infield emissions of the surveyed farms showed no response to the introduction of wheat into the rotations, which may have been a result of similar fertilization rates in all the rotations.

The significant difference in the infield emissions between the surveyed conventional tillage and no-till systems seem to indicate that GHG reductions can be made through management strategies not associated with chemical inputs. The continuation of this study will be able to examine how the factors of synthetic N use and tillage practice may combine or interact to affect GHG emissions on farms in Southern Wisconsin. 'Best practice' measures employed in the WICST project that apply targeted rates of N fertilization may not be representative of general practice in Southern WI, and the study of infield emissions from 'real-world' farms may be able to provide a clearer picture of Southern Wisconsin's agricultural contribution to GHG emissions.

Total GHG Emissions

Total GHG emissions (fig. 3) reflect that the largest source of variation thus far has been in the embedded emissions. Except in the case of the WICST systems, total differences in GHG emissions were accounted for by differences in embedded emissions. The introduction of wheat into a corn-soybean rotation reduced infield emissions in the case of the WICST Chemlite rotation (fig. 2) and thus increased the magnitude of the total reduction. This is most likely due to the reduced use of synthetic N in the Chemlite rotation in favor of green manure. The green manure, in the form of Red Clover (*Trifolium repens* L.) and a reduced rate of overall N application, reduced the total infield emissions in WICST. This

was due to calculations in the IPCC equations where organic N contributes less to infield emissions of N₂O than synthetic N (IPCC 2006).

Energy

The energy analysis of the corn-soybean and corn-soybean-wheat systems is generally consistent with the findings of the GHG comparisons. The introduction of wheat into a corn-soybean rotation resulted in decreased energy use in the WICST and on-farm conventional systems (Fig. 4). However, the source for reduction was inconsistent. The WICST reduction was a result of reduced pesticide, fertilizer and propane use. Interesting to note, is that the energy use attributed to diesel, was much higher in the WICST corn-soybean-wheat rotation. The surveyed conventional system reduction was due mostly to the use of propane for corn grain drying, though there was also a slight reduction in pesticide use. The surveyed no-till systems provide an interesting contrast to both the other energetic comparisons, and the GHG evaluations. In this instance, the introduction of wheat did not reduce energy use. This, as in the case with the GHG emissions, was a result of uncharacteristically low moisture content in the corn at harvest, resulting in less energy use for corn grain drying. However, these results are not conclusive given current lack of comparison with other farms.

CONCLUSIONS

The combined results of the energy and the GHG analysis indicate that energy use and GHG emissions are fairly well correlated though the sources for reductions can be variable. In the case of the WICST and no-till systems, overall reductions in GHG emissions correlated with increased energy use. Because of the inter-annual variability in weather and thus variable need for propane in grain drying, many more farms will have to be surveyed before an average value for grain drying in different systems is established. WICST provides a unique opportunity to examine average grain drying values over a twenty year period and a similar sample size of surveyed farms may provide an opportunity to evaluate more consistent values for sources of GHG emissions and energy use. Although this study, to date, is unable to draw significant conclusions, we are already able to see that sources of GHG and energy increases and reductions can be variable. We believe the degree of this variation will be able to provide agronomists and policy makers with an assessment of GHG emissions and energy use by cropping system based in real-world scenarios. This information will also be invaluable in developing strategies that address climate change and national energy security.

REFERENCES

- Cruse, M. et al. 2010. Fossil energy use in conventional and low-external-input cropping systems. *Agronomy Journal*: 102(3): 934-941
- Environmental Protection Agency (EPA). 2012. 2012 Draft U.S. greenhouse gas inventory report. <http://epa.gov/climatechange/emissions/usinventoryreport.html>. Verified 2 March 2012
- Gelfand, I., S. Snapp, G. P. Robertson. 2010. Energy Efficiency of Conventional, Organic, and Alternative Cropping Systems for Food and Fuel at a Site in the U.S. Midwest. *Environ. Sci. Technol.* 44, 4006–4011.M.
- Graboski. 2002. Fossil energy use in the manufacture of corn ethanol. <http://www.oregon.gov/ENERGY/RENEW/Biomass/docs/FORUM/FossilEnergyUse.pdf?ga=t>. Verified 25 February 2012
- IPCC. Direct N₂O Emissions from managed soil: Equation 11.1 (IPCC 2006); <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html>. Verified 14 February 2012.
- Kustermann, B. et al. 2007. Modeling carbon cycles and estimation of greenhouse gas emissions from organic and conventional farming systems. *Renewable Agriculture and Food Systems*: 23(1); 38–52.
- Lazarus, W. F. 2009. Machinery cost estimates. University of Minnesota Extension. <http://www.extension.umn.edu/distribution/businessmanagement/df6696.pdf>. Verified 14 February 2012
- Meyer-Aurich, A. 2006. Cost efficient rotation and tillage options to sequester carbon and mitigate GHG emissions from agriculture in Eastern Canada. *Agriculture, Ecosystems and Environment*. 117; 119-127.
- National Propane Gas Association (NPGA). 2001. Facts about propane. NPGA Bulletin 3026. http://www.npga.org/files/public/Facts_About_Propane.pdf. Verified 25 February 2012
- Pimentel, D. 1980. Handbook of energy utilization in agriculture. CRC Press, Inc. Boca Raton, Fla.
- Pimentel, D. 2003. Ethanol Fuels: energy balance, economics and environmental impacts are negative. *Natural Resources Research*. 12(2); 127-134
- Schnepf, R. 2010. U.S. Farm Income. Congressional Research Service report for Congress. <http://www.nationalaglawcenter.org/assets/crs/R40152.pdf>. Verified 2 March 2012
- Shapouri, H. 2004. The 2001 Net energy balance of corn ethanol. USDA. http://www.usda.gov/oce/reports/energy/net_energy_balance.pdf. Verified 2 March 2012
- Sheehan, J. et al. 1998. An overview of biodiesel and petroleum diesel life cycles. NREL/TP-580-24772. <http://www.nrel.gov/docs/legosti/fy98/24772.pdf>. Verified 25 February 2012
- USDA Fact Sheet. 2012. State Fact Sheets: United States. <http://www.ers.usda.gov/statefacts/US.HTM> Verified 2 March 2012

Figure 1. Comparison of similar systems with the WICST project. Systems are WICST No-till Corn-Soybean (WICST ntcs); WICST Corn-Soybean-Wheat (WICST csw). Corn-Soybean (cs); Corn-Soybean-Wheat (csw); No-Till Corn-Soybean (ntcs); No-Till Corn-Soybean-Wheat (ntcsw); The 'WICST' values are long-term averages, whereas the others are from the surveyed farms.

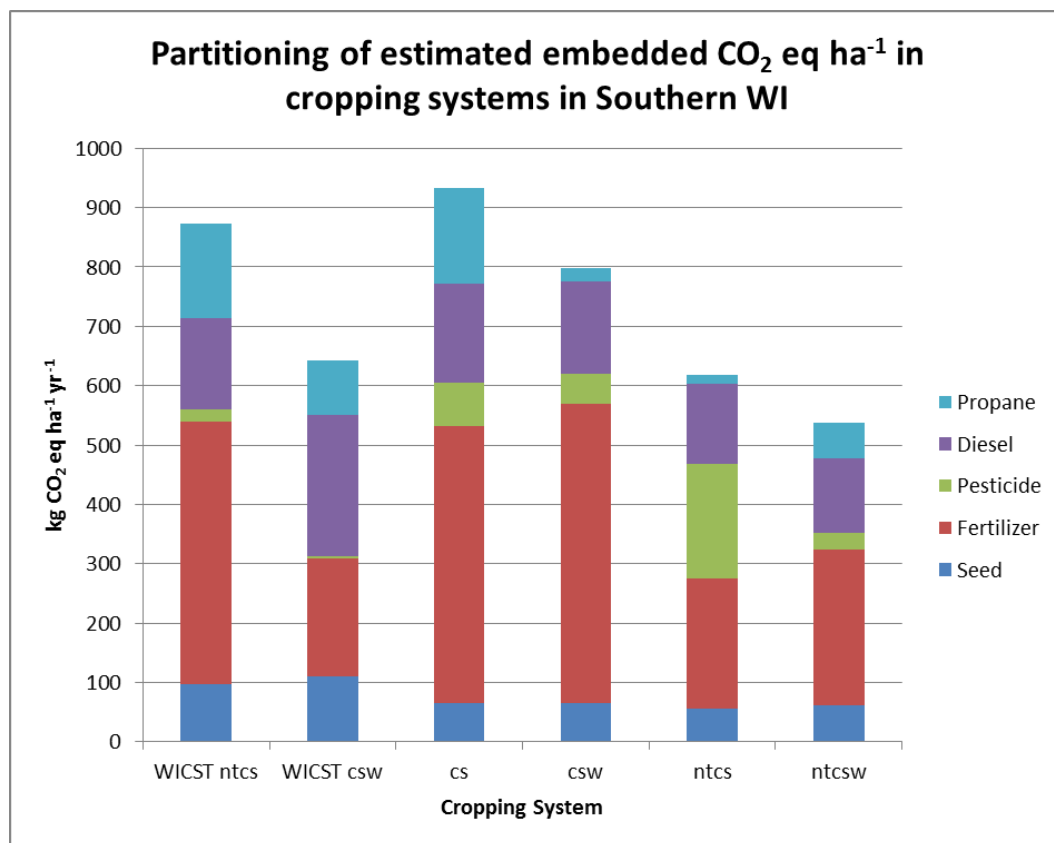


Figure 2: Comparison of the infield GHG emissions as determined by the IPCC equations outlined in Ch. 11 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Systems are WICST No-till Corn-Soybean (WICST ntcs); WICST Corn-Soybean-Wheat (WICST csw). Corn-Soybean (cs); Corn-Soybean-Wheat (csw); No-Till Corn-Soybean (ntcs); No-Till Corn-Soybean-Wheat (ntcsw); The 'WICST' values are long-term averages, whereas the others are from the surveyed farms.

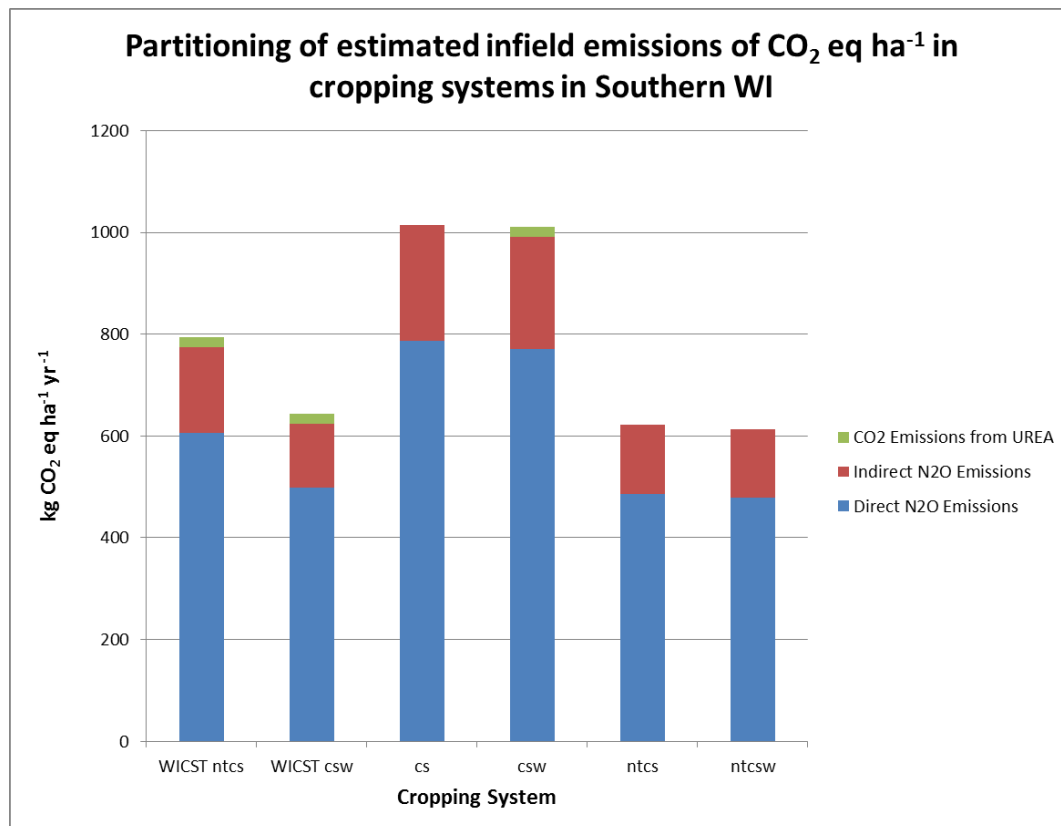


Figure 3. Total estimated GHG emissions ($\text{kg CO}_2 \text{ eq ha}^{-1} \text{ yr}^{-1}$). Systems are WICST No-till Corn-Soybean (WICST ntcs); WICST Corn-Soybean-Wheat (WICST csw). Corn-Soybean (cs); Corn-Soybean-Wheat (csw); No-Till Corn-Soybean (ntcs); No-Till Corn-Soybean-Wheat (ntcsw); The 'WICST' values are long-term averages, whereas the others are from the surveyed farms.

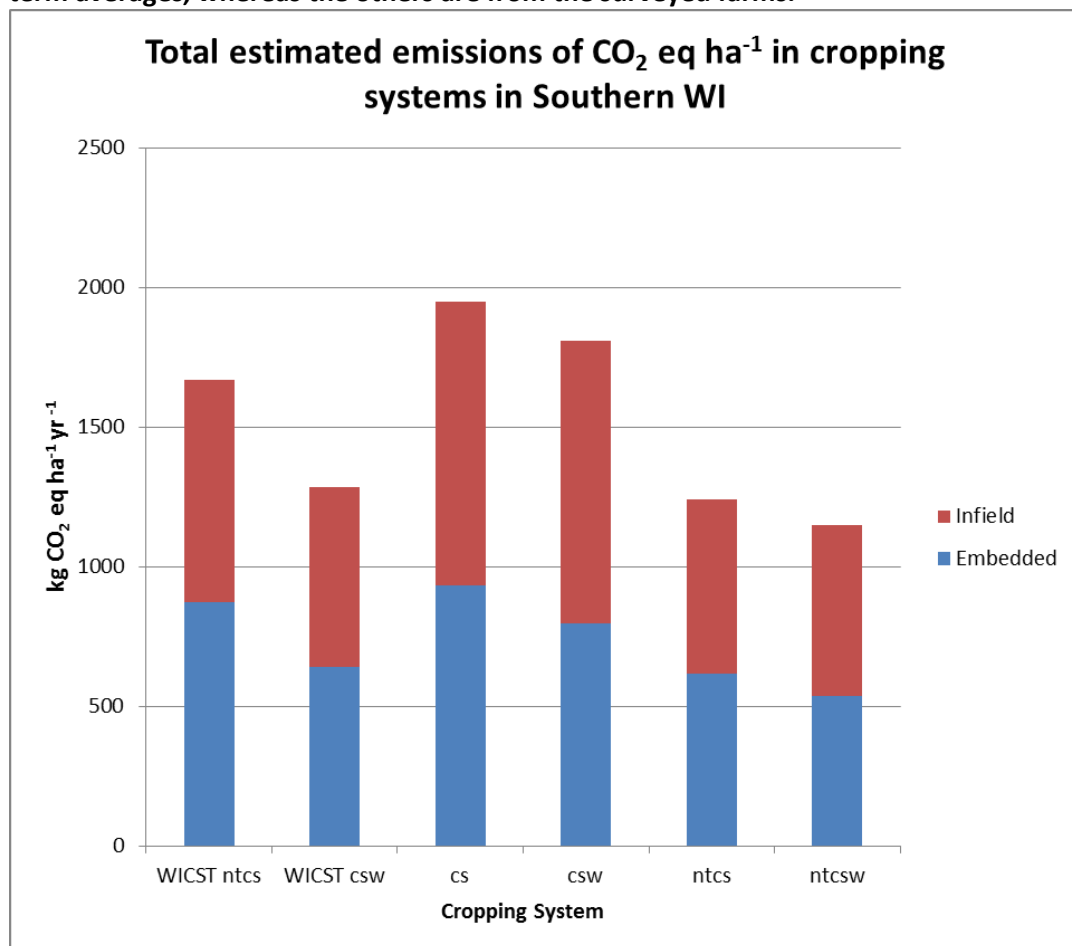
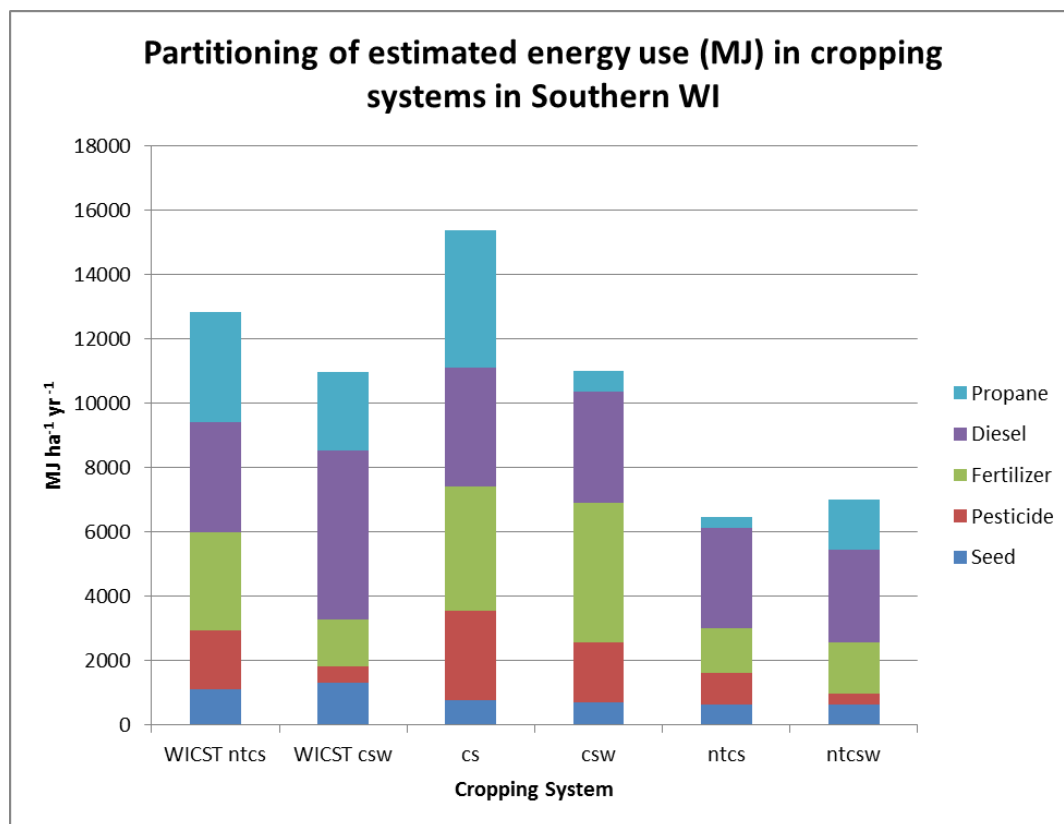


Figure 4. Energy use comparison between WICST and surveyed cropping systems. Systems are WICST No-till Corn-Soybean (WICST ntcs); WICST Corn-Soybean-Wheat (WICST csw). Corn-Soybean (cs); Corn-Soybean-Wheat (csw); No-Till Corn-Soybean (ntcs); No-Till Corn-Soybean-Wheat (ntcsw); The 'WICST' values are long-term averages, whereas the others are from the surveyed farms.



MULTI-CROP ANNUAL FORAGE PRODUCTION FOR IMPROVED MANURE MANAGEMENT IN WISCONSIN

Kathy Vazquez. Joshua Posner

Most Midwest dairies continue to operate integrated crop-livestock systems. In Wisconsin, approximately 2/3 of the dairy farmers are able to produce 90% of their herds feed requirements, while having adequate cropland to recycle manure nutrients (Powell *et al.*, 2007). However, in order to remain economically viable the demographics of the dairy industry have been changing rapidly. In 2011, the average number of Wisconsin dairy farms declined by 1.1 % losing 610 farms ,while increasing milk production by 1% (USDA-NASS, 2012). A recent review of dairy farmers suggests that this trend, towards consolidation to fewer but larger production systems, will continue (MacDonald *et al.*, 2007). With larger herd sizes, farmers are becoming increasingly burdened with finding areas and times to apply the additional manure (Carpenter *et al.*, 1998).

To accommodate increasing herd size, over 3 million acres of Wisconsin's total cropland has become devoted to corn and forage production, the majority which is used as feed (USDA-NASS, 2012). An important element of nutrient management plans require that manure application to corn (*Zea mays* L.) and other annuals, be applied at rates and times when it can be utilized by that crop. Full season annual crops can limit farmers' opportunities to apply manure and incorporate nutrient inputs. Historically, much of the manure has been spread in the fall or winter on frozen ground prior to spring planting. However, stringent nutrient management policy has standardized spreading practices for the larger dairies (CAFOs) by regulating the amount, placement and timing of manure (USDA-NRCS, 2006). Inappropriate timing of manure applications and excessive spreading rates can adversely affect water quality through runoff into streams and leaching into groundwater.

By increasing the number of opportunities for nutrient applications with multiple annual grasses, manure can be applied several times during the year to more closely match forage N requirements. McCormick (2006) has suggested that the incorporation of different annual forages into the grain-crop rotation would offer additional forage harvesting opportunities that could reduce livestock winter feeding costs. Fall planted forages, such as oat (*Avena sativa* L.), have the potential to produce high quality and high yielding feed (Contreras-Govea and Albrecht, 2006). In a recent study, Coblenz (2011) has suggested that fall planted oats can be used as fall forage on dairy farms. Furthermore, research has shown that grasses have the potential to reduce NO₃-N leaching (Jewett and Thalen, 2007; Kaspar *et al.* 2007), scavenge excess soil N (Jewett and Thalen, 2007), increase P and K uptake (Singer *et al.*, 2008), and suppress weed growth (Duiker and Curran, 2005). Also, oat and rye (*Secale cereale* L.) are very efficient at P and K uptake in fields that were treated with poultry fertilizer (Pederson & Brink, 2000). Grasses efficient use nutrient uptake makes them ideal for crops for recycling slurry components. The placement of slurry throughout the growing season, allows for manure storage facilities to be emptied, decreasing the need for additional autumn and winter manure storage (Bittman *et al.*, 2005).

Previous studies indicate that Wisconsin dairies apply manure more frequently to fields that are closer to barns than to outlying fields (PATS, 2005; Powell *et al.* 2007) because transportation costs are higher than the perceived value of the manure (Saam *et al.*, 2005). The repeated use of certain fields for nutrient recycling has contributed to an inefficient use and environmentally unsound phosphorus buildup on many farm operations. The adoption of a multiple annual grass system would increase manure application windows, due to opportunities provided between plantings. Furthermore, the subsequent corn silage crop, with no additional nutrient inputs, would draw down accumulated N and P. This system could be rotated throughout the farm allowing for a more effective nutrient management strategy.

The objectives of this study was to develop annual forage crop systems that 1) create summer windows for manure spreading, 2) effectively utilizes the manure, 3) is economically as well as environmentally sound, 4) is competitive with corn silage yields, and 5) produces forage of high feeding value.

MATERIALS AND METHODS

System Selection

Three systems were developed that will facilitate two additional opportunities for summer spreading. The systems are:

1. Spring planted oats (*Avena sativa* L.)/peas (*Pisum sativum* L.), summer planted sudangrass, (*Sorghum bicolor*) (cut 1x), fall planted oats (O/PSO).
2. Fall planted winter rye (*Secale cereale* L.) (cut 1x), spring planted sudangrass (cut 2x), fall planted oats (RSO).
3. Fall planted winter rye (cut 2x), fall planted oats (RO).

Corn silage (CS) functioned as the 'standard' system since it is the dominant forage option on Wisconsin dairy farms. Dairy slurry manure was applied prior to planting each at specified rates (see table 1). The plots were planted to corn in the following year to test the residual effect of the treatments on corn yield without additional N input.

Table 1: Seasonal depiction of manure rates, application period, multi-crop rotation schedule and seeding rate.

Crop System		Manure Application Windows and Crop Planting Periods				Manure Total	
		Fall		Spring	Summer		
CS ^a	Seed Rates (seeds/a)			Corn (34,000)			12,000
	Manure Rates (gals/a)	12,000					
	Commercial Fertilizer (lbs/a)			65			
O/PSO ^a	Seeding Rates (lbs/a)			Forage Oats/ Trapper Peas (60/60)	BMR Hybrid Sudangrass (35)	Forage Oats (90)	28,000
	Manure Rates (gals/a)	8,000		12,000	8,000		
RSO ^a	Seeding Rates (lbs/a)	Winter Rye (160)			BMR Hybrid Sudangrass (35)	Grain Oats (90)	28,000
	Manure Rates (gals/a)	8,000		12,000	8,000		
RO ^a	Seeding Rates (lbs/a)	Winter Rye (160)					24,000
	Manure Rates (gals/a)	8,000		8,000	8,000		
^a CS= Corn Silage; O/PSO=Forage Oats/ Trapper Peas – Sudangrass (1 cut) – Oats; RSO = Winter Rye – Sudangrass (2 cuts) – Oats; RO = Winter Rye (2 cuts) - Oats							

Sites and Experimental Design

Plots were laid out at two sites: (i) the University of Wisconsin-Agricultural Research Station near Arlington (UW-AARS) (43° 18'N, 89° 21'W) on Plano silt loam soil and (ii) at Quinney Farm, in association with Michael Fields Agricultural Institute (MFAI-QF) near Sugar Creek (42° 41'N, 88° 38'W) on Miami silt loam soil. The experimental design was a randomized block design with the four replications and systems randomly assigned to each replication. Plot size was arranged to accommodate field equipment used to spread dairy manure slurry.

The trial commenced in the Fall of 2010 (Startup 1) and again in the Fall of 2011 (Startup 2) at each site resulting in four environments that experienced differences in precipitation, soil type, manure nutrients, and field management. The previous crop at Arlington Startup I was spring wheat with no recent manuring history (15 yrs), while the Startup II was the previous site of an oat variety trial with no recent manure history. At the Quinney site (Startup I), the field was previously planted to perennial ryegrass and had been manured prior to establishing the experiment. The previous crop for Startup II was a frequently-manured orchardgrass lay in its second year of establishment.

Agronomic Practice

Planting periods and seeding rates differed for each annual forage system (see Table 1). Manure was applied prior to each planting at desired rates (see Table 1) and incorporated with a field cultivator or disk tiller. Winter rye was planted in late-September (Startup I) and mid-October (Startup II) at a rate of 160 lbs/a across all plots. Glyphosate was used to kill winter rye in CS and O/PSO plots in the fall (Startup I) or the following spring (Startup II). No herbicide was applied to the established winter rye at either site located at MFAI-QF. The first cut of rye was harvested at bootstage in RSO and RO systems, while the second cut of rye in the RO system occurred at tillering. 'ForagePlus' oats were planted in early-August in the RO system at a rate of 160 lbs/a. Forage and grain oats were harvested after first hard frost (25°C) when oats were either in pre-boot or bootstage (forage) and vegetative (grain).

In the O/PSO system, 'ForagePlus' oats and trapper peas were planted in mid-April at a rate of 60lbs each. Oat/pea mix was harvested when peas were flowering and oats were in bootstage. Restraints on field equipment resulted in delayed sudangrass planting in Startup I. 'Pro-Max' hybrid BMR sudangrass was planted in late-June (O/PSO) and early-July (RSO) at a rate of 35 lbs/a. The first and second cut of sudangrass occurred at pre-bootstage. 'Drumlin' grain oats were planted in O/PSO plots in mid-August at a rate of 160 lbs. As a consequence of the late planting date, oats were not planted in the RSO plots. The second cut of sudangrass was allowed to grow until the first frost, when it was harvested at pre-bootstage.

Sampling

Forage Yield and Nutritive Value. A randomly selected area from the center of the plots were harvested with a 3-pt tractor-drawn sickle bar mower from an area of 7' x 30' at Arlington or a self-propelled sickle bar mower (3' x 50') at Quinney at the appropriate growth stage. For rye and oatlage, harvest was taken at bootstage; oat/pea mix about 75 days after planting (DAP) when peas were flowering and oats were in boot; sudangrass was harvested when it reached about 6-8 ft tall (preboot or about 60 DAP); and corn silage at 65% whole plant moisture. After weighing the entire fresh sample on a pad scale, a grab sample of the forage was collected, weighed fresh, dried at 60° F until it reached constant weight, weighed again to determine moisture content and to correct yields to a dry matter (DM) basis. Dried samples were ground in a Wiley hammermill through a 1 mm screen and sent to the UW Soil and Plant Analysis Lab using NIRS to predicted forage quality parameters of most interest to a dairy producer.

Soil Nutrient Monitoring

Prior to manure application in the setup year, six cores (0.75" D x 6" depth) of soil were collected and mixed from each plot to obtain baseline soil fertility status. Soil samples were analyzed for organic matter, pH, STP and STK by the UW Soil and Plant Analysis Laboratory (Madison, WI). Base line values are represented in Table 2.

After the final harvest the following fall, soil cores were pulled to monitor nutrient buildup/drawdown. Deep soil samples were collected (1.25" D probe, down to 3 ft) and analyzed by foot for $\text{NO}_3\text{-N}$ in the fall after all crops were harvested. Soil cores were separated into 0 to 12, 13 to 24, and 25 to 36 inch segments. Three cores were taken per plot and within plot segments were combined and blended together. Fall nitrates were monitored at the end of each field season to evaluate possible N buildup and to monitor environmental impacts of reoccurring nutrient applications.

Table 2: Soil chemical properties¹ at research sites prior to onset of Startup I (Fall 2010). Soil test data signify concentrations of soil available P and K.

Site	Soil Type	pH	OM %	P mg kg ⁻¹	K
UW-AARS	Plano silt loam	6.6	3.9	29	121
MFAI-QF	Miami silt loam	6.9	2.4	30	100
¹ Mean of 16 samples taken in 2009, 6" depth, before treatments imposed					

Manure Rates and Nutrient Characterization

Samples were collected the day of manure applications, frozen, and then sent to UW Soil and Plant Analysis Lab (Marshfield, WI) for nutrient analysis. This allowed us to show the seasonal changes in the manure nutrients and solids as it was subjected to the seasons while being stored in an open manure pit. As seen in Table 3, nutrient levels were similar to UW standard values stated for Wisconsin farms (Laboski *et al.*, 2006).

Table 3: Average nutrient concentration for slurry (standard deviation in parenthesis) for University of Wisconsin- Arlington Agricultural Research Station (UW-AARS) and Michael Fields Agricultural Institute-Quinney Farm (MFAI-QF).

Site	DM ^a %	Total N	Total P	Total K
			kg m ⁻³	
UW-AARS ¹	4.57 (0.39)	2.55 (0.70)	0.45 (0.03)	2.27 (0.18)
MFAI-QF ²	7.28 (1.46)	2.31 (0.56)	0.53 (0.04)	2.53 (0.16)
UW Standard for Slurry ³	6	2.88	0.48	1.99
^a DM, Dry Matter				
¹ Mean of 6 samples taken before application, 2010 - 2011				
² Mean of 5 samples taken before application, 2010 - 2011				
³ Laboski <i>et al.</i> , 2006				

Estimated total nutrients applied as manure to each system are shown in table 4. Manure applications were based on first year available nutrients in surface applied dairy slurry. Nutrient budgets were created to estimate total phosphorus build-up within each system as a result of repeated manure applications (not shown). As the field season progressed, repeated application of slurry to plots resulted in soil compaction and banding patterns that contributed to uneven forage growth.

Table 4: Average annual nutrient application for Start I (2010-2011) at the University of Wisconsin-Arlington Agricultural Research Station (UW-AARS) and Michael Fields Agricultural Institute-Quinney Farm (MFAI-QF).

		Crop System											
		CS ^a			O/PSO ^a			RSO ^{ab}			RO ^a		
		N	P	K	N	P	K	N	P	K	N	P	K
		kg ha ⁻¹											
Site	Nutrient												
UW-AARS	Manure	287	50	255	669	118	595	478	84	425	573	101	510
	Commercial Fertilizer	73	0	0									
MFAI-QF	Manure	259	60	284	605	140	664	432	100	474	518	120	569
	Commercial Fertilizer	73	0	0									

^a CS= Corn Silage; O/PSO=Forage Oats/ Trapper Peas – Sudangrass (1 cut) – Oats; RSO = Winter Rye – Sudangrass (2cCuts) – Oats; RO = Winter Rye (2 cuts) - Oats

^b Due to a late planting of sudangrass, oats were not planted in Startup I RSO and system only received 20,000 gals/a of slurry.

RESULTS AND DISCUSSION

2010 Field Demo

A field demonstration was conducted at UW-AARS in 2010 to determine the feasibility of a multi-crop annual forage system as a method for opening up in-season manure windows. The demo consisted of the same multiple crop systems stated above, with the exception that in the O/PSO and RSO treatments fall oats were not planted due to the research constraints. Oats were incorporated into these two systems in the replicated trial to add an extra manure application window and provide additional autumn forage.

Table 5: Forage dry matter yields for multi-crop systems receiving manure at Arlington field station, 2010 season.

Crop	Crop System			
	CS ^a	O/PSO ^{ab}	RSO ^{ab}	RO ^a
Corn Silage, t dm/a	8.5			
Winter Rye, t dm/a (Cut 1)			2.7	2.7
(Cut 2)				0.3
Forage Oats/Trapper Peas, t dm/a		2.2		
Sudangrass, t dm/a (Cut 1)		2.1	2.4	
(Cut 2)			2.1	
Oats, t dm/a		x	x	2.3
Total Forage, t dm/a	8.5	4.3	7.2	5.3

^a CS= Corn Silage; O/PSO=Forage Oats/ Trapper Peas – Sudangrass (1 cut) – Oats; RSO = Winter Rye – Sudangrass (2cCuts) – Oats; RO = Winter Rye (2 cuts) - Oats
^b Fall oats were not planted in 2010 demo for O/PSO and RSO systems.

All treatments accumulated less total yield than corn silage but the RSO was closest yielded 85% of the control while opening up 2 additional windows for manure spreading. The RO system while yielding 65% of the control allowed more flexibility for manure application by having the ground fallow for a few months in early summer.

Table 6: Forage nutritive value for the multi-crop system demonstration plots at Arlington, 2010 season

		Crop System														
Crop		CS ^a			O/PSO ^{ab}				RSO ^{abc}				RO ^{ac}			
		NDF-d	Crude Protein	Tissue K	NDF-d	RFQ	Crude Protein	Tissue K	NDF-d	RFQ	Crude Protein	Tissue K	NDF-d	RFQ	Crude Protein	Tissue K
Corn Silage		61.8	8.5	0.97												
Winter Rye	(Cut 1)															
	(Cut 2)												38.5	53	12.1	1.26
Forage Oats/Trapper Peas Mix					48.6		14	2.13								
Sudangrass	(Cut 1)				63.7	136	12.3	2.7	54.8	108	17.4	3.42				
	(Cut 2)								66.3	138	12.5	3.2				
Oat													73.2	195	17.3	4.48

^a CS = Corn Silage; O/PSO = Forage Oats/ Trapper Peas - Sudangrass (1 cut) - Oats; RSO = Winter Rye - Sudangrass (2 Cuts) - Oats; RO = Winter Rye (2 cuts) - Oats

^b Fall oats were not planted in 2010 demo for O/PSO and RSO systems.

^c Cut 1 of winter rye in crop systems RSO and RO data was not processed by laboratory.

All treatments were higher in CP than the standard corn silage treatment. RFQ varied as some cuts more appropriate for heifers (i.e. rylage) while others were fine for lactating cows (oat/peas, fall oats, sudangrass). Fall oats provided superior nutritive value compared to other crops (NDF-d, CP, RFQ) but the tissue K concentrations were disconcertingly high. Generally, tissue K should not be above 3% of the forage DM and this material certainly should not be fed to dry cows. Previous studies have found that oats sown in autumn were higher in nutritive value than oats sown in the spring (Contreras-Govea and Albrecht, 2006; Coblenz *et al.*, 2012).

CONCLUSIONS

The data from the 2010 demonstration plots suggests that the multi-crop annual forage system can provide differing feed qualities that would accommodate a variety of dairy cows, from dry to milking. The winter rye, sudangrass (cut 2x), and oats (RSO) system appears to be the most competitive in terms of yield, when compared to corn silage. With preliminary data from Startup I, it can be inferred that the addition of oats to RSO could add approximately 1.5 to 2.0 t/a (not shown). The winter rye-oats (RO) system produced the least amount of feed. However, this might be an interesting rotation for farmers who spread daily, since there is long period during the summer when slurry can be applied.

REFERENCES

- Barham, B.L., J. Foltz, and U. Adams. 2005. Expansion, Modernization and Specialization in the Wisconsin Dairy Industry. Program on Agricultural Technology Studies. Research Summary 7: 1-6.
- Bittman, S., L.J.P. van Vliet, C.G. Kowalenko, S. McGinn, D.E. Hunt, and F. Bounaix. (2005) Surface-banding liquid manure over aeration slots: A new low-disturbance method for reducing ammonia emissions and improving yield on perennial grasses. *Agron. J.* 97:1304-1313.
- Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. Nonpoint pollution of surface water with phosphorus and nitrogen. *Ecological Applications.* 8:559-568.
- Cherney, J.H., Q.M. Ketterings, D.J. Cherney, and M.H. Davis. 2010. Timing of semisolid dairy manure applications does not affect yield and quality of orchardgrass. *Agron. J.* 102:553-558.
- Coblenz, W.K., M.G. Bertram, and N.P. Martin. 2011. Planting date effects on fall forage production of oat cultivars in Wisconsin. *Agron. J.* 103:145-155.

- Coblentz, W.K., M.G. Bertram, N.P. Martin, and P. Berzaghi. 2012. Planting date effects on the nutritive value of fall-grown oat cultivars. *Agron. J.* 104: 312-323.
- Contreras-Govea, F.E., K.A. Albrect. 2006. Forage production and nutritive vales of oat in autumn and early summer. *Crop Sci.* 46: 2382-2386.
- Laboski, C.A.M., J.B. Peters, and L.G. Bundy. 2006. Nutrient applications guidelines for field, vegetable, and fruits crops in Wisconsin. Univ. of Wisconsin Cooperative Extension Publications, Univ. of Wisconsin-Madison, Madison, WI.
- Lamb, J.F.S, M.P. Russelle, and M.A. Schmidtt. 2005. Alfalfa and reed canarygrass response to midsummer manure application. *Crop Science.* 45: 2293-2300.
- Hadrich, J.C., T.M. Harrigan, C.A. Wolf. 2010. Economic comparison of liquid manure transport and land application. *Applied Engineering in Agriculture.* 25:743-758.
- Jewett, M.R., and K.D. Thelen. Winter cereal cover crop removal strategy affects spring soil nitrate levels. *J. Sustain. Agric.* 29:55-67.
- Kaspar, T.C., D.B. Jaynes, T.B. Parkin, and T.B. Moorman. Rye cover crop and gamagrass strip effects on NO₃ Concentration and load in tile rainage. *J. Environ. Qual.* 36: 1503-1511.
- Komiskey, M.J., T.D. Stuntebeck, D.R. Frame, and F.W. Madison. 2011. Nutrients and sediment in frozen-ground runoff from no-till fields receiving liquid-dairy and solid beef manures. *Journal of Soil and Water Conservation.* 66: 303-312.
- MacDonald, J.M., W.D. McBride, and E.J. O'Donoghue. 2007. Low cost drive production to large dairy farms: profits and losses lead to fewer dairy farms and more large operations. *Amber Waves.* 5: 30-35.
- McCormick, J.S., R.M. Sulc, D.J. Barker, and J.F. Beurerlein. Yield and nutritive value of autumn-seeded winter-hardy and winter-sensitive annual forages. 2006. *Crop Science.* 46: 1981-1989.
- PATS. 2005. Manure management on Wisconsin livestock farms. [Online]Available at: www.pats.wisc.edu/pubs/4; verified 23 January 2012.
- Pederson, G.A., and G.E. Brink. Maximizing nutrient uptake by forages. *American Forage and Grassland Council Proceedings* 9: 257-259.
- Powell, J.M., D.B. Jackson-Smith, D.F. McCrory, H. Saam, and M. Mariola, 2007. Nutrient management behavior on Wisconsin dairy farms. *Agron. J.* 99:211-219.
- Saam, H., J.M. Powell, D.B. Jackson-Smith, W.L. Bland, and J.L. Posner. 2005. Use of animal density to estimate manure nutrient recycling ability of Wisconsin dairy farms. *Agricultural Systems.* 84:343-357.
- Singer, J.W. C.A. Cambardella, and T.B. Morgan. 2008. Enhancing nutrient cycling by coupling cover crops with manure injection. *Agron. J.* 100: 1735-1739.
- USDA-NASS. 2012. Wisconsin annual milk production-2011. [Online] Available at: [www.nass.usda.gov/Statistics by State/Wisconsin/Publications/Dairy/anmkpd.pdf](http://www.nass.usda.gov/Statistics_by_State/Wisconsin/Publications/Dairy/anmkpd.pdf); verified 3 March 2012.
- USDA-NASS, 2012. Wisconsin crop production. [Online] Available at: [http://www.nass.usda.gov/Statistics by State/Wisconsin/Publications/Crops/crop_prod_ann.pdf](http://www.nass.usda.gov/Statistics_by_State/Wisconsin/Publications/Crops/crop_prod_ann.pdf); verified 3 March 2012.

APPENDIX

2009 Agronomic Calendar for WICST (Fld 440)

Corn Phase					
Rotation Treatment #	CS1 1	CS2 3	CS3 4	CS4 7	CS5 13
2009 Crop	CORN	CORN	CORN	CORN	CORN
Previous crop (2008)	Corn	Soybeans	Wheat then berseem+oats	Alfalfa II	Alfalfa I
Plot #'s	109,204,306,412	101,214,303,401	104,201,301,402	111,209,305,409	114,211,312,403
Primary Tillage	Disk-Chiseled 11-10-08	None	Disk-Chiseled 11-10-08	Disk-Chiseled 11-10-08	Chisel plow w/sweeps 11-10-08
Secondary Tillage	Field cultivator 2x 5-1-09	Strip tilled 11-5-08 (DW's 4-row unit)	Field cultivator 3x: 5-1, 5-12, 5-18-09	Field cultivator 2x 5-1-09	Field cultivator 3x: 5-1, 5-12, 5-18-09
Variety Planting Date Rate	Pioneer 35F40+poncho1250 5-4-09 34,000 sd/a	Pioneer 35F40+poncho1250 5-4-09 34,000 sd/a	Viking 5305+NII 5-18-09 38,000 sd/a	Pioneer 35F40+poncho1250 5-4-09 34,000 sd/a replanted 6-16-09 ¹	Viking 5305+NII 5-18-09 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	82% 4-29-09 160 lb N/a Per PPNT	28% 6-11-09 135 lb N/a Per PPNT; 101 132 lb/a TSP; 101, 401 75 lb/a KCl	1.5 ton/a pelletized poultry manure 4-24-09	None	None
Manure Credit	None	None	None	16k gpa 11-5-08	8k gpa 11-4-08
Pesticides:	Pre-emrg: 5-8-09 Dual II Mag 24 oz/a Post-emrg: 6-15-09 HonchoPlus 24 oz/a, Laudis 3 oz/a	Pre-emrg: 5-8-09 Dual II Mag 24 oz/a, HonchoPlus 24 oz/a Post-emrg: 6-15-09 HonchoPlus 24 oz/a, Laudis 3 oz/a	None	Pre-emrg: 5-8-09 Dual II Mag 24 oz/a Post-emrg: ---- Sick corn –no weeds	None
Rotary hoe (RH) /tine weed (TW)	None	None	RH: 6-1, 6-11 TW: 5-22	None	RH: 6-1, 6-11 TW: 5-22
Cultivation	None	None	'Wilrich' 6-16-09 'Yetter' 6-25-09	None	'Wilrich' 6-16-09 'Yetter' 6-25-09
Hand weed	No	No	Border rows	No	Border rows
Harvest & Yield	11-11-09 196.8 bu/a	11-11-09 205.2 bu/a	11-11-09 170.2 bu/a	10-9-09 silage 6.9 ton DM/a	11-11-09 194.2 bu/a
Fall Practices	Chop stalks 11-12-09; Disk-chisel plow 11-23-09	None	Chop stalks 11-12-09; Disk-chisel plow 11-23-09	Manure 11-17-09 16000gpa; Disk-chisel plow 11-23-09	Chop stalks 11-12-09; Manure 11-17-09 16000gpa; Disk-chisel plow 11-23-09
Crop 2010	Corn	Soybean	Soybean	D.S. Alfalfa	Oats/Alfalfa

¹ first planting of corn died from carry-over of herbicide that was mistakenly applied last fall; silage was removed since grain didn't mature

Baited ground squirrels burrows with 'Revenge' on and around no-till corn and pasture plots 5-21-09; minor issue in 2009
Alleys: roto-tilled about 1x/month during the summer.

2009 Agronomic Calendar for WICST (Fld 440)

Soybean and Wheat Phases			
Rotation Treatment #	CS2 2	CS3 6	CS3 5
2009 Crop	No-till Soybean	Soybean/Winter Wheat	Wheat/Berseem Clover+oats
Previous crop (2008)	Corn	Corn	Soybeans
Plot #'s	108,206,310,408	102,212,313,407	106,202,307,411
Primary Tillage	None	Disk-chisel plow 11-10-08	Fall disked 1x after soybean harvest to prep seedbed- 10-13-08
Secondary Tillage	None	Field cultivator: 5-12-09 and 5-18-09	None
Planting Date	5-18-09	SB: 5-18-09 WW: 10-13-09	WW: (10-13-08) – moderate winterkill ¹ Cover crop: 8-13-09
Variety Rate	'Dairyland 2200(RR)' inoc=cell tech 225,000 seed/a (3128 sd/lb)	Sb: BR 16A7 (3300 sd/lb) inoc=cell tech 196,000 sd/a WW: untrt'd 'Kaskaskia' ~150 lb/a	WW: untrt'd Pion. 25R47 1.6 million seeds/a Berseem/Kame oats: 10 and 40 lb/a
Fertilizer	50-100 lb/a 0-0-60	90 lb/a 0-0-50 in start box; all but plot 407; +102 160 lb/a 0-0-50	160 lb/a 0-0-50; 1 ton/a CPM 4-24-09
Pesticides	Burndown: 5-8-09 Dual II Mg, 24 oz/a, 2,4-D ester 8oz/a, Honcho Plus 24 oz/a Post-emrg: 6-23-09 GlyfosXtra	None	None
Rotary Hoe (RH) /tine weed (TW)	None	RH: 0 TW: 5-22, 5-26, 6-4, 6-11	TW 5-8-09 (fairly ineffective as weeds already too big)
Cultivation	None	'Wilrich' 6-25-09; 7-6-09	None
Hand weed	None	Border rows	None
Harvest & Yield	10-13-09 48.4 bu/a	10-12-09 49.6 bu/a	Wheat: 60.6 bu/a on 8-4-09 Straw: 0.83 tons DM/a on 8-7-09
Fall Practices	Manured eastern 15' 16,000 gpa 11-10-09 Strip tilled with 4-row unit 11-23-09	Flatten ridges with shallow disking 10-13-09, No-till drilled wheat @ 155 lb/a 'Kaskaskia'	Disked 2x 8-7-09; Quack digger 1x 8-12-09; field cultivator 1x and seeded berseem clover/oats with NT drill 8-12-09; Manured eastern 15' 16,000 gpa 11-10-09 Fall disk-chisel 11-23-09
Crop 2010	Corn	Wheat / Clover	Corn

¹ some winterkill in each plot but plot 307 all dead; chopped and removed weeds 6-25-09

2009 Agronomic Calendar for WICST (Fld 440)

Forage Phases						
Rotation Treatment #	CS4 10	CS4 9	CS4 8	CS5 12	CS5 11	CS6 14
2009 Crop	Dir. Sd. Alfalfa	Estab. Alfalfa I	Estab. Alfalfa II	Oats/Alfalfa	Estab. Alfalfa I	Pasture
Previous crop (2008)	Corn	D.S. Alfalfa	Alfalfa I	Corn	Oat/Alfalfa	Pasture
Plot #'s	107,205,309,404	105,203,308,406	113,210,311,414	103,213,314,410	110,208,304,413	112, 207,302, 405
Primary Tillage	Disk-chisel plow 11-10-08	None	None	Disk-chisel plow 11-10-08	None	None
Secondary Tillage	Field cultivator 4-10-09 2x	None	None	Field cultivator 4-10, 4-13 1x	None	None
Variety Planting Date	'Summergold' 4-10-09 (rep 2 wet; seeded 5-19-09 and again 8-12-09)	'Golden Harv 707' 4-30-08	-----	Org. Kame oats; Org. WL 347LH alfalfa 4-13-09	'Esker' oats & untreated 'Pion. 54H91' 4-30-08	None
Rate	12 lb/a	-----	-----	64 and 15 b/a	-----	
Fertilizer (see map for rates)	None	0-0-60 6-1-09 250 lb/a	0-0-60 6-1-09 250 lb/a	None	0-0-50 6-1-09 300 lb/a	60 lb N/a (urea) on each plot, June 1; 0-0-60 per STK
Manure credit	16,000 gpa 11-5-08	None	None	16,000 gpa 11-5-08	None	Grazed May 6-Oct 7th
Pesticides (as needed)	Herbicide: Post-emrg: 6-9-09 Pursuit 3 oz/a; 7-1-09 Raptor 3oz/a Insecticide: 7-1-09 & 7-31-09 Warrior 2 oz/a	Insecticide: None	Insecticide: None Herbicide: 10-9-09 Mirage Plus 40 oz/a (ineffective)	None	None	Spot sprayed thistles with Stinger
Harvest & Yield	1 st : 7-20-09 2 nd : 8-25-09 1.35 tons DM/a	1 st : 5-30-09 2 nd : 7-8-09 3 rd : 8-13-09 4 th : 10-19-09 5.63 tons DM/a	1 st : 5-30-09 2 nd : 7-8-09 3 rd : 8-13-09 4 th : 10-19-09 4.53 tons DM/a	1 st : 6-29-09 2 nd : 8-25-09 2.14 tons DM/a	1 st : 5-30-09 2 nd : 7-8-09 3 rd : 8-13-09 4 th : 10-19-09 5.14 tons DM/a	Hayed 207 5-30 & 405 6-30-09 Clipped 1 st cycle post-graze all others Hay enclosure: 2.87 t dm/a
Fall Practices	None	None	Manure 11-17-09 (16000 gpa); Chisel plow w/sweeps 11-24-09	None	Manure 11-17-09 (8000 gpa); chisel plow w/sweeps 11-24-09	None
Crop 2010	Alf I	Alf II	Corn	Alf I	Corn	Pasture

2009 Proposed Agronomic Calendar for WICST (Fld 440)

Satellites				
	Flex-till 3-phase system			Biofuel
2009 Crop	Corn	Drilled Soybeans /Winter Wheat	No-till Wheat/Red Clover	Switchgrass
Previous crop (2008)	Wheat/red clover	Corn	Soybeans	switchgrass
Plot #'s	C, D	B, F	A, E	501, 504, 508
Primary Tillage	Disk-chisel plowed 11-10-08	None	None	None
Secondary Tillage	Field cultivator 2x; 5-1-09	None	None	None – burned plots 4-11-09
Planting Date	5-4-09	5-18-09	No-till drill red clover 4-13-09	Planted 8-17-07
Variety Rate	Pioneer 35F40 +poncho1250 34,000 sd/a	SB: Kaltenberg1809 RR 225,000 seed/a (2900 sd/lb)	RC: 'Arlington' 12 lb/a	'Forestberg' 10 lb PLS/a
Fertilizer	100 lb/a 5-14-42, Sat C 75 lb/a 0-0- 60, 132 lb/a TSP; 60 lb N/a as 28% per PPNT 6-11-09;	Sat B 132 lb/a TPS on 4-29-09; B and F 150 lb/a 0-0-60 5-1-09	50 lbs N/a (urea) 4-15-09 Sat A 132 lb/a TSP 4-29-09; A&E 150 lb/a 0-0-60 5-1-09	None
Pesticides (as needed)	Pre-plant: none Post emrg: full rate 6-15-09 Honcho Plus 24 oz/a, Laudis 3 oz/a	Pre-plant: 5-8-09 Dual II Mag, 24 oz/a; 2,4-D ester 8 oz/a, Honcho Plus 24 oz/a; Post emrg: 6-23-09 Glyphos Xtra 24 oz/a	None on wheat; Sprayed Mirage Plus 10-9-09 40 oz/a (ineffective)	Honcho Plus 24 oz/a 4-23-09 24oz/a
Rotary Hoe/Tine	None	None	None	None
Cultivation	None	None	None	Hand pulled c. thistle 6-9-09
Harvest & Yield	11-11-09 195.8 bu/a	10-13-09 50.4 bu/a	8-4-09 Wheat: 71.8 bu/a 8-6-09 Straw: 0.92 ton DM/a	10-29-09 1.98 Tons DM/a
Fall Practices	Disk-chiseled 11-23-09	Disk-chiseled 11-23-09	fall chisel w/sweeps 11-24-09	None
Crop 2010	Spring wheat	Spring wheat	Spring wheat	Switchgrass

2010 Agronomic Calendar for WICST (440)

ARLINGTON RESEARCH STATION

Corn rotations					
CROP-2010	CORN	CORN	CORN	CORN	CORN
Rotation	CS1	CS2	CS3	CS4	CS5
Treatment #	1	2	5	8	11
Plot #'s	109, 204, 306, 412	108, 206, 310, 408	106, 202, 307, 411	113,210, 311,414	110, 208, 304, 413
Primary Tillage	Disk-chiseled 11-23-09	Strip-tilled 11-23-09	Disk-chiseled 11-23-09	Chisel w/sweeps 11-24-09	Chisel w/sweeps 11-24-09; and 5-2-10
Secondary Tillage	Field digger 4-28-10 (2x)	None	Field digger 4-28, 5-18-10	Field digger 4-28-10 (2x)	Field digger 5-6-10, 5-18-10
Planting Date	Dekalb 52-59	Dekalb 52-59	Viking 0.6710	Dekalb 52-59	Viking 0.6710
Variety	102d, Triple stk	Triple stack	98d, 5-19-10	Triple stack	5-19-10
Rate	4-29-10 34,000 seeds/a	4-29-10 34,000 seeds/a	36,000 seeds/a	4-29-10 34,000 seeds/a	36,000 seeds/a
Starter Fertilizer	100 lb 5-14-42	100 lb 5-14-42	None	100 lb 5-14-42	None
Nitrogen Fertilizer	160 lb N/a ¹ 4-19-10 (82%/PPNT)	135 lb N/a 6-7-10 (28%/PPNT)	None	None	None
Manure	None	None	1.5 ton/a CPM 4-16-10	16,000 gal/a 11-12-09	8,000 gal/a 11-12-09
Pesticides/ Herbicides	<u>Pre-emrg:</u> 5-4 2.5 pt/a of Surpass EC <u>Post-emrg:</u> 6-17 22 oz/a Mirage+, 3 oz/a Laudis	<u>Burndown:</u> 4-18 22 oz/a of Mirage+, 8 oz/a Radar LV <u>Post-emrg:</u> 6-17 22 oz/a Mirage+, 3 oz/a Laudis	None	<u>Pre-emrg:</u> 5-4 2.5 pt/a of Surpass EC <u>Post-emrg:</u> 5-27 24 oz/a of Mirage+, 3 oz/a Laudis	None
Rotary Hoe/ Tine Weed	None	None	RH:5-27-10 RH: 6-7-10	None	RH: 5-27-10 RH: 6-7-10
Cultivation	None	None	6-17, 6-29-10	None	6-17, 6-29-10
Harvest	10-5-10 206.3 bu/a	10-5-10 214.6 bu/a	10-13-10 183.8 bu/a	10-5-10 222.5 bu/a	10-13-10 182.1 bu/a
Fall Practices	Chopped stalks 10-15-10 Disk-chisel 11-8-10	None	Chopped stalks 10-15-10 Disk-chisel 11-5-10	Chopped stalks 10-15-10 Manure 11,800 gpa 11-2-10 Disk-chisel 11-5-10	Chopped stalks 10-15-10 Manure 11,800 gpa 11-2-10 Disk-chisel 11-5-10
Crop 2011	Corn	Soybean	Soybean	D.S. Alfalfa	Oats/Alfalfa

1 Plot 204 got 120 lb N/a while other 3 plots got 160 lb N/a per PPNT

Soybean and Wheat Rotations			
CROP-2010 Rotation Treatment #	NR Soybean CS2 3	WR Soybean/Wheat CS3 4	Wheat/Berseem Clover CS3 6
Plot #'s	101, 214, 303, 401	104, 201, 301, 402	102, 212, 313, 407
Primary Tillage	None	Disk-chiseled 11-23-09	disk 1x 10-13-09
Secondary Tillage	None	Field digger 5-18-10	None
Planting Date	5-6-10	SB: 5-19-10 WW: 9-30-10	WW: Oct 13, 2009 CC: 8-11-10 Both with NT drill
Variety Rate	Pion. 92Y511 (RR) 225,000 seeds/a 2,500 sd/lb	Sb: Blue River 16A7 225,000 seeds/a; 3,000 sd/lb WW: untrt'd Kaskasia 140 lb/a	Untrt'd Kaskaskia: 155 lb/a; 12 lb/s berseem; 40 lb/a oats
Fertilizer	None	None	None
Pesticides/ Herbicides	<u>Burndown:</u> 4-18-10 Mirage+, <u>Post-emerg:</u> 7-2-10 Mirage+, Dual II Mag	None	None
Rotary Hoe/ Tine Weed	None	RH: 5-27-10 TW: 6-10-10, 6-17-10	TW: 4-15-10
Cultivation	None	6-29-10	None
Harvest	10-7-10 65.5 bu/a	9-28-10 61.9 bu/a	Wheat: 7-13-10; 61.7 bu/a Straw: 7-27-10; 1.11 T DM/a
Fall Practices	Manure eastern 15' 11-4-40 Strip tilled 11-8-10	Disk to flatten ridges Drill wheat	Disk 7-30-10 Quack digger 8-6-10 Field cultivator 8-11-10 Plant berseem/oats 8-11-10 Disk-chiseled 11-8-10
Crop 2011	Corn	Wheat / Red Clover	Corn

Forage rotations						
CROP-2010 Rotation Treatment #	D.S. Alfalfa CS4 7	Alfalfa I CS4 10	Alfalfa II CS4 9	Oats/Alfalfa CS5 13	Alfalfa I CS5 12	Pasture CS6 14
Plot #'s	111,209, 305,409	107,205, 309,404	105, 203, 308, 406	114, 211, 312, 403	103, 213, 314, 410	112, 207, 302, 405
Primary Tillage	Disk-chiseled 11-23-09	None	None	Disk-chiseled 11-23-09	None	None
Secondary Tillage	Field cultivator 3-24-10 (2x); Cultimulcher 3-29	None	None	Field cultivator 3-24-10 (2x); Cultimulcher 3-29	None	None
Planting Date Variety	3-30-10 Dairyland 'Hybrid2400' ¹	4/10/09 <i>SummerGold</i>	4/30/08 <i>GH 707</i>	3-30-10 untrt Pion 53H92 'Forage Plus' oat	4/13/09 <i>WL347LH alf,</i> <i>Kame oats</i>	3/19/10 Kopu II
Rate	12 lb/a	12 lb/a	12 lb/a	Alf - 12 lb/a oats 40 lb/a	Alf - 12 lb/a oats 40 lb/a	3.6 lb/a
Fertilizer	None	125-250 lb/a KCl	250-500 lb/a KCl	None	600 lb/a K2SO4	60 lb N/a on 6-17-10 and on 9-15-10; KCl on 405
Manure	16,000 gal/a 11-12-09	None	None	16,000 gal/a 11-12-09	None	Grazing 6 heifers
Pesticides/ Herbicides	Herbicide <u>Post-emerge:</u> Raptor 6-5-10	Insecticide None	Insecticide None	None	None	Spot spray thistles with Milestone
	Insecticide Warrior II 7-26-10		Herbicide 10-8-10 32 oz/a Mad Dog+ and 16 oz/a Radar LV			
Harvest	6-28-10 8-5-10	5-28-10 6-30-10 7-29-10	5-28-10 6-30-10 7-29-10	<u>Oatlage:</u> 6-24-10 <u>Haylage:</u> 8-5-10	5-28-10 6-30-10 7-29-10 9-15-10	Clipping as needed. Hay harvest 112 on 6-1-10; 40 5 on 6-9-10
	2.52 T DM/a	6.07 T DM/a	6.19 T DM/a	3.39 T DM/a	5.66 T DM/a	
Fall Practices	None	None	Manure 8k gpa 11-2-10 Chisel plowed 11-5-10	None	Manure 11.8k gpa 11-2-10 Chisel plowed w/sweeps 11-8-10	None
Crop 2011	Alf I	Alf II	Corn	Alf I	Corn	Pasture

¹Plot 305 was reseeded May 6th due to residual herbicide effect from 2 yrs earlier

	Satellites			
	Old Flex-till 3-phase system			Biofuel Research
2010 Crop	Spring wheat	Spring wheat	Spring wheat	Switchgrass
Previous crop (2009)	Corn	Soybeans	Wheat/red clover	switchgrass
Plot #'s	C, D	B, F	A, E	501, 504, 508
Primary Tillage	Disk-chiseled 11-23-09	Disk-chiseled 11-23-09	fall chisel w/sweeps 11-24-09	None
Secondary Tillage	Field cultivator for seedbed prep 3-30-10			None – burn plots 4-5-10
Planting Date	3-30-10			Planted 8-17-07
ariety Rate	Spring wheat 120 lb/a			‘Forestberg’ 10 lb PLS/a
Fertilizer (See map)	70 lbs N/a (urea) on 4-23-10 North: 75-150 lb/a 0-0-60; 120 lb/a 0-46-0 at Sat F only South: 150-200 lb/a 0-0-60; 120 lb/a 0-46-0 on all 4-12-10			50 lb N/a on most of plot (34-0-0)
Pesticides (as needed)	4-28-10:1 pt/a 2, Radar LV			4-12-10: 22 oz/a Mirage Plus; 5-10-10: 1 pt/a Radar LV
Harvest & Yield	7-27-10: North 24.3 bu/a South 19.5 bu/a Straw was chopped back on ground due to heavy weed pressure			1.6 Tons DM/a
Fall Practices	Tilled field then established winter rye for Annual Forage trial on 9-22-10			None
Crop 2011	Various forage treatments			Switchgrass

Appendix III. Soil test phosphorus, STP, (0-6" depth) on WICST at Arlington Research Station (1992-2010).																			
System/plot#	STP (ppm)																		
	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10
CS1 trt 1 109,204,306,412	93	84	91	88	91	83	82	80	76	85	91	79	83	87	70	67	63	57	57
CS2 trt 2 108,206,310,408	79	65	68	67	66	61	59	75	69	70	77	63	77	71	61	57	55	47	33
CS2 trt 3 101,214,303,401	89	78	89	72	83	72	75	62	53	57	59	52	55	59	74	38	38	33	49
CS3 trt 4 104,201,301,402	69	64	68	65	66	55	55	46	43	48	45	36	48	44	39	34	32	31	44
CS3 trt 5 106,202,307,411	--	57	63	52	57	56	47	67	49	55	64	49	61	61	48	46	42	38	41
CS3 trt 6 102,212,313,407	--	53	57	49	49	48	45	52	51	51	59	54	51	50	48	37	40	36	32
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	60	77
CS4 trt 8 113,210,311,414	105	81	92	93	94	81	91	93	81	81	101	97	95	93	95	85	74	61	59
CS4 trt 9 105,203,308,406	--	62	65	74	91	72	66	79	78	80	83	80	90	92	72	72	66	67	73
CS4 trt 10 107,205,309,404	77	71	72	67	77	76	63	66	74	86	84	73	91	94	79	64	63	61	52
CS5 trt 11 110,208,304,413	103	88	93	91	96	82	90	81	75	95	103	83	93	107	90	79	79	63	45
CS5 trt 12 103,213,314,410	72	67	72	64	72	66	59	68	60	65	80	70	70	75	58	50	57	46	56
CS5 trt 13 114,211,312,403	--	73	83	78	76	71	66	68	71	77	80	74	86	82	71	62	56	49	77
CS6 trt 14 112,207,302,405	--	82	84	75	74	73	64	68	64	73	54	69	78	76	90	55	60	47	49
Switchgrass ¹ 501, 504, 508	---	---	---	---	---	---	67	63	61	75	75	65	63	73	56	58	59	53	56
High div. prairie 502, 506, 509	---	---	---	---	---	---	67	68	60	70	74	61	69	70	54	50	56	52	62
Low div. prairie 503, 505, 507	---	---	---	---	---	---	62	65	65	68	69	59	61	69	58	55	55	50	50

¹ plots were in corn from 1999-2006, then seeded to switchgrass Aug 2007

Appendix IV. Soil test potassium, STK, (0-6" depth) on WICST at Arlington Research Station (1992-2010).																			
System/plot#	STK (ppm)																		
	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10
CS1 trt 1 109,204,306,412	219	295	228	241	257	254	229	217	203	194	202	225	227	246	244	214	206	221	204
CS2 trt 2 108,206,310,408	239	229	183	182	214	178	184	197	169	153	179	172	177	194	180	124	144	148	119
CS2 trt 3 101,214,303,401	198	264	214	208	230	224	212	164	128	126	131	138	154	148	161	162	139	126	133
CS3 trt 4 104,201,301,402	189	251	182	175	209	166	180	124	104	109	95	102	125	113	128	96	103	105	113
CS3 trt 5 106,202,307,411	---	226	171	164	191	172	150	174	145	136	140	152	154	165	163	106	132	120	108
CS3 trt 6 102,212,313,407	---	201	142	149	155	136	131	149	130	110	133	132	125	133	155	137	108	120	109
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	126	124
CS4 trt 8 113,210,311,414	203	170	154	184	189	153	166	179	128	96	142	156	112	124	169	120	124	103	114
CS4 trt 9 105,203,308,406	---	170	128	160	228	143	115	134	133	107	91	153	135	131	149	128	148	131	103
CS4 trt 10 107,205,309,404	189	224	155	153	196	205	141	133	137	163	111	124	153	180	175	140	131	143	128
CS5 trt 11 110,208,304,413	198	236	172	185	201	153	154	135	95	108	122	98	115	126	118	94	121	112	103
CS5 trt 12 103,213,314,410	181	210	144	127	143	128	98	110	87	75	103	121	89	127	106	97	111	104	109
CS5 trt 13 114,211,312,403	---	211	173	180	174	153	153	130	120	110	101	117	117	132	134	105	114	98	109
CS6 trt 14 112,207,302,405	---	186	157	176	208	210	180	202	148	153	163	175	174	165	180	141	141	152	138
Corn'98-06 Switchgrass'07 on 501, 504, 508	---	---	---	---	---	---	182	130	160	155	168	156	145	164	191	168	167	170	164
High div. prairie 502, 506, 509	---	---	---	---	---	---	230	163	151	178	183	165	156	161	193	148	160	155	179
Low div. prairie 503, 505, 507	---	---	---	---	---	---	203	170	168	139	169	154	151	158	190	162	162	179	154

Appendix V. WICST Phosphorus Soil Depth Test Results (0-6”, 6–12”, 12-24" , 24-36”) Arlington Research Station																	
		0-6”				6-12”				12-24”				24-36”			
		Year since treatment inititation ¹															
System	Trt.	0	7	12	18	0	7	12	18	0	7	12	18	0	7	12	18
CS1 c-c-c	1	105	91	85	59	65	43	43	29	59	29	28	25	85	ns	51	51
CS2 c-sb-c	2	88	48	77	56	47	35	58	43	50	10	70	21	73	ns	98	44
CS2	3	98	66	57	37	43	30	38	22	24	28	23	23	51	ns	53	46
CS3 c-sb-w	4	57	45	36	33	38	21	27	19	16	23	24	23	39	42	31	39
CS3	5	105	66	55	50	59	34	43	31	20	20	28	28	43	ns	50	46
CS3	6	69	48	59	40	24	35	32	23	22	7	31	24	47	ns	52	44
CS4 c-a-a-a	7	115	90	95	66	46	47	52	38	35	31	29	31	57	ns	48	55
CS4	8	93	45	108	62	39	34	45	33	32	8	31	25	52	ns	54	54
CS4	9	66	66	80	74	44	38	45	43	21	25	25	25	45	52	45	52
CS4	10	77	66	91	66	34	40	62	57	51	52	77	46	86	75	103	77
CS5 c-o/a-a	11	53	96	95	71	20	44	48	46	8	28	41	34	5	ns	68	50
CS5	12	70	77	80	51	27	36	29	32	22	16	30	29	47	ns	54	43
CS5	13	84	66	74	53	42	34	30	35	21	29	23	27	36	41	41	40
CS6 pasture	14	114	74	73	61	56	52	53	40	74	43	81	40	96	ns	92	57

¹ Treatments within a system were phased in over time in a staggered start. At year 0, samples taken in the year prior to the treatment start year – 1989; treatments 1, 3, 5, 7, 11, 14; 1990 trts 2, 6, 8, 12; 1991: trts 4, 9, 13; and 1992: trt 10. By 1993, all treatments established.

ns = no samples taken for 24-36" (starting using hydraulic probe in 1998)

Appendix VI. WICST Potassium Soil Depth Test Results (0-6”, 6–12”, 12-24", 24-36”) Arlington Research Station																	
		0-6”				6-12”				12-24”				24-36”			
		Year since treatment inititation ¹															
System	Trt.	0	7	12	18	0	7	12	18	0	7	12	18	0	7	12	18
CS1 c-c-c	1	257	257	194	204	143	100	83	81	125	74	88	89	135	ns	121	112
CS2 c-sb-c	2	283	144	179	140	126	130	96	81	125	124	104	81	123	ns	110	98
CS2	3	199	214	126	121	121	91	90	75	134	83	99	92	155	ns	118	103
CS3 c-sb-w	4	195	135	102	102	124	91	71	72	86	121	89	83	98	123	94	88
CS3	5	236	209	136	134	133	95	80	72	126	80	93	86	156	ns	119	104
CS3	6	200	129	133	103	78	95	78	70	88	108	86	79	100	ns	104	96
CS4 c-a-a-a	7	277	180	127	131	123	81	68	60	126	80	82	76	131	ns	96	100
CS4	8	256	124	149	115	126	121	67	59	86	106	82	73	119	ns	106	85
CS4	9	214	115	152	158	103	79	66	69	85	95	69	71	101	133	95	98
CS4	10	189	133	153	128	96	91	89	88	109	101	102	88	111	124	118	106
CS5 c-o/a-a	11	163	201	108	93	113	86	64	68	120	80	80	79	115	ns	102	96
CS5	12	211	176	103	106	83	98	64	63	85	113	91	81	113	ns	105	91
CS5	13	293	153	117	114	123	89	67	76	98	99	79	82	95	114	92	89
CS6 pasture	14	266	208	153	149	143	101	85	60	154	86	89	72	135	ns	116	93

¹ Treatments within a system were phased in over time in a staggered start. At year 0, samples taken in the year prior to the treatment start year – 1989; treatments 1, 3, 5, 7, 11, 14; 1990 trts 2, 6, 8, 12; 1991: trts 4, 9, 13; and 1992: trt 10. By 1993, all treatments established.

ns = no samples taken for 24-36" (starting using hydraulic probe in 1998).

Appendix VII. Fall nitrates in the top 3-ft of soil at Arlington Research Station in 2000-2010.

Crop	System†	Phase	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
			lbs NO ₃ ⁻ -N/acre at 3-ft depth										
Corn	CS1-Conv	Cont. Corn	130	79	110	110	82	116	67	42	18	75	61
	CS2-Conv	After Soybeans	107	68	55	59	77	91	76	40	17	129	97
	CS3-Org	After clover/oats	61	81	44	96	70	66	56	47	23	58	57
	Flex-till-Conv	After red clover	50	58	52	111	57	97	94	49	26	---	---
	CS4-Conv	After 3 yrs. Alf	189	171	140	187	142	148	170	84	35	188	143
	CS5-Org	After 2 yrs. Alf	120	154	121	142	151	160	139	127	60	115	99
Soybean	CS2-Conv	After Corn - drilled	81	101	71	108	61	83	74	57	29	60	39
	CS3-Org	After Corn-wide row	68	53	64	100	55	76	99	59	44	65	37
	Flex-till-Conv	After Corn	84	61	64	97	63	64	69	87	41	---	---
Wheat	CS3-org	Wheat - Clover/oats	57	53	37	46	45	39	52	28	15	58	13
	Flex-till-Conv	Wheat - Red Clover	49	65	33	45	46	43	65	49	17	---	---
Alfalfa	CS4-Conv	Dir-seeded Alfalfa	69	101	96	101	75	89	84	59	38	98	32
	CS4-Conv	Alfalfa Hay I	66	85	66	93	69	64	78	47	31	91	25
	CS4-Conv	Alfalfa Hay II	98	83	87	58	87	54	81	80	45	85	56
	CS5-Org	Alfalfa seeded with Oats	65	72	77	98	69	96	77	50	35	75	27
	CS5-Or	Alfalfa Hay	70	71	57	79	56	54	85	51	29	83	32
Pasture	CS6-Conv	Rotational Grazing	59	50	50	76	88	78	86	66	28	75	82
Check	Native mix	High diversity Prairie	45	26	19	37	32	27	63	21	13	45	19

† Conv=conventional, Org= organic

Appendix VIII. 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	10.9	4.9	8.4
-----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
2010	4.7	19.8	7.6	18.1

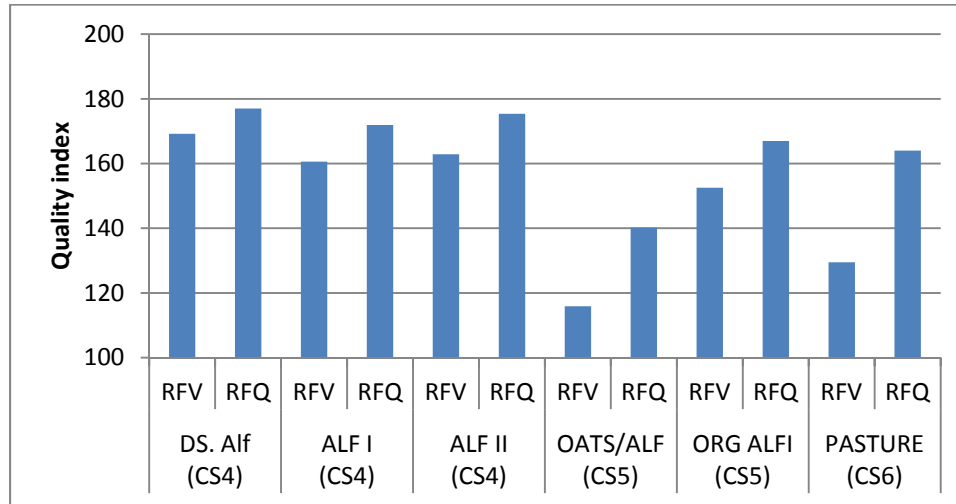
¹ Manure applied previous fall before tillage unless otherwise noted. Year of credit for corn shown.

² Manure applied prior to spring planting.

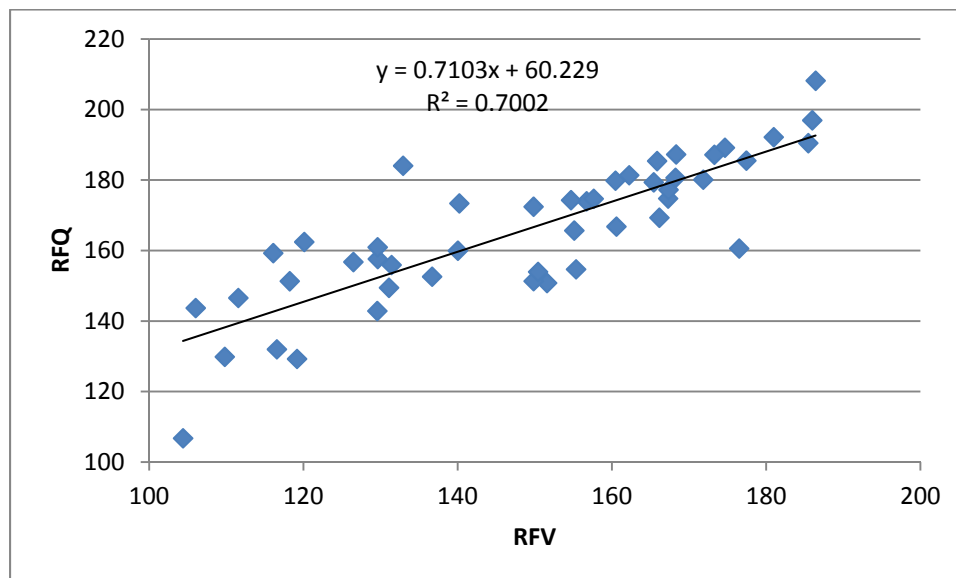
³ Missing or not sampled. The average value from 1992-1995 was used for the nutrient credit.

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 ~600 hd; housed 275 hd) resulted in very dilute manure

Appendix IXa. RFV vs. RFQ on WICST forage systems (2003-2010 avg).

Note from top figure that systems with high grass component (oats/alf and pasture) have a higher differential between RFV and RFQ. CS4 is conventional alfalfa system and CS5 is organic alfalfa system. DS. ALF is seeding year of pure alfalfa; ALF I is 1st production year; ALF II is 2nd production year; OATS/ALF is an alfalfa under-seeding with an oat nurse crop; PASTURE is cool-season grass/legume mix managed grazing with dairy heifers.

Appendix IXb. RFV vs. RFQ from WICST forage systems (2003-2010).

Appendix Xa. Corn seeding rate and plant population at Arlington Research Station over the course of the trial.

YEAR	Conventional		Organically managed	
	SEEDED RATE	PLANTS PER ACRE	SEEDED RATE	PLANTS PER ACRE
1992	32,100	28,200	32,100	24,700
1993	32,500	31,317	32,500	24,150
1994	31,500	26,750	34,000	28,425
1995	31,500	28,200	34,000	28,200
1996	31,500	30,133	34,000	26,950
1997	31,217	30,700	34,000	32,450
1998	32,000	28,139	34,500	27,083
1999	32,000	29,242	34,500	27,075
2000	32,000	29,538	34,500	24,075
2001	32,000	31,483	34,500	28,875
2002	32,000	28,033	34,500	27,675
2003	32,000	28,900	34,500	29,725
2004	32,000	30,717	34,500	22,100
2005	32,000	29,350	34,500	23,325
2006	34,000	29,567	38,000	26,925
2007	34,000	32,068	38,000	34,250
2008	34,000	31,833	38,000	31,950
2009	34,000	30,250	38,000	34,425
2010	34,000	31,217	36,000	27,225

* conventional = CS1, CS2, CS4; organically managed = CS3 and CS5

Appendix Xb. Soybean seeding rate and plant population at Arlington Research Station over the course of the trial.

YEAR	Conventional		Organically managed	
	SEEDED RATE	PLANTS PER ACRE	SEEDED RATE	PLANTS PER ACRE
1992	235,000	118,548	156,000	70,350
1993	235,000	179,822	156,000	135,250
1994	235,000	187,489	175,000	152,125
1995	235,000	156,016	200,000	199,542
1996	235,000	151,497	175,000	105,583
1997	250,000	231,709	190,000	141,200
1998	250,000	249,709	190,000	x
1999	250,000	178,826	190,000	64,300
2000	250,000	238,244	190,000	77,827
2001	250,000	177,570	190,000	152,136
2002	250,000	173,408	190,000	66,000
2003	250,000	139,189	190,000	124,300
2004	250,000	209,939	190,000	87,450
2005	225,000	108,515	170,000	91,000
2006	225,000	195,604	190,000	92,350
2007	225,000	242,308	190,000	142,300
2008	225,000	149,824	190,000	157,333
2009	225,000	141,963	190,000	97,350
2010	225,000	147,050	225,000	141,000

* conventional = CS1, CS2, CS4; organically managed = CS3 and CS5

x = missing data

Appendix XII. WICST Fall Legume Nitrogen from Plowdown Crop Preceding Corn Phase at Arlington (2005-2010).

Year	Crop System†	Crop‡	Foliage (Tops)		Roots		Total
			lbs DM/a	%N§	lb DM/a	%N	lbs N/a
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
2009	3	Berseem clover/oats	1392	2.89	1234	1.43	58
2009	FT	Red clover	3221	2.95	1396	2.47	129
2009	4	3-yr Alfalfa	0	0.00	5084	2.36	120
2009	5	2-yr Alfalfa	0	0.00	5065	2.28	115
2010	3	Berseem clover/oats	3993	2.08	1422	1.23	101
2010	4	3-yr Alfalfa	1119	4.19	5246	2.33	168
2010	5	2-yr Alfalfa	1140	4.43	3893	2.33	141

† 3 = organic corn-soybean-wheat/berseem clover+oats; FT=low input corn-soybean-wheat/red clover; 4 =conventional corn-alfalfa-alfalfa-alfalfa; 5 =organic corn-oats/alfalfa-alfalfa

‡ Berseem clover/oats (organic system) seeded in August after wheat harvest; red clover (FT system) interseeded into wheat in early Spring

§ % N is weighted across weight of botanical components (legume, oats, weeds, quackgrass)

Summary of Cover Crops on WICST

Green manure crops for organic grain systems (corn-soy-wheat/clover rotation) have been used on the Wisconsin Integrated Cropping Systems Trial (WICST) since 1991 at 2 sites in southern Wisconsin (see p. 223 & 224 of 9th WICST Technical Report). Inter-seeded red clover drilled into winter wheat (in early spring) was the primary green manure crop until 2004; in 2005, we shifted to a sequential seeding of berseem clover and oats after wheat harvest. Without any summer tillage after wheat harvest, we were finding increasing foxtail and quackgrass pressure in the following corn crop. We anticipated that we would fix less N with the later seeded cover crop and have a period when the field would be “open” with the potential for increased erosion. However, late July is usually a hot and dry part of the season and an ideal time to break the weed growth cycle—especially to desiccate quackgrass rhizomes. The inter-seeded red clover at plowdown averaged across the 20 site-yrs was 2.4 tons DM/a (1.6 tons/a aboveground +0.8 tons/a belowground) with 127 lbs/a N (16 of the 20 site-yrs had an N credit over 100 lbs/a). The shorter season oat/berseem cover crop (planted in mid-August) resulted in an average of 2.2 tons

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total DM/a and about 80 lbs N/a (80% from oats, 20% from clover). However, in this shorter data set with berseem clover/oats, 2 of 6 site-yrs had total biomass yields less than 1.1 ton DM/a due to a dry period following planting (with less than 1" of rain in the 3 weeks following planting). We did find however that ground cover was quickly re-established due to inclusion of oats in the cover crop mix. Although the comparison in this report is not from side-by-side plots, biomass yields and N levels from a sequentially seeded oat/berseem following wheat (6 site-years) yielded about 80% that of inter-seeded red clover (20 site-years). Although not solely due to reduced weed pressure, organic corn yields from 2002 to 2005 averaged 106 bu/a while from 2006 to 2009 the average was 163 bu/a.

WICST

General:

Stevenson, G.W., J.L. Posner, J. Hall, L. Cunningham, and J. Harrison. 1994. Addressing the challenges of sustainable agriculture research and extension at land-grant universities: Radially organized teams at Wisconsin. *Am. J. Altern. Agric.* 9:76-83.

Posner, J.L., M.D. Casler, and J.O. Baldock. 1995. The Wisconsin integrated cropping systems trial: Combining agroecology with production agronomy. *Am. J. of Alt. Agric.* 10:3:98-107.

Posner, J.L., J.O. Baldock, and J.L. Hedtcke. 2008. Organic and conventional production systems in the Wisconsin Integrated Cropping Systems Trial: I. Productivity 1990-2002. *Agron. J.* 100:253-60.

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

Soil Biology Research:

Garlynd, M.J., A.V. Kurakov, D.E. Romig, and R.F. Harris. 1994. Descriptive and analytical characterization of soil quality/health. *In: J.W. Doran et al. (Eds.) Defining Soil Quality for a Sustainable Environment. Soil Sci. Soc. Amer. Special Pub.* 35:159-168.

Kruath, S.J. and D.K. Young. 1994. First records of Encocephalidae (Hemiptera-Heteroptera) from Wisconsin. *Ent. News* 105(3):159-160.

Romig, D.E., M.J. Garlynd, R.F. Harris, AND K. McSweeney. 1995. How farmers assess soil health and quality. *J. Soil Water Conserv.* 50:229-236

Romig, D.E., M.J. Garlynd, and R.F. Harris. 1996. Farmer based assessment of soil quality. *In J.W. Doran and A.J. Jones (Eds.) Methods for assessing soil quality. SSSA Special Publ. #49. Am. Soc. of Agronomy. Madison, WI.*

Goldstein, W. 2000. The effect of farming systems on the relationship of corn root growth to grain yields. *Amer. J. of Altern. Agric.* 15(3):101-109.

Rebeck, D.B. Hogg and D.K. Young. 2002. Effect of four cropping systems on the abundance and diversity of epedaphic springtails (Hexapoda:Parassecta:Collembola) in Southern Wisconsin. *Community and Ecosystem Ecology.* 31:1:37-46

Simonsen, J., J. Posner, M. Rosemeyer, and J. Baldock. 2010. Endogeic and anecic earthworm abundance in six Midwestern cropping systems. *Applied Soil Ecology* 44:147-155

Jokela, William, J.L. Posner, J. Hedtcke, T. Balser, and H. Reed. 2011. Midwest Cropping Systems Effects on Soil Properties and on a Soil Quality Index. *Agron. Journal* 103:5:1552-62.

Organic weed control:

Mulder, T.A. and J.D. Doll. 1993. Integrating reduced herbicide use with mechanical weeding in corn. *Weed Tech.* 2:382-389.

Mulder, T.A. and J.D. Doll. 1994. Reduced input corn weed control: The effects of planting date, early season weed control, and row-crop cultivator selection. *J. Prod. Agric.* 7:256-260.

Bernstein, E., J.L. Posner, D. Stoltenberg, and J. Hedtcke. 2011. Organically-Managed No-Tillage Rye-Soybean Systems: Agronomic, Economic, and Environmental Assessment. *Agron J.* 103:4:1169-1179.

Drainage, Hydrology:

Iragavarapu, T.K., J.L. Posner, and G.D. Bubenzer. 1998. The effect of various crops on bromide leaching to shallow groundwater under natural rainfall conditions. *J. Soil and Water Conserv.* 53(2):146-151.

Gish, T.J., K.-J. S. Kung, D.C. Perry, J. Posner, G. Bubenzer, C.S. Helling, D.J. Kladvko, and T.S. Steenhuis 2004. Impact of preferential flow at varying irrigation rates by quantifying mass fluxes. *J. Environ. Quality* 33:1033-1040

Avila-Segura, M, P. Barak, J. Hedtcke and J.L. Posner. 2011. Nutrient and alkalinity removal by corn grain, stover and cob harvest in Upper Midwest USA. *Biomass and Bioenergy* 35:1190-1195.

Satellite Activities**Cover Crop Research:**

Stute, J.K. and J.L. Posner. 1993. Legume cover crop options for grain rotations in Wisconsin. *Agron. J.* 85:1128-1132.

Stute, J.K. and J.L. Posner. 1995. Synchrony between legume nitrogen release and corn demand in the Upper Midwest. *Agron. J.* 87:1063-1069.

Stute, J.K. and J.L. Posner. 1995. Legume cover crops as a nitrogen source for corn in an oat-corn rotation. *J. of Prod Agric.* 8:3:385-390.

Mallory, E.B., J.L. Posner, and J.O. Baldock. 1998. Performance, economics, and adoption of cover crops in WI cash grain rotations. On-farm trials. *Am. J. Alt. Ag.* 13(1):2-11.

Krusenbaum and other on-farm Grazing Projects

Posner, J.L., G.G. Frank, K.V. Nordlund, and R.T. Schuler. 1998. Constant goal, changing tactics: A Wisconsin dairy farm start-up. *Am. J. Alt. Ag.* 13(2):50-60.

Hedtcke, J.H, J.L. Posner and M. E. 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. D. Egan and J.A. Harrington (eds). Madison, WI Aug 8-12, 2004. Pp.188-191.

Posner, J.L. G.G. Frank, K.V. Nordlund, 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.

Hedtcke, J.H, J.L. Posner, M. E. 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.

Manure Management: Linking cash grain and dairy farms via manure contracts

Cook, A.R. J.L. Posner, and J.O. Baldock. 2007. Effects of dairy manure and weed management on weed communities in corn on Wisconsin cash-grain farms. *Weed Tech*. 21:389-395.

Wagner T., J.L. Posner, and L. Paine. 2008. Manure management on a township scale: Using a land evaluation approach in Wisconsin. *J. of Agriculture, Food and Environmental Sciences*. 2:1

Sanford, G., J.L. Posner, R.T. Schuler, J.O. Baldock. 2008. Effect of dairy slurry application on soil compaction and corn (*Zea mays* L.) yield in Southern Wisconsin. *Soil and Tillage* 100:42-53.

Sanford, G., A.R. Cook, J.L. Posner, J.L. Hedtcke, J.A. Hall, J.O. Baldock. 2009. Linking Wisconsin Dairy and grain farms via manure transfer for corn production. *Agron. J.* 101:1:167-174

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

Opening summer windows for manure spreading

Hedtcke, J., J. Posner, J. Hall, R. Walgenbach, J. Baldock. 2010. Orchardgrass ley for improved manure management in Wisconsin: I. Forage yield, environmental impact, and production costs. *Agron. J.* 102:956-963.

Hedtcke, J., J.L. Posner, W. Coblenz, J. Hall, R. Walgenbach, and J. Davidson. 2011. Orchardgrass ley for improved manure management in Wisconsin: II. Nutritive value and voluntary intake by dairy heifers. *Agron. J.* 103(4):1106-1114.