THE WISCONSIN INTEGRATED CROPPING SYSTEMS TRIAL
Eleventh Report - 2005 & 2006

Compiled by Janet Hedtcke and Josh Posner, July 2008

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PROLOGUE

This is the eleventh 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 fifteen production years (1990 – 2004). In this report, we discuss the results of the 2005 & 2006 growing seasons. This is the fourteenth 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 2006, all the treatments of the Cropping Systems had completed at least four full cycles of their respective rotations. Also included in this report are research results of satellite trials conducted both on-farm and adjacent to the WICST core trials.

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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, and the Arlington Research Station (ARS) is 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.

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

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

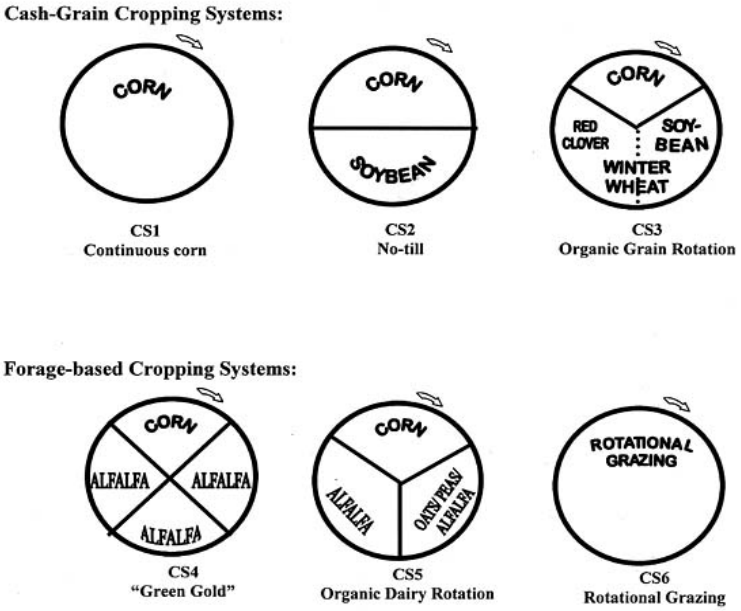


Figure 1b. Schematic diagram of the cropping systems of the WICST experiment.

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

Rotation	Predicted Yield/acre	Mean above ground productivity[1]	Mean energy input[2]	Energy output/input[3]	Variable costs[4]	Chemical inputs			Erosion[5]
						N Fertilizer on corn	Herbicide	Insecticide	
		Lb/a/yr	Mcal/a/yr	ratio	$/a/yr	lb/a	AI/a	AI/a	t/a/yr
R_1									
Continuous Corn	150 bu	15,780	2369	6.0	140	150	Atrazine 2 lb Alachlor 2 lb	Counter 1.4 lb	4.1
R_2									
Drilled Soybean	55 bu	12,510	1788	6.9	104	110	Bladex 2.5 lb Alachlor 2.5 lb	0	4.0
Corn	160 bu						Sencor 0.5 lb Treflan 1.5 lb		
R_3									
Row soybean	40 bu	10,010	763	12.6	50	0	0	0	2.9
Wheat	60 bu/2t straw								
Corn	120 bu								
R_4									
Seeding alfalfa	3t dm	10,710	1188	13.7	110	10	Eptam 2.9 lb	Lorsban 1.0 lb	1.9
Hay I	5t dm						Bladex 2.0 lb		
Hay II	5t dm						Alachlor 2.5 lb		
Corn	160 bu								
R_5									
Oats/alfalfa	60 bu/2t dm	9,440	811	18.2	45	10	0	0	1.6
Hay I	4t dm								
Corn	120 bu								
R_6									
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

Table 1. Yields (LSMeans) from WICST at Arlington Agric. Research Station, 1993-2006

	Corn	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
		bu/acre													
CS_1	Continous corn	123.7	178.1	143.1	131.5	128.6	196.2	170.4	161.6	193.6	192.2	175.0	193.9	197.3	192.7
CS_2	After sb (No Till)	129.8	190.2	167.7	140.0	157.4	212.6	162.9	162.9	207.7	159.2[1]	176.5	189.0	210.2	190.6[1]
CS_3	Organic 3-crop	87.1	188.4	155.6	83.4	147.6	197.8	155.6	132.8	155.5	157.8	110.0	-[2]	102.2	144.8
Chemlite	Low input 3-crop	-	-	146.5	150.9	158.8	199.8	156.2	155.4	190.5	173.8	155.2	223.8	201.5	199.8
CS_4	After 3-yrs alf	165.1	196.5	167.5	151.2	159.1	226.8	189.7	179.4	227.8	186.6	190.6	212.7	231.4	217.7
CS_5	After 2-yrs alf (org)	119.1	198.8	157.1	153.6	155.3	205.1	181.9	135.2	181.2	174.1	149.7	-[2]	128.3	189.0
LSD (0.05)		*7.3*	*9.1*	*9.4*	*16.5*	*10.2*	*9.6*	*15.1*	*25.1*	*18.4*	*18.5*	*17.9*	*5.6*	*21.6*	*4.4*
	Soybeans	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
		bu/acre													
CS_2	Drilled – No till	52.8	42.7[3]	58.1	53.7	51.9	63.6	59.2	56.3	51.6	54.5	35.6	49.8	59.0	63.8
CS_3	Organic 3-crop	53.3	44.4	63.3	60.2	48.8	51.9	31.0	40.9	35.4	50.9[1]	32.5	33.6	24.6	58.7
Chemlite	Low input 3-crop	-	-	66.6	60.2	46.1	62.5	48.7	52.0	39.7	60.8	22.6	47.5	54.5	54.2
LSD (0.05)		*NS*	*NS*	*2.6*	*4.0*	*NS*	*13.3*	*3.4*	*3.8*	*11.1*	*4.8*	*2.6*	*7.0*	*5.2*	*7.6*
		1993	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
	Wheat grain	bu/acre													
CS_3	Organic 3-crop	28.6	60.9	69.3	46.9	55.3	58.2	57.6	42.6	55.5	70.5	53.6	34.9	49.8	66.6
Chemlite	Low input 3-crop	-	-	76.9	45.8	51.9	61.3	59.8	52.9	54.9	78.3	67.1	38.5	79.3	109.7
LSD (0.05)				*NS*	*1.3*	*NS*	*1.2*	*NS*	*1.0*	*NS*	*NS*	*NS*	*NS*	*21.5*	*0.14*
	Wheat straw	tons DM/acre													
CS_3	Organic 3-crop	1.44	1.44	1.22	1.55	0.97	0.58	0.63	0.83	0.71	1.43	0.33	0.54	0.65	1.04
Chemlite	Low input 3-crop	-	-	1.50	1.68	0.99	0.73	0.66	0.75	0.66	1.79	0.39	0.48	1.17	1.13
LSD (0.05)				*0.10*	*0.11*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*0.01*	*NS*	*0.23*	*0.01*
	Seeding yr. Forage	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
		tons DM/acre													
CS_4	Direct seeded	3.27	3.21	3.19	1.57	3.56	2.63	2.27	2.59	3.21	2.96	2.91	1.85	1.71	2.81
CS_5	Oats/peas/alf	NA	3.37	3.21	2.68	4.66	5.67	4.69	4.14	4.53	3.56	2.30	4.35	3.02	4.62
LSD (0.05)		*0.51*	*NS*	*NS*	*0.90*	*NS*	*0.67*	*0.34*	*0.24*	*1.27*	*NS*	*NS*	*1.06*	*0.19*	
	Estab'd Forage	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
		tons DM/acre													
CS_4	Hay I	3.93	4.56	4.02	4.16	5.08	4.30	4.49	5.44	5.89	5.18	4.83	5.09	4.63	4.53
CS_5	Hay I	4.65	5.30	4.89	4.43	4.99	4.45	5.49	5.86	5.29	5.10	5.94	4.88	3.88	4.39
CS_4	Hay II	3.25	3.68	2.24	3.78	4.50	4.13	4.06	5.31	5.53	4.50	3.37	5.15	3.11	3.85
CS6	Pasture	-	-	-	-	-	-	-	-	-	-	-	5.48	2.61	5.80
LSD (0.05)		*0.95*	*0.34*	*0.47*	*0.64*	*0.42*	*NS*	*0.32*	*0.29*	*0.43*	*0.46*	*0.71*	*NS*	*0.50*	*0.51*

[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.

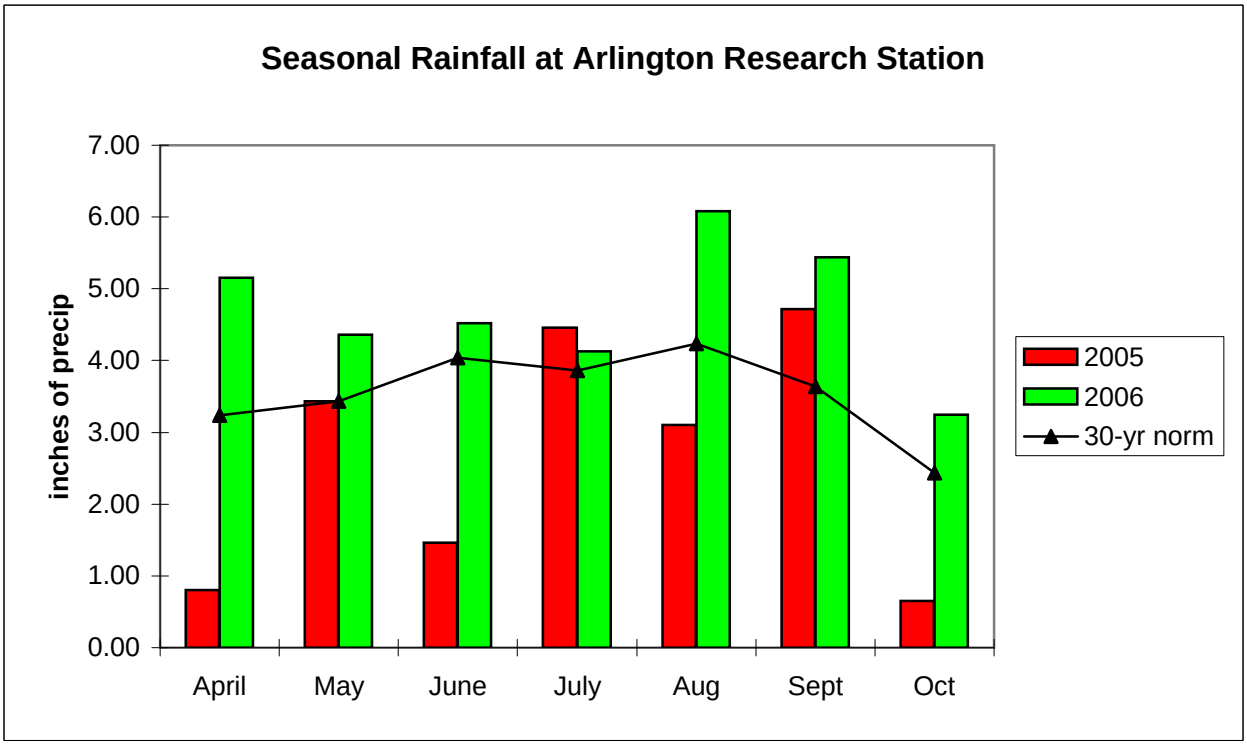
CORE TRIAL DATA

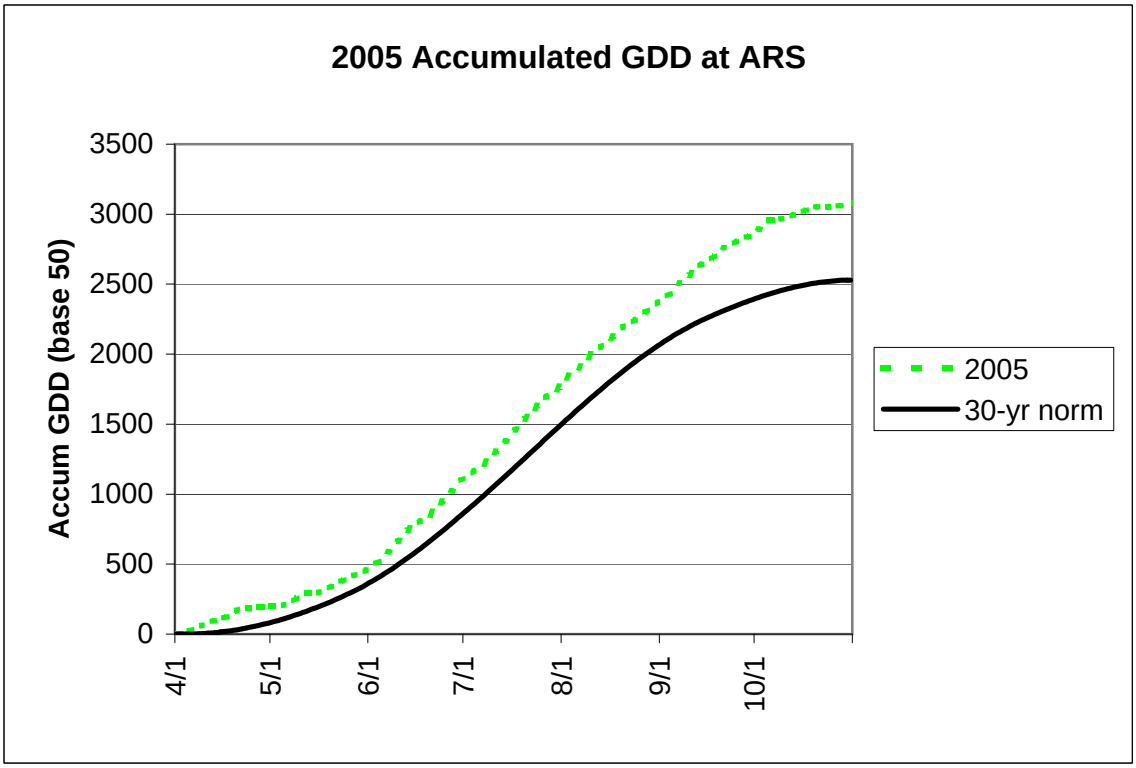
Growing season rainfall (inches) at the Wisconsin Integrated Cropping Systems Trial sites.

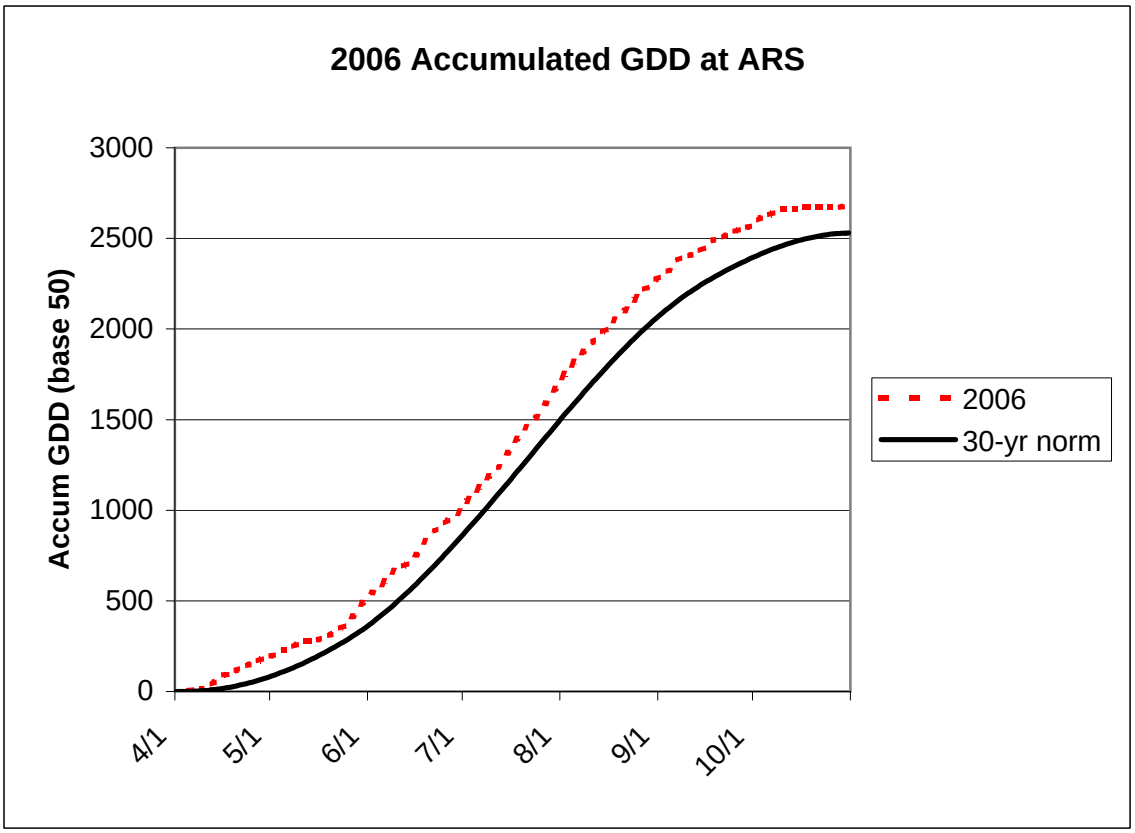
A. Arlington Research Station1

Month	2006	(*)	2005	(*)	30-year average 1971 - 2000
April	5.15	1.91	0.80	-2.44	3.24
May	4.36	0.93	3.43	0.00	3.43
June	4.52	0.48	1.46	-2.58	4.04
July	4.13	0.27	4.46	0.60	3.86
August	6.08	1.84	3.10	-1.14	4.24
September	5.44	1.80	4.72	1.08	3.64
October	3.25	0.82	0.65	-1.78	2.43
Growing Season Total	32.93	8.05	18.62	-6.26	24.88
Yearly Total	39.40	6.60	28.04	-4.76	32.80

* Deviation from 30-year average




2005 Accumulated GDD at ARS
Accum GDD (base 50)
3500
3000
2500
2000
1500
1000
500
0
4/1
5/1
6/1
7/1
8/1
9/1
10/1
2005
30-yr norm


2006 Accumulated GDD at ARS
Accum GDD (base 50)
3000
2500
2000
1500
1000
500
0
4/1
5/1
6/1
7/1
8/1
9/1
10/1
2006
30-yr norm

Arlington Agricultural Research Station – 2005 Report

Janet Hedtcke and Bill Stangel

Although May rainfall was close to the long term average (3.4"), both April and June were very dry (25 to 36% of normal). These conditions resulted in poor red clover establishment in the CS6 pastures (drilled April 9) as well as the alfalfa underseeded with oats (CS5 drilled April 14). Corn grain however, did well throughout the state in 2005 because the spring drought was followed by adequate rainfall in July and August (7.6"). Although maturity was somewhat delayed due to the early season stress, a warm September (16 days with temps above 80°F) resulted in good dry down conditions for the grain with moisture levels < 20% at harvest. Soybeans yields were reasonable when weeds were controlled.

The superimposed manure trial on the border rows of the cash grain systems continued this season as part of Linking Farms Project of importing manure from dairy to cash grain systems. 2005 marks the 3rd year of manuring the corn phase in CS1, CS2, and CS3. As in previous years, the eastern 15' of plots going into corn received 12,000 gal/a of dairy slurry (broadcast) on November 15, 2004 using the Calumet tanker. Manure was chiseled in within 72 hrs for CS1 and CS3; manure applied to CS2 was left on the surface.

Early in the cropping season, remedial applications of potassium were applied to the high input plots where STK has dropped from the excessively high range to high, optimum, and even low response ranges in CS4 (high input forage system). Quackgrass had become an increasing problem in the organic CS3 and CS5 corn plots. To manage this in CS3, the wheat plots, harvested in mid-July, were tilled in late July and again in early August to expose/desiccate the quackgrass roots and then reseeded with berseem clover and oats. The goal was to establish a smother/green manure crop in preparation for the corn phase in 2006. The cover crop of berseem clover and oats was left standing over winter; as both crops will winterkill. Fall biomass of tops and roots were sampled to get an estimate of the N credit offered by the cover crop. A second strategy to reduce quackgrass pressure in the organic rotations was to fall moldboard plow the corn phase in both rotations as well as the 'Alfalfa I' plots in CS5. The plan is the use the moldboard plow until each plot has been done once and then we'll go back to using the chisel plow.

Corn Phase

Corn in CS1, CS2, and CS4 were all planted on April 29 at 32,000 seeds/A with a 105-day corn, Growmark FS4453. Starter fertilizer (5-14-42) was used on CS1, CS2, and CS4 at 100 lb/a as well as pre-emergence grass herbicide and post emergence broadleaf herbicide. Soil samples were collected in April for PPNT (continuing database) but N was sidedressed according to the PSNT in June. The PSNT (6/8/05) indicated N was necessary for CS1 (120 lb N/a) and CS2 (113 lb N/a) corn (applied as liquid urea), while the manured strips and corn in CS4 required no additional N sidedressing. The corn in the organic systems was planted on May 18th with an organic variety NC+42A32 but heavy weed pressure limited yields to less than 130 bu/a. Ground squirrels continue to be a problem on the CS2 corn particularly the plots close to pasture. The burrows continue to get baited with rodenticide (zinc phosphide) but it appears to be ineffective. Despite these gaps from the ground squirrels, the no-till corn out performed CS1 by

13 bu/a-- probably due to increased water availability, common to no-till systems, in this drought year.

The mean yields from 2003-2005 showed the manured edges in the conventional systems to be similar to the non-manured centers with ~50% less N fertilizer inputs (i.e. 66 vs. 122 lbs N/a). However, in CS3, heavy weed pressure has masked the effect of manure in 2005. The previous two years showed a significant effect of manure on CS3 corn out yielding the non-manured corn by 11 bu/a.

Soybean Phase

Soybeans were planted on May 10 and May 18 for CS2 and CS3/Chemlite respectively. A Roundup Ready (RR) variety was used on CS2 (Cropland RT 2089) and Chemlite (Dairyland DSR 184RR); an organically grown food-grade variety was planted in CS3 (IA 1008). As with the corn in CS2, the no-till beans performed the best in this dry summer showing the benefit of moisture conservation inherent in no-till systems. Aphids were also a problem and were managed in CS2 and Chemlite with a late July application of 'Warrior' insecticide. Yields were excellent for CS2 (59 bu/a) and Chemlite (55 bu/a) but markedly lower (25 bu/a) in CS3 due to heavy giant foxtail pressure. Due to frequent rains in May, only one rotary hoe and 1 row cultivation was done and the new tine weeder arrived too late to be effective on giant foxtail already > 3" tall. Beans however, were dry in time for wheat planting by October 5th.

Wheat/Red Clover Phase

Growing conditions in the fall of 2004 allowed good wheat stands but winterkill was prevalent during the open/icy conditions of January 2005. This left gaps for weeds to thrive. Yields were only 50 bu/a on the organic plots (CS3) vs. 79 bu/a on Chemlite. This is most likely due to the spring-applied N added to the Chemlite plots.

Forage Phases

'Magnum V' was seeded on April 14th in both CS4 and CS5. In addition CS5 was planted with, 'Forage Plus' oats and Trapper field peas. The alfalfa in CS4 was stunted, chlorotic, and non-competitive with weeds due to the dry April weather. Post-emergence herbicide was delayed until the alfalfa plants recovered. The oats and peas in CS5 seeding seemed to be growing well but the alfalfa underneath was slow to grow. The alfalfa roots were likely infected with disease or had succumbed to desiccation and as a result, only one cutting was taken before reseeding 'WL346LH' alfalfa on August 17th. Two cuts were taken from the new seeding in CS4 and 4 cuts were taken on all of the established forage plots. We continued to collect yield data from the exclusion areas within each pasture using a sickle-bar mower. Pasture quality was again comparable to the established alfalfa but 2005 yields were only much lower (only 67% of alfalfa). The cool season grasses in the pastures were more severely hampered by the dry conditions in April and June than the established alfalfa stands. The heifers received supplemental hay was supplemented starting July 8 through mid-August and again in mid-September to the end of the season. This was the situation across southern Wisconsin as graziers scrambled to buy more hay. Heifer performance was less than ideal at 1.4 lb gain/day.

Arlington Agricultural Research Station – 2006 Report

Janet Hedtcke, Bill Stangel and Josh Posner

The 2006 season was excellent for grain and forage production. Frequently and timely rainfall benefited most crops for most of the season, though the onset of hot summer temperatures and dry weather in mid-July during corn pollination was probably the cause of reduced seed set on the cobs. Soybeans produced some of the highest yields in 2006 over the history of WICST. The season came to an abrupt end in mid-October with frigid temperatures and snow beginning Oct 10th. As a result, fall field work was challenging and some tillage was done under less-than--ideal soil conditions.

Weed seed bank, as a "system criteria" has been measured for the last three years in the plots that are coming out of corn. The soil is sampled (0-6") in mid-April and put into flats in the greenhouse and the weed seeds then germinate and are counted. Also, to quantify weed pressure further, weed biomass was collected in the corn phase across the systems in August 2006 from the plot centers (Table 1). Plot edges (manured and non-manured) in CS1 and CS2 were also sampled. The analysis shows the edges to be significantly more weedy than the centers for both grass and broadleaf weeds (data not shown; $p<0.0001$) but there was no effect of manure on weed biomass in either CS1 or CS2. Giant foxtail was the predominant grass in CS3 (the summer fallow seems to be suppressing the quackgrass) while lambsquarter and pigweed are the primary broadleaf weeds; thistle has been observed in many plots along the edges as well. In order to deal with this problem of additional weed pressure along the plot borders, it was decided to keep the alleyways between plots tilled, and in the high input systems (CS1, CS2, CS4) we are considering more aggressive herbicide treatments, as it is obvious the weeds are migrating from the alleys.

Table 1. Weed pressure across systems from middle of plot in 2006.

	Grass	Broadleaf
	Dry biomass (grams/25sq ft)	
CS1	9.8b	7.5b
CS2	18.4b	5.0b
CS3	74.3a	10.0a
CS4	9.2b	5.6b
CS5	20.2b	4.4b
Overall p-value	*0.0001*	*0.3340*

In the fall of 2005, it was decided to switch manure sources from semi-solid (West pit; stanchion barn) to slurry (East pit; freestall barn) as well as manure application equipment. This decision was partly based on improving application precision which was difficult with the 'Slinger' spreader. Further, as the trend across Wisconsin of herd expansion and larger manure storage continues, we felt it was more common to use slurry rather than semi-solid manure. Thirdly, we wanted to be in step with the new 590 standards and improve the nutrient management on WICST which meant partitioning the manure differently between alfalfa and corn phases, with less applied after alfalfa plowdown and more in front of the alfalfa seeding. On November 10, 2005, manure was applied with a custom operator's equipment (7800 gal tractor-pulled tanker) with manifold system for uniform application followed by an airway for minor incorporation.

Within 3 days, manure was incorporated (with the chisel plow) on CS1 and CS3 and surface applied (other than the airway) on CS2. It was immediately obvious that this application equipment was uniform and precise.

Corn Phase

Corn was planted on April 28th in the conventional systems and on May 23rd in the organic systems. A stretch of cold, wet weather stalled plant emergence for 2 weeks starting around May 8th. On the other hand, corn planted in late May emerged within 4 days during an unusually hot period around Memorial Day. It was evident from the PPNT that there was little residual N carried over from last fall in CS1 and CS2. The PSNT called for full N rates on CS1 and CS2 even. Nitrogen was sidedressed with 28% but in hind sight, it would have been better to apply N pre-plant or at least apply more N in the starter. System 2 (no-till c-sb) was particularly chlorotic for several weeks before and immediately after sidedressing. For 2007, it was decided to increase the N-application as starter fertilizer from the current 5 to 20-30 lb N/a as well as going back to preplant N applications. The stands in CS3 continue to be less than optimal even though we used corn with the seed coating 'Natural II' this season. The same variety planted on the same date in CS5 and in the 'Organic corner' doesn't seem to have this problem. Is untreated corn following small grains at higher risk to insects/disease than corn following alfalfa or soybeans?

Soybean Phase

Soybean yields were impressive, with 64 bu/a for the no-till drilled beans and 59 bu/a for the organic beans in CS3. It seems the combination of moldboard plowing last fall after the corn phase and timely mechanical weed control this spring were crucial. The addition of the tine weeder has given us a tool to use during the period between the last rotary hoeing and before the plants are large enough to withstand row cultivation. Hand weeding was again limited to 2 man-hours/acre which is about the limit possible on organic farms. Further, during this hand weeding phase, plots can be scouted as well which improves overall management.

Wheat/Red Clover Phase

Summer tillage after wheat harvest in CS3 was continued this summer. The 'quack digger' was used 2x before preparing the seedbed for berseem clover companion seeded with oats. Red clover was kept in on the Chemlite wheat plots since weed control is not a problem and yields were phenomenal at 2.87 tons DM/a (and 135 lb/a of N credit). The summer seeding of oats and berseem cover crop was well established but biomass estimates were much less that the spring established red clover and only provided a nitrogen credit of 45 lb N/a.

Forage Phases

This was also an excellent year for grass and forages. The pastures approached 6 tons DM/a benefiting from a June application of N (60 lb N/a) and frequent rains. Heifers had their best performance in years (2.2 lb/d). 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 have also been a problem in the alfalfa requiring insecticidal treatments on CS4. Alfalfa stand establishment in CS4 and CS5 continues to be a struggle in cold, wet springs likely due to diseases like aphanomyces present in the soil. However, adequate moisture throughout the season provided three forage cuttings.

WICST EDUCATIONAL OUTREACH 2005 and 2006

Janet Hedtcke[1]

In addition to quantifying production, profit, and environmental impacts of different farming systems, WICST serves as an 'honest broker' for discussing the importance of a prosperous and environmentally sound agriculture, how these values will affect the future of farming in Wisconsin, with results having policy ramifications. To this end the desire is to inform and educate the farm and non-farm population by informing them of the constraints and opportunities in maintaining a healthy and productive landscape.

WICST continues to serve as an 'outdoor laboratory' for learning about issues of sustainable agriculture such as crop rotation, environmental stewardship, and economic sustainability. Multi-disciplinary research is continually encouraged and sought after. In addition to field tours, we have disseminated WICST results at local and regional events as well as scientific meetings. Table 1 summarizes the outreach and educational activities for WICST in 2005 and 2006. WICST abstracts, theses and publications are listed in Appendix XI.

Our website (www.cias.wisc.edu/wicst) continues to get updated to provide information for a worldwide audience and we frequently receive emails and phone calls generated by the website.

On-station. Field tours were given throughout each year to several groups including extension agents, local farmers, and UW students and foreign visitors. The major outreach activities were the Agronomy/Soil Science Departments' annual field day (140 visitors) in 2005 which included a tent-session focused on our Linking Farms Project and student tours for youngsters learning about crops and agriculture. WICST, in collaboration with Grassworks, also featured an Uruguayan speaker presenting data on cropping systems of Uruguay.

In addition to field days, WICST held its annual winter meeting on February 18, 2005 and February 17, 2006 discussing WICST data to a mixed audience of farmers, USDA staff, UW faculty, UW Extension, Ag consultants, UW students, and MFAI collaborators. Topics included soil chemical and biological characteristics of the WICST systems; nutrient management; an update on the Linking Farms project; as well as on-farm experiences in with land use such as grazing and alternative forages. Organic crop production and weed control was also an important discussion point at the meetings. Linking Farms data was shared with the collaborating farmers in the winter of 2006/07 at three of the dairies involved in the project.

Local/Regional. Research data from the WICST projects was presented in both oral and poster form at ASA, CSSA, SSSA annual meetings in Salt Lake City, Utah (2005) and Indianapolis, Indiana (2006). Other presentations were made by Posner and Hall on cropping systems and ecosystem services to USDA-ARS and NSF in the past 2 seasons. Hall and Hedtcke attended the North Central Cover Crops Summit sponsored by the Kellogg Biological Station in Battle Creek, Michigan where researchers from the Great Lakes region addressed research themes around perennialization and increasing the use of cover crops. A large team effort included 3 on-farm

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presentations in the winter of 2006-07 to discuss the data with the collaborating farmers in the Linking Farms project and to talk about future research ideas with them.

Table 1. Outreach activities involving the WICST project in 2005 and 2006.

	EVENT	LOCATION	DATE	ATTENDANCE
2005				
	NSF -Valuation of Ecosystem Services and Agriculture Workshop	Austin, TX	January	
	WICST Winter Meeting	Madison, WI	February 18	32
	'Land Use in WI' Soils mini course at plots	Arlington, WI	Late May/early June	20
	SE Grazing Network: Quinney Farm Field day	Elkhorn, WI	July 20	20
	Agronomy/Soils Field Day – tent session	Arlington, WI	Aug 31	100+
	CSP field day in	Beaver Dam, WI	Sept 28	100
	NSF -Valuation of Ecosystem Services and Agriculture Workshop	Augusta, MI	Oct 26-28	
	ASA, CSSA, SSSA	Salt Lake City, UT	Nov. 6-10	1500
	Review Panel for the Long-term Field Experiment to Evaluate Sustainability of Organic and Conventional Cropping Systems	Beltsville, MD	Nov. 17-18	
2006				
	WI Fertility, AgLime & Pest Mgt Conf.	Madison, WI	Jan. 17-19	300
	ARS Dairy Forage Stakeholder Conference	Madison, WI	Jan 19-20	25
	WICST Winter Meeting	Madison, WI	February 17	29
	McKnight Foundation's Feedstocks for Biofuels Symposium	MN	March	
	Local area schools crops tours	Arlington, WI	May 8-12	100
	'Land Use in WI' Soils mini course at plots	Arlington, WI	Late May/early June	20
	SE Grazing Network: Quinney Farm field day		May 30	30
	NCR Cover Crop Summit	Battlecreek, MI	Aug. 2-3	30
	Alejandro Francisco La Manna	Arlington, WI	Aug. 9	35
	ASA, CSSA, SSSA	Indianapolis, IN	Nov 12-16	1500
	Linking Farms On-farm presentations to grain and dairy farmers at 3 dairy farms	Elkorn, WI Arlington, WI Fitchburg, WI	Winter 2006-2007	6 8 5

COMPARISON OF WICST FORAGE SYSTEMS:
Productivity and Profitability from 2004 to 2006

Janet Hedtcke[1] and Josh Posner[2]

INTRODUCTION

The dairy industry is undergoing rapid change within Wisconsin (CIAS 2005; PATS 2005). In addition to the trend of increasing animal concentration and custom feed production, other producers are looking to alternative markets such as grass-fed and organic labels to increase their profitability. Each strategy implies a somewhat different forage production approach. In this study we are looking at the productivity and quality of conventionally produced forage and comparing it to an organic forage rotation and a grazing system, all of which have been in place for over 15 years on the WICST project.

METHODS

The three forage-based cropping systems of WICST include the industry standard - an intensively managed alfalfa system (a-a-a-c), an organic forage rotation including a companion seeding of alfalfa with oats (o/a-a-c) and a permanent cool-season grass-legume pasture rotationally grazed by dairy heifers. The conventional and organic forage systems receive dairy manure before and after the corn phase while the pasture receives the droppings by the heifers and more recently, 50 lbs N/a (as urea) in late spring.

First-year established forage production of conventional and organic forage system and continuous production of the pasture were evaluated between 2004 and 2006. The target was to harvest the conventional system 4 times during the first hay year while the organic forage and pasture exclosures were harvested 3-4 times/year depending on regrowth.

Proc mixed with repeated measures was used to test systems. All effects in the model are fixed except replicate, which is random. Alpha=0.10. Forage yields were measured and grab samples taken on each plot at each harvest for forage quality analysis. Milk2000 (Shaver et al. 2000) was used as a measure of feed value and is expressed as pounds of milk per ton DM of forage.

RESULTS

Surprisingly, mean yields during the three-year study were equal ($p<0.2339$) among the three systems at 4.56 ton DM/a. However the year by system interaction was highly significant (**Fig. 1**). The conventional and organic forage systems, primarily based on alfalfa, were comparable in yield two of the three years. But in the dry year of 2005, the organic system produced less than the conventional and the pasture system produced poorly (**Fig. 1**). In 2004 and 2006, April through September rainfall was 24 and 28 inches respectively, slightly above the 30-yr norm of 23 inches, but the 2005 season only received 18 inches and nearly a third came after the final cutting (August 19th). The cool-season grasses in the pasture with their relatively shallow root systems restricted production in dry conditions, commonly referred to as the 'summer slump'. Patchy winterkill in January of 2005 impacted the established alfalfa stands reducing yields from the previous year. Machinery traffic in 2006 may also have impacted alfalfa yields more so compared to pasture which only has the weight of the animals.

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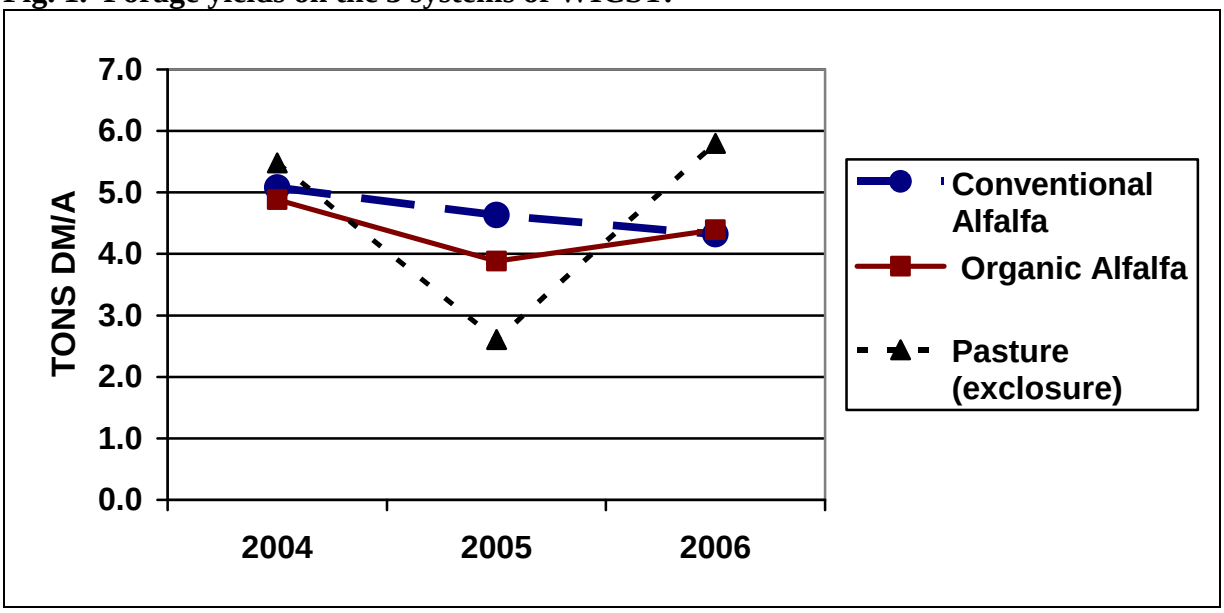
Fig. 1. Forage yields on the 3 systems of WICST.



(hay1.lst)

Milk per ton across years was highest for pasture at 3318 lbs ($p<0.0001$) and there was also a year effect ($p<0.0001$). Milk per ton was generally higher in the dry year of 2005 (**Table 1**). Crude protein, weighted on yield, was consistently highest for conventional but all systems were above the 17% level recommended for lactating dairy cows (NRC, 2001).

Table 1. 'Milk2000' output on the 3 forage systems of WICST

	2004	2005	2006
	----------lbs milk/ton DM----------		
Conventional Alfalfa (CS4)	3,064c	3,250b	2,866d
Organic Alfalfa (CS5)	2,785d	3,226b	3,128c
Pasture exclosure (CS6)	3,054c	3,440a	3,461a
*p-value (year*system)*	*0.0001*		

(asamilk1.lst)

One thing that isn't obvious from the yield values is the amount of weeds in the system. In the seeding phase of CS5, first crop has a lot of annual weeds such as pigweed and lambsquarter, which often forces an early harvest to keep the weeds from maturing. While the annual weeds are reduced in abundance after harvesting the seeding phase, the following established hay phase has a higher component of quackgrass than the other systems. Below-ground biomass data from 2005 shows that quackgrass rhizomes were 20% of the CS5 biomass vs. just 4% of the CS4 root biomass (Table 2). Though not a major factor in reducing forage quality (Table 3), the quackgrass can be a problem in the subsequent corn phase.

Table 2. Composition of below-ground biomass from plowdown alfalfa phase preceding corn in 2005			
	biomass in g/m^2 (% of total)		
	Alfalfa	Quackgrass	Annual weeds
Conventional Alfalfa (CS4)	348 (82)	14 (4)	62 (14)
Organic Alfalfa (CS5)	372 (79)	102 (20)	6 (1)

Table 3. Quality comparisons weighted by seasonal yield (2002-2006)			
	RFQ	% crude protein	lbs milk per ton
Conventional Alfalfa I (CS4)	167	21.0a	3,057b
Conventional Alfalfa II (CS4)	176	20.8ab	3,118b
Organic Alfalfa (CS5)	162	19.6bc	3,028b
Pasture exclosure (CS6)*	162	18.1c	3,320a
p-value	*0.4590*	*0.0270*	*0.0486*

* 2004-2006 only

(forage.lst)

CONCLUSIONS

WICST data has shown that alternative forage production systems are competitive with the conventional approach. Both organic forage production and rotationally grazed pasture are productive systems with suitable quality forage for many classes of livestock but are more risky in drought years. The combination of good productivity and quality with reduced inputs make these alternative systems competitive with the high input alfalfa system.

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ANALYSIS OF WICST CROPPING SYSTEM 5 ALFALFA K FERTILIZATION TRIAL

Jon Baldock, Janet Hedtcke, Josh Posner

INTRODUCTION

After approximately 15 years, several plots in the organic dairy rotation (CS5; corn-oats/alfalfa-alfalfa) of WICST have soil test K (STK) levels that have decreased to the optimum level or below so alfalfa yield may be limited. This is despite manure applications in 2 out of 3 years of this rotation. Potassium sulfate (K_2SO_4) is an organically approved fertilizer that should increase K availability to alfalfa. Some organic advocates suggest that organically managed soils may be more efficient in making nutrients available to plants than traditional soil tests predict. Since our plots have been managed organically since 1990, we felt that the system was at or near equilibrium. In 2005 and 2006, we superimposed a potassium study on the alfalfa production phase of CS5 to determine if we should start applying K to these organic plots.

METHODS

To determine if applying K_2SO_4 fertilizer might reverse the decrease in STK and ensure adequate plant K content for optimum yields, 360 lbs/acre of K_2SO_4 (as 50% K_2O equivalent, this was an addition of 160 lb/a K_2O) was top dressed on a portion of three plots after first cutting in 2005 and to another three plots in 2006. In CS5, the soil pH levels are near optimum for alfalfa production and the yield levels historically have been in the 3.5 to 4.5 ton DM/a range, similar to those in the conventional alfalfa plots. Three soil test and plant analysis samples were taken on the treated area and an adjacent untreated area in mid-to-late August just prior to harvesting the third cutting of alfalfa. Since there were 2 years x 3 plots (or blocks) x 2 treatments x 3 samples there were 36 observations in this trial. Whole above-ground alfalfa plants were taken as the plant part in both years as well as the top six inches of the plant in 2006. Though whole plant samples don't have established plant analysis norms, the relative whole plant analysis K content (WPAK) should provide insight into whether or not the K_2SO_4 fertilization increased K uptake. Also, the soil test results should determine if there was a measurable increase in plant available STK in such a short time after fertilization. In addition to also sampling the top six inches of the plant (TopPAK) in 2006, yield data was collected from each area that year. To reduce the legacy of this study on future crops in the rotation, the fertilizer treatments were not randomly assigned to the areas within each plot, but this has been ignored in the following analysis.

The model equation for the statistical analysis of WPAK and STK was

$Y_{hijk} = \mu + Yr_h + \beta_i + \tau_j + (Yr\beta\tau)_{hij} + \delta_{hijk}$, where

- Y_{hijk} = the hijk-th observation on STK or WPAK;
- μ = the overall mean;
- Yr_h = the effect of the h^{th} year, h=1,2;
- β_i = the effect of the i^{th} block, i=1,2,3;
- τ_j = the effect of the j^{th} treatment, j=1,2;
- $(Yr\beta\tau)_{hij}$ = the year x block x treatment interaction, that is, the deviation of the hij^{th} year x block x treatment combination from the additive effects of the first three terms in model;
- δ_{ijk}= the sampling error, k=1,2,3; (the deviations between samples within an area).

The model used had treatment as the only fixed effect and we pooled experimental and sampling errors since each contributed an insignificant amount relative to the residual. Thus, the expected or average values are $E(\tau_j)= 0$; and the variance is $Var(\tau_j)=Q[\Sigma(\tau_j)]$; that is, the fixed effect has a mean of zero and a variance that is a function of its sum of squares. Examination of normal scores plots showed WPAK and STK data to be normally distributed and only a hint of skewness for WPAK mostly due to one outlier. Residual scores plots showed a fairly random distribution for WPAK but one outlier in STK tended to suggest a hint of increasing variability with increased STK levels. We did not remove the outlier since we didn't have an insight to its history and considered it part of the variability inherent in field-scale studies. For the data collected in 2006 only (yield and TopPAK), the block, treatment, and block x treatment effects were considered fixed because the results only apply to this trial this one year.

RESULTS

Table 1 shows there was a significant difference between the fertilized and unfertilized areas in STK (P=0.03%) already two months after the fertilizer was applied. Table 2 illustrates that the difference was due to fertilizer raising the STK from 90 ppm, which was in the low category (70 to 90 ppm), to 121 ppm, which was in the high category (121 to 150 ppm). The advantage for fertilized over unfertilized areas was consistent over blocks and years (Table 3). The year x treatment interaction was not significant for WPAK or STK using the likelihood ratio test [p-values of 0.75 and 0.32, respectively (Littell et al., 2006)].

Peters et al (2005) recommend approximately 200 lb K2O/a be applied annually to optimize yield and stand quality and to maintain soil test in the optimum category. They also found that keeping STK levels in the optimum range was the best strategy for keeping forage tissue K levels in acceptable ranges for use as dry cow and early lactation dairy feed as high tissue K levels (>3%) can cause serious metabolic disorders.

The increase in STK due to addition of K_2SO_4 led to a significant increase in WPAK (P=0.01%, Tables 4). The fertilized WPAK (2.45%) was significantly more than that of the unfertilized treatment (1.96%), and is sufficient to avoid predicted yield loss (Table 5). Similar to STK, the WPAK advantage for fertilized over unfertilized areas was consistent over blocks and years (Table 6). The Sufficiency Range method of interpreting plant analyses judged the WPAK in the no added K treatment as "low" in 15 of 21 samples and the WPAK in the added K treatment as "low" in only 5 of 21 samples (Pearson's Chi-Square test was highly significant at 0.2%). The PASS system, which considers both the absolute and relative nutrient concentrations, put 19 of the 21 untreated samples in the almost certain yield response category but only 7 of 21 of the added K treatment in that same category (Pearson's Chi-Square test =0.01%). The low K concentrations may be due to sampling the entire plant instead of the top six inches for which the norms were developed (see 2006 data at end of this report) or because there was not sufficient time from fertilizer application to plant sampling for much K uptake to occur.

Nevertheless, the significant, linear dependence of WPAK on STK (Fig. 1) suggests that sufficient plant levels of K can be achieved by raising STK. This relationship also suggests that a STK level of near 112 ppm will be necessary to reach a WPAK level that would not be considered low by either the Sufficiency Range or the PASS systems (e.g., 2.30%). This is

lower than the STK level of 150 ppm that Dwayne Rohweder advocated for alfalfa lending support to the contention of some organic advocates that organically managed soils make nutrients more available to plants than traditional soil tests predict. However, a disclaimer is necessary: To soundly test differences in nutrient uptake efficiency between organic and conventional systems, a more thorough, randomized experiment with alfalfa managed both organically and conventionally, with and without K fertilizer, would be necessary to compare the slopes of the WPAK vs. STK. Of course the method is not limited to alfalfa or to K; any crop and nutrient combination for which there are adequate soil and plant assays could be studied. In such studies it is debatable whether top-six-inch or whole-plant samples would be best.

2006 Season -Additional Data

As alluded to earlier, the top-six-inch samples of alfalfa have established norms for which yield predictions have been made. In 2006, like the WPAK data, we found that TopPAK was significantly higher ($p<0.01\%$) under the fertilized treatment vs. the no K treatment but unlike WPAK data, both treatments had levels sufficient for maximum yield potential (Table 8). Because TopPAK was sufficient in the no K plots, we found no yield response to the added K. This may be an effect of the season (Fig. 2) which had ample rainfall and thus probably more available K for uptake. In contrast, 2005 was much dryer but we can only speculate that reduced K uptake may have reduced yields in plots with STK levels in the optimum or lower range.

SUMMARY

This trial demonstrates that K_2SO_4 is an effective means of increasing STK and PAK (both whole plant and top 6 inches) in alfalfa in CS5 of the WICST. However, one year of yield data did not show a benefit from added K. Nonetheless, this trial illustrates how an experiment might be designed to test the hypothesis that that organically managed soils may make nutrients more available to plants than traditional soil tests predict. We will use this data to aid our fertility management on the organic WICST plots but a more elaborate, trial should be conducted that is not constrained by the bigger objectives of a long-term research trial such as WICST.

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Table 1. Type 3 Analysis of Variance for STK

Source	DF	Sum of Squares	Mean Square
trt	1	8867.361111	8867.361111
year	1	306.250000	306.250000
block	2	3213.500000	1606.750000
block*year	2	740.166667	370.083333
Residual	29	15439	532.395594

Effect	Num DF	Den DF	F Value	Pr > F
trt	1	29	16.66	0.0003

Table 2. STK Least Square Means for Treatments.

trt	Estimate	Standard Error	DF	t Value	Pr > |t|
K	121.28	7.5926	29	15.97	<.0001
no K	89.8889	7.5926	29	11.84	<.0001

Table 3. STK Means for Block*Treatment Combinations.

Obs	year	block	trt	FREQ	STK (ppm)
1	2005	1	K	3	155.667
2	2005	1	no K	3	87.667
3	2005	3	K	3	130.000
4	2005	3	no K	3	98.000
5	2005	4	K	3	109.000
6	2005	4	no K	3	70.667
7	2006	1	K	3	112.000
8	2006	1	no K	3	96.667
9	2006	3	K	3	116.667
10	2006	3	no K	3	101.333
11	2006	4	K	3	104.333
12	2006	4	no K	3	85.000

Table 4. Type 3 Analysis of Variance for WPAK (whole plant analysis K)

Source	DF	Sum of Squares	Mean Square
trt	1	2.141344	2.141344
year	1	2.064011	2.064011
block	2	0.744739	0.372369
block*year	2	0.560039	0.280019
Residual	29	2.129956	0.073447

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
trt	1	29	29.16	<.0001

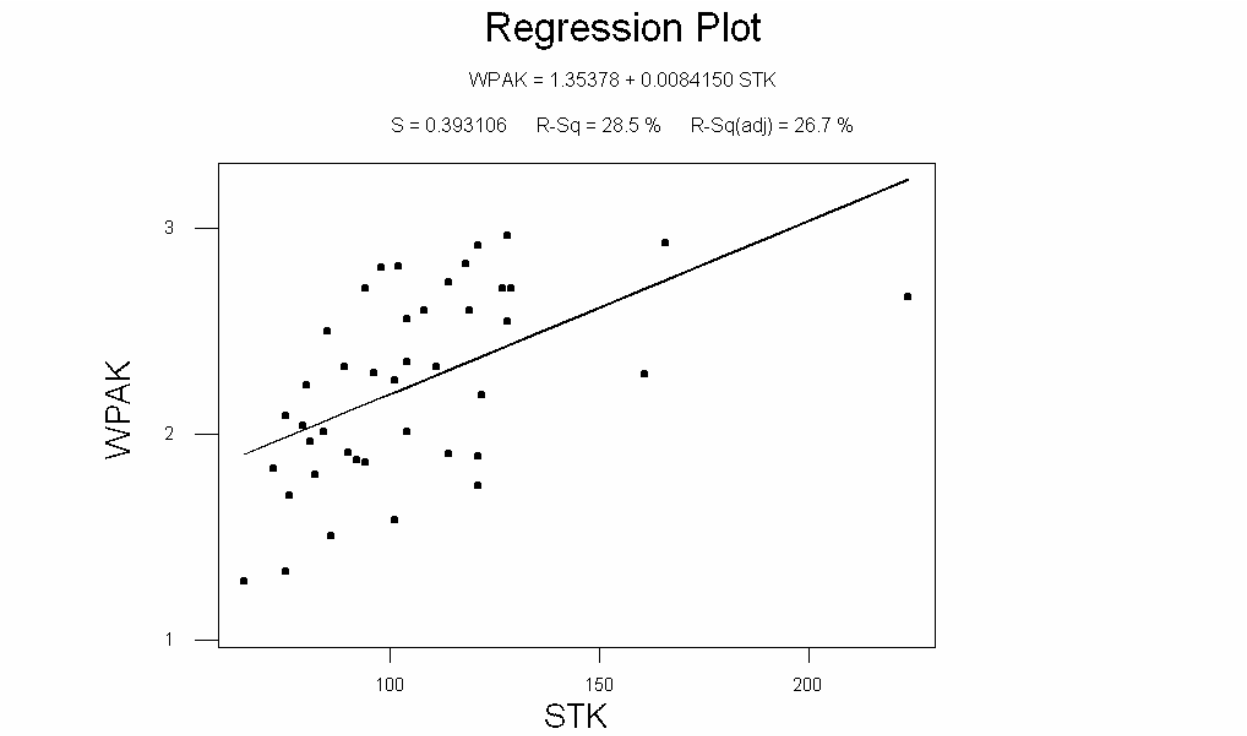
Table 5. WPAK Least Squares Means for Treatments.

trt	Estimate	Standard Error	DF	t Value	Pr > |t|
K	2.4483	0.2489	29	9.84	<.0001
no K	1.9606	0.2489	29	7.88	<.0001

Table 6. WPAK Least Squares Means for Block*Treatment Combinations.

Obs	year	rep	trt	FREQ	WPAK
1	2005	1	K	3	2.25000
2	2005	1	no K	3	1.59333
3	2005	3	K	3	2.36667
4	2005	3	no K	3	2.26000
5	2005	4	K	3	1.84000
6	2005	4	no K	3	1.48000
7	2006	1	K	3	2.71000
8	2006	1	no K	3	2.19000
9	2006	3	K	3	2.71000
10	2006	3	no K	3	2.22000
11	2006	4	K	3	2.81333
12	2006	4	no K	3	2.02000

Fig 1. Linear Fit of WPAK(%) by STK (ppm) on 2 years of data (n=42).




```
The regression equation is
WPAK = 1.35 + 0.00842 STK

Predictor        Coef     SE Coef          T        P
Constant       1.3538      0.2311       5.86   0.0001
STK          0.008415    0.002109       3.99   0.0001
```

Table 7. Summary of Fit – WPAK as linear function of STK.

Measure	Value
RSquare, %	28.5
RSquare Adj, %	26.7
Root Mean Square Error	0.3931
Observations (or Sum Wgts)	42

Table 8. Type 3 Tests of Fixed Effects for TopPAK

Effect	Num DF	Den DF	F Value	Pr > F
rep	3	16	1.46	0.2627
trt	1	16	39.05	<.0001
rep*trt	3	16	2.04	0.1495

Least Squares Means

Effect	trt	Estimate	Standard Error	DF	t Value	Pr > |t|
trt	K	3.2175	0.07383	16	43.58	<.0001
trt	no K	2.5650	0.07383	16	34.74	<.0001

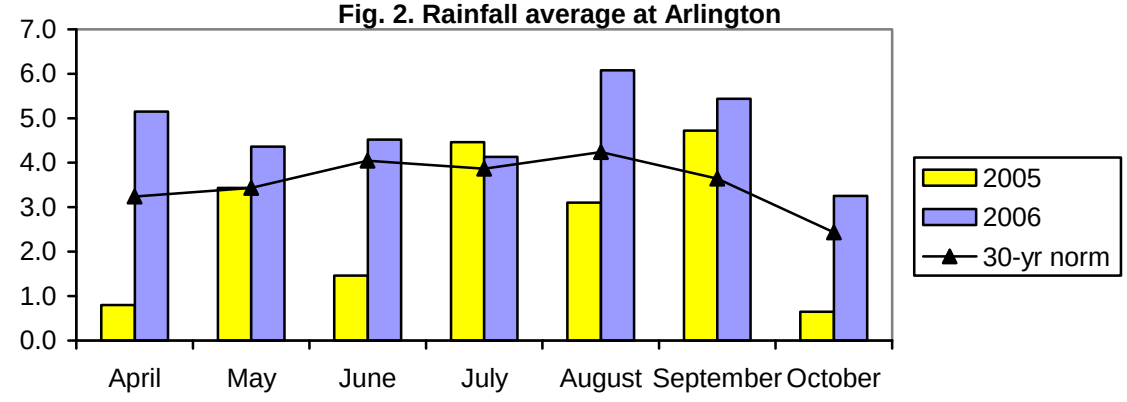
Table 9. Type 3 Tests of Fixed Effects for Yield

Effect	Num DF	Den DF	F Value	Pr > F
rep	3	16	4.31	0.0208
trt	1	16	1.55	0.2313
rep*trt	3	16	1.30	0.3100

Least Squares Means

Effect	trt	Estimate	Standard Error	DF	t Value	Pr > |t|
trt	K	0.9425	0.05541	16	17.01	<.0001
trt	no K	1.0400	0.05541	16	18.77	<.0001

Fig. 2. Rainfall average at Arlington



ROTATIONAL GRAZING WITH DAIRY HEIFERS ON WICST:

a. Pasture Productivity, Heifer Weight Gain and Profitability (2000-2006)

Janet Hedtcke[1] and Josh Posner[2]

INTRODUCTION

Profitable livestock production is the objective of all forage systems. Managed grazing continues to be an attractive option for many because of its relatively low capital investment as well as the aesthetically pleasing and appealing lifestyle it offers. The business of custom raising dairy heifers has grown rapidly in the 1990's and by 2000 it was estimated that 27% of these operations used pasture for raising heifers (Wolf 2002). Further, grass fed livestock operations are finding a niche market with health conscious consumers. Some literature has indicted that the milk and meat from grass-fed cattle are higher in conjugated linoleic acids and these reduce the risk of cancer (Floris et al, 2006, White et al, 2001, Jahreis, 1997). Providing adequate forage availability and quality throughout the growing season is essential for optimal animal performance, but can be more challenging with grazing than haying--particularly in dryer years which can dramatically affect pasture rest and regrowth cycles. In this report, we focus on the productivity and profitability of the grazed paddocks on WICST in 2005 and 2006 and place that data in the context of 2000 through 2006 seasons.

MATERIALS AND METHODS

Background

Pastures were established at the Arlington Agricultural Research Station (ARS) in 1990. Initially, species included red clover (*Trifolium pratense*), smooth bromegrass (*Bromus inermis*) and timothy (*Phleum pratense*); later, orchardgrass (*Dactylis glomerata*), perennial ryegrass (*Lolium perenne*) and reed canarygrass (*Phalaris arundinacea*) were also included (see Table 1 for recent seeding dates and rates). At ARS, severe winterkill of the grasses required reseeding in 1992 and slow establishment due to drought delayed grazing until the spring of 1993. Red clover has been frost seeded (no-till drilled) at 8-12 lb/a nearly every other year since disease (i.e. verticillium wilt) tends to reduce its longevity. Severe drought in the spring of 2005 caused the failure of the clover seeding that year so it was seeded again in 2006.

Table 1. Seeding information on the Arlington pasture plots on WICST since 2000.

Year	Date	Variety and Species	Seeding rate lb/a
2001	April 13	'Arlington' red clover	12
2003	April 2	'Arlington' red clover	8
2005	April 9	'Arlington' red clover	12
2006	March 29	'Marathon' red clover 'Elgon' perennial ryegrass	10 4

Pasture Management

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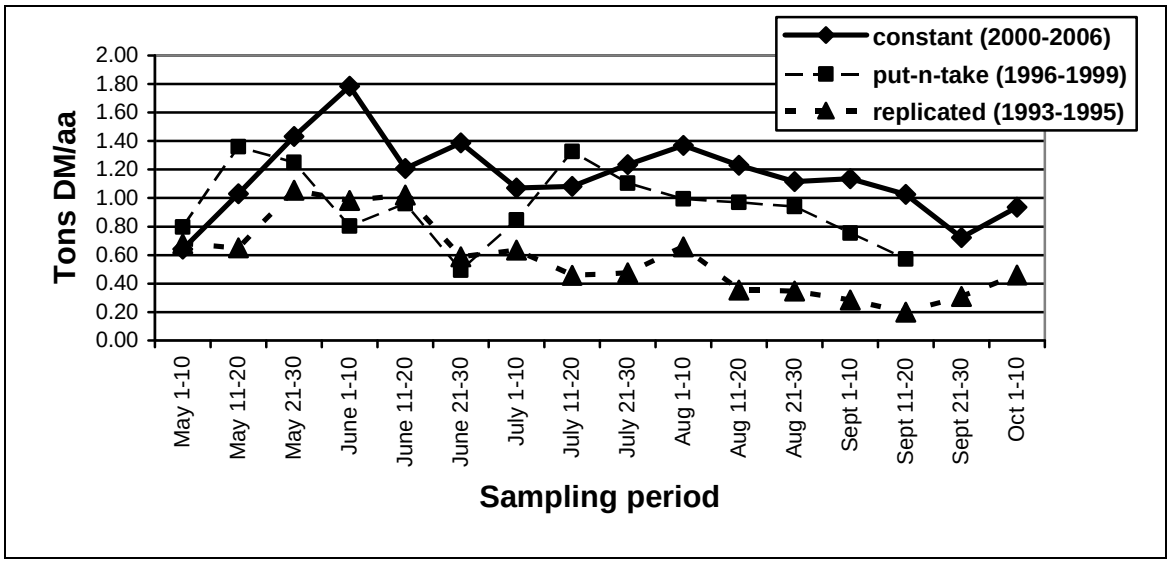
Throughout the history of the trial, dairy heifers were cycled 5-6 times per season through the four pasture plots at each site. Three grazing management strategies have been used over the 15 years of WICST (see WICST 9th Report, p. 21).

- 1992-1995. A replicated management system where there were 2 heifers/plot on each of the 4 plots = 8 heifers;
- 1996-1999: A put-and-take system of initially a 12 heifer cohort until about June 10th and then a 6 heifer cohort that continued to rotate among the 4 plots;
- 2000-present: A constant stocking rate of four-to-five heifers for the entire season, again treating them as a cohort across the plots.

The disadvantage of this "cohort" system is that there are not 4 replicate plots per year, each with its individual forage productivity and animal weight gain, but instead, a single result. However, 'year' replaces replicates in the analysis of variance of heifer performance. This system with its constant stocking rate has resulted, not surprisingly, in some haying in the early spring (average annual yield of 0.62 tons DM/a; Appendix 1). Although each season is different, our strategy has been to take hay from one plot in mid-May, before the paddocks get too mature and a second paddock in mid/late June if the intervening period has had good moisture and the pasture is again regrowing adequately. With the higher temperatures of summer, the paddocks grow more slowly and the growing heifers keep up with production. Occasionally, hay supplementation has been offered if forage regrowth in the middle of summer is not adequate. In 2003 and 2005 the heifers were fed some of the harvested hay in late summer. In addition, body condition is continuously monitored to determine corn supplementation rate. In general 2 lbs/d is fed to each animal for most of the season.

As can be seen in Figure 1, the current stocking rate and treating the animals as a cohort is offering the animals more forage throughout the season than the other two earlier systems. It appears that during both the replicated management system (2 heifers/plot on 4 plots = 8 heifers) and the put-n-take system (12-then-6 heifers on 4 plots) the paddocks were overstocked and with our current stocking strategy, we are making better use of our forage resource.

Fig. 1. Forage availability on CS6 over the course of the trial under 3 stocking systems (management system p-value = 0.1258)



In both 2005 and 2006, 5 heifers at approximately 500# each were placed on the 2.8 acres of pasture for a stocking rate of 1.8 animals/acre (~0.9 animal units/acre). Paddocks were subdivided with temporary internal fencing. Heifers moved through each paddock in about a-week-to-9 days, allowing each paddock to recover for about 4 weeks. As in past years, seasonal *available forage or herbage mass* was estimated by clipping to ground level (i.e. 1 to 2-in. stubble), on a weekly basis, four random quadrats ($0.5m^2$) in the next area that the animals would be moved into. This information was graphed by pooling the harvest quadrat data and, depending on the period, each point represents the mean of between 6-12 sampling events that fell within the indicated 10-day period across the seasons (Fig. 1).

Forage was then dried (in 60°C oven for 48 hr) and expressed on a dry matter basis. Samples were also sent to the UW Soil and Plant Analysis Lab (SPAL) for quality analysis where NIRS was used to estimate crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF). Since 2002, RFQ (relative forage quality) has been provided with the forage analysis. It is more accurate predictor of quality than relative feed value (RFV) because it uses fiber digestibility as an indicator than just the amount of fiber present. This improvement is especially important for graziers as their paddocks are primarily grasses that have a higher digestible fiber than many legumes.

Herbicide. The plots are regularly scouted and spot-sprayed for thistle (Canada and biennials, *Cirsium* spp.) using stinger in a backpack sprayer (7ml of stinger/gal water). Typically, thistles have been found along the fenceline where the mower can't reach and less than 1 gallon of solution has been applied each year.

Clipping. Mechanical clipping (forage returned to plot) with a rotary mower (to about 4" stubble height) following a grazing episode has frequently been done after the 2nd or 3rd pass through the paddocks. This removes any escaped stems and seed heads as well as cuts back refused, overgrown forage, a strategy that improves pasture stand and quality. This activity is usually un-

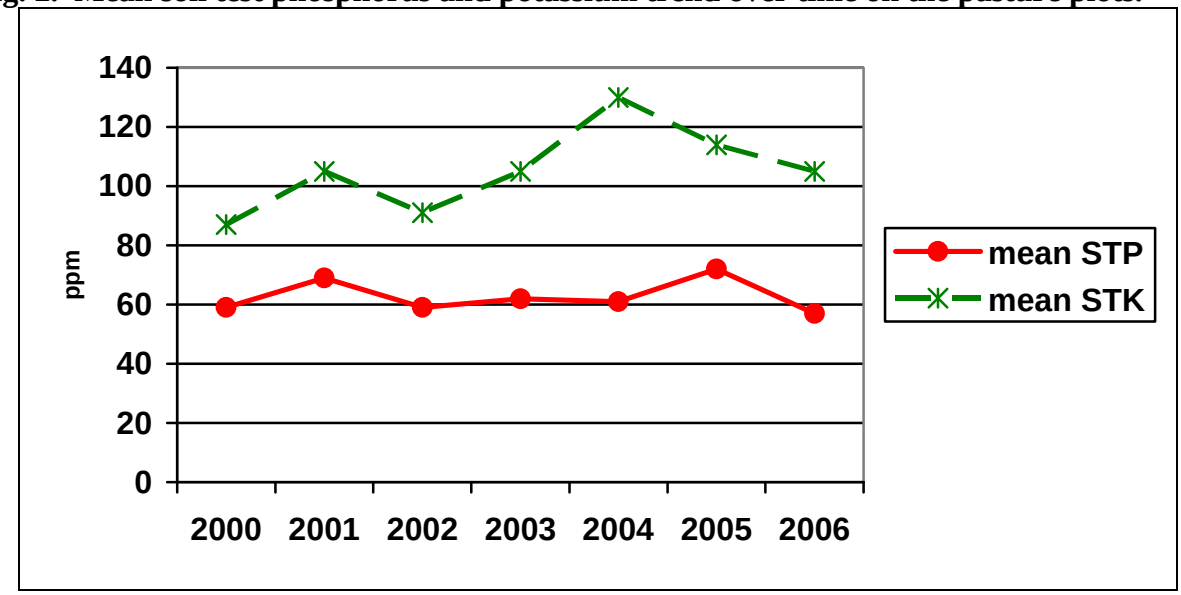
necessary beyond mid-July.

Nutrient management. In the past seven years, nitrogen fertilizer has been used sparingly (applied in 2000 and 2006 1x at 50 lb N/a) to simultaneously increase pasture grass production without depressing the clover component of the sward. Applications have been made in late-May to early June, based on moisture and growth rate (Cosgrove, 2006).

One would expect that soil test phosphorus (STP) and soil test potassium (STK) to remain fairly constant on the grazed plots since all the manure is directly returned to the paddocks. However, there is a small annual input and offtake of phosphorus and potassium. The grain supplement fed the heifers (approximately 1700 lb/year) results in annual input of approximately 8.5 lbs P/a/yr and 10.5 lbs K/a/yr. The annual net removal in the hay (approximately 0.62 tons DM/a/yr) is equivalent to 4 lb P/a/yr and 25 lb K/a/yr. And finally there is the weight gain of the animals (300 lbs live weight /hd) which results in another removal of 9 lb P/a/yr and 2 lb K/a/yr). The net annual budget is well balanced for P (-4.5 lbs/yr) while K was being drawn down at a slightly faster rate (-16.5 lbs/yr) for the years between 2000 & 2006.

This calculated phosphorus nutrient budget is well reflected in the soil test values (Fig 2). On the other hand, the soil test K levels climbed and then started to drop once we increased the stocking rate in 2003. Due to the heterogeneity of the individual samples (3 per paddock) we are now entering a maintenance fertility plan with K applications on a plot-by-plot basis.

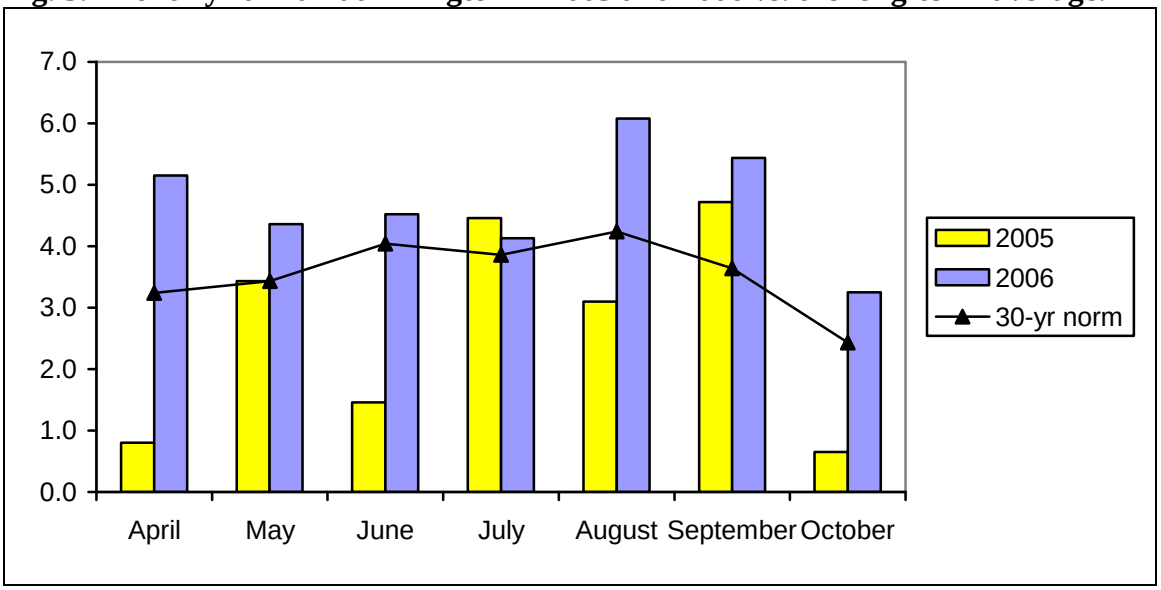
Fig. 2. Mean soil test phosphorus and potassium trend over time on the pasture plots.



Weather

The 2005 season is remembered overall as a drought year because there was little residual subsoil moisture, and both April and June were dry (Fig 3). Consequently, the spring flush was very limited for most of the season. In stark contrast to 2005, 2006 was excellent for forage production with frequent and timely rainfall, though the season ended abruptly in early October when low temperatures and frigid wind chills common to the latter half of the month forced us to return the cattle to the barn.

Fig. 3. Monthly rainfall at Arlington in 2005 and 2006 vs. the long-term average.



Heifer Management

2005. This marks the first year where the replacement heifers used on WICST have been raised off site. As part of a UW CALS, DFRC and NRCS collaboration, a new federal research facility, including a heifer rearing facility, was built at the Marshfield Research Station in central Wisconsin. More coordination was necessary to bring the heifers down to Arlington before the start of grazing and it was a challenging start to the grazing season. Ten animals were weighed at Marshfield, 5 remained there as the control and the other 5 were transported to Arlington on May 11th. As these heifers had never seen grass pasture before, an adjustment period should have been included. When the heifers were placed on pasture about 5 days after arriving in Arlington, two escaped (but were safely rounded up and returned to the pasture). The grazing season went from May 16th to November 1st (168 days on pasture). Due to a drought during the summer months, pasture grass growth was severely impacted in early June and supplemental hay was fed most of the summer for a total of 1601 lbs (*as fed)* supplemented to the group (320 lbs/hd). This was a common situation across farms in southern Wisconsin. Supplemental grain was also fed each day (2 to 4 lbs/hd/d) for a season total of 362 lbs/hd.

*2006***.** This season, five heifers were brought down from Marshfield in late April and were put on secure pasture with woven wire fence. The heifers were adapted for 10 days on this pasture and were trained with the electric fence. Another 5 animals served as the confinement group which remained housed at Marshfield. Both groups of heifers were shrunk weighed on May 1st and the grazing group was placed on pasture on May 2nd until October 25th (176-day season). An extended unseasonably cold, blustery, rainy weather pattern set in on May 11th which forced us to pull the heifers off the plots for about 6 days so they could have access to the barn. The season was cut short of our November 1st target date due to extreme cold conditions in late October. Heifers cycled through the plots 5 times this season. Ample rainfall, excellent water holding capacity of the soil, and cooler than average temperatures all contributed to excellent forage production throughout the season. No supplemental hay was fed in 2006, but grain was

again fed at 2 lb/hd/day for most of the season except for May and the last two weeks of October when 4 lbs/hd/day was supplemented (seasonal total was 440 lb/hd). Another improvement this year was reinstalling the shelter structures at the opposite end of the plot as the water tank. This shelter provided some wind, rain and sun protection and the animals seemed to use it frequently. This may also help reduce the build up of nutrients at the water cup were animals tend to stay during the warm part of the day. Several studies show that when daily temperatures exceed 80° F, cattle spend considerable time near the water (Mathews et al, 1994; Sugimoto et al, 1987) if no shade is provided.

Economics

The Stocker Enterprise Budgets for Grass-based Systems (Schuster et al 2001) was used as a model to estimate gross margins for the pasture system (CS6). In a national survey (with the Midwest having the highest response rate of the 4 regions), Wolf (2003) reported that the most common payment method was a fixed daily charge per head (52% of professional heifer grower respondents) and over half of the respondents indicated an average charge between $1.40 and $1.60/heifer per day. A regional research article revealed that the custom grazing heifer raiser in Minnesota was getting $1.28 per head per day (Rudstrom et al, 2005). The price differential reflects who pays for supplemental feeding, breeding and vet costs, etc. In our analysis, heifer income was based on a rate of $1.39/hd/d (average of $1.28 and $1.50) because we charged supplemental feed to the system but could not estimate vet or breeding costs. Farm size was fixed at 150 acres. Heifer expenses (supplemental feed, minerals, labor) and pasture expenses (reseeding, fertilizer, fuel, custom haying, etc.) were then deducted from heifer income. Supplemented grain was priced as purchased off-site (Delong prices) vs. produced on-site. The fencing and water systems were amortized over 20 years. Stocking density was about 1.2 AU/acre for the grazing months (i.e. average heifer weight over season was ~ 650 lbs * 5 head; grazing area of 2.8 acres; 1000 lbs live weight = 1 AU). The economic analysis is made over the grazing season, not over an entire calendar year.

RESULTS AND DISCUSSION

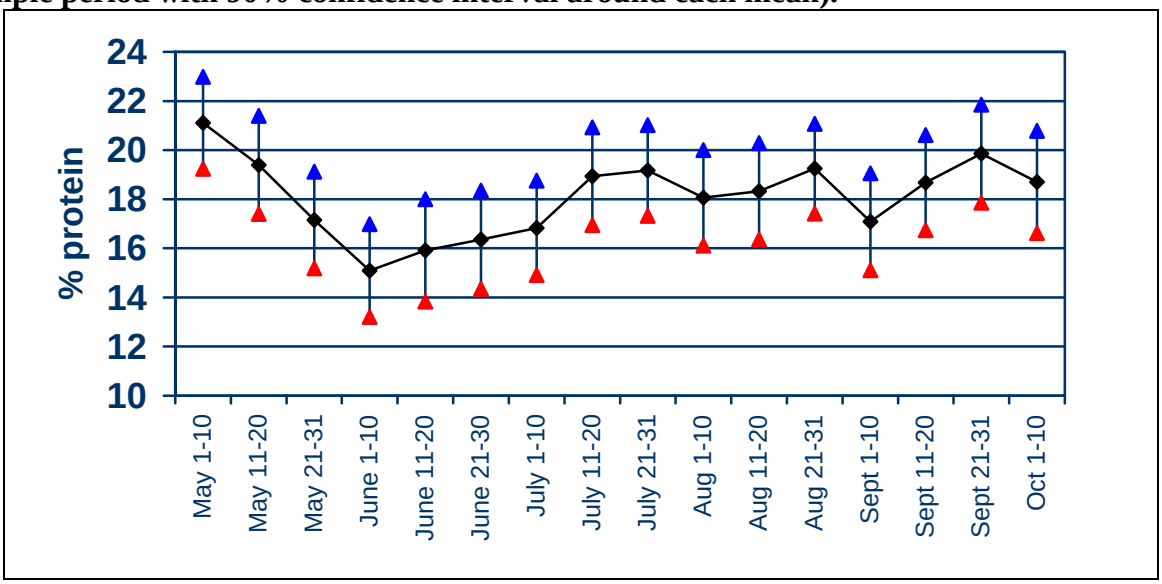
Long-term Productivity

A common thumb rule graziers use is to present the animals with a ton of forage for each grazing event. This is based dry matter intake of 4% body weight and a take half – leave half approach for optimal plant regrowth. As already presented, under constant stocking rate management (since 2000), the pasture plots have produced well with about a ton of available dry matter/acre as the heifers moved to new grass (Fig. 1). The growth curve suggests that our stocking rate is about right so that a relatively constant supply of forage is available in each cycle, other than what is harvested as hay from the spring flush, as previously discussed.

Forage Quality

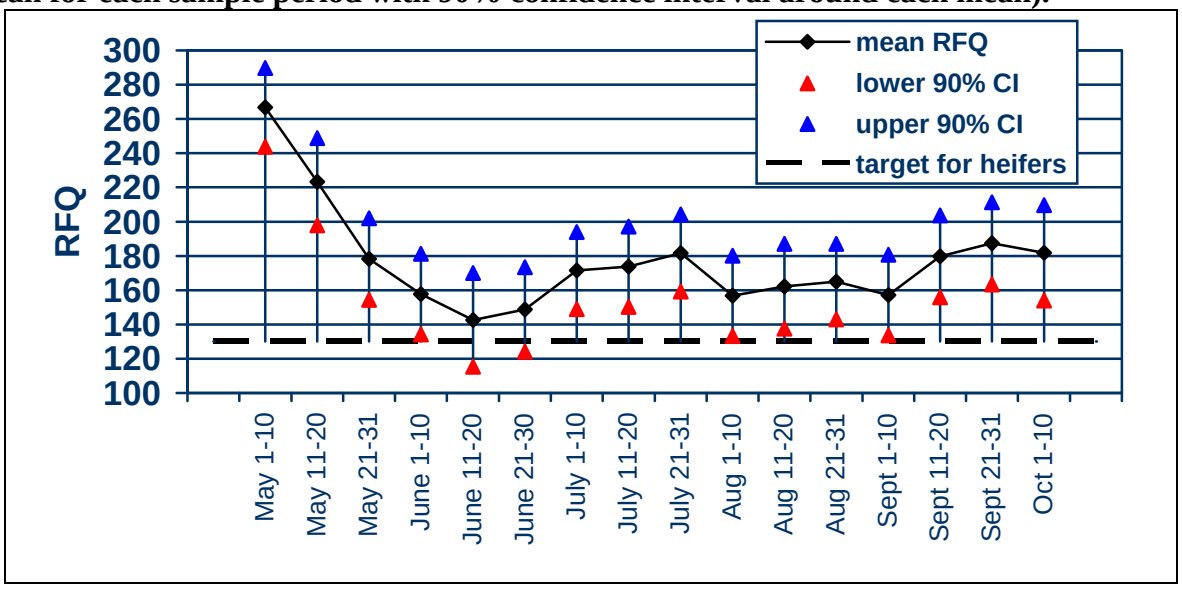
Forage quality has been very good with protein levels fairly steady within the season (Fig 3). Average crude protein was 18% and peaked at 21% when grass regrowth was leafy and legumes were prevalent. Generally, protein levels dropped as low as 14% during mid-June as grasses matured. The forage quality in the first weeks on June is significantly lower than in early May or later in the summer when the grasses are predominately leaves. Overall, the pastures provide sufficient, if not excessive, CP for growing dairy heifers.

Fig 3 . Pasture crude protein at Arlington from 2000-2006 (the line is the mean for each sample period with 90% confidence interval around each mean).



Since 2002, the UW Soil and Forage Analysis Laboratory has used RFQ as an energy estimate of forage, and though the RFQ differs from the calculated RFV (see Table 3), the same scale as RFV is used to determine which class of livestock the forage is most suited to (Undersander, pers. comm., 2007). Relative feed value averaged 177 across years ranging from 143 to 267 (Fig 4). As can be seen in this figure, early May forage is very lush and almost too 'rich' for heifers which passes through their gut very quickly and results in thin manure.

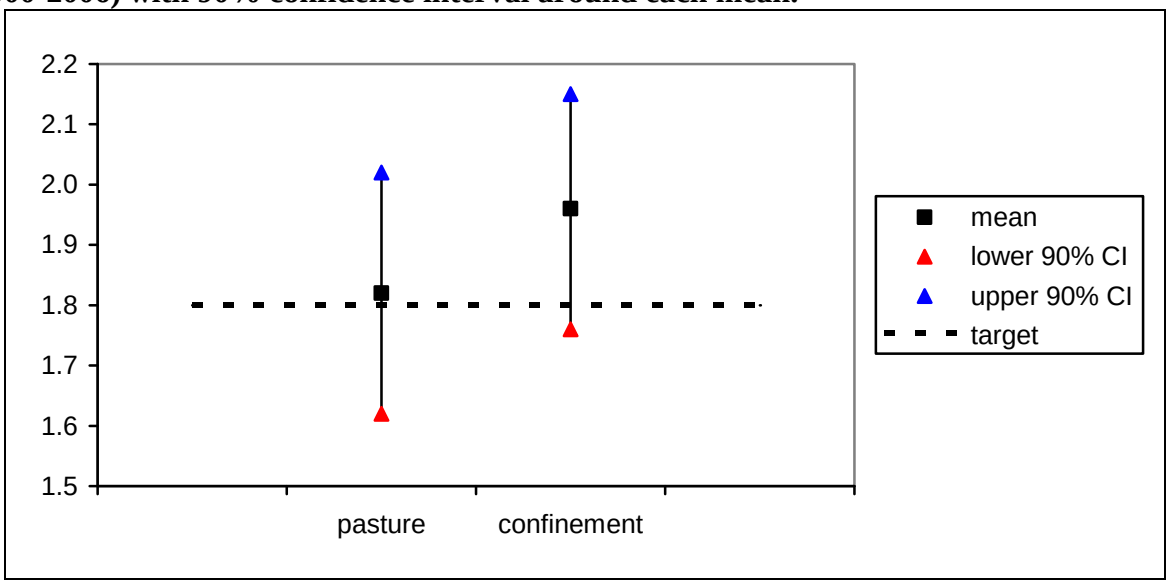
Fig. 4. Pasture relative forage quality (RFQ) at Arlington from 2000-2006 (the line is the mean for each sample period with 90% confidence interval around each mean).



Heifer performance

Using years as our replication factor for heifer performance, since 2000, there were 32 animals on the grazing treatment and 39 animals on the confinement treatment (7 years of data). Using 1.8 lb/day weight gain target (which puts these heifers at the right size for breeding in the fall), grazing was not statistically different from the goal as shown by the 90% confidence intervals in Fig. 5. It appears however, that our minimal grain supplementation will continue to be necessary, to provide more energy in early spring or late fall weeks when Owens et al. (1993) showed that pastures can be energy-limiting to meet the needs for growing large framed heifers such as Holsteins. Shelter also seems to have improved overall condition of the heifers. The daily ration fed to the confinement group at Marshfield, on per heifer basis, is typically 11 # alfalfa haylage (18% CP, 63% DM), 5 # corn silage (7% CP, 38% DM) and 5 # of 38%corn-32%soybean meal-23%oat, 4% molasses mix (16% CP, 0.5%P, 0.62%K, 90% DM).

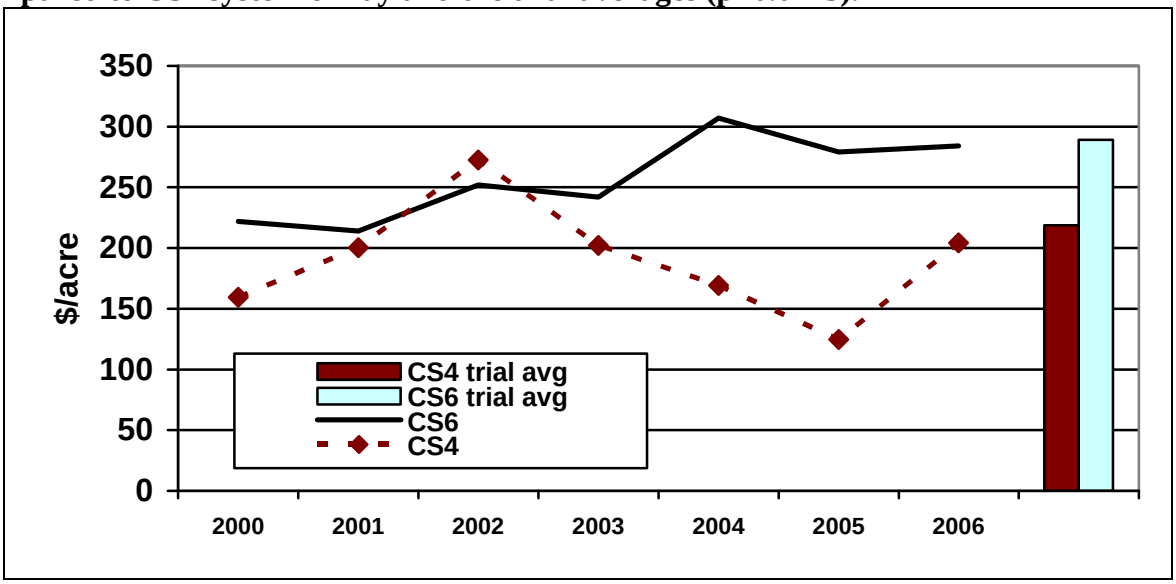
Fig.5. Heifer performance under managed grazing on WICST compared to confinement (2000-2006) with 90% confidence interval around each mean.



Economics

On these plots, it appears that 5 head (1.2 AU/a) is the near optimal stocking rate. Since 2000, profitability has increased with a higher stocking rate and more days on pasture. Starting in 2003, we tweaked our stocking rate from 4 to 5 heifers (with stocking rates of 6 or more (Fig. 1), the pasture productivity was reduced). Likewise as we discussed in the WICST 10th Technical Report (p. 16), for improved profitability, it is important to maximize days on pasture and since 2004, we've averaged 170 days on pasture. This helps defray pasture costs as well as interest on the fence and water systems over more days. Compared to the conventional mechanically harvested forage system (CS4, which includes 1 year of corn and 3 years of alfalfa sold at market value), it is interesting to note that the pasture system (custom rates at $1.39/hd/d) had higher gross margins in 6 of the last 7 years (Fig. 6).

Fig. 6. Gross margins on the pasture system (CS6) using a custom rate of $1.39/hd/d compared to CS4 system of hay and the trial averages (p<0.0223).



When comparing daily feeding costs per head on pasture vs. confinement, the pasture had lower costs of $0.31 vs. $0.75 in confinement. Rudstrom et al (2005) showed similar results of $0.28 vs. $0.77 per head per day. Further, he showed that labor and machinery costs in the grazing system were less than half that of confinement.

CONCLUSION

On the prime agricultural land at Arlington, intensive rotational grazing with modest corn supplementation permits dairy heifers to gain weight at the recommended 1.8 lbs/head/day. Optimal stocking rate on these plots is 5 heifers per season (1.2 AU/a) as both paddock and heifer performance has improved. Maintaining good soil fertility will be important to achieve productive swards. Gross margins on the pasture system are encouraging, primarily due to the low input costs and excellent outputs.

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APPENDIX

Appendix 1. Record of mechanical harvest of excess forage of entire pasture plot (2000-2006 at ARS).

Year	Date	Plot	Biomass (tons DM/plot)	Crude Protein (%)	RFV* or RFQ
2000	May 16	207	0.81	18.1	120*
	June 16	302	1.18	9.6	82*
	Seasonal total		*1.99*		
2001	May 25	207	1.07	-	101*
	June 30	405	0.73	10.7	89*
	Seasonal total		*1.80*		
2002	May 6	207	0.84	-	-
	May 16	405	0.66	18.7	132*
	Seasonal total		*1.50*		
2003	June 24	405	1.51	12.9	102*, 136
	Seasonal total		*1.51*		
2004	May 25	302	1.12	19.3	105*, 131
	Seasonal total		*1.12*		
2005	June 15	302	0.51	10.6	85*, 125
	June 21	405	1.41	9.7	79*, 112
	Seasonal total		*1.93*		
2006	May 22	302	0.39	15.0	132*, 187
	June 8	207	1.05	12.6	96*, 138
	June 19	405	0.96	8.3	77*, 108
	Seasonal total		*2.40*		
2000-2006 avg			***1.75/2.8a= 0.63 tons DM/a***	***13.2***	

*RFV was replaced with RFQ midway through 2002

Appendix 2. Comparison of RFV to RFQ over the season (across 7 seasons at Arlington)

Time period	**RFV**	**RFQ**
May 1-10	171	267
May 11-20	149	223
May 21-30	128	178
June 1-10	111	158
June 11-20	99	143
June 21-30	111	149
July 1-10	115	171
July 11-20	125	174
July 21-30	121	182
Aug 1-10	116	157
Aug 11-20	122	162
Aug 21-30	129	165
Sept 1-10	117	157
Sept 11-20	130	180
Sept 21-30	140	187
Oct 1-10	132	182
Seasonal mean	**126**	**177**

Appendix 3. Yearly gains between pasture and confinement groups and overall means.

	# days on pasture	Pasture (n)	Confinement (n)	*p-value*
2000	161	1.76 (4)	2.21 (6)	*0.0016*
2001	153	1.63 (4)	1.72 (6)	*0.6239*
2002	163	1.82 (4)	2.20 (6)	*0.0304*
2003	139	2.03 (5)	2.19 (6)	*0.1474*
2004	167	1.92 (5)	1.62 (5)	*0.0017*
2005	168	1.39 (5)*	2.01 (5)	*0.0503*
2006	176	2.21 (5)	1.74 (5)	*0.0016*
Mean	**161**	**1.82 (32)**	**1.96 (39)**	***0.3387***

*low gains due to drought summer and no pregrazing adaptation period (and animals weighed before trucking)

SUMMARY OF YIELDS ON WICST "PRAIRIE" CORN PLOTS 2001 – 2006

Gregg Sanford[*], Joshua Posner[†], Janet Hedtcke[‡]

INTRODUCTION

In the spring of 1999 two tall-grass prairie treatments were established in what had previously been a grass waterway in the southern tier of the WICST plots at the Arlington Research Station. The purpose of the prairie plots was to create a native grasslands benchmark for the environmental variables being monitored on the WICST plots. The two prairie treatments established were a high diversity (25 species) and a low diversity or CRP mix (6 species). In order to compare the soil productivity of the prairie plots to the cropping systems plots a continuous corn treatment, identical to CS1 in the WICST plots, was included. The three treatments were established in a completely randomized design with three replicates each. (Fig.1). After eight years of growing continuous corn along side the prairie diversity plots, we evaluated the prairie corn and CS1 data in order to lay the groundwork for future research in these plots. For this analysis we evaluate only the last six growing seasons (2001 to 2006). USDA considers a field in continuous corn beginning with the third consecutive year of corn production. For more information on the prairie establishment, please see the 8th (2000) and 9th (2002) WICST technical reports (p. 199 & p.136 respectively).

METHODS

Although production strategy and practices were identical between the "prairie" and CS1 corn, some differences did exist. CS1 corn was replicated 4 times in the main experiment and prairie corn was replicated 3 times in the prairie diversity trial. Also, total plot size differed: The CS1 plots were 24-rows wide while the prairie corn plots were only 18-rows wide. Despite this difference, yield estimates were taken from the middle 12 rows in both treatments. Initial grid sampling done in 1989 indicate that by locating the prairie diversity trial in a former waterway, the soils were somewhat shallower, slightly lower in organic matter and somewhat lower in fertility than generally found on the CS1 WICST plots (see Table 1). Elevation of these newly planted corn plots was also 2 feet below the CS1 plots on average. Details on the initial grid sampling (90' x 90') conducted in 1989 on the WICST research area can be found in the 1st WICST technical report (1991). In addition to minor soil and topographic differences, due to their proximity to the prairie plots and reduced number of border rows (3 vs. 6), we observed that the prairie corn generally had more weed pressure, from sunflowers (*Helianthus spp.*) and goldenrods (*Solidago spp.*) as well as occasionally lower plant populations due to greater rodent damage than the CS1 plots in WICST.

STATISTICAL ANALYSIS

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In this analysis, year is treated as a random effect. This is done to broaden our inference range about how CS1 and prairie corn would continue to behave relative to each other in years to come. In addition year was treated as a repeated measure. This allows us to account for auto-correlation between years within the same plot. For example we would expect soil test phosphorus (STP) values from the same plot, sampled in consecutive years, to be related to each other.

RESULTS AND DISCUSSION

Statistics and Model Fitting

Due to the potential for covariance among the yield measurements taken each year from the exact same plots, eight covariance structures were evaluated in this model. The results from these evaluations indicated that the first order antedependence covariance structure best fit the data (lowest AIC and BIC). This structure allows for both unequal variances, and covariances which decrease as time (years) between measurements increases. The final repeated measures model using the first order antedependence covariance structure was further compared to the same model in which no repeated measures was used. It was found to offer a significantly better fit (AIC of 317.1 vs. 341.1 and $p < 0.001$). These results confirm that the repeated measures model was appropriate for this analysis. However, despite the improved model fit using repeated measures, system (CS1 vs. prairie corn) differences were found to be significant whether the technique was used or not (see below).

Yields and Environmental Indicators

Prairie corn plot yields have averaged six bushel acre^{-1} lower (182.1 vs. 188.5 bu ac^{-1}, p = 0.0001 w/repeated measures, p = 0.0012 w/o repeated measures) than CS1 corn between 2001 and 2006. However, as can be seen in Figure 2, yield variability is greater in the prairie corn plots with the lowest yield reported in 2002 (140 bu ac^{-1}) and the highest in 2006 (200 bu ac^{-1}), actually surpassing CS1 corn yields. The 2002 growing season showed the greatest difference in corn yield between the two systems. Although both systems received 130 lbs acre^{-1} N fertilizer (Table 2), our hypothesis is that increased rodent damage in the prairie corn (24,000 vs. 28,000 pl/ac) (Fig. 3) accounted for much of the yield difference (52 bushels acre^{-1}).

In all years nitrogen was applied according to the pre-plant nitrate test (PPNT) taken in April prior to corn planting. Despite the PPNT results for prairie corn in 2003 indicating 166 lbs acre^{-1} available nitrogen in a 2 ft. profile, an additional 80 lbs acre^{-1} was added to these plots (Table 2). This most likely explains why fall nitrate levels at the end of that season were significantly higher under the prairie corn plots compared to CS1 (Fig. 4).

Although soil test phosphorus (STP) and soil test potassium (STK) remained lower in the prairie corn plots over the six year period (Fig. 5 & Fig. 6), levels for both nutrients were in the excessively high range (Kelling et al. 1998) indicating that these differences were not yield limiting. Interestingly STP is being drawn down in both systems at a similar rate (Fig. 4), but STK is increasing in both systems with CS1 increasing at twice the rate of the prairie corn plots (Fig. 5). The increase in STK may be an artifact however of our

sampling technique (0-6") as increasing surface residues result in a reallocation of K toward the surface.

CONCLUSIONS

Although prairie corn plots yields were generally similar to the WICST continuous corn plots between 2001 and 2006, yield variability is greater in the prairie corn plots. We hypothesize that this variability is largely the result of shallower soil depth as well as occasionally greater rodent and generally greater weed pressures in the prairie corn plots due to their proximity to the prairie. Soil test values are lower on the prairie plots but still in the exceedingly high range and fall nitrates with the exception of one year and early spring nitrates were generally similar between systems. Based on this yield and soil evaluation, we have concluded that the prairie establishment was done on soils similar to those under the general WICST plots.

In the spring of 2007 corn production was discontinued in these plots to prepare for an early fall planting of warm season switchgrass (*Panicum virgatum*). This change will allow us to look at the productivity of alternative biomass production strategies (corn, alfalfa, switchgrass, and native prairie) and their long-term impact on soil parameters.

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TABLES AND FIGURES

Table 1. Yield and soil characteristics from WICST uniformity year (1989)

	CS1 (n=18)			Prairie Plots (n=30)		
	N[*]	$\bar{X}$	SEM[†]	N	$\bar{X}$	SEM
Yield[‡]	18	126.2	3.4	24	131	2.9
STP[§]	9	110.6	11.5	12	108.0	11.1
STK[**]	9	274.0	40.4	12	258.8	30
pH	9	6.4	0.1	12	6.7	0.0
OM (%)	9	4.7	0.2	12	3.9	0.2
depth of A horizon (in)	18	11.1	0.6	24	10.7	0.8
depth to mottles (in)	18	40.5	2.0	24	33.6	2.3

Table 2: Spring Residual Nitrogen and Rates of Applied Fertilizer

	Spring residual Nitrate-N (lb ac^{-1} to 2-ft. depth)		Actual lb N $acre^{-1}$ applied	
	CS1 $\bar{x}$	*Prairie corn* $\bar{x}$	*CS1*	*Prairie corn*
2001	83	115	100	80
2002	53	52	130	130
2003	105	166	100	80
2004	53	53	160	160
2005	72	82	119	117
2006	60	56	140	140

[*] N = number of sampling stations on which data was collect in the uniformity year (prior to plot layout) that fall within current prairie corn and CS1 plots
[†] SEM = standard error of the mean (SEM = $s/(n^{½})$)
[‡] yield in bushels $acre^{-1}$
[§] STP = soil test phosphorus (ppm)
[**] STK = soil test potassium (ppm)

Figure 1: Map showing prairie and prairie-corn plots randomized in the Southern tier of the Wisconsin Integrated Cropping Systems Trial (WICST)

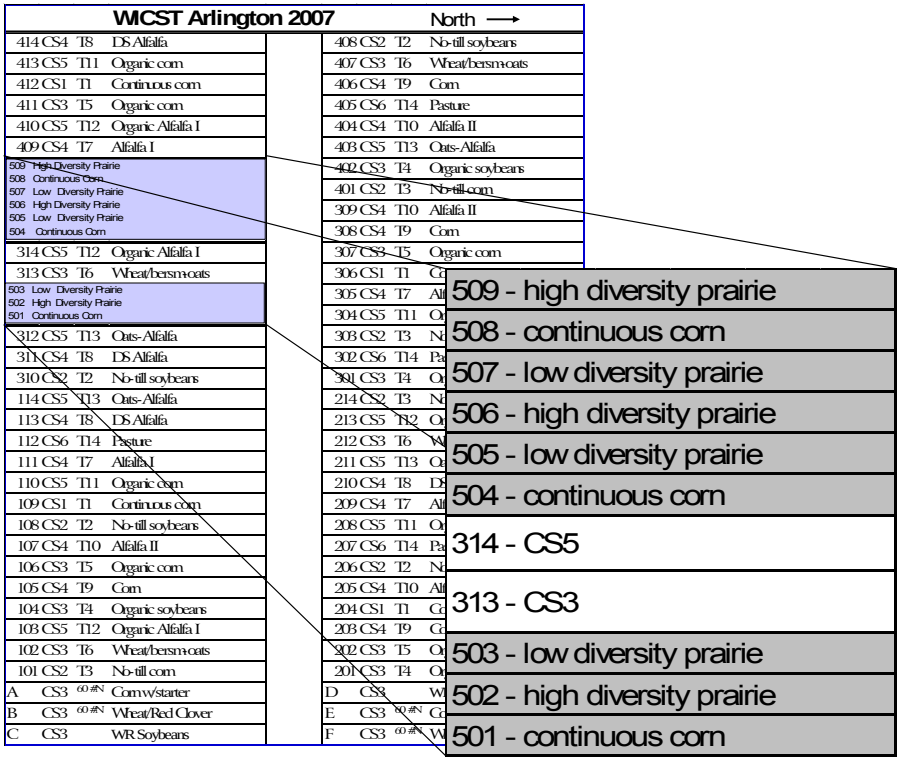


Figure 2: 2001 to 2006 Corn Yield in Bushels Acre^{-1} for Prairie Corn and CS1

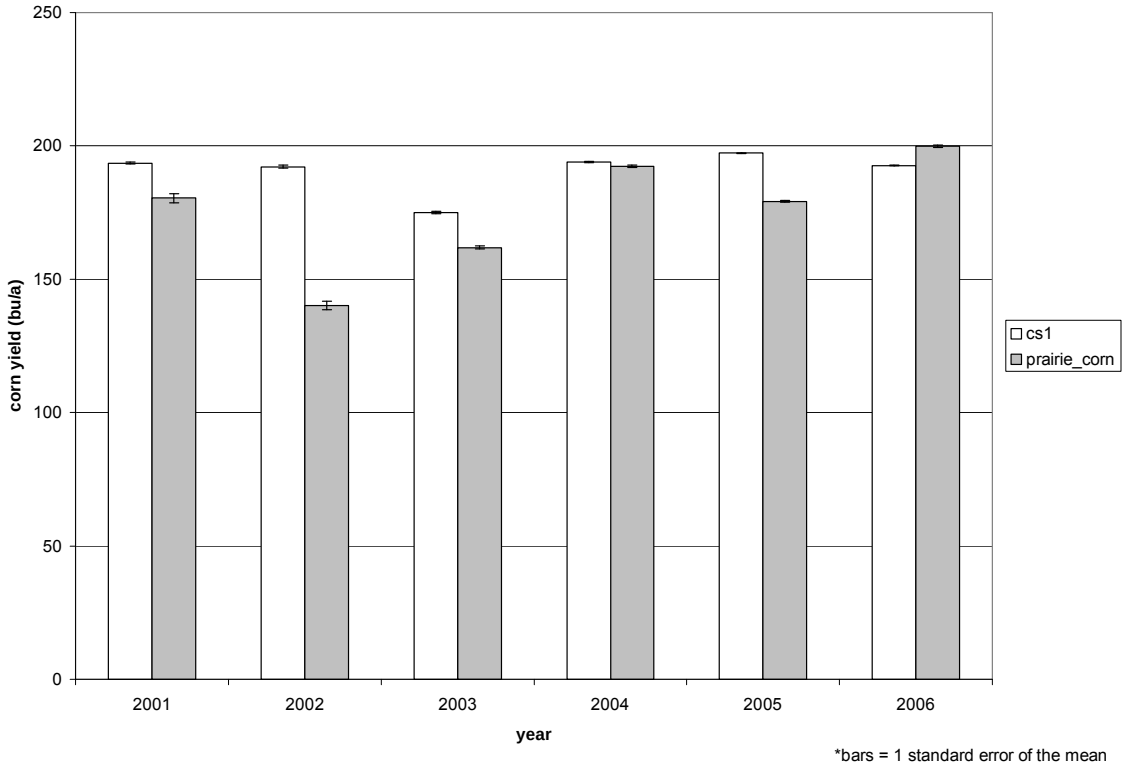


Figure 3: Plants Populations and Least Significant Differences (2001 to 2006)

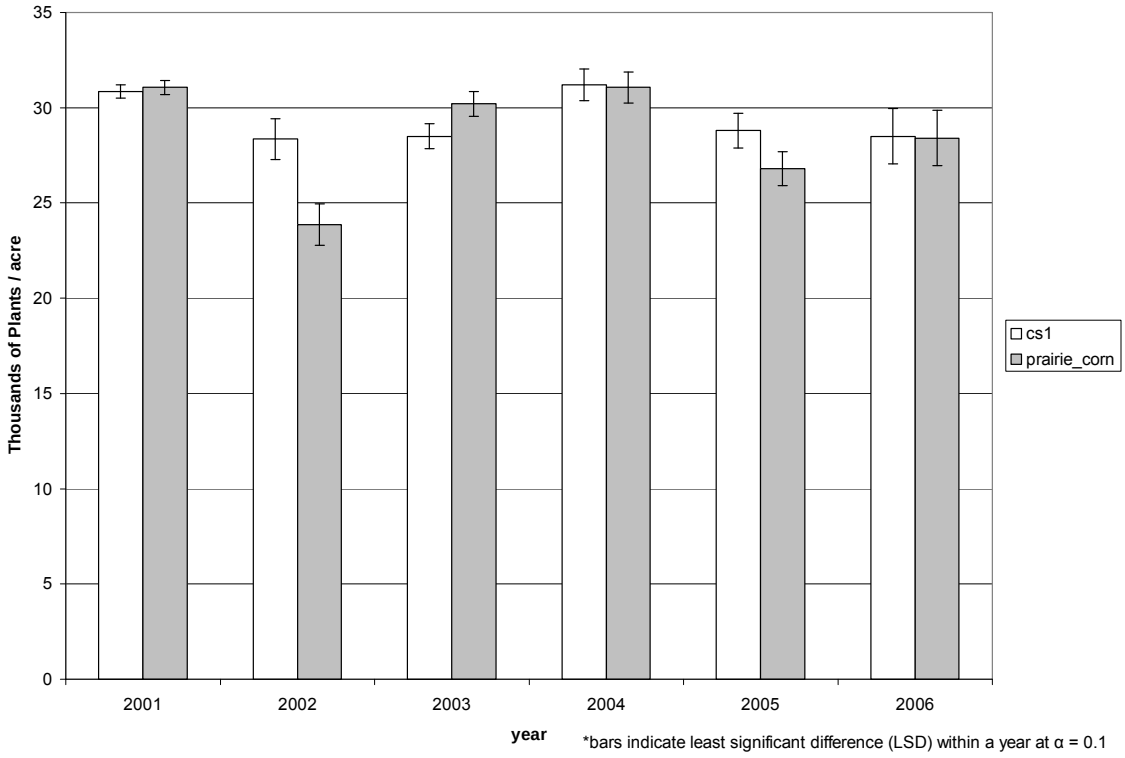


Figure 4: Post-harvest profile nitrates (0 to 3 ft.)

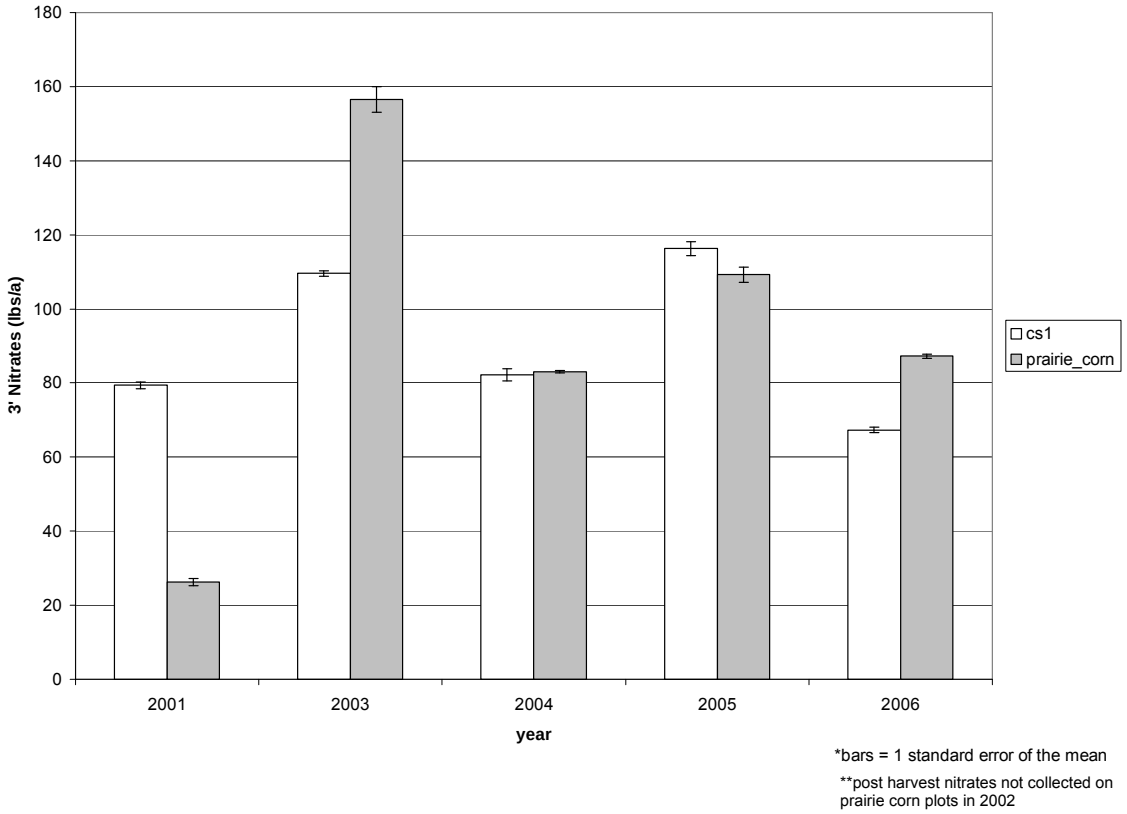


Figure 5: Soil Test Phosphorus (STP) for Prairie Corn and CS1 (2001 to 2006)

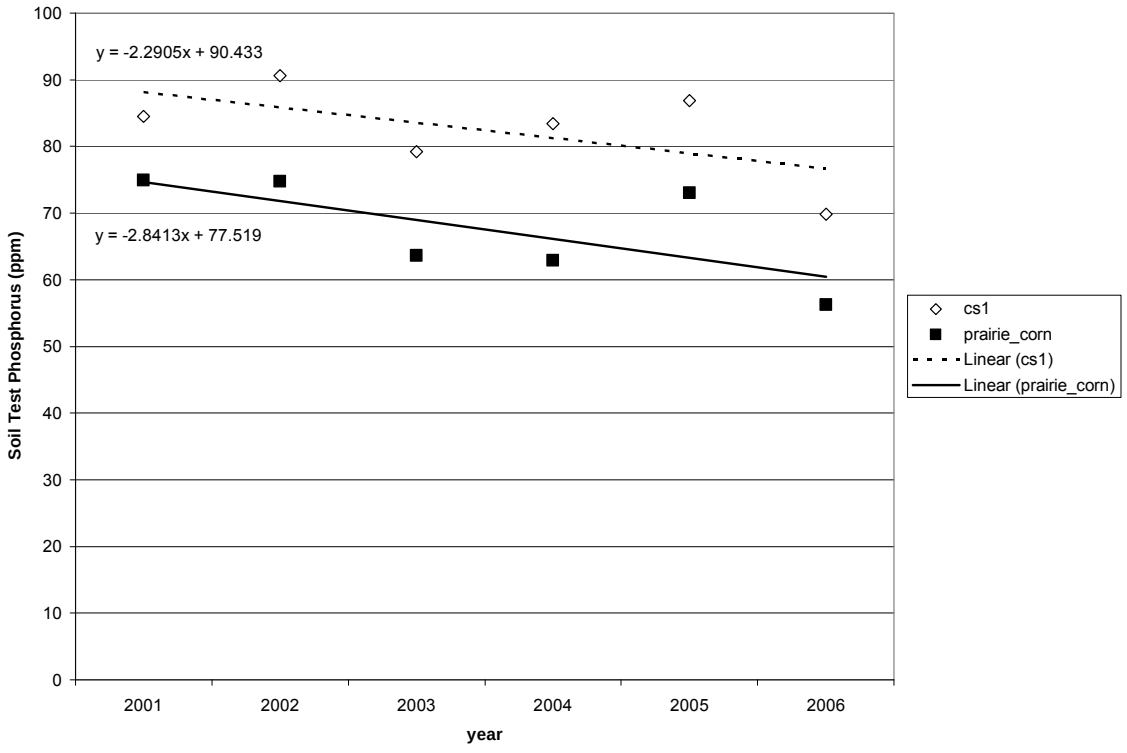
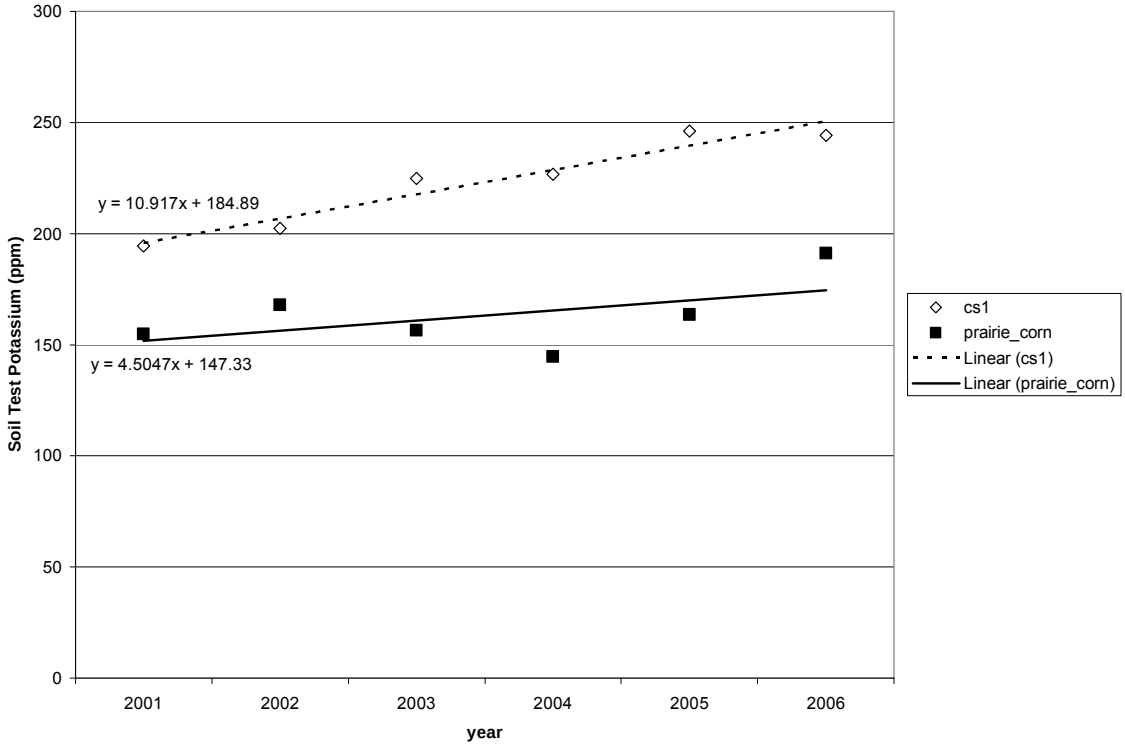


Figure 6: Soil Test Potassium (STK) for Prairie Corn and CS1 (2001 to 2006)



Appendix I. LSMEANS of various measurements on continuous corn (CS1) vs. prairie plots at Arlington

	1998	1999	2000	2001	2002	2003	2004	2005	2006
Corn yields	|---bu/a---|								
CS1	196.2	170.4	161.6	193.6	192.2	175.0	193.9	197.3	192.7
Prairie corn	-	167.1	160.9	180.4	140.3	161.9	192.4	179.2	199.9
p-value		*0.7967*	*0.9395*	*0.3291*	*0.0080*	*0.0684*	*0.4724*	*0.0014*	*0.0520*
lsd (0.10)		24	17	25	25	11	4	6	6
STP	|---ppm---|								
CS1	77	66	74	72	75	77	73	82	64
Prairie corn	63	49	59	62	59	62	52	68	51
High diversity prairie	62	55	58	57	58	59	58	65	49
Low diversity prairie	57	51	63	56	53	57	50	64	53
p-value	*0.0122*	*0.3856*	*0.0039*	*0.3114*	*0.0948*	*0.0163*	*0.0413*	*0.1045*	*0.2102*
lsd (0.10)	9	20	7	17	15	11	14	14	14
STK	|---ppm---|								
CS1	193	193	200	147	163	213	187	236	233
Prairie corn	138	106	158	107	129	144	104	154	180
High diversity prairie	194	139	149	130	144	153	116	151	182
Low diversity prairie	167	146	166	91	129	142	111	148	180
p-value	*0.5454*	*0.1179*	*0.0734*	*0.2615*	*0.6420*	*0.0447*	*0.1350*	*0.0830*	*0.2760*
lsd (0.10)	75	61	35	52	58	46	69	68	59
Fall nitrates to 3 ft depth	|---lbs NO_3^--N/a---|								
CS1	148	87	130	79	110	110	82	116	67
Prairie corn	137	106	174	105	-	157	83	109	87
High diversity prairie	119	89	45	26	19	37	32	27	63
Low diversity prairie	168	87	54	38	-	28	30	28	64
p-value	*0.3841*	*0.1585*	*0.0008*	*0.0033*	*0.0041*	*0.0004*	*0.0025*	*0.0005*	*0.0815*
lsd (0.10)	52	16	41	44	37	37	24	31	16

INCREASING CROP ROTATION DIVERSITY: A COMPARISON OF CONVENTIONAL GRAIN SYSTEMS ON WICST (1998-2006).

Janet L. Hedtcke and Joshua L. Posner

INTRODUCTION

Since the mid-20th century, with the advent of cheap fertilizer and herbicides, many farmers have adopted high chemical input, low cropping diversity systems. However, the recent trend of increasingly high input costs has more and more farmers rethinking this strategy. As crude oil costs have skyrocketed (>$130/barrel in July 2008), many inputs derived from petroleum (fertilizer, pesticide, fuel) have also increased. For example, fuel and fertilizer have practically doubled in the last decade (ERS, 2008). In addition, seed costs have rapidly increased with trait technology fees. Furthermore, growing environmental concerns have increased the interest in expanding or diversifying cash-grain rotations to include legumes to reduce N inputs and reduce pest pressure by adding non-host crops.

Data from the Wisconsin Integrated Cropping Systems Trials (WICST) show environmental advantages of reducing inputs with an organically managed three-crop system, but yields are often lower than in the high input, less diverse systems, particularly in years with wet springs (Posner et al, 2008). However, this comparison of cropping diversity was confounded with the fact that the three-phase system was managed using no chemicals. To more cleanly compare crop diversity, it was decided to set up a satellite site and conduct the same 3-phase system, but using Best Management Practices (BMP), to compare to the less diverse one- or two-crop systems of WICST.

Other researchers have found that expanded rotations combined with low input levels can be quite competitive with shorter rotations that rely on high chemical inputs (Singer and Cox, 1998a and 1998b; Clark et al., 1999; Katsvairo and Cox, 2000). Although some authors have been working with a four-phase rotation that included alfalfa (Dobbs et al., 1988; Exner et al., 1999; Singer et al, 2003), this system requires grain producers to have a market for hay and either own or contract out for the hay-making field equipment. Keeping within the frame of cash-grain operations, we decided to compare systems with varying degrees of commodity crop diversity.

In this report, we compare three grain-based systems conducted under BMP recommendations addressing the following questions:

- Does greater crop diversity improve production?
- Does greater crop diversity improve profitability?
- Does greater crop diversity reduce negative environmental impact?

MATERIALS & METHODS

Site selection and treatments. The Wisconsin Integrated Cropping Systems Trial is a long-term trial that compares production, economic, and environmental impacts of six cropping systems common to the upper Midwest. Prior to being used for research, this land was in a dairy rotation of corn and alfalfa with frequent manure applications. Soil fertility was very high and weed pressure was low. Further description of the background

details, design and conduct of the main WISCT cropping systems can be found in Cunningham et al. (1992) and Posner et al. (1995).

In 1995, a satellite three- phase rotation of corn-soybean-winter wheat/red clover ('ChemLite') was initiated at the Arlington site. In this three-phase rotation the soybeans were planted in 30" rows to facilitate cultivation, while the beans in the NT two-phase rotation (CS2) were drilled. Due to the need to plant wheat following the soybean phase, a shorter cycle bean variety was also used when compared to CS2 (1.9 vs. 2.4). The corn hybrid was generally the same in all three systems.

Design and setup. The experiment was set up with two replicates of ChemLite in a randomized complete block adjacent to the main WICST experiment. In this analysis, due to their proximity, just CS1 (continuous corn) and CS2 (No-till corn-soybean) in Reps 1 and 2 of WICST were used (Fig. 1). All plots were 0.70 acres and field-sized equipment was used. Each phase of each system existed each year during the trial so year and phase are not confounded. Management inputs and outputs, commodity prices, and weather data have been recorded each year. Soil fertility levels were monitored from annual soil sampling in the fall after grain harvest. Soil nitrate data was collected each fall from each phase of each system down to a 3-ft depth using a hydraulic probe.

Statistical Analysis. Data from 1998-2006 were used for most of the analysis but 2007 yield data was also included since it was available at the time of preparing this report. Because ChemLite didn't have a staggered start like the other systems, we decided to start the analysis after it completed the first cycle of its 3-yr rotation. System (or phase) was considered fixed in this analysis. Year, rep and interactions of these with the fixed effect were considered random. Proc Mixed of SAS was used to generate least square means with the subject of repeated measures being plot within system. Preliminary tests (LeVene's) showed variances to be homogeneous between the core WICST plots and the ChemLite experiment for all the dependent variables. Normal-scores plots verified normality.

Agricultural Budgeting Calculation Software (ABCS; Frank and Gregory, 2000) was used to determine net returns (to labor, capital, and management). Net returns were calculated on a system basis. The plots were scaled up to a 1000-acre farm and yearly input prices (seed, fertilizer, herbicide etc.), yields, and commodity prices were entered for each system. Harvest-time commodity price (mid-October to mid-November average price without storage option using the posted country price for Columbia County) was used across systems.

Inputs. A general description for each system is described below and a list of inputs and field operations for each system are shown in Table 1.

Continuous corn inputs. Inherent to a mono-cropping system is a high reliance on synthetic fertilizer and chemicals for herbicides and insecticides. Nitrogen rates were adjusted with the residual N in the profile according to the Pre-plant Nitrate Test ((Bundy et al., 1995) with maximum applied rates at 160 lb N/a.

NT c-sb Inputs. This system received inputs according to BMP's and university recommendations. Like the continuous corn system, N additions were based on the Pre-plant Nitrate Test which adjusted for soybean legume credits and residual nitrate-N from the previous fall and typically, rates were lower than for the continuous corn. Pre- and post-emergent herbicides were applied in both phases of the system at standard rates. Full season transgenic (i.e. glyphosate resistant) soybeans varieties were often used.

ChemLite Inputs. Generally, three chemical inputs were added to ChemLite: starter fertilizer, N fertilizer, and post-emergence herbicides. The fertilizer was added during the corn and wheat phases. The red clover that was drilled into the winter wheat stand in early spring and was plowed down at the end of the season providing additional N credits. Post-emergence herbicide was applied in either 15" bands over the row or broadcast on the whole field at half rates, on the corn and soybeans. Herbicides were applied as deemed necessary, and in some years, no herbicides were applied. Mechanical tillage with a rotary hoe and row cultivator was used in the row crops to compliment the chemical weed control. Generally, no pesticides were used during the wheat phase.

RESULTS & DISCUSSIOIN

Agronomic Performance. Corn yields were similar among the three systems (about 190 bu/a) and all were substantially higher than the corn in the organic system (Table 2). However, there was a slight yield advantage for the NT soybeans over those in ChemLite which is mainly a function of the increased plant density in drilled vs. rowed beans (Table 3). Overall, wheat yields were about 10 bu/a higher in ChemLite than the organic system and would have been higher if the N inputs were more consistent on ChemLite. For example, from 2002-2007 when N was applied each year, wheat yields from ChemLite were 20 bu/a higher than the organic system. The straw yields were similar between ChemLite and the organic system and both were modest due to the high cutting height adjusted for the underseeded red clover.

Soil test phosphorus has been deliberately been drawn down from initial excessively high levels (Fig. 2). Each of these systems received starter fertilizer (about 10 lbs P/a) during the corn phase to increase nutrient uptake in cold wet springs. As can be seen, STP in ChemLite is being drawn down at a much higher rate than continuous corn or the NT c-sb system (14 vs. 1.5 and 4 ppm/yr, respectively) because of only having the starter input every third year, as well as the straw removal in the wheat phase. None of the systems have reached the 'optimal' STP levels but ChemLite will in the next few years.

Similar to STP, STK has also been drawn down from initial excessively high rates (Fig. 3). ChemLite has fallen below the optimal levels and now requires potash fertilizer inputs to maintain fertility while the STK in the other two systems is being maintained with the more frequent starter fertilizer inputs.

Economic Analysis. Input costs by phase of each rotation are shown in Table 3. The corn phase was the highest cost crop in the rotation and overall the continuous corn was

nearly twice that of ChemLite. However, the NT c-sb and ChemLite had similar input costs due to lower diesel fuel inputs but higher N and pesticide purchases. The gross margins of these systems are reported in Fig 4. There was no statistical difference between the three systems when government subsidies are included and all three conventional systems were significantly lower than the organic system when organic feed-grade premiums are included.

Environmental Impact.
Soil nitrates, measured after crop harvest, across systems were arithmetically lowest for Chemlite but only continuous corn was significantly higher (Fig 5; $p<0.0015$). This can be explained by lower N inputs in the expanded rotation due to N credit from green manure. In addition, the winter wheat phase acts like a sponge to hold/use the nitrates that may be leached otherwise. However, the fall nitrates in ChemLite were double the background levels one would find in a prairie (horizontal line in Fig. 5) but at much less risk for leaching than continuous corn.

There were small differences in soil erosion potential between the three conventional systems (Fig. 6) and they are all well below the tolerable soil loss ('T') for these soils of 5 ton/a/yr level. However, the organic 3-yr grain system had alarmingly high soil erosion hazard, due to annual tillage and repeated cultivations (see bottom of Fig 6). The soil conditioning index (SCI), which is a yardstick for estimated organic matter accumulation (> 0 means OM accumulation) tended to be highest for systems with more corn in the system due to its high biomass production. The soil tillage intensity rating (STIR) was obviously best in the no-till system, and was better for ChemLite vs. continuous corn primarily due to the wheat phase which reduced overall system tillage. Again, the organic system performed poorly in both the SCI and STIR and should not be used on slopes >4%.

CONCLUSION

In general, increasing grain crop diversity did not increase crop yields or profitability when government programs are included. In the organic system, although yields were significantly lower, profitability was higher due to organic premiums. In terms of environmental impact, potential nitrate leaching was lower in the ChemLite and no-till systems compared to continuous corn and all three provoked relatively little soil erosion. The soil-conditioning index was highest and soil tillage intensity rating lowest for the no till system. Continuous corn, due to its high biomass production outperformed the ChemLite for soil conditioning, but had a higher tillage intensity rating due to annual tillage and cultivation, while the wheat/red clover phase in the ChemLite system resulted in a lower rating. It is interesting to note that for these three criteria of estimated erosion, organic matter accumulation and intensity of tillage, the organic system scored more poorly than any of the three conventional systems.

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Fig. 1. Schematic of the plot layout of WICST core plots (shaded plots are compared in this study) and satellite (ChemLite) to the east.

Table 1. Cropping System Comparison

	Systems		
Inputs	Cont. corn c-c-c-	NT C-Sb	ChemLite c-sb-w/rc
N lb/a (per PPNT)	160	120	60 on corn 60 on wheat
Soil insecticide	Yes	No	No
Herbicide	Full rate	Full rate	Lower rates
Tillage intensity	Low (chisel plow and seedbed prep); occasional row cultivation	None	Moderate (chisel plow, seedbed prep, rotary hoe, row cultivation)

C=corn; sb=soybean; w=wheat; rc=red clover

Table 2. Yields across systems (1998-2007 average).

	Corn	Soybean	Wheat grain	Wheat straw
System	----------Bu/a----------			Tons dm/a
Cont. corn	188	----	----	----
No-till c-sb	187	55	----	----
ChemLite	185	50	69	0.83
P-value	*0.95*	*0.03*	*0.02*	*0.08*
*Organic grain**	*135*	*41*	*58*	*0.79*

**shown for comparison; not part of the statistical analysis*

Table 3. Input costs by phase and system (1998-2006)

	Corn	Soybean	Wheat +**red clov**.	**System**
	$/a			
Cont. corn	218a	---	---	**218a**
No-till c-sb	197b	90	---	**143b**
Chemlite	186b	79	114	**126b**
P-value	*0.01*	*0.03*	*0.11*	***0.01***
*Organic grain**	*145*	*91*	*96*	*111*

* *shown for comparison; not part of the statistical analysis*

Fig. 2. STP trends (1995-2006) across the systems

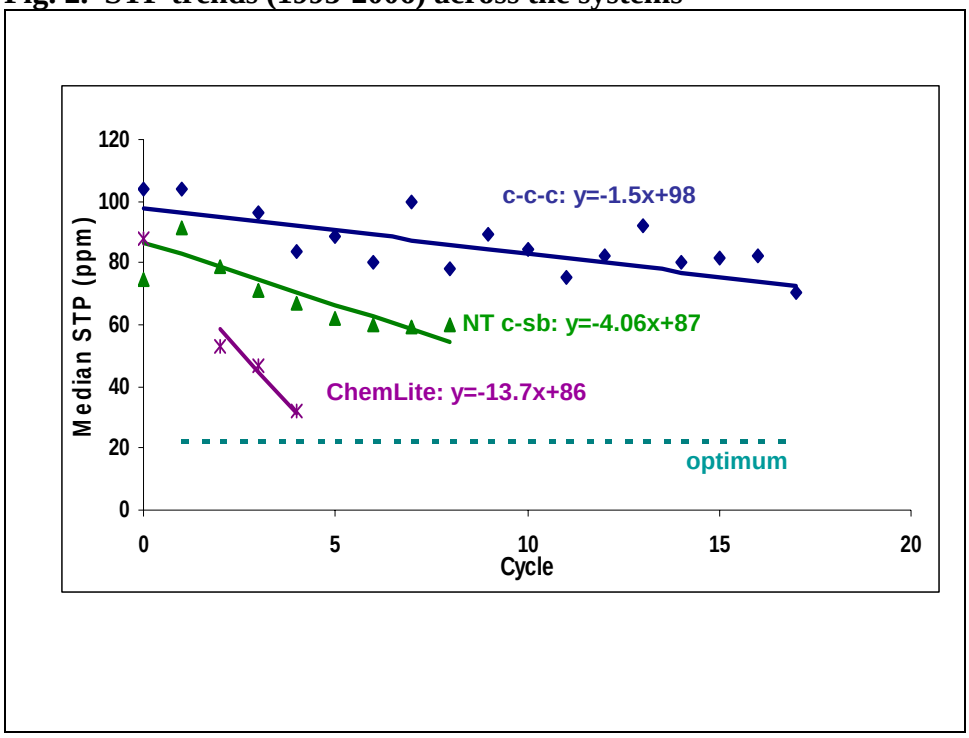


Fig. 3. STK trends (1995-2006) across the systems

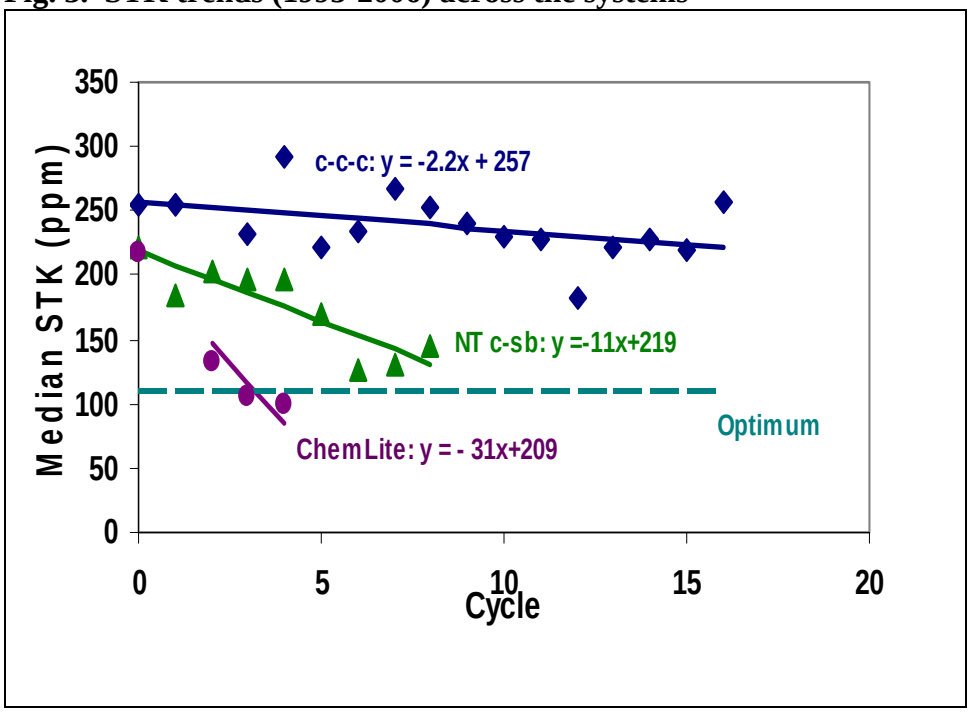


Fig. 4. Average gross margins of various grain systems (1998-2006) including government payments

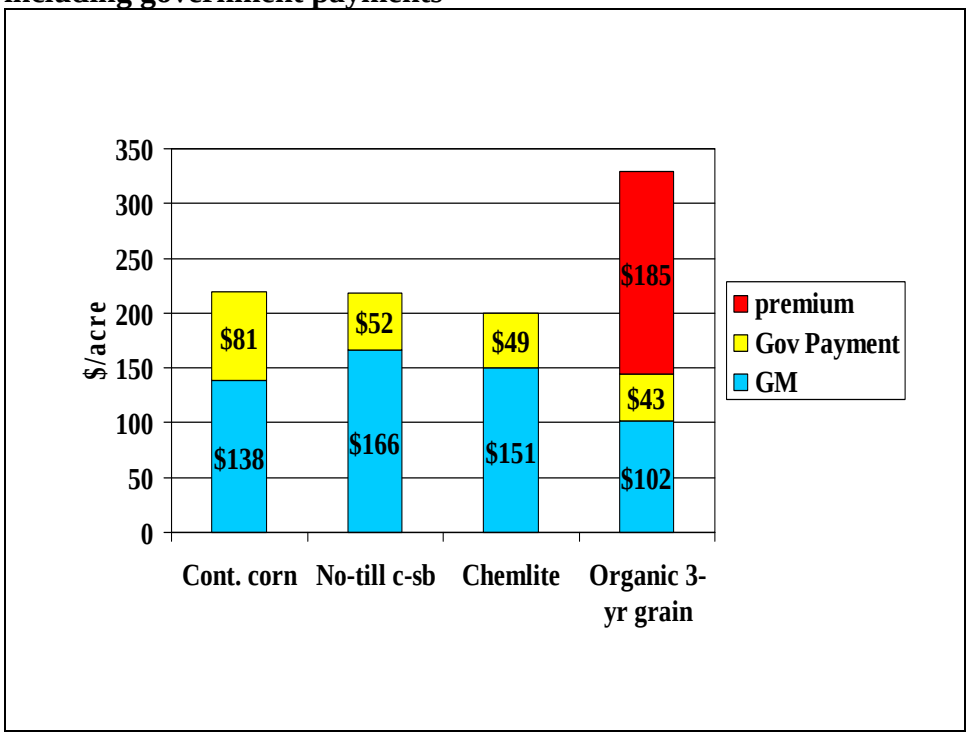


Fig. 5. Fall soil nitrates to 3-ft. depth of each system (1999-2006 average).

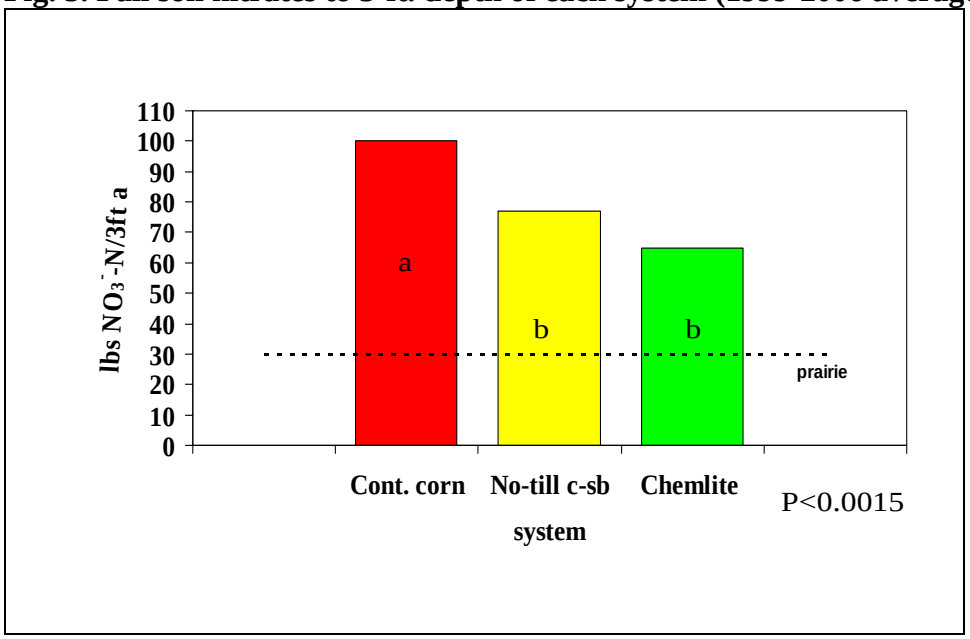


Fig. 6. Soil loss estimates on a 4% slope, 150-ft run (RUSLE2).

RUSLE2 output

System	Soil loss tons/a/yr[1]	SCI [2] (-2 to +2)	STIR[3] (0 to 200; <30 very good)
Cont. corn	2.0	0.66	100
No-till c-sb	0.6	0.80	5
Chemlite	2.8	0.09	79
Organic	*10.0*	*-1.3*	*200*

1 assuming 4% slope, 150 ft run, contours
2 SCI= soil conditioning index
3 STIR=soil tillage intensity rating

ADDRESSING ORGANIC CORN AND SOYBEAN PLANT POPULATIONS IN THE WICST TRIAL

Janet Hedtcke, Joshua Posner, Gregg Sanford

INTRODUCTION

An important strategy for obtaining economic yields is ensuring good stand establishment. In conventional systems, in addition to using high quality seed, farmers rely on effective chemical seed treatments to help ensure vigorous stands. For a number of years, however, the WICST organic plots have had difficulties in achieving target populations of corn and soybeans. This paper summarizes WICST data from 1992-2006 with the objective of explaining the evolution of crop stands in the organic rotations and defining a monitoring strategy for the future.

METHODS

Among the range of cropping systems on WICST are two organic systems: a 3-yr organic grain system and a 3-yr organic dairy system. Additional details on the design and conduct of the WICST trial are provided in Posner et al. (1995). Since the beginning of the trial in 1992, corn and soybean plant counts have been made after the final cultivation (usually during last two weeks of June). In five random areas of the plot (center 12 rows), plants were counted from a 17'5" length in the 30" row crops. Typical corn seeding rates have been 32,000 seeds/acre for the conventional systems and 34,500 seeds/acre for the organic corn, where 5-10% loss from mechanical tillage was expected (Mulder, 1996). With organic soybeans the target seeding rates were 190,000 or about 10% higher than usual seeding rates with conventional 30" row soybeans. Below a 100,000 plants/acre optimal yields are no longer attainable.

From 1990 through 2002, corn and soybean seed used in the organic systems was actually conventional seed with a standard seed treatment (e.g. ApronXL, Captan, Cruiser, MaximXL, etc.). In October of 2002, the National Organic Program established rules for organic farming systems which prohibited the use of synthetic seed treatments for organic production. Therefore, from 2003 to 2005 organic seed without seed treatment was used, and in 2006, Natural II, an approved organic seed treatment, was added to the organic corn production system. No seed treatment is currently recommended for organic soybean production.

RESULTS

Corn

Long-term data from the WICST trials show the corn stands from all the systems have fallen short of the target population of 32,000 plants/acre. However, the organic systems, CS3 (grain-based system) and CS5 (forage-based system), have been consistently lower than other systems and on average, CS5 generally has had better stands than CS3 (Table 1).

Table 1. Corn populations on the WICST systems across reps, sites and years[1].	
System	Plants/acre
CS1 (c-c-c)	28,567a
CS2 (NT c-sb)	28,615a
CS3 (org c-sb-w/clov)	25,200c
CS4 (c-a-a-a)	29,033a
CS5 (org c-o/a-a)	27,229b
[1] data set includes Arl 1992-2006 and LAC 1992-2000	

Poor emergence in both organic systems has been associated especially with wet springs and to a lesser extent with cool springs—especially at Lakeland (Tables 2a and 2b) even though planting has often been delayed to mid-to-late May.

Table 2a. Characterization of the organic corn systems at Arlington.

Year	Planting date	Characterization of spring weather[1]	Organic grain system (CS3)	Organic forage system (CS5)	Organic grain system (CS3)	Organic forage system (CS5)
		Rain/heat units[2]	***Plants/acre***		***Bu/acre***	
1992	May 12	Normal/Normal	24,700	No data	99	112
1993	May 13	Wet/normal	20,800	27,500	87	119
1994	May 5	Dry/normal	28,050	28,800	188	199
1995	May 12	Wet/normal	28,100	28,300	156	157
1996	May 13	Normal/cool	26,950	26,950	83	154
1997	May 14	Dry/cool	30,900	34,000	148	155
1998	May 15	Wet/normal	26,083	28,083	198	205
1999	May 13	Wet/normal	26,000	28,300	156	182
2000	May 15	Wet/normal	22,800	25,350	133	135
2001	May 1	Wet/normal	27,850	29,450	156	181
2002	May 14	Normal/cool	28,700	26,650	158	174
2003	May 23	Normal/cool	28,600	30,850	110	150
2004 (replnt)	May 27 /June 16	Wet/cool	21,600	22,600	0*	0*
2005	May 18	Dry/cool	23,200	23,450	102	128
2006	May 23	Wet/normal	21,150	32,700	145	189

[1] wet or warm $\geq$ 20% above the 30-year norm; dry or cool $\geq$ 20% below the 30-year norm (1960-1990)
[2] rain: April + May, corn growing degree-day heat units: May
* corn did not mature and was harvested as snaplage

Table 2b. Characterization of the organic corn systems at Lakeland.						
Year	**Planting date**	**Characterization of spring weather[1]**	**Organic grain system (CS3)**	**Organic forage system (CS5)**	**Organic grain system (CS3)**	**Organic forage system (CS5)**
		Rain/heat units[2]	***Plants/acre***		***Bu/acre***	
1992	May 8	Dry/cool	24,250	No data	73	102
1993	May 14	'Normal'/cool[3]	21,100	24,800	78	81
1994	May 4	Dry/cool	30,350	30,850	187	198
1995	May 20	Normal/cool	28,200	28,850	131	144
1996	June 26	Wet/cool	26,850	25,850	45	57
1997	May 21	Normal/cool	24,250	25,750	134	151
1998	May 22	Normal/normal	No data	No data	129	93
1999	May 27	Wet/cool	27,667	28,333	90	128
2000 (replnt)	May 24/ June 23	Wet/cool	18,500	19,333	32	58

[1] wet or warm $\geq$ 20% above the 30 year norm; dry or cool $\leq$ 20% below the 30 year norm (1960-1990)
[2] rain: April + May, heat units: May
[3] nearly 5 in. of rain fell in late April creating a situation of planting into cold wet soils in May

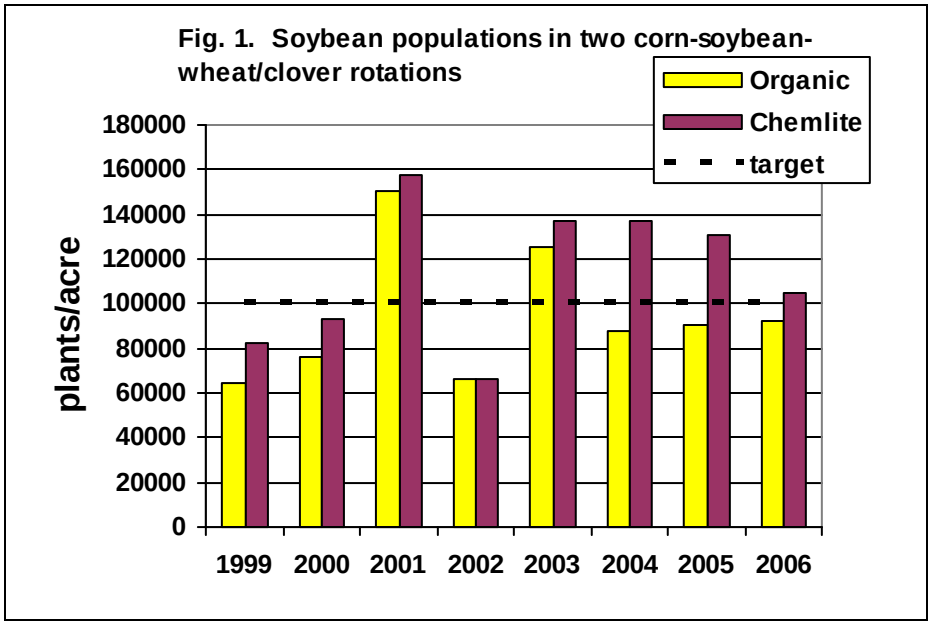
In 2004 at Arlington, the cold and wet spring resulted in such poor corn stands in CS3 and CS5 that they were replanted. It is noteworthy that the same variety planted on the same date in a newly certified organic field with similar soil (1/2 mile away) had a reasonable stand. Our hypothesis is that without seed protection, and with cool, wet soils, the corn seed was susceptible to insects and disease. At the WICST site, unlike the newly certified area, a substantial amount of weeds had been plowed down prior to planting, and in hind site, likely attracted heavy seed corn maggot (*Delia platura* Meigen) infestation.

Another aspect of stand and yield is soil fertility. Corn in CS5 has a higher level of available nutrients because it is following plowed-down alfalfa and manure additions. Where CS3 corn is grown without manure inputs, it follows only a short cycle green manure crop so may be less vigorous and thus more susceptible to delayed emergence. As Tables 2a and 2b show, in 12 out of 14 years at Arlington and 7 out of 9 years at Lakeland, CS5 out-yielded CS3 by more than 5 bu/a. When collapsed across sites, a chi-square fit test shows this proportion (i.e. 19 of 23 site-years where CS5>CS3) to be significant ($p<0.0016$) when tested against the null hypothesis of CS3=CS5. A similar pattern is evident for corn populations in Tables 2a and 2b.

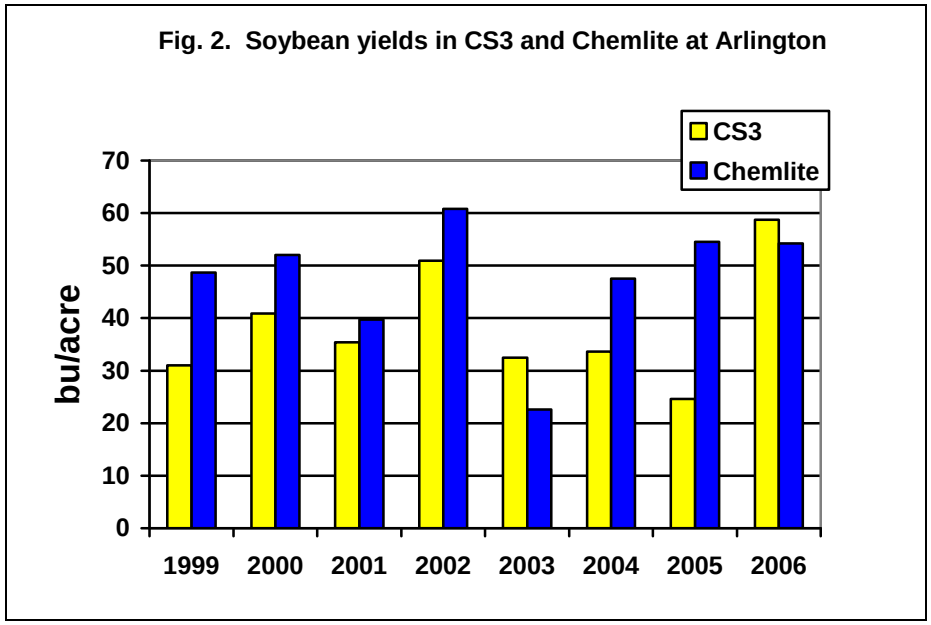
Wide-row Soybeans

At the Arlington site we have the same rotation (c-sb-w/red clover) in both an organic (CS3) and in a reduced input system (Chemlite). Despite being lower mathematically, the organic system did not have significantly lower soybean populations than the low input system (the major difference between the two systems during the soybean phase was that in Chemlite, herbicide was used). One explanation for relatively better soybean stands is that the soybeans were planted later than the corn and tended to emerge quickly. Nevertheless the organic soybeans have

frequently been below the lower threshold of 100,000 plants/acre for optimum yields (6 out of 8 years; Fig. 1).



We feel this is because the CS3 soybeans are rotary hoed 2x, and cultivated 2x in general (plus tine weeded in 2006) while Chemlite soybeans often get about half the mechanical weed control. With the exception was in 2003, when herbicide injury severely reduced the Chemlite yields, the improved weed control and better stands explain why yields are almost always higher in this system (Fig 2).



Recent Cultural Changes

Machinery: Recently we have purchased additional mechanical weed control tools at the Arlington Research Station. In 2005, the station acquired a tine weeder (also called a coiled tine harrow) which provides more effective control of larger in-row weeds that the rotary hoe. In 2006, a high-clearance rotary hoe was purchased which had sharper teeth and allowed more residue to flow through than the previous hoe. In addition, a disk-hiller cultivator (similar to a ridge-till cultivator) was purchased to help bury in-row weeds that escaped the rotary hoe or tine weeder.

In the summer of 2005, we determined it was necessary to manage the weeds in the organic systems with a different strategy as CS3 had tremendous annual weed infestations (primarily giant and yellow foxtail) and both CS3 and CS5 had an escalating perennial weed (quackgrass) problem. First in CS3, we tilled the land with the quack digger after wheat harvest (2-3x) to expose/desiccate the quackgrass roots and then we established a smother/cover crop with berseem clover and oats in early August. Then prior to the corn phase in both CS3 and CS5, we implemented the moldboard plow rather than chisel plow, to help suppress quackgrass and bury annual weed seed. The plan was to carry this out for the 3 years of the rotation to manage all the plots in the system the same way.

Seeding rates: In 2006, we increased seeding rate in the organic corn phases to 38,000 seeds/a but decided to leave soybean planting rates the same.

Seed Treatment: We began using Natural II seed coating on the organic corn seed in 2006. Despite the use of Natural II, stand issues in CS3 have remained a problem (Table 2a) although average yields were surprisingly high (144 bu/a). Yields in CS5 averaged 189 bu/a with ideal populations and more available nitrogen.

CONCLUSION

Erratic yields have plagued the organic grain production system (CS3) and they appear to be due to poor stands, weed pressure, and in the case of corn -available nitrogen. We are anticipating with the use of higher planting rates (38,000 seeds/ac) and seed treatment (Natural II) in corn, we can improve on the very poor stands of the past three years (2004-2006). Improved stands will, we anticipate, help in improved weed control as will our more aggressive tillage prior to corn planting and new cultivating equipment. Although we will stay at the same planting rates in soybeans (190,000 seeds/ac), our expectation is improved weed control in the corn as well as the soybeans will help with improved yields. Closer monitoring and scouting will be done on WICST in collaboration with UW Entomology. And we will set up a protocol to take plant counts after each tillage pass. Plant analysis data may be a valuable indicator of plant vigor between CS3 and CS5.

CITATIONS

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Organic and Conventional Production Systems in the Wisconsin Integrated Cropping Systems Trials: I. Productivity 1990–2002

Joshua L. Posner,* Jon O. Baldock, and Janet L. Hedtcke

ABSTRACT

During the last half-century, agriculture in the upper U.S. Midwest has changed from limited-input, integrated grain–livestock systems to primarily high-input specialized livestock or grain systems. This trend has spawned a debate regarding which cropping systems are more sustainable and led to the question: can diverse, low-input cropping systems (organic systems) be as productive as conventional systems? To answer this question, we compared six cropping systems ranging from diverse, organic systems to less diverse conventional systems conducted at two sites in southern Wisconsin. The results of 13 yr at one location and 8 yr at the other showed that: (i) organic forage crops can yield both as much dry matter as their conventional counterparts and with quality sufficient to produce as much milk; and (ii) organic corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], and winter wheat (*Triticum aestivum* L.) can produce 90% as well as their conventionally managed counterparts. The average yields for corn and soybean, however, masked a dichotomy in productivity. Combining Wisconsin Integrated Cropping Systems Trial (WICST) data with other published reports revealed that in 34% of the site-years, weed control was such a problem, mostly due to wet spring weather reducing the effectiveness of mechanical weed control techniques, that the relative yields of low-input corn and soybean were only 74% of conventional systems. However, in the other 66% of the cases, where mechanical weed control was effective, the relative yield of the low-input crops was 99% of conventional systems. Our findings indicate that diverse, low-input cropping systems can be as productive per unit of land as conventional systems.

SOUTHERN WISCONSIN and much of the upper U.S. Midwest were home to integrated grain–livestock production systems from the 1880s to the early 1960s (Felstehausen, 1986; Parr and Hornick, 1992). However, since the introduction of herbicides and chemical fertilizers, many of the integrated farms in this region have used those inputs to specialize in either livestock or in grain production. As specialization progressed, some of the inputs that made the trend possible have been found in unintended places in the environment such as surface water and ground water. The awareness that modern agriculture has been a major contributor to nonpoint pollution (Gish and Sadeghi, 1993; Oberle and Burkart, 1994; Barbash et al., 2001) and the suspicion that it has fostered socioeconomic problems in rural areas led to calls for farming systems to be more sustainable. This spawned a debate, in which proponents of organic and other low-input systems, and even some mainstream agriculturalists, cited the large farm size, lack of integration of crops with livestock, environmental pollution, and diminished biological diversity as reasons why conventional agriculture was not sustainable (National Research Council, 1989; Rodale, 1990; Parr and Hornick, 1992). Advocates of conventional agriculture countered that organic and related systems were not productive enough to meet society's food and fiber requirements nor were they profitable enough to support farms and the infrastructure on which farms depended (Council for Agricultural Science and Technology, 1990; Wagner, 1990; Avery and Avery, 1996).

Before the year 2000 most of the scientific literature suggested that organically managed cropping systems were less productive than the higher-input systems (Klepper et al., 1977; Berardi, 1978; Helmers et al., 1986; Crosson and Ostrov, 1990). Comparing separate surveys of 960 conventional farmers and 58 certified organic farmers in Ohio for the 1990 crop-year indicated that the organic farm yields as a percentage of their conventional counterparts were 76% for corn, 76% for soybean, 70% for wheat, and 68% for hay (Batte et al., 1993). On the other hand, a few studies indicated that organic yields were nearly equivalent to yields on conventional farms (Lockeretz et al., 1978; Lockeretz et al., 1981; Cacek and Langner, 1986).

In 1989, in response to the debate about the relative agricultural sustainability of low input and conventional systems, a large-scale, long-term study entitled the Wisconsin Integrated Cropping Systems Trials (WICST) was initiated at two locations in southern Wisconsin to compare the productivity, profitability, and environmental impact of a range of grain and forage-based cropping systems (Posner et al., 1995). The three standards of comparison were chosen because, despite the wide range of opinions on the definition and determination of sustainability, most agreed that at least those three criteria

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Abbreviations: GDD, growing degree days; NIRS, near infrared spectrophotometry; REML, restricted maximum likelihood; RFV, relative feed value; WICST, Wisconsin Integrated Cropping Systems Trial.

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				
					Estimated annual N–P–K input†			Pest control methods	
Code	Enterprises	External input level	Crop rotation	Primary tillage	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 1 of CS4 was sole seeded; the alfalfa in Phase 1 of CS5 was companion seeded with the oat–pea mix.

had to be met (Hildebrand, 1990; Keeney, 1990; Rodale, 1990). In this paper we focus on the question of productivity. Specifically, our objective was to determine whether biologically diverse, low-input cropping systems, as proposed by Harwood (1985) and Altieri (1987) could be as productive as simpler, high-input conventional cropping systems.

MATERIALS AND METHODS

Cropping System Trials and Terminology

Cropping system terms and definitions used in this paper are similar to those originated by Cochran (1947) and Yates (1954) and more recently restated by Cady (1991). By *cropping system* we mean the combination of a crop rotation and a management philosophy, which is more general than Cady's definition of it as a crop rotation and a set of specific management practices. Substitution of a management philosophy for specific practices allows the flexibility to adjust the practices to the needs of each crop rotation and keep up with rapid advances in varieties, weed control, tillage, and so forth (Frye and Thomas, 1991). We used a panel of farmers and researchers to guide such changes and ensure that they were consistent with the overall philosophy of each system (Posner et al., 1995). By choosing only the treatment combinations that are appropriate for each crop rotation, every cropping system is compared near its optimal level and the problem of impractically large, full-factorials trials are avoided (Cady, 1991). This flexibility and efficiency in cropping systems trials comes at a price; that is, the ability to identify specific causes of differences among systems is mostly lost.

There are a plethora of descriptive names that might be given to the low-external-input, biologically diverse cropping systems examined in the WICST. A few examples include alternative (Crosson, 1989; Madden, 1989), low-input (Weil, 1990; Liebman and Davis, 2000), integrated (Krall and Schuman, 1996), regenerative (Rodale, 1985), sustainable (Harwood, 1990), and organic (Rodale, 1990; Mader et al., 2002). Together they represent a spectrum that ranges from zero input of both manufactured fertilizers and pesticides to limited inputs of either or both. We chose to use the term *organic* to refer to the specific low-input systems in the WICST because it represents the complete absence of manufactured pesticides and fertilizers and there are clear standards for that system.

Design and Establishment of the Experiment

The ongoing WICST experiment consists of six cropping systems, replicated four times and situated at two locations in southern Wisconsin (the second site was terminated in 2002). 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). Specifically, the cash grain systems were a high-external input, continuous corn (CS1) system; a moderate-external input, corn–soybean (CS2) system, and an organic corn–soybean–winter wheat with frost-seeded red clover (*Trifolium pretense* L.) (CS3) system (Table 1). Forage systems include a high-input, corn–alfalfa (*Medicago sativa* L.) system (CS4); an organic inputs system of corn, alfalfa, oat (*Avena sativa* L.) plus field pea (*Pisum sativum* L.) mix, followed by a year of alfalfa hay (CS5); and a rotationally grazed pasture (CS6) seeded to a mixture of red clover, timothy (*Phleum pratense* L.), brome grass (*Bromus inermis* L.), and

orchardgrass (*Dactylis glomerata* L.) (Table 1). The key differences in cultural practices among the systems are described in Table 1. The organic grain and organic forage systems (CS3 and CS5) could not be certified organic, because they lack a 10-m buffer zone around each plot, and the same field machinery was used interchangeably on both conventional and the organic plots without previous cleaning. Also, before 2002 we used conventional, not certified organic seed. Except for these discrepancies, these grain and forage plots meet all the (other) USDA requirements for a certified organic system (USDA, 2007).

The trials were established in 1989 with all 24 ha at each location planted to corn to improve the uniformity of crop history and to allow baseline measurements to be made. Some of the baseline variables, especially yield, 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 (Posner et al., 1995; Loughin, 2006). 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 large, 0.3-ha plots allowed field work to be done with farm scale equipment. Grain and dry matter yields were measured by first running the harvest wagons across a farm scale and then taking several small samples that were composited and then frozen. Grain crop samples were analyzed for moisture, protein levels, and nutrient content (P and K), while forage samples (both hay and pasture) were tested with near infrared spectrophotometry (NIRS) to determine relative feed value (RFV) (Rohweder et al., 1978). In the rotational grazing system, randomly selected samples (4 × 0.5 m^2) were hand-cut each week with a shears at ground level just before grazing by the heifers (Marten, 1989). Additional details on the design and conduct of the WICST trial are provided in Posner et al. (1995).

Locations and Analytical Methods

Arlington and Elkhorn are in Major Land Resource Area 95B, which covers most of south central and southeastern Wisconsin (USDA, 1981). Soils in this area are primarily prairie-derived soils (Mollisols) and vary along two gradients, the depth of silt loam loess cap over glacial till, and internal soil drainage. One location was the somewhat poorly drained Lakeland Agricultural Complex on the Walworth County Farm near Elkhorn, WI (42°39′ N; 88°29′ W). The dominant soil types at this location are a Pella (fine-silty, mixed, mesic Typic Haplaquolls) and a mottled variant of Griswold (fine-silty, mixed, mesic Typic Argiudolls). The other location was a well-drained site at the University of Wisconsin Arlington Research Station (43°18′ N; 89°21′ W) near Arlington, WI, on a Plano silt loam (fine-silty, mixed, mesic Typic Argiudolls). For the most part, both locations had been in a dairy–forage cropping system of corn and alfalfa with manure returned to the land for the 20 yr before establishing the trial. As a result, both locations (0–15 cm) initially had high organic matter levels (47 and 52 g kg^{-1} at Arlington and Elkhorn, respectively), medium soil pH levels (1:1.3 soil/water, 6.5 and 6.3), high soil test P (108 and 58 mg kg^{-1} Bray I), and high soil test K (255 and 188 mg kg^{-1} exchangeable K). Although the two sites have nearly equivalent length of cropping season (April–October) and cropping season rainfall totals (622 mm at Arlington, 638 mm at Elkhorn), the Arlington site is approximately 90 km further north and has 1408 growing degree days (GDD) while Elkhorn is warmer and has 1760 GDD (base temperature 10°C) (National Oceanic and Atmospheric Administration, 2007).

Statistical Analyses

Initially, we analyzed the crop yields and quality data across both locations for each of the four test crops (crops that were in more than one cropping system) from the year they began in all the appropriate cropping systems through 1998 using the restricted maximum likelihood (REML) facility of SAS PROC MIXED (SAS Institute, 1999). These combined analyses ended at 1998 because crop sequence modifications were made in two cropping systems at the Elkhorn site in 1999. We used the following linear, additive model in these analyses:

$$Z_{ijkl} = \mu + L_i + Y_j + LY_{ij} + B_k(L_i) + YB_{jk}(L_i) + S_l + LS_{il} + YS_{jl} + LYS_{ijl} + \varepsilon_{ijkl}$$

where Z_{ijkl} was the observed yield or quality measurement for the $ijkl$th case, μ was the overall mean, L_i was the effect of location i, Y_j was the effect of year j, LY_{ij} was the effect of location i by year j, $B_k(L_i)$ was the effect of block k nested within location i, $YB_{jk}(L_i)$ was the effect of year j by block k within location i, S_l was the effect of cropping system l, LS_{il} was the effect of location i by cropping system l, YS_{jl} was the effect of year j by cropping system l, LYS_{ijl} was the effect of location i by year j by cropping system l, and ε_{ijkl} was the residual error for $i = 1, 2$; $j = 1,..., 9$ depending on crop and location; $k = 1,..., 4$; and $l = 1,..., 6$ depending on crop and location. Years, blocks, and their interactions were random factors in these analyses so the inference space extends beyond the particular levels of these factors. We made specific comparisons among the cropping systems with SAS's estimate statement. To determine the significance of the year × system and year × location × system variance components, we used the likelihood ratio test (Littell et al., 1996). These tests as well as the tests of the fixed effects were done at $\alpha = 0.1$. We also analyzed the data for nontest crops (crops that occurred in only one system) across sites and years with the above model by omitting the terms and indices for cropping system.

The analyses outlined above did not use the staggered start to estimate both a fixed effect of years (e.g., technological advances) and a random effect of years (e.g., weather effects) (Loughin, 2006). This deviation from optimal analyses occurred because in staggered starts for studies involving crop rotations there is an additional fixed effect of time due to agroecological factors, namely cycle. The differing cycle lengths among the cropping systems in this study made it very difficult to estimate all three time effects at once and especially difficult to ascertain the random effect of years because that effect was nested within the various cycles. Furthermore, preliminary analyses showed that the weather related effects of years were much larger than the cycle effects. Based on these considerations, we ignored the effect of cycle in this paper, but plan to report on it in a later article. In completing the

analyses combined over locations and years without regard to cycles, we found that examining the effect of years within sites in more detail would be useful for a few crops. For these cases, we omitted the terms and indices involving location from the above model to conduct these analyses. The latter analyses also allowed us to include the data through 2002 at Arlington.

RESULTS AND DISCUSSION

Test Crops

Fixed Effect of Cropping Systems

In the analyses of the four test crops, the effect of cropping systems on yields combined across years and locations was statistically significant for corn, soybean, and first-year established alfalfa hay; but not for seeding-year forage (Table 2). Although organic systems produced significantly less grain than the conventional systems (Table 3), their performance was better than anticipated based on previous research. For corn, the organically managed cash grain system (CS3) yielded 91% as much corn as the average of the two conventional cash grain systems (CS1 and CS2). Similarly in the forage systems, the organically managed corn (CS5) produced 88% as much as conventionally managed corn (CS4). In the case of soybean, the organically managed crop in CS3 yielded 92% as much as the conventionally managed crop in CS2. For forage dry matter yields, the organic system (CS5) actually produced more than the conventional system (CS4) in both the establishment year (22% more) and the first full-year of alfalfa hay (10% more). The advantage for the organic system in the establishment year was not significant due to greater variability and fewer years of data; but the effect was significant for the first full year of alfalfa.

Crop rotation and manure use contributed to the significant difference among cropping systems. Specifically, corn that received the benefits of both crop rotation and manure in CS4 yielded 1.5 Mg ha^{-1} more grain than the continuous corn in CS1 that received neither. Also, the CS4 corn produced 0.8 Mg ha^{-1} more grain than the CS2 corn that had the benefit of crop rotation, but not manure. Furthermore, average corn grain yields were 0.8 Mg ha^{-1} greater in the two forage systems (CS4 and CS5) than in the three cash grain systems (CS1, CS2, and CS3), which again provided evidence of the sizeable positive influence of manure and forage legumes on corn production. The benefits of crop rotation and manure, which include both crop nutrients and other effects, have been reported frequently (Shrader et al., 1966; Baldock and Musgrave, 1980; Porter et al., 1997).

Fixed Effects of Location and Cropping System × Location

In three of the four test crops—corn, seeding-year forage, and first-year alfalfa—the difference between locations was significant ($p < 0.01$) (Table 2). Explicitly, the Arlington site produced 25% more corn grain, 25% more first-year alfalfa, and 92% more seeding-year forage than the Elkhorn site (data not shown). The advantage for Arlington was likely due to the better drained soils. The large main effects of cropping system and location can often lead to significant interactions. However, the comparisons among cropping systems were consistent across the two sites so the location × system interactions were not significant for these three crops. On the other hand, in the fourth test crop, soybean, the effect of location was not significant (the Arlington mean was only 2.4% greater than the Elkhorn mean); but the location × system interaction was significant. While the organic (CS3) soybean yielded 99% of soybean in the conventional system (CS2) at Arlington, the ratio was only 85% at Elkhorn. More frequent problems with mechanical weed control in the CS3 system at the poorly drained Elkhorn site likely contributed to this location × system interaction (see below). Thus, the relatively small location × system interaction in soybean and the lack of this interaction in the other three test crops (despite the large difference in drainage) suggest that these results are widely applicable across locations on prairie-derived soils in the U.S. upper Midwest.

Table 2. Significance level of fixed effects in mixed model for test crop yields in the Wisconsin Integrated Cropping Systems Trials combined across years and locations (Arlington and Elkhorn, WI).

Source of variation	Corn 1993–1998		Soybean 1990–1998		Forage seeding‡ 1990–1998		Established alfalfa hay 1991–1998	
	df	Yield	df	Yield	df	Yield	df	Yield
System, S	4	**	1	†	1	NS	1	*
Location, L	1	†	1	NS	1	*	1	*
L × S	4	NS	1	*	1	NS	1	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

† Significant at the 0.10 probability level.

‡ Seeding year forage in CS4 was alfalfa; in CS5 it was alfalfa with a companion seeding of oat plus pea. There were no forage yields in 1991–1993 and 1996 because the oat crop was harvested for grain.

Table 3. Least squares mean yields for all crops, except pasture, in the Wisconsin Integrated Cropping Systems Trials combined across years and locations (Arlington and Elkhorn, WI).

System	Corn grain 1993–1998	Soybean grain 1990–1998	Wheat grain 1991–1998	Seeding year forage 1990–1998†	First-year alfalfa 1991–1998	Second-year alfalfa 1992–1998
	Mg ha^{-1}					
CS1	8.61					
CS2	9.40	3.58				
CS3‡	8.17	3.28	3.22			
CS4	10.15			5.61	9.03	8.06
CS5‡	8.95			6.86	9.91	
SEM§	1.02	0.16	0.33	0.74	0.43	0.46

† Not including years when the oat crop in CS5 was harvested as grain.

‡ Organic systems.

§ Standard error of the mean.

Random Effects of Year, Block, and Their Interactions

Table 4 presents the variance components for the four test crop yields as a measure of the variability across the random factors in the analyses (Littell et al., 1996). While there are some interesting features in the first four rows of Table 4, we have focused on the year × system (row 5) and year × system × location (row 6) interactions that measure how consistently the cropping systems performed across years and year-site combinations. With the four test crops, the three-way interaction was larger than the two-way interaction and statistically

significant using the likelihood ratio test. This indicates that further analyses to explain the variability is warranted and that it might be best done on individual sites. This was a fortuitous result because it allowed us to include the additional years (1999–2002) available at Arlington. We did not have to examine forage crop yields in more detail because the estimated year × system variance components for both forage crops were zero (Table 4, row 5), which means the differences in forage production between the organic and conventional systems were very stable across years. However, the results for the two grain crops were not consistent across years as manifested by the moderately large and statistically significant variance components for year × system (Table 4). This variability fit our observations of the trials that there was a large range in annual grain yields in the organic systems depending on how favorable the weather was for mechanical weed control. Others have reported similar observations (Liebhardt et al., 1989; Porter et al., 2003). Consequently, we attempted to quantify this effect in more detail as part of the within-site analyses using the method of separating the results into logical groups (that is, ones with different responses and hopefully smaller variance components) as outlined by Littell et al. (1996).

Table 4. Variance components from mixed model analyses of test crop yields in the Wisconsin Integrated Cropping Systems Trials.

Column	Source	Corn grain 1993–1998	Soybean 1990–1998	Seeding year forage 1990–1998	First-year alfalfa 1991–1998
1	Year, Y	4.68	0.00	0.35	0.00
2	Block (Location), B(L)	0.05	0.00	0.00	0.00
3	Y × B(L)	0.02	0.02	0.15	0.00
4	Y × L	2.01	0.24	1.46	2.01
5	Y × System	0.20	0.06	0.00	0.00
6	Y × L × System	0.57	0.07	3.06	0.60
7	Residual	0.59	0.11	0.65	1.56

Table 5. Variance components in analyses of corn yields across all years compared with grouped by effective (good years) versus ineffective (poor years) mechanical weed control years in the Wisconsin Integrated Cropping Systems Trials at Elkhorn and Arlington, WI.

	Elkhorn			Arlington		
Parameter	All 6 yr	4 good years	2 poor years	All 10 yr	6 good years	4 poor years
Year × system (Mg ha^{-1})^2	0.85**	0.25**	0.59NS†	0.69‡	0.37**	0.42**
Residual (Mg ha^{-1})^2	0.99	0.49	1.94	0.38	0.29	0.52

** Significant at the 0.01 probability level.

† NS, not significant at the 0.10 probabiliy level.

‡ Significant at the 0.10 probability level.

Table 6. Variance components in analyses of soybean yields across all years compared with grouped by effective (good years) versus ineffective (poor years) mechanical weed control years in the Wisconsin Integrated Cropping Systems Trials at Elkhorn and Arlington, WI.

	Elkhorn			Arlington		
Parameter	All 9 yr	5 good years	4 poor years	All 13 yr	8 good years	5 poor years
Year × system (Mg ha^{-1})^2	0.19**	0.10**	0.30**	0.23**	0.06*	0.35**
Residual (Mg ha^{-1})^2	0.10	0.05	0.11	0.10	0.13	0.06

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

Logical Groups for Corn at Elkhorn and Arlington

In the preliminary analysis across all 6 yr at Elkhorn, and 10 yr at Arlington, corn grain yields in the two organic systems (CS3 and CS5) averaged about 90% of those in the conventional systems (CS1, CS2, and CS4). The year × system variance component was significant (Table 5) at both locations and we suspected a large portion of this variation across years was due to inconsistent weed control. The field crew reported problems controlling weeds in the organic systems in 1993 and 1998 at Elkhorn and 1993, 1996, 2000, and 2001 at Arlington (Posner, 1990–2002). When we broke the data into two sets of years based on weed control, the analyses confirmed the deviations between them. In the problematic years, the organic corn produced only 69% (Elkhorn) and 80% (Arlington) as much grain as the conventional systems (data not shown). On the other hand, during the 4 yr at Elkhorn and 6 yr at Arlington when mechanical weed control was successful, the organic systems had yields equivalent to the conventional systems. Also, the year × system variance components were smaller within the two weed control groups compared with the ungrouped variance component, indicating the year-to-year results were more consistent when grouped with the larger gain occurring in the good-weed-control years (Table 5).

Logical Groups for Soybean at Elkhorn and Arlington

Across all 9 yr at Elkhorn, and 13 yr at Arlington, soybean grain yields in the organic system (CS3) averaged about 85% (Elkhorn) to 90% (Arlington) of those in the conventional systems (CS2). Even though there was less variability in soybean than in corn production across years, the year × system variance component was significant (Table 6), apparently due in part to differences in mechanical weed control in the organic systems. During the springs of 1992–1994, and 1998 at Elkhorn and 1992, 1994, and 1999–2001 at Arlington, it was difficult to control weeds mechanically (Posner, 1990–2002). During those years, CS3 soybean grain production averaged only 78% of that in CS2 at both locations. However, in the 5 yr with better mechanical weed control at Elkhorn and eight at Arlington, CS3 soybean grain yields averaged 91% (Elkhorn) and 96% (Arlington) of those in CS2. Thus, partitioning by the effectiveness of the mechanical weed control elucidated the differences between the organic and conventional systems that had been obscured when all years were pooled together for analysis.

The findings of the grouped analyses showing that the organic systems produced corn and soybean 90 to 98% as well as the conventional systems in years when mechanical weed control was effective, but produced only 69 to 80% as well when weed control was not effective were reinforced by "satellite" chemical weed control trials conducted on a portion of the organic grain plots at both locations in 1994–1998. Doll et al. (1999) reported that when post emergence herbicide was applied on subplots during the corn phase of the organic grain systems, mechanical weed control yields were nearly equal (89–97%) to those treated with herbicides in years when mechanical weed control was successful. However, in years when mechanical weed control was ineffective, the mechanical weed control treatment only yielded 71 to 80% of the treatment in which herbicides were used. For soybean, Doll et al.

Table 7. Summary of low-input versus conventional cropping system yields from field trials for row crops and nonrow crops as influenced by weed control.

Study citation	State	Sites	Site-years	Weed control†	Low-input yield as a percent of conventional system yield			
					Corn	Soybean	S. grain‡	Forage
					%			
Liebhardt et al., 1989§	PA	1	1	poor	84			
		1	1	good	112			
		1	2	unrated		103	90w	
Porter et al., 2003	MN	2	6	poor		64		
		2	8	good		98		
		2	14	unrated	92		100o	96
Delate and Cambardella, 2004	IA	1	1	good	114	111		
Smith and Gross, 2006	MI	1	4	poor	72			
WICST	WI	2	6, 9¶	poor	75	79		
			10, 13¶	good	98	94		
			15, 16#	unrated			93w	100

† Weed control in the low-input system determined by visual ratings or biomass.

‡ Small grain: w = wheat and o = oat.

§ Results given here are after three transition years. Authors presented forage yields for low-input systems, but no comparison to conventional yields.

¶ Number of site-years for corn and soybean, respectively.

Number of site-years for wheat and forage crops, respectively.

(1999) found yields with mechanical weed control alone were 87 to 96% of the subplots with herbicide treatment when good mechanical weed control was possible and only 70 to 84% when it was not.

Wet weather during the early part of the growing season was the major reason that mechanical weed control was difficult in some years. Of the six site-years in which mechanical weed control in corn was a problem, all had more than 140% of the normal May plus June rainfall. Further, of the nine site-years with difficulty controlling weeds in the organically managed soybean crop, six were in the same category of high May plus June rainfall. The greater rainfall needed to seriously limit mechanical weed control in corn compared with soybean fits with our observation that the taller stature of corn allowed more aggressive, rescue type cultivation compared with what could be done in soybean when earlier mechanical weed control attempts had been prevented or were ineffective.

Nontest Crops

Wheat yields in the organically managed system, CS3, averaged 3.22 Mg ha^{-1} (Table 3). Because wheat only occurred in one cropping system, we used the mean yield for the two counties where the trials were conducted for the same period (1991–1998), which was 3.45 Mg ha^{-1} (Wisconsin Agricultural Statistics Service, 1991–1998), to serve as a conventional standard. Thus, the organically managed CS3 wheat yielded 93% of the mean county yields and the difference was not significant because it was less than the standard error of the mean for CS3 wheat (Table 3). The only cropping system with a second full year of alfalfa was the conventionally managed CS4, where the second full year alfalfa yielded significantly less than the first full year (Table 3). To determine the productivity of the rotational pasture system, CS6, we hand sampled the forage at Arlington in 1994 through 2002. The mean and 90% confidence interval for the dry matter yield was 11.16 ± 2.15 Mg ha^{-1}. The mean yields of alfalfa in CS4 and CS5 both fell within that interval. Therefore, the forage dry matter yields in CS6 were virtually the same as those in CS4 and CS5.

Forage quality is as important as dry matter yield in determining animal production in the form of meat or milk, which is the ultimate goal of forage production. We used RFV as a measure of forage quality and estimated milk production with the MILK91 program (Undersander et al., 1993). Not surprisingly, in the establishment year there was a 23 point (Arlington) to 35 point (Elkhorn) RFV advantage for the conventionally managed CS4 forage that was primarily composed of alfalfa compared with the organically managed CS5 forage that was composed of alfalfa and the companion-seeded oat/pea. The RFV of the pasture samples was 120 ± 10, which was also significantly lower than for alfalfa in CS4, but not for alfalfa in CS5. However, the differences in RFV were offset by larger dry matter yields so there were no significant differences in estimated milk production with MILK1991 between the three forage systems at either location.

Correspondence with Previous Results and Implications

This report on the WICST adds a substantial number of site-years to the compilation of field trials comparing organic and other low-input cropping systems to conventional cropping systems in the northern tier states (Table 7). In addition, combining the WICST outcomes with the previous information gives rise to a clear pattern that shows weed control in the low input systems is a key contributor to the observed differences. Specifically, when there is a problem controlling weeds in the low-input systems, corn yields reported from these trials ranged from 72 to 84% of the corn yields in the conventional systems. Similarly, when there is a problem controlling weeds in the low-input systems, soybean yields in those systems ranged from 64 to 79% of the soybean yields in the conventional systems. However, when low-input weed control was successful, corn yields in the low-input system were 98 to 114% of the conventional corn yields and low-input soybean yields were 94 to 111% of conventional soybean yields (Table 7). This pattern did not appear to be a factor in non row-crop yields because none of the reports mentioned weed control and the low-input system production was 90 to 100% of that in conventional systems (Table 7). Thus, we conducted or found 37 site-years of comparisons of low-input to conventional corn, and of these, only 11 had depressed yields that averaged 75% of conventional corn due to difficulty controlling weeds in the low-input systems. In the other 26 site-years, the mean yield of the low-input corn was 101% of the mean for conventional corn. Correspondingly, researchers have compiled at least 39 site-years of low-input to conventional soybean comparisons. In 15 of those 39 cases, there was a problem controlling weeds in the low-input sys-

tems, and low-input soybean only yielded 73% of the conventional soybean. However in the other 24 cases, the low-input soybean averaged 97% of conventional soybean.

Based on the above summary, we estimate that the frequency of weed control problems and subsequent reduced yields in low-input row crops is roughly 34 out of every 100 cases and the corresponding relative yield is approximately 74%. We also estimate that in the other 66% of cases when mechanical weed control was successful, the yield of the low-input row crops was equal to that of 99% of conventional cropping systems. Low-input small grain and forage yields averaged 97% of conventional cropping systems over all site-years. Hence, the overall relative yield for low input systems compared with conventional in these reports for corn and soybean was 90%, and it was 97% for small grain and forage crops. Clearly, field research has answered the question, "Can biologically diverse, low-input cropping systems be as productive as conventional cropping systems"? with a qualified yes and has refuted the most dire warnings against wide-adoption of low-input cropping systems (Aldrich, 1978; Wagner, 1990; Avery and Avery, 1996). On the other hand, the results have distinctly identified weed control in row crops as a major problem in low-input cropping systems that occurs more often than desirable. While the issues of insect control, disease control, nutrient supply, and soil erosion must be addressed in low-input systems, they are not mentioned as frequently for reducing yield as is poor weed control (Crosson, 1989; Porter et al., 2003). Regarding solutions, some may already exist. That is, the studies reported here relied primarily on rotary hoeing and standard row-crop cultivating for mechanical weed control so intra-row weeders, flame weeders, and more preplant tillage may improve mechanical weed control. Furthermore, there are other physical and cultural weed control methods that are being studied (Melander et al., 2005). The point is, field research on low-input cropping systems plainly shows that on the one hand they are more productive and promising than some have claimed, but on the other, substantial research on how to improve weed control in row-crops in these systems is needed.

Two final caveats on the implications of these results are in order. First, to keep this study and report focused, we have concentrated on low-input vs. high-input cropping systems and too often the debate has been left in this all or nothing framework. But obviously, the WICST results and the other studies summarized in Table 7 strongly support an intermediate approach. For example, farmers could rely more heavily on mechanical weed control in dry years when this method usually works well and chemicals often do not, but rely more on herbicides in wetter years when mechanical weed control is less effective and herbicides are commonly effective. Lastly, as supportive as these results are for low-input cropping systems, we caution that this report was on per-land-unit-productivity only. Aggregate productivity is another issue (Lee, 1992). Both measures of productivity form only one facet of the overall goal of finding cropping systems that are sustainable. More research is needed to assess the economic and environmental impact of low-input farming systems.

CONCLUSIONS

We conclude that on prairie derived soils of the U.S. upper Midwest, (i) Organically managed and similar low-input forage crop systems can yield as much, or more, dry matter as their conventionally managed counterparts with quality sufficient to produce as much milk as the conventional systems; (ii) organically managed and similar low-input corn, soybean, and winter wheat can produce about 90% as well as their conventionally managed counterparts; and (iii) the productivity of corn and soybean averaged over a number of site-years masks a large dichotomy related to the effectiveness of mechanical weed control in the low-input systems. Combining WICST data with other published reports on low-input systems revealed that in roughly 34% of the site-years, weed control was such a problem, mostly due to wet weather, that the relative yields of the low-input systems were approximately 74% of conventional systems. However, in the other 66% of the cases, where mechanical weed control was successful, the yield of the low-input crops was 99% of conventional systems.

Consequently, we conclude that, in the majority of the cases, biologically diverse, low-input cropping systems can be as productive per unit of land managed as conventional systems. However, more research is needed on all aspects of sustainability and particularly on how to improve weed control in low-input row crops wet growing seasons.

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KRUSENBAUM FARM

A Constant Goal, Changing Tactics: The Krusenbaum Dairy Farm (1996–2005)

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Abstract

This case study documents the trajectory of a successful alternative dairy farm in southeastern Wisconsin. The 1990s were a difficult period for dairying and the Krusenbaum family entered this shifting field in 1990 with a 37-cow Holstein herd in a stanchion barn, 88 tillable hectares, and a vision to gradually develop a biodynamic dairy. Low milk prices and the unrelenting workload associated with conventional dairying forced the family to look for alternative strategies. By 1995 they had converted all their land to 47 rotationally grazed paddocks, increased herd size to 70 cows, and their annual net farm income had grown to a solid $54,000. The workload remained very heavy and

during the next few years they introduced a swing-16 milking parlor that approximately doubled their milking efficiency and allowed them to again increase herd size, implemented seasonal dairying, and constructed an outwintering shed (1997) that greatly facilitated animal management during the winter. By 2002 the farming system had been, by and large, consolidated and by not focusing solely on milk production and crossbreeding with non-Holstein breeds, the herd benefited from improved reproductive vigor. They were then able to synchronize annual calving and the herd's maximum nutritional needs with the spring flush of their pastures, which resulted in lowered purchased feed costs per cow. By this time, annual milk production was fairly constant (around 7,400 kg Rolling Herd Average [RHA]), herd health was good, and annual net farm income had grown to $75,600. In 2003 the farm became certified organic. With this change the value of the milk increased dramatically from $0.31/l to $0.45/l ($14.27 to $20.24/hundredweight), but feed costs climbed sharply due to the high cost of organic feed, as did labor costs due to the decision to train new farmers in grass-based dairying rather than simply hire employees. Due to very sound farm management, good money management and an entrepreneurial philosophy, this farm, by most performance standards, is now both highly profitable and environmentally sound and the families living on it have a good quality of life.

Key words: Management Intensive Grazing; seasonal dairying; subacute ruminal acidosis (SARA); mastitis; organic dairying; share milking; case study

A Constant Goal, Changing Tactics: The Krusenbaum Dairy Farm (1996–2005)

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Introduction:

The 1990s were a difficult period for dairying in Wisconsin. The trend of decreasing profit margins that began in the mid-1980s continued as the cost of production increased and real milk prices declined. Net dairy farm numbers continued to decline at the long-term rate of 4–5% per year, from approximately 34,000 at the beginning of the decade to 21,000 in 2000; by 2005 there were only 15,300[1]. The general profile of the remaining dairy farms has also been changing. Whereas between 1985 and 1995, about 90% of the dairies were moderate-sized (30–100 cows), had 70% of the dairy cows, and produced about 70% of the milk[2], by 2002, there was a greater concentration of production in large farms. The farms that had more than 200 cows represented only 7% of the dairymen, but they had 31 % of the cows and produced 34% of the milk. The under-100-cows group represented only 80% of the dairy farmer population, had 50 % of the state dairy herd, and produced 46% of the milk[3].

An in-depth analysis of the loss in overall dairy farms numbers in Wisconsin had found that while the exit rate, as a percentage of remaining dairymen, has been fairly constant since the mid-70s, the entry rate had dropped off significantly in the 90s[4]. An interesting alternative to the capital-intensive, large-scale confinement operations is the use of the low capital-intensive strategy of Management Intensive Grazing (MIG). It has been estimated that as many as 30% of the new entrants into dairying during the late 90s were primarily using rotational grazing to feed their cows, and a surprising 23% of all

dairy farms were using managed grazing (moving the animals at least once a week) in their operation by 2003[5]. The Krusenbaum family entered this shifting field in 1990 and what follows is the sequel (1996 to 2005) to an earlier article[6] describing the farm start-up (1990–1995).

A look back:

In March of 1990, the Krusenbaum family leased a dairy farm in southeastern Wisconsin and purchased the existing herd of 37 Holsteins. Their original plan was to establish a mixed farm that included dairying, cash crops, tree crops, and vegetables. By the end of 1995, however, the entire farm was seeded down and rotationally grazed (88 hectares in 47 paddocks, 4 ha in a woodlot, 4 ha in buildings) (**Figure 1**), they were milking 70 cows on a strictly seasonal basis (cows were dried-off in mid-January and began calving in mid-March), and production was at 7,700 kg (17,000 pounds) of milk as measured by Rolling Herd Average (RHA). Net farm income (return to the operator and family's unpaid labor and management time) per cow was $790 or $54,000 for the farm[6]. The family was however, getting ready to install a new "swing-16" milking parlor (16 milking machines running while on the other side of the pit, 16 more cows are being prepared to be milked) in May 1996. It was estimated that this change would double their milking efficiency (from 40 cows to 80 cows/hour) and allow them to immediately increase herd size from 70 to 90 cows with the goal of going up to 120. The expectation was that the larger herd size would help the family meet its financial objectives, and the combination of the grazing, the new swing-16 parlor and further improvements in winter management of the livestock (an outwintering shed was constructed in fall 1997) would

help the family reach its “quality of life” objectives. Both members of the couple had experience working on dairy farms prior to starting their own and they knew the work was satisfying but could become both very physically taxing and consume their lives, seven days a week, leaving little time for family and community. As a result, they continued their focus on the way they would work, but also grew very optimistic about the role that grazing could play in revitalizing the dairy industry and set for themselves, as another “quality objective,” teaching others how to develop Management Intensive Grazing dairies.

Methods:

We continued to monitor three broad sets of variables: 1) agronomic performance (agricultural production and land stewardship); 2) milk production and herd health; and, 3) economic performance. Farm data were collected using a number of different techniques. Soil sampling and on-farm trials were continued, and agronomic and grazing diaries were maintained. Herd production data were monitored by registering with the national Dairy Herd Improvement Association (DHIA) program, and economic data were analyzed using the Agricultural Accounting Management Systems (AAMS) software developed by the University of Wisconsin’s Center for Dairy Profitability[7].

The monitoring data are presented on three tables following a similar format. The ten years are divided into three periods: 1) A transition period (1996 & 1997) when the swing parlor and outwintering shed (Photo 1) were built and herd size grew rapidly; 2) an equilibrium period (1998–2002) when the farm settled into a routine of milking 110–120 cows; and 3) the recent period (2003–2005) when the farm became certified organic.

Where possible, following the data from this organic period is a column representing a "benchmark" based on a large set of conventional (primarily confinement) dairy farmers. These were developed from either a dairy economic survey (the annual Wisconsin Milk Production Costs Survey-UW Center for Dairy Profitability[8]; or from the annually available Dairy Herd Improvement Association Benchmarks[9].

I. Agronomic Performance

1. Using the land to feed the herd

The Krusenbaum farm has 88 hectares of pasture that include a mixture of bromegrass (*Bromus inermis* L.), orchardgrass (*Dactylis glomerata* L.), perennial ryegrass (*Lolium perenne* L.), quackgrass (*Elytrigian repens* L.), alfalfa (*Medicago sativa* L.), red clover (*Trifolium pratense* L.), ladino, and white clover (*Trifolium repens* L.). During the grazing season, the milk herd is moved to fresh grass after each milking (2x/day), and then followed by the heifers. The 1.6 ha (4 acre) paddocks are generally grazed for a day and a half by the milk herd (100 cows, 570 kg each) and then followed over the next day and a half by the heifers (50 heifers, 360 kg each). Regrowth permits cycling through the paddocks five to seven times a season (April 15–Nov. 15). The interval between grazing events starts in the spring at about 14 days, and during the heat of the summer, may be as long as 45 days. In an average year about 56 ha are hayed in May, and up to 20 ha in June for winter feed. Most of 1000–1200 round bales (270 kg DM) are wrapped put up as high-quality balage. As herd numbers climbed on the farm, an additional 9 hectares (1995) and 24 hectares (2002) were rented on a long-term basis and custom harvested as haylage.

Repeated sampling during the reporting periods indicated that good-quality forage was available throughout the grazing season [Crude Protein (CP) = 20–28%; Relative Feed Value (RFV) 160–180]. However, sward density was lower than desired and trials with potassium fertilization and adding additional manure were undertaken, as well as testing the value of annual frost seeding of red and ladino clover and ryegrass into the paddocks. Although the increased soil fertility treatments had no impact on paddock productivity, several activities that have been continued maintain, and in some cases increase sward density. They include: 1) frost-seeding legumes on a rotating pattern into the paddocks in March; 2) clipping the paddocks for weeds and refused forage in June and again in July; as well as 3) extension of the "rest" periods between grazing beginning in June from 15 to 30 days. This latter approach has been the most effective. Nevertheless, summer rainfall remains the largest determinant of forage production. Poor pasture and forage production were recorded in 1995, 1997, 2002, and 2005. Moisture deficits were the common factor in these years: June 1995 rainfall was only 25% and July 2002 was only 15% of the 30-year norm; while the dry spring of 1997 (50% of long term average for April/May) was exacerbated by the previous year's late summer (August/September) rainfall of only 4.3 cm (20 cm norm), resulting in depleted subsurface moisture. Forage production was the lowest in 2005 due to the combined problems of moderate to severe winterkill on the pastures and hay ground during the open, icy month of January, and grazing season rainfall (April–October) was the lowest it had been since they moved on to the farm. Winter feed storage dropped to a low of 200 t (DM) while in normal years it is closer to 650 t (DM).

The stocking rate on the farm, when the rented area is included is similar to the benchmark operations (**Table 1 line 1**) and well above the recommended limit of at least 0.72 ha/cow. [10] During the expansion stage (1996 and 1997), purchased feed costs per cow were high (**Table 1 line 2)**. This was due to the back-to-back seasons of low winter moisture reserve and low grazing season rainfall resulting in poor paddock production. During the equilibrium stage (1998–2002), with more normal rainfall, paddock production increased and feed purchases per cow returned to $294 or only 50% of the conventional benchmark herds. Once the farm became certified and organic corn and alfalfa was required, feed purchases/cow increased, especially during the dry year of 2005 ($950/cow). As a result average feed purchases are now slightly higher than that of conventional dairies of approximately the same size.

2. Evolving machinery park on the farm

Initially the farm was set up with a typical complement of equipment for a small conventional dairy farm. During the first six years (1990–1995) machinery costs per hectare were fairly constant ($62/ha)[6] due to the costs incurred as their row crop equipment became unnecessary and was sold (at a loss), and to their decision to buy equipment allowing them to wrap round bales and make round bale silage. The more recent data (**Table 1 line 3)** shows that machinery costs on the farm have climbed somewhat as herd size increased, resulting from their decision to buy newer equipment to meet the increased need to put up winter-feed. However, machinery costs still represent, only about 50% of the University's estimates for a conventional dairy farm. [11] The explanation for the difference is that less machinery is needed on a rotational grazing

operation and it is used on relatively few acres. For example, on a conventional dairy all the fields are crossed with machines several times a year in a typical corn and alfalfa rotation. Fuel use per cow **(Table 1 line 4)** also remains low and well below the conventional benchmark farms.

3. Manure management, farm gate budgets, and soil test values

Manure spreading on the farm is based on regular soil testing every three years (one composite sample every 3 ha). Generally there is enough manure in the out-wintering barn to manure 16 hectares (25 tons/ha) in the spring and the yard scrapings in the winter are equivalent to approximately 30 tons/week. Generally manuring rotates around the farm over a six or seven year cycle with greater emphasis on manuring the low soil test rented fields and less emphasis on the fields near the tree lines where manure accumulates during winter feeding from the round bales.

The increase in herd size from 70 (1995) to 120 animals (1998) was accompanied by only a modest change in estimated nutrient accumulation on the farm. (**Table 1 line 6**). This was due to the fact that more land was rented for making hay, keeping purchased feed to a minimum as well as giving them a larger base for spreading manure. Due to modest phosphorus and protein feed purchases the P-budget is generally in balance and this is reflected by soil test values (0–15 cms) taken in 2007. Although the farm mean of 112 ppm is high (31 sampling stations), it has been constant, in spite of the increased number of animals. Potassium accumulation however, has been taking place, but this is a good thing as soil test levels have been low on the farm (1990 = 81 ppm; 2007 = 114

ppm) and an increase in soil organic matter levels (1990 = 2.7%, 2007 = 3.3%) due to the perennial sod has also been noted.

4. Land Stewardship

The entire farm has been in grass since 1995 and beginning in 1997, increased attention was paid to “traffic problems” caused by wet winters and rotational grazing. With the construction of the outwintering shed, they have had the option to keep the animals off the paddocks during the muddy season (March/April) and to feed them near the shed. This has prevented a lot of pugging in the paddocks and damage to the sward. The second investment was to put in new 5 to 7 meter wide lanes with the help of a Natural Resources Conservation Service (NRCS) EQIP cost-sharing program ($18,000 farm; $50,000-Federal Government). The improved lanes and well-designed culverts greatly facilitate animal and machinery movement and ultimately animal health.

II. Milk Production and Herd Health

Throughout most of the dairy industry, the primary emphasis of herd performance is maximized milk production per cow per day. While milk production is always important, in grazing dairies it becomes less important than synchronizing the time of maximal nutrient needs of the herd with the season of maximal pasture growth. This concept underlies many of the herd management strategies employed by the Krusenbaum dairy in its evolution to a grazing dairy operation.

1. Herd size

Between 1996 and 1997 the herd increased in size from approximately 70 to 120 cows as shown in **Figure 2**. Once achieving a herd size of approximately 120 cows, herd size remained relatively stable until late in 2002. A drought in the spring and summer of 2002 created a severe shortage of stored forage heading into the winter and a decision was made to reduce herd size temporarily to 60 cows rather than purchase feed for the winter. Because relatively few cows are culled from the dairy, herd size rebounded to a total of 95 in 2003, 100 in 2004, and approximately 115 by the grazing season of 2005.

2. Milk production

The most common index of herd milk production in the US dairy industry is Rolling Herd Average Milk (RHA) (**Table 2 line 1**). RHA is an estimate of the average total weight of milk produced per cow in the herd over the previous 365 days. While RHA is obviously primarily a reflection of level of milk production of the cows, it is influenced greatly by length of dry periods, calving intervals, and other herd management factors. For example, increasing the length of the dry period of a cow does not change the number of cow-days in the herd, but would reduce the number of days when milk is being produced.

In addition to increasing herd size for the 1997 grazing season, the practice of shutting down milking operations early in the year was modified as shown in **Figure 2**. In order to take a break from milking in winter, they had to stop milking a number of good producing cows relatively early in their lactation, which became viewed as very costly a practice every year. From 1997 and on, the number of cows being milked through the

winter usually stabilized at approximately 40%. There were cases however, when winter labor was short and they did close down milking altogether. Nevertheless, in the summer months, it was typical for 100% of the cows to be producing milk. This change in winter milking policy resulted in reductions in the average length of dry periods from 83 days in 1994 & 1995[6], to close to the industry standard of 62 days by 2002 (**Table 2 Line 2**). Milk production per cow climbed slightly following the transition period and by 2002, RHA milk at 7,355 kg per cow per year was about 80% of the average DHIA Holstein herd production. Milk production per cow climbed again slightly during the organic phase but now represents only 78% of the average DHIA Holstein herd production (2003–2005) (**Table 2 Line 1)**. While below average milk production per cow may appear to be undesirable, it may be consistent with achieving the larger goal of maximizing pasture use efficiency.

3. Herd reproduction

In the MIG system, unlike a system that depends on stored feed, it is crucial that the majority of the herd calves just prior to the onset of the spring flush in the pastures when the feed is most abundant and of highest quality. Approximately 60 days after the birth of the calf, a cow reaches her peak milk yield, which coincides with her peak nutrient needs and her maximal intake of feed. Following peak, milk production declines gradually over the subsequent months until the cow is “dried off” or milking ceases. As a dry cow, she will consume less than half the amount of feed per day as when she was at peak milk production. To maintain this rhythm of the majority of the herd calving in March and April, the rate of successful identification of “heat” (estrus) and insemination

every 12 months must be very high. If for example the herd calving interval were to spread to 13 months for six years, cows would calve in the autumn and would require stored feed for most of their peak production period. Thus in a seasonal grazing dairy, reproductive management to achieving a 12-month calving interval becomes actually more important than increasing milk production per cow (**Table 2 Line 3**).

Maintaining an annual calving cycle in dairy cows has become a very difficult process that is rarely achieved in the industry today. In a review of reproductive trends in the US dairy industry, Lucy reported average calving intervals of 13.3 months in 1970 had stretched to 14.7 months by 2000[12]. The longer calving intervals were mirrored by reduced fertility, measured as services per conception, which increased from 1.8 in 1970 to 3.0 in 2000. During this same 30-year period of time production increased from 6,400 to approximately 9,000 kg of milk per cow per year. Simply stated, reproduction and milk production appear to be antagonistic.

In the case of a grazing dairy where there is a seasonality of forage availability, it appears that if lower production is the price that must be paid to maintain an annual calving rate—farm profitability may not be adversely affected, as it would in a dairy based on stored feeds. While this dairy is below average in terms of milk production, it has achieved the unusual accomplishment of a 12.1 month calving interval over the past several years—a full two months sooner than in the conventional herds in Wisconsin (**Table 2 Line 3**). The seasonal imperative for spring calving also means that replacement heifers must be managed so that they calve at 23 to 24 months of age, not at 27 months as is the average in the conventional herds (**Table 2 Line 4**).

In 1994–1995, 56% of the herd was culled[6]. Many of these cows were sold because their calving intervals had stretched to where they would not calve back in the desired early spring "calving window." By moving to a more flexible seasonal milking program and having animals in excellent reproductive health, the farm was able to reduce its culling rate to 24% in recent years, dramatically less than the 38% culling rate common in the industry (**Table 2 Line 5**). This number is even more remarkable considering that only half of these animals were involuntary culls (disease, don't get pregnant), while the remainder were sold to other dairies (pregnant but going to calve outside the "calving window"). In conventional dairies, nearly 100% of the cull animals are involuntary and sent directly to the slaughterhouse.

4. Herd Genetics

One of the reasons for the lower milk production per cow on this farm is due to genetic selection for traits other than milk production. In 1995, the adult cowherd was 100% Holstein with most cows fathered by high production bulls using artificial insemination.[6] During the transition period however, much of the service sires or semen being used in the active breeding program was purchased from New Zealand Friesian bulls and a number of cows were being bred to non-Holstein bulls. The primary cross has been between Holstein and Jersey, but semen from Normande, Dutch Belted, and Scandinavian Red bulls has been used to breed some Holstein cows. Because the semen of several breeds was purchased from several countries, comparable genetic index values cannot be provided in this discussion. This policy continued during the new equilibrium phase and by 2002, 30% of the cows in the herd were crossbreds and by the end of 2005,

45% of the cows were crossbreds (**Table 2 line 6**). In comparison to the overall industry, approximately 95% of the dairy cows in the AgSource data set maintained by Wisconsin's DHIA testing service were purebred Holsteins in 2005.

Milk volume from the crossbreds is expected to be less than that of purebred Holsteins because the starting point of the other breeds is so much less[13]. However, the crossbred cows are expected to show hybrid vigor resulting in increased fertility, longevity, and calf viability[14]. The current excellent reproductive performance of the herd may be partly due to absolute reduction in milk yield of the herd as sire selection has not emphasized milk volume, partly due to improved fertility related to hybrid vigor of the crossbred cows and of course, excellent management. Again, both factors of reduced yield and hybrid vigor would favor reproductive health so that calving can coincide with the spring flush of pasture growth.

5. Herd Health

Mastitis

While pastures presents very clean conditions for the cows and are associated with excellent mastitis control, outwintering the cows on pastures presents risks for cows in the late winter and early spring. When the stanchion barn was converted into a milking parlor in 1996, the cows no longer had a barn for housing. And as the frost leaves the soil in March and April, the feeding areas in fields can become muddy and soiled and the teats become contaminated, a risk factor for mastitis infections.

The standard monitor of mastitis is the herd average somatic cell count (SCC). Herd average SCC of 150,000 per milliliter of milk or lower is considered excellent,

whereas herd average SCC greater than 500,000 is considered to represent herds where a large proportion of the cows have infections of their mammary glands. As shown in **Figure 3**, and **Table 2 line 7)** the herd SCC exceeded 500,000 in the early months of both 1996 and 1997, a problem attributed to the outside conditions. Although the herd SCC improved when the grazing season began, mastitis problems in the first weeks after calving are a serious health and production risk to the cow.

Because of these mastitis problems with the fresh cows, and for cow comfort, a barn with a straw bedded pack and cement floor outside feeding area was constructed and used first during the winter of 1997–98 (**Photo 1**). The new barn improved hygiene of the cows through the late winter and early spring and was associated with excellent mastitis control from the summer of 1997 through 2000. An increase in herd SCC in the winter of 2001 was not diagnosed as to cause.

Since the herd achieved organic status, the use of antibiotics into the mammary glands called “dry cow treatment” has been discontinued. Dry cow treatments are a standard practice in the US dairy industry, as they have been shown to eliminate some of the existing subclinical infections and have been effective in reducing the number of new cases. The herd average SCC during the first three years of the organic phase has averaged 293,000, a modest increase over the prior years (**Table 2, Line 7**). While managing the herd on pasture resulted in excellent udder cleanliness and reduced risk of mastitis infections, the inability to use antibiotics in an organic dairy reduces the ability to manage mastitis infections and has resulted in an increased somatic cell count for the herd.

Subacute ruminal acidosis

Milk production declined 13% in 1996 and 1997 from prior levels. For example, in June of 1995, the herd had averaged 80 lbs of milk per cow per day, but produced 66 and 67 lbs per cow per day in each of the subsequent June test dates respectively. Herd average milk fat percentage reached very low levels of 2.7% in the grazing season of 1997. Because low production and low milk fat percentage is commonly found in herds experiencing subacute ruminal acidosis (SARA), an investigation was conducted. Using the rumenocentesis test[15], a positive diagnosis of SARA was made. SARA usually occurs in cattle being fed diets with an excess of starch, resulting in excessive production of volatile fatty acids and lower ruminal fluid pH below 5.5[16]. In grazing cattle, highest milk yields are associated with ruminal pH between 5.8 and 6.2[17].

Following the diagnosis, various modifications were made to the feeding program to reduce the ruminal acidosis problem. The daily feeding of corn grain (7 kg/day) was reduced and by 2001 was approximately 3.5 kg/cow/day. The reduction in corn grain was replaced by increased consumption of purchased alfalfa silage and by 2001 ruminal pH values returned to the normal range. This modified feeding program replacing grain with forage may partly explain, along with genetics, why the Rolling Herd Average (RHA) milk production is below that of comparable conventional dairies. Similarly, the improved control of ruminal acidosis will have contributed, along with crossbreeding with breeds that produce higher fat content milk, in the increased milk fat percentage in the past few years (**Table 2, Line 8**). As with many grazing based farms, overall health of the herd has been good and veterinary expenses ($84/cow/year) now represent about 80% of the costs incurred by conventional dairies (**Table 2 line 9)**. Even these numbers are a

bit high and this is largely due to a commitment to animal welfare and high quality health care. They do not spare expense on animal health. A result of this philosophy is that these dairy cows remain in the production herd for an average of 4.2 lactations while the industry average is 2.7.

III. Economic Performance

As with any business, success must also be measured in economic terms. **Table 3** summarizes several whole-farm economic indicators and provides industry benchmark comparisons from similarly sized farms (80 to 120 cows) from the AgFA survey results[8]. Total farm income/cow was fairly constant from 1996–2002, while actual herd numbers markedly increased from 69 in the fall of 1995 to 115 in the fall of 2001. And then total farm income/cow increased dramatically once the farm became certified organic and was nearly equivalent (94%) to the conventional dairy benchmark (**Table 3 row 2)**. Most of this income was from the sale of milk and it appears that, although production levels were lower on the Krusenbaum farm (by 2,000 kg/cow from **Table 2 line 1**), high organic milk prices ($0.45/l vs $0.31/l) mostly offset this effect.

An historical strength in the Krusenbaum system has been their low cost structure (inputs, labor, and interest payments). Basic cost per hundredweight equivalent (CWT EQ) is a measure of the input costs that farmers incur in generating total farm income, by converting all their income streams (milk, cull animals, custom work, and crop sales) to milk equivalents (**Table 3 row 3**). During the equilibrium phase these input costs were 85% that of conventional dairymen. Since becoming certified organic, however, basic costs have gone up and now are equivalent to baseline sample, in large part due to the

increased cost of buying certified organic feed. This measure does not include the effects on cash expenses associated with paid labor or debt servicing. In fact, on many farms labor and interest payments add greatly to the actual costs of production. On the Krusenbaum farm, cash labor expenses/cow to non-family members were lowest during the equilibrium stage (1998–2002). Although labor costs for the recent period are still only 75% of those on conventional farms, they have more than doubled from that lowest point, primarily due to the presence of a pair of interns (married couple) and part-time employment of neighbor (**Table 3 row 4)**. The third component of the cost structure for producing milk is debt servicing. It is especially noteworthy that although the Krusenbaum farm has a modern milk parlor, an outwintering shed, and a good line of farm equipment, it is carrying only 40% as much debt per cow as the benchmark farmers (**Table 3 row 5**).

The third group of economic variables reflects the actual income available to the farm family. Net Farm Income From Operations per cow (NFIFO, **Table 3 row 6**) is strictly the return to family labor, management, and equity capital. Due to the construction of the swing parlor and outwintering shed plus the adoption of seasonal dairying during the transition period, the farm experienced a low NFIFO/cow during those two years. However, during the equilibrium phase, when the construction was paid for and milk production was up, NFIFO per cow improved markedly. This number is also enhanced by a number of additional enterprises on the farm. They raise about 25 steers; have range-grown broilers and eggs and grow a few pigs every year that they market (gross sales $40,000). During the organic period, although production costs had risen (inputs, labor), the high price of organic milk ($0.45/l) resulted in still higher returns per

cow, equal that of the conventional benchmark herds. And this was accomplished at only 80% milk production levels. Net farm income on the Krusenbaum farm (**Table 3 row 7**) both during the new equilibrium period and organic period has been nearly equivalent (102% and 99% respectively) to conventional benchmark farms. The NFIFO/cow and Net Farm Income both clearly indicate that this farm is a financial success.

Conclusions:

The Krusenbaum farm, from all the indicators, is a success. The home farm plus rented land is supplying most of the dairy feed, the presence of well-managed pasture and improved lanes have resulted in almost no soil erosion on the farm, and soil test phosphorus levels are remaining constant while needed levels of potassium and organic matter are increasing. Milk production is modest but steady, the problem of subacute ruminal acidosis has been solved. Most striking is the reproductive health of the herd, which allows for an excellent synchronization of herd feed needs with the spring flush of forage. Net farm income on the farm is equivalent to that of the benchmark sample, adequate labor has markedly reduced the stress of farming and the low level of annual interest payments all bode well for the future.

This farm has been a success; we hypothesize, for the following three reasons:

The production strategy underpinning the farm operations is valid: Almost all of the herd management decisions have been focused on synchronizing calving with the spring flush of pasture assuring that when the herd's nutritional needs are the highest, high quality, cheap forage is plentiful.

Management has been creative and flexible:

Farm management: The Krusenbaums have continually tried to improve their system through the building of an outwintering shed, a new parlor, expanding the cow lanes, and shifting to strictly seasonal and then backing off to partially seasonal dairying. Although it took nearly two years to develop a diet that reduced rumen acidosis, by working closely with nutritionists they were able to solve the problem.

Investment decisions: The family was not afraid to invest money to improve their operation. Although an indirect measure of their willingness to invest, depreciation per cow over the past 10 years has been $420 or $61/cow higher than the confinement dairy benchmark sample. They have a modern milking parlor, outwintering building and a first rate line of equipment for putting up forage as balage for winter feeding. Due to attention to detail, they have made each of these investments generate additional income due to the resulting labor savings or quality of the feed they harvested.

Money management: They have kept their debt-to-asset ratio low by shopping around for money when they needed it. Although they now have one of the largest dairy grazing operations in the state, they are carrying relatively little debt.

Entrepreneurial spirit: The Krusenbaums have continually looked for ways to develop value-added products and synergies on their farm, allowing them to increase farm income. They raise about 25 steers each year, which they market. They introduced a small poultry and egg operation that follows the rotating herd in the paddocks and helps break up the manure pies, and they have had several pigs/year that rut in their outwintering shed helping to mix the hay and manure pack into compost. They also collaborated in an unsuccessful effort to market part of their milk as a grass-fed, locally produced cheddar cheese, but discontinued their participation when it proved

uneconomical. The successful initiatives play a small but important role in the profitability of this operation.

The family has always prioritized quality of life issues: Dairying can result in a crushing lifestyle. Since the Krusenbaum's started in 1990, the issue of quality of life has driven most of their major decisions. Starting with the shift from conventional to rotational grazing (1993and 1994), the purchase of modern baling and wrapping field equipment (1995 and 1996), the shift to partial seasonal dairying and herd expansion and the construction of the dairy parlor (1996 and 1997), and the building of the outwintering shed (1997) have helped them meet their goal to make dairying a good family enterprise. And most recently, they have been dedicating more time and resources to training a new generation of dairymen using MIG techniques. In addition to participating in the University's School for Beginning Dairy Farmers and a local grazing network, they have developed a share milking agreement (2006). (Under this contract the young couple who were interns and want ultimately to own their own dairy manage the farm, pay 16% of the variable costs. In return they keep 16% of the monthly milk check, get free housing, and are building equity by keeping every fifth heifer calf**.)** The Krusenbaum's focus on quality of life issues was one of their most important decisions and they are today as enthusiastic about dairying, as when they started in 1990.

Acknowledgements:

The Krusenbaum's have been unstinting in their honesty and graciousness in sharing information with the project team over the past 18 years. This would also would not have

been possible without the close collaboration of the Michael Fields Agricultural Institute of East Troy, Wisconsin.

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Captions

Table 1. Agronomic performance on the Krusenbaum farm.

Table 2. Herd performance on the Krusenbaum farm.

Table 3. Economic performance on the Krusenbaum farm.

Figure 1. Map of Krusenbaum field layout.

Figure 2. Evolution of adult cow numbers on the Krusenbaum farm.

Figure 3. Herd average somatic cell counts.

Photo 1. The interior of the barn constructed in 1997 for the wintering of the cow herd.

Table 1. Agronomic performance on the Krusenbaum farm.

Agronomic Criteria	Krusenbaum Farm			Benchmark
	Expansion Phase 1996 & 1997	New Equilibrium 1998–2002	Organic 2003–2005	Conventional Dairy Farms 2003–2005[a]
1. Stocking rates (ha/cow)	1.14	1.01	1.12	1.3
2. Purchased feed ($/cow)	550	294	754	663
3. Machinery costs ($/ha)	82	131	na	256[b]
4. Fuel costs ($/cow)	46	38	72	109
5. Fertilizer & lime ($/ha)	1	2	8	81
6. Farm gate nutrient budget				
N (kg/ha)	58	67	na	22[c]
P (kg/ha)	12	10	na	7[c]
K (kg/ha)	45	67	na	27[c]

(a) Reference values from the annual Wisconsin Milk Production Costs Survey-UW Center for Dairy Profitability. Mean results from participating dairy farms with 80-120 cows. Sample size from 2003 to 2005 was 145 farms.
(b) Assuming an average equipment complement for a 120 ha dairy farm with 40% of the area in hay and 60% in new seedings and corn (Univ. of Wisconsin-Extension, 2001).
(c) Farm gate budget from survey of 19 dairy farms in southern Wisconsin (Fisher et al. 1996).

Table 2. Herd performance on the Krusenbaum farm.

Herd Performance Criteria	Krusenbaum Farm			Benchmark
	Expansion Phase 1996 & 1997	New Equilibrium 1998-2002	Organic 2003-2005	Conventional Dairy Farms 2003-2005[a]
1. Rolling herd average (kg/cow)	6,850	7,355	7,432	9,477
2. Days dry per year	77	60	57	63
3. Calving interval (mo)	12.8	12.1	12.1	14.1
4. First lactation cows, avg age at calving (mo)	24	23	24	27
5. Culling rate (% of herd)	37	29[c]	24	37
6. Holstein cows (% of herd)	100	70	55	95
7. Somatic cell count (x 1000/ml)	384	241	293	326
8. Milk fat (%)	3.18	3.49	4.02	3.82
9. Veterinary costs ($/cow/yr)	74	69	84	106[b]

(a) Reference values, AgSource, Wisconsin DHIA, All Holstein Herds, Dec, 2003–2005.
(b) Reference values from the annual Wisconsin Milk Production Costs Survey-UW Center for Dairy Profitability. Mean results from participating dairy farms with 80–120 cows. Sample size from 2003 to 2005 was 145 farms.
(c) Excludes 2002 when 50% of the herd was sold following a drought and a shortage of forage to winter the herd.

Table 3. Economic performance on the Krusenbaum farm.

Economic Criteria	Krusenbaum Farm			Benchmark
	Expansion Phase 1996 & 1997	New Equilibrium 1998–2002	Organic 2003–2005	Conventional Dairy Farms 2003–2005[a]
1. Average number of cows	85	111	96	96
2. Total farm income ($/cow)	2,520	2,779	3,709	3,946
3. Basic cost ($/CWT EQ)[b] (2)	8.56	7.55	8.75	8.68
4. Labor costs ($/cow)[c]	252	128	272	362
5. Interest payment ($/cow)	160	114	62	159
6. NFIFO ($/cow)[d]	242	670	775	752
7. Net farm income ($/year)	23,240	75,600	73,595	74,088

(a) Reference values from the annual Wisconsin Milk Production Costs Survey-UW Center for Dairy Profitability. Mean results from participating dairy farms with 80-120 cows. Sample size from 2003 to 2005 was 145 farms.

(b) Basic cost per CWT EQ measures the input costs that farmers incur in generating total farm income, by converting all their income streams (milk, cull animals, custom work, and crop sales) to milk equivalents.

(c) Direct labor costs for non-family members minus benefits

(d) Net Farm Income From Operations (NFIFO) is the return to the operator family's unpaid labor and management plus the return to their equity capital

Figure 1. Map of Krusenbaum field layout.

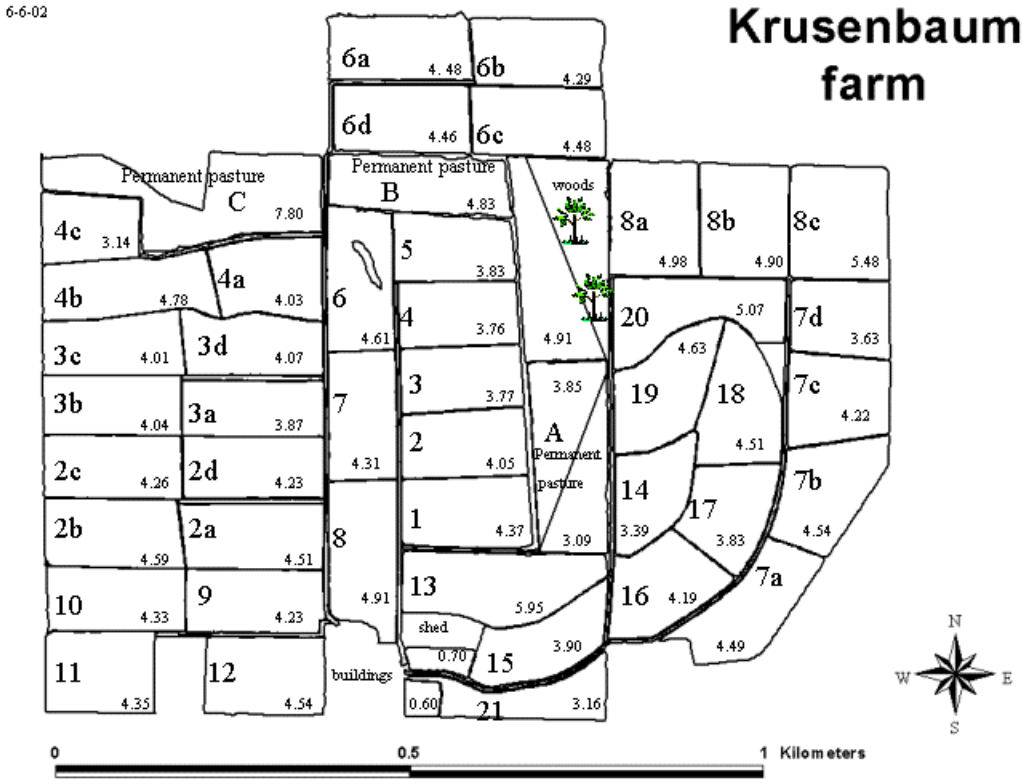


Figure 2. Evolution of adult cow numbers on the Krusenbaum farm.

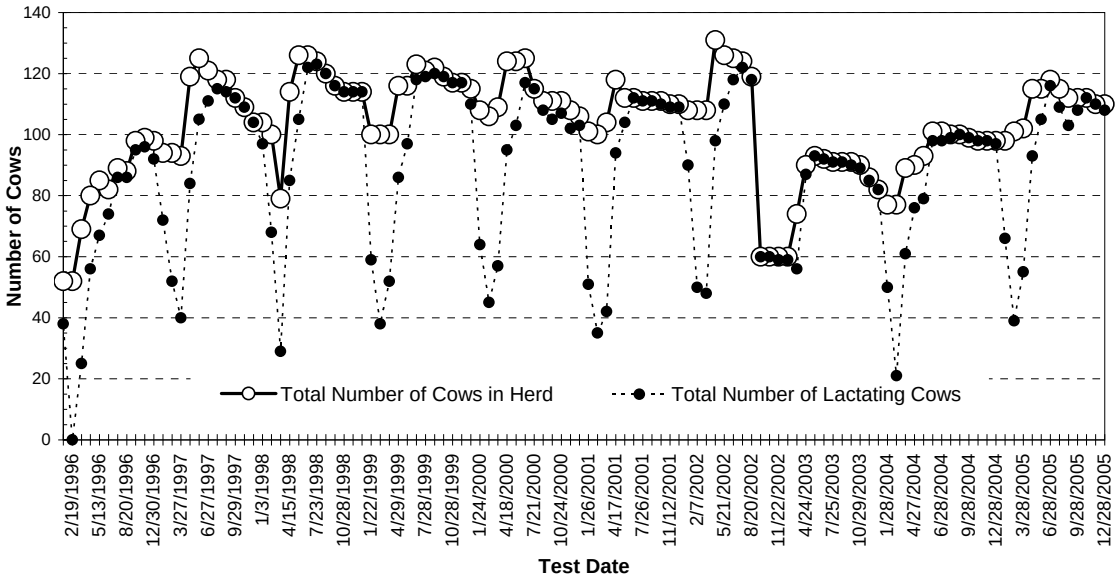
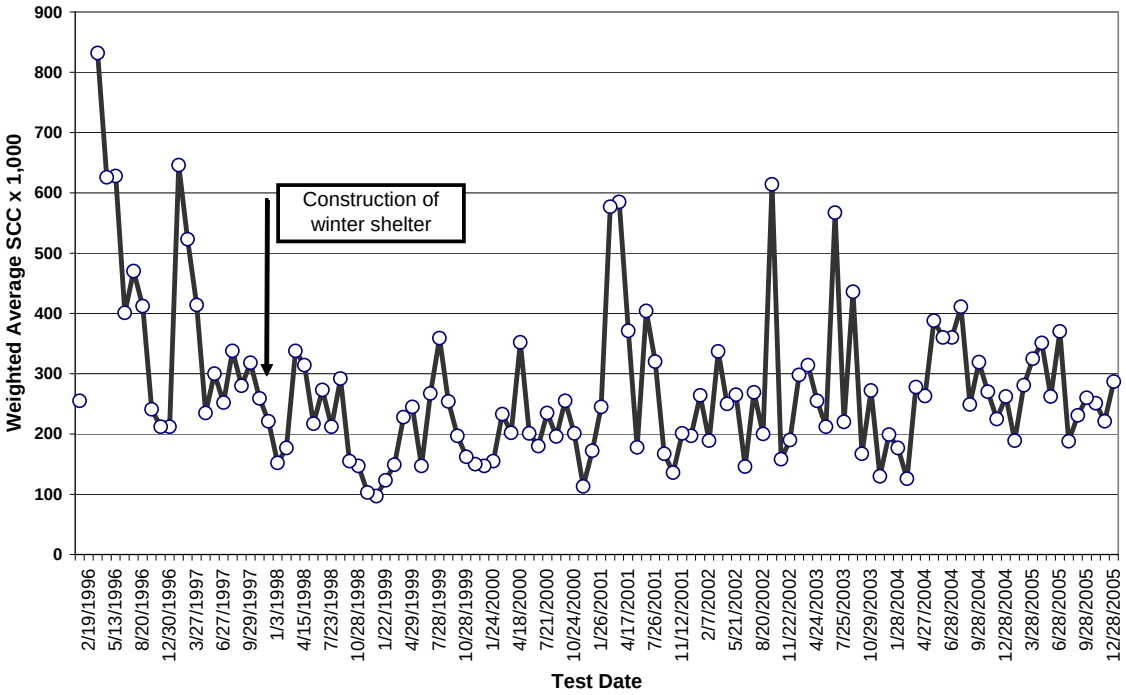


Figure 3. Herd average somatic cell counts.



SOIL TEST TRENDS FROM PERMANENT STATIONS AT THE KRUSENBAUM FARM

Janet Hedtcke and Josh Posner

INTRODUCTION

In March of 1990, the Krusenbaum family leased a dairy farm in southeastern Wisconsin and purchased the existing herd of 37 Holsteins. Their original plan was to establish a mixed farm that included dairying, cash crops, tree crops and vegetables. This endeavor proved to be too labor intensive and by the end of 1995, the entire farm was seeded down to grass and legume forage and they rotationally grazed the farm (220 acres in 47 paddocks, 10 acres in a woodlot, 10 acres in buildings; Fig 1). During this transition, they increased their herd and were milking 70 cows on a strictly seasonal basis, and production was at 17,000 pounds of milk as measured by Rolling Herd Average. Since the shift from row crops to management intensive grazing (MIG) in the mid-'90's, the Krusenbaum's have been managing their land organically (later certified organic in 2001) and have been monitoring nutrient management with periodic measurements of soil fertility around the farm. The purpose of this note is to present:

- Surface soil fertility trends across the farm; and,
- After more than a decade of no-till grazing, can we identify soil fertility stratification in the top 36 inches of the soil profile?

METHODS

The farm is in Elkhorn and is characterized by gently rolling topography with some potholes in various areas and knolls in other areas. There are a few paddocks with scattered oak trees and a wooded area that has never been farmed. The majority (62%) of the farm is McHenry silt loam on 2-6% slopes with another 14% of McHenry with 6-12% slopes. In some places, the soil depth is relatively shallow and sampling to 3 feet proved to be very difficult.

In 1990, 31 permanent stations were established across the farm using line transects and siting poles (Fig 2). The sampling scheme also included two additional stations on the neighbor's land in a corn-soybean rotation as well as a never-tilled check in a zone of occasionally grazed oak savanna (managed oak savanna, MOS) in Paddock C. In time however, as herd size increased and grazing replaced cropping, this area was integrated into the grazing system and is no longer the non-agricultural check. In the spring of 2008, a new reference point was established in the one remaining non-grazed area on the farm in the overgrown oak savanna (unmanaged oak savanna, UMOS) just north of paddock A. All soil samples were tested for soil test phosphorus (STP), soil test potassium (STK), organic matter (OM) and pH.

The stations were sampled at various times and depths over the past two decades (Table 1). In 2001, these stations were geo-referenced with a sub-meter accurate GPS unit. In 2007, a tractor mounted hydraulic probe was used and nearly all the stations were sampled to 3 ft. (Prior to this, stations were sampled by hand which led to some missing samples at the greater depths). The 3-ft cores were divided into 4 segments: 0-6", 6-12", 12-24" and 24-36".

Organic matter: This was measured by loss-on-ignition. We report on OM levels in the top 6" across the farm and then use a regression to characterize OM accumulation trends over time. It has generally been agreed that most changes in OM happen in the upper depths of the soil where

tillage, residue decomposition, and the majority of micro- and macro-fauna activity occurs (Conanat et al. 2007).

Phosphorus and Potassium. We report on mean STP and STK levels in the top 6" and then used regression to characterize soil test trends. In addition, we report on STP and STK trends by depth to see if nutrient stratification was taking place. Our hypothesis was that in a no-till grazing system, nutrient levels would decrease more rapidly at depth than at the surface due to the annual additions of manure. And finally, we looked at STP and STK as a function of distance from the barn. Historically with conventional dairy farms, fertility circles tend to exist, with the greatest nutrient concentration nearest the barn since it is here where manure is more frequently spread and nutrient levels decreasing on the fields that are less accessible (e.g. further away) (Powell et al., 2007). Our hypothesis was that there would be a more uniform distribution of nutrients on grazing farms where the herd itself does the distribution. In Figure 2 we have created 4 zones in concentric circles away from the barn to analyze nutrient spatial distribution.

RESULTS

Organic matter. As is shown in Fig. 3, OM levels in the top 6" were very modest across the farm at 2.5% when monitoring was initiated in 1990. The neighboring grain farm had OM levels below 2%. At our undisturbed MOS station, organic matter levels were slightly above 4%. Beginning in 1995 (when the farm was converted to MIG) mean OM levels began to build on the farm. The literature shows that frequently tilled soils lose OM due to oxidation but gradually OM builds back up with reduced tillage (Conanat et al. 2007).

The regression equation for surface OM levels over time from the 31 stations is

$$\mathbf{OM=2.48 + 0.06yr \quad and \ R^2 \ of \ 39.6\%}$$

Even though there is a fair amount of variability around the mean in any given year, this analysis indicates a general trend of an annual increase of 6% in OM across the farm (Fig. 4). From this regression analysis, the slope was significantly different from zero at $p<0.0001$.

Soil Test Phosphorus Trends. As with most dairy farms, surface soil levels of STP (0-6") have been high since the monitoring began (generally ~ 110 ppm P). In spite of the increased stocking rate, STP levels have not risen and have even had a modest decrease since 2001 due to strategic manure export to rented hay ground (Fig. 5). There is no manure in the neighbor's cash grain system, so levels are lower (85-100 ppm) but still excessively high. The benchmark STP from the MOS (1991) and the UMOS (2008) were 22 and 12 ppm respectively giving an indication of what soil fertility levels were prior to the introduction of agriculture in the area.

Contrary to our expectations, regressions on STP by depth indicated that levels were decreasing across all depths (the slopes were not equal to zero at $p<0.0139$) (see Fig. 6)—and, it appears that the upper 2 depths were declining at a faster rate than the lower 2 depths. However, there was not enough evidence to reject the common slopes hypothesis ($p<0.2448$) so the hypothesis of nutrient stratification is not borne out by this data set.

Soil Test Potassium trends. Levels of STK have been a challenge to maintain without inorganic fertilizer. Unlike STP, the surface STK levels were hovering around the optimal level (STK=100 ppm) in 1990 for forage production and were somewhat lower than the neighbor's field (STK=130 ppm) used for corn and soybean production (Fig. 7). The more recent readings however, do show that STK levels are improving, most probably due to the increased stocking rate. STK levels from the MOS (1991) and the UMOS (2008) were 65 and 66 ppm respectively.

The regression analysis by depth for STK does seem to suggest that the nutrient stratification hypothesis may be correct (Fig. 8). STK levels of the surface 6" have been increasing while at lower depths (e.g. 12-24 and 24-36") STK levels are dropping. This may be an effect of the perennial sod rooting depth, where they can actively mine K from the soil from lower depths, and the deposition of manure on the surface. However, we cannot reject a 'common slopes' hypothesis ($p<0.4361$) so it is hard to conclude that nutrient stratification is taking place. Nonetheless, Figure 9 clearly shows the STK intercepts at each time period are different by depth.

Spatial distribution of nutrients on the farm: It is interesting to see some differences between 1990 and 2007 using the concentric ring analysis. As reported earlier, we can see in Figure 10a that there has been an overall drop in STP on the farm over time ($p<0.0823$), and soil test levels among the 4 rings were different ($p<0.0068$) and do appear to be evolving to a more homogeneous level. With STK there has been a general build up on the farm over time ($p<0.0089$). And, while in this case the soil test readings are not significantly different among rings (Figure 10b), there again appears to be a tendency to have more homogeneous reading in 2007. At both sampling times however, we do see the lowest soil test levels at the stations furthest from the barn (Ring 4). This probably reflects less frequent manuring during the time of conventional dairying and now, perhaps haying rather than grazing takes place more frequently on those paddocks. Although not statistically conclusive, it does appear that with management intensive grazing, nutrients are more homogeneously distributed on the farm.

A note on pH. Over the years, and without lime additions, pH has remained constant 6.9 (Standard error=0.04) under MIG. This is largely a factor of the highly buffered soil but also due to good nutrient balance under MIG. The ideal pH range for a grass-legume mixed pasture is 6.0 according to the UW soil test recommendations (Kelling et al., 1998).

SUMMARY

This long-term monitoring effort on the Krusenbaum farm has revealed some interesting trends. Organic matter levels have increased on the farm, and the Krusenbaum's have been somewhat successful in drawing down STP and maintaining STK. Nutrient stratification in the soil profile does not appear to be happening with STP (just a general drawdown) but does appear to be occurring with STK (surface horizon accumulating potassium). Initial (1990) and recent (2007) soil tests indicate that the distant fields have lower soil test values than near fields. It does appear however that under MIG, soil test levels are more similar in rings 1-3 than they were under conventional management.

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Fig 1. Paddock Map

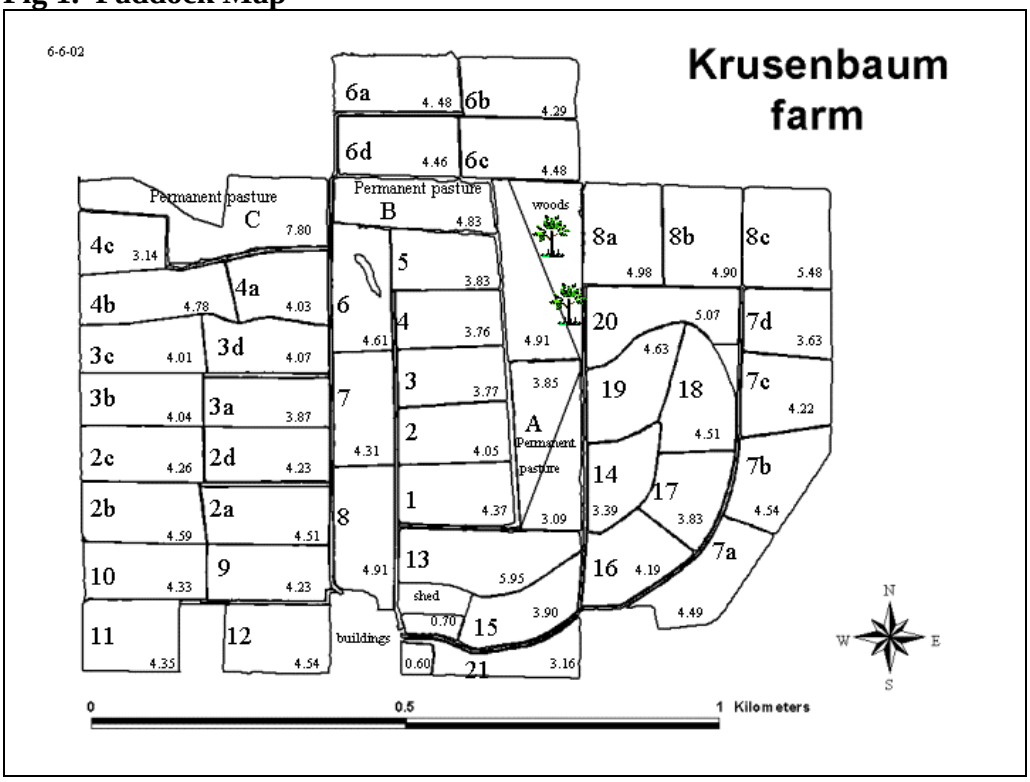


Fig. 2 Station map with concentric rings around barn.

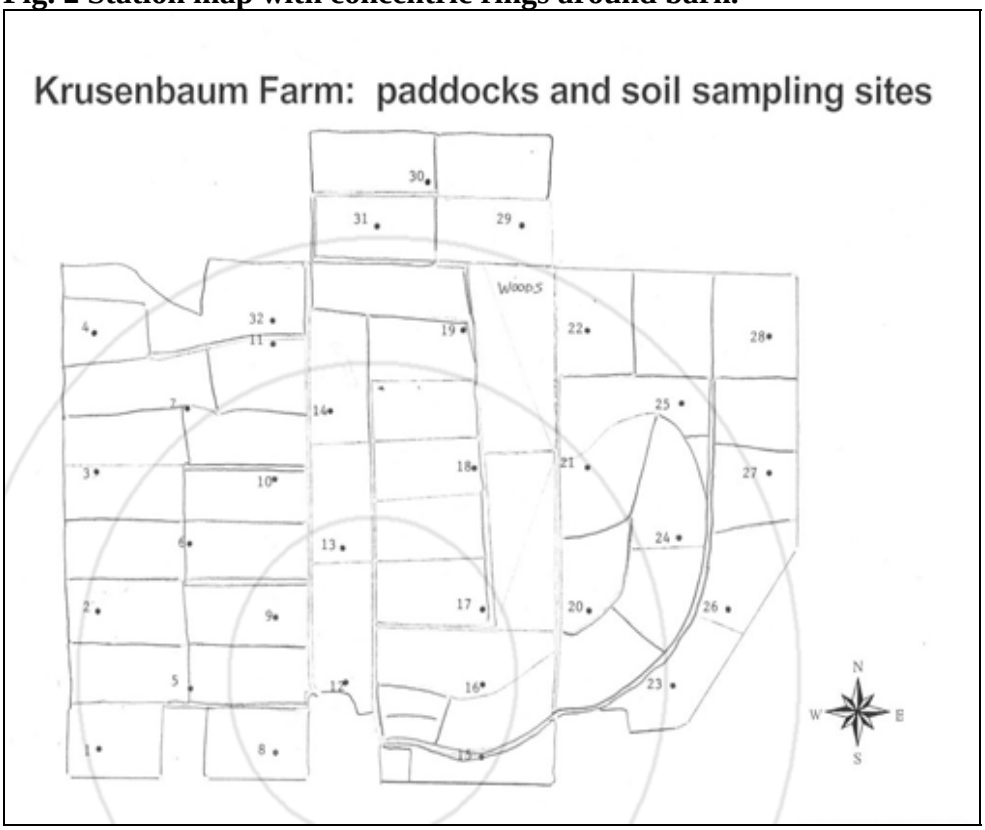
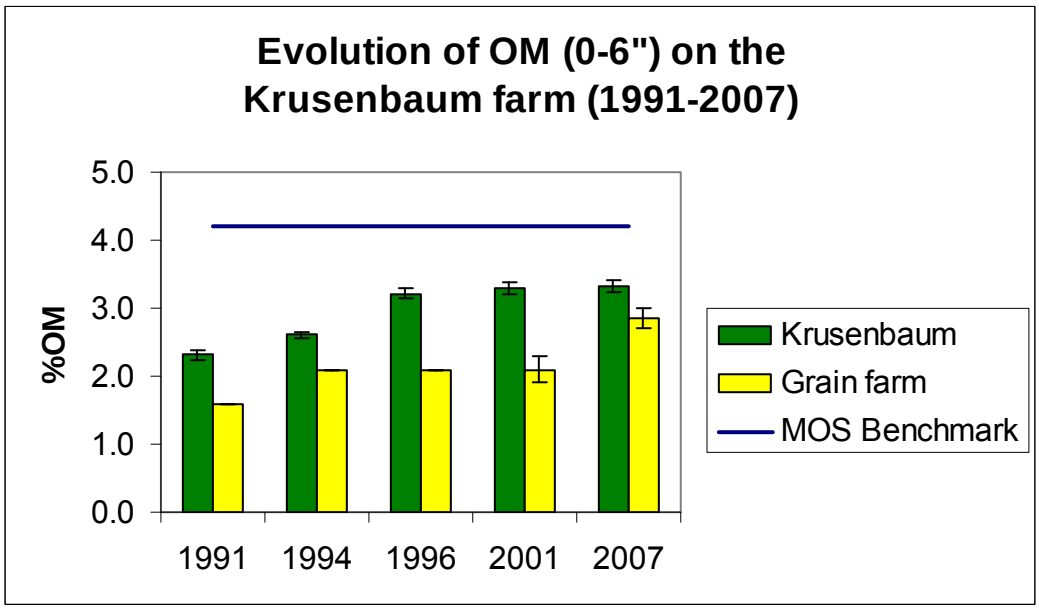


Table 1. Sampling history on the permanent stations

	Depth			
year	A (0-6")	B (6-12")	C (12-24")	D (24-36")
1990	√	√	√	√
1991	√			
1994	√			
1996	√	√	√	√
2001	√	√		
2007	√	√	√	√

Shaded rows are used for time trend regression on depth

Fig. 3



MOS – managed oak savanna site in 1991 (never-tilled)
vertical bars are standard error of the mean

Fig. 4. Change in OM (0-6”) over time on Krusenbaum farm

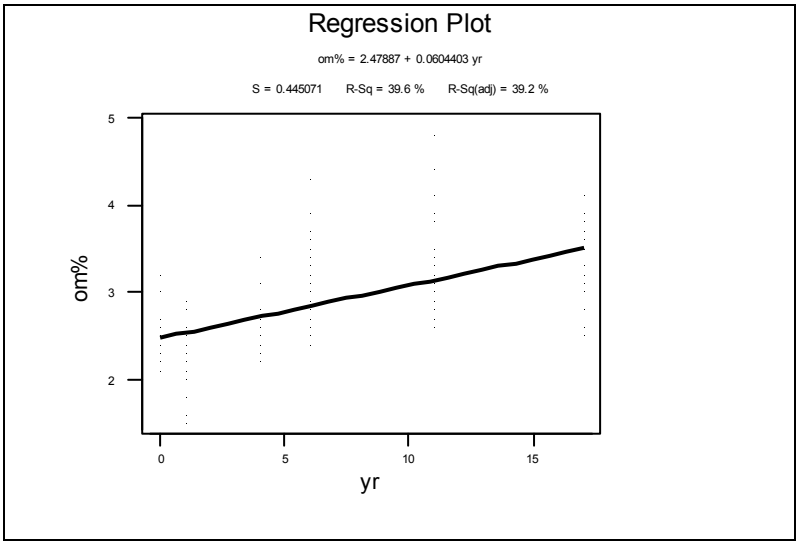
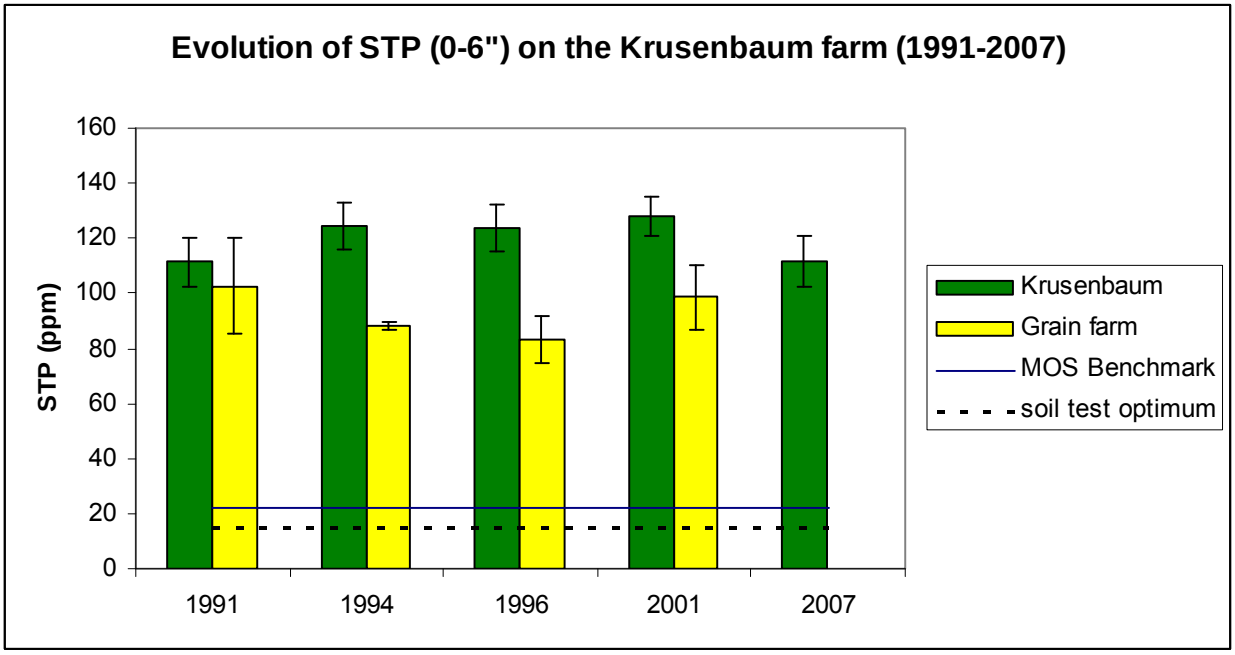


Fig. 5.



MOS – managed oak savanna in 1991
vertical bars are standard error of the mean

Fig. 6

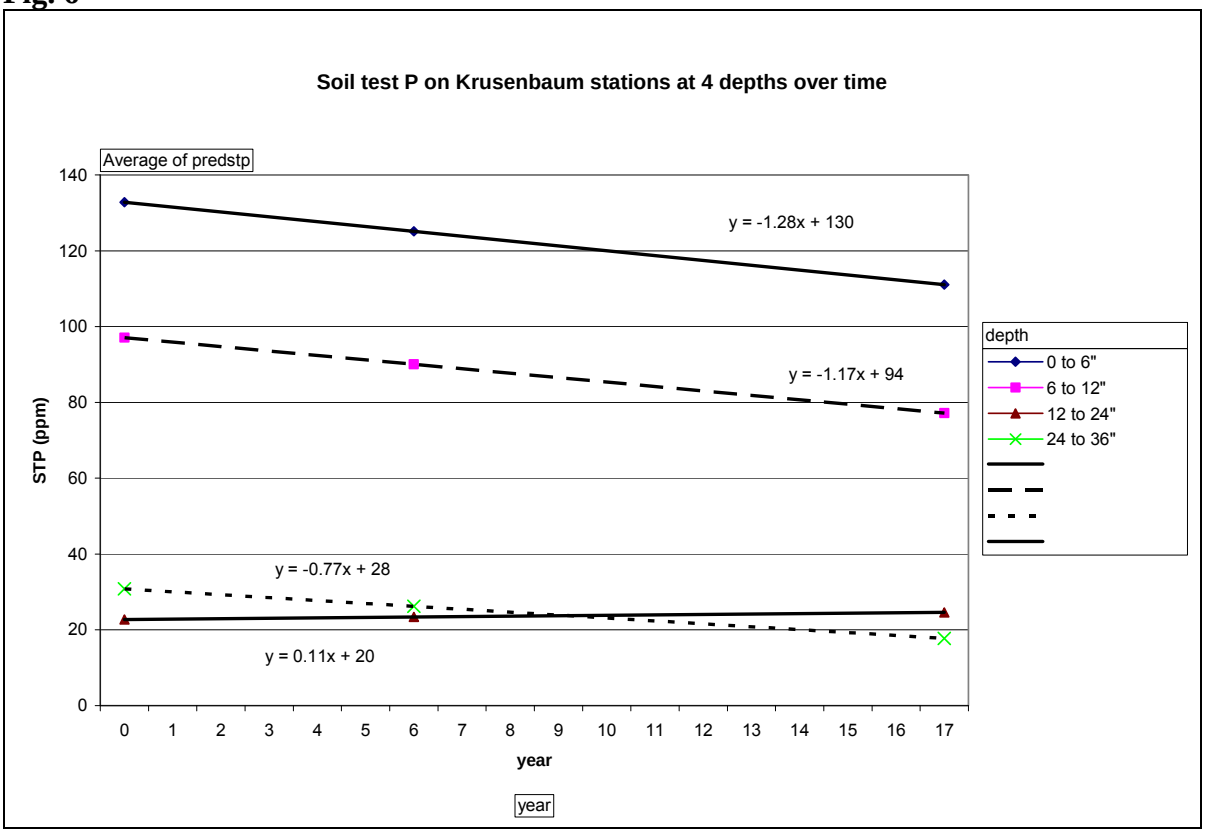
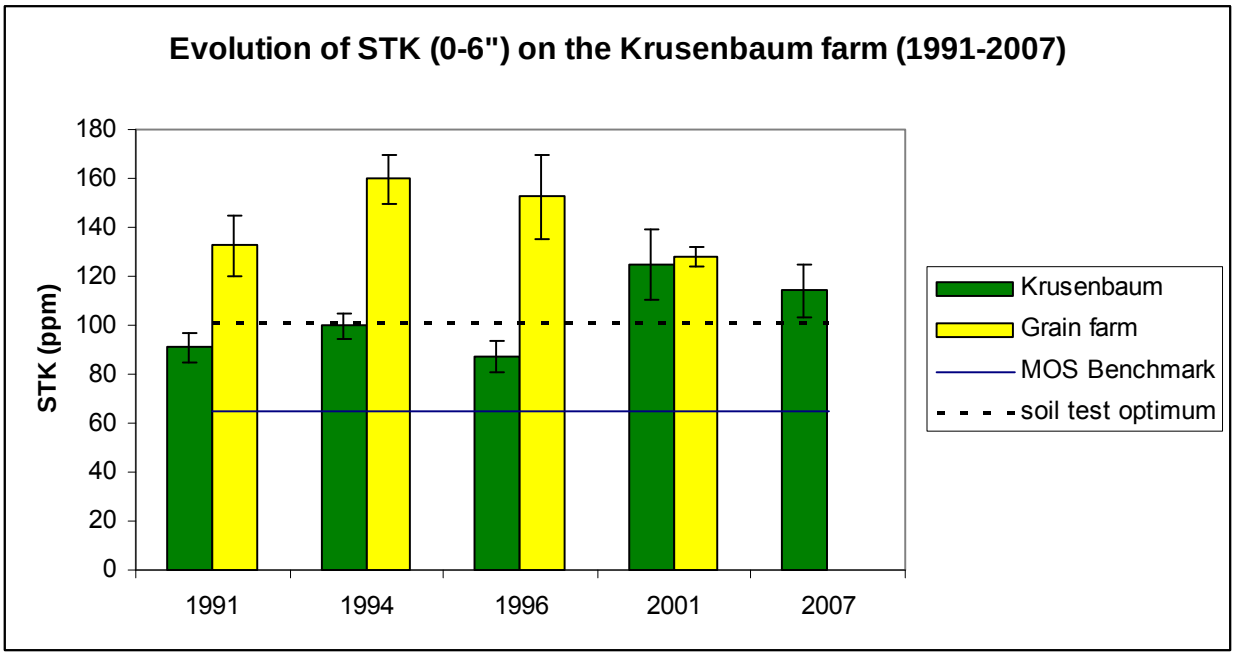


Fig. 7.



MOS – managed oak savanna in 1991
vertical bars are standard error of the mean

Fig. 8

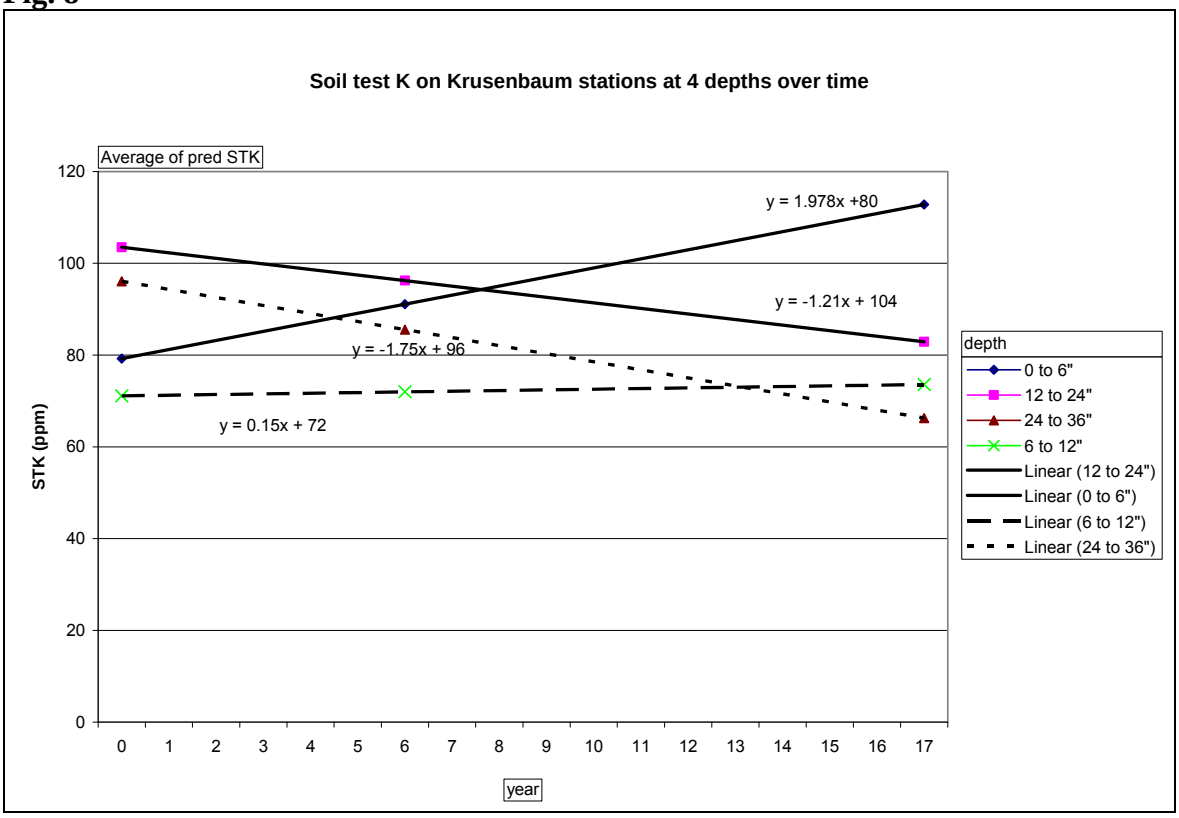

Soil test K on Krusenbaum stations at 4 depths over time
Average of pred STK
STK (ppm)
year
y = 1.978x +80
y = -1.21x + 104
y = -1.75x + 96
y = 0.15x + 72
depth
0 to 6"
12 to 24"
24 to 36"
6 to 12"
Linear (12 to 24")
Linear (0 to 6")
Linear (6 to 12")
Linear (24 to 36")

Fig. 9

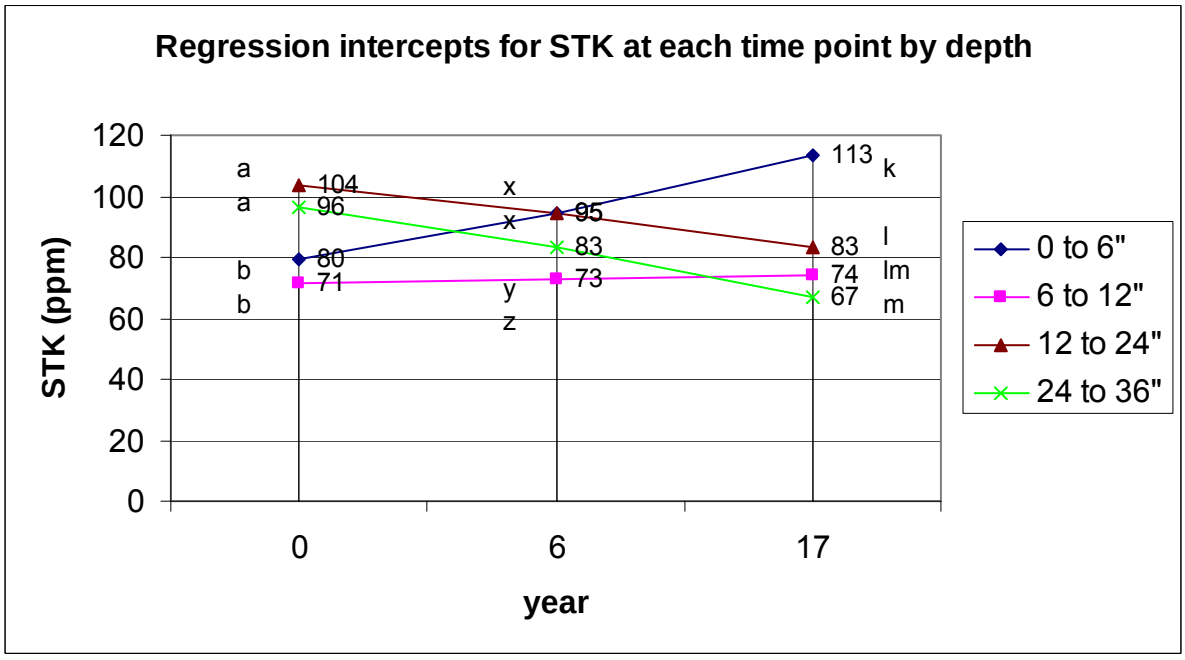

Regression intercepts for STK at each time point by depth
STK (ppm)
year
a
a
b
b
104
96
80
71
x
x
y
z
95
83
73
113
k
83
l
74
lm
67
m
0 to 6"
6 to 12"
12 to 24"
24 to 36"

Fig. 10a.

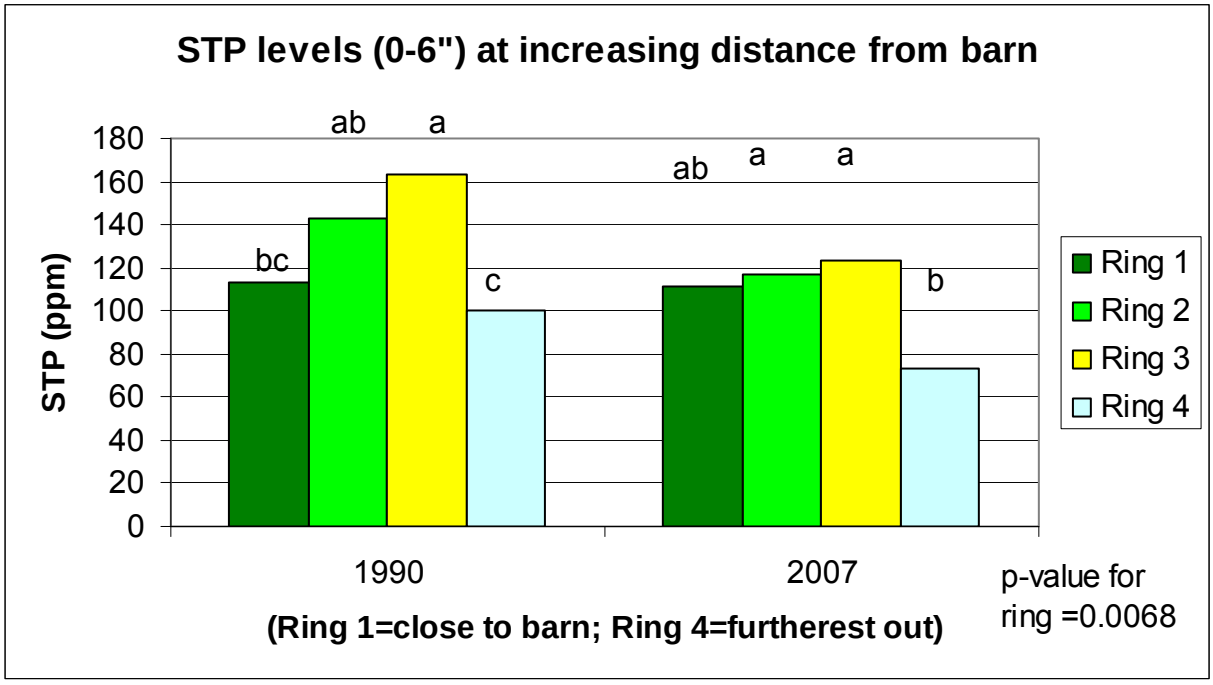
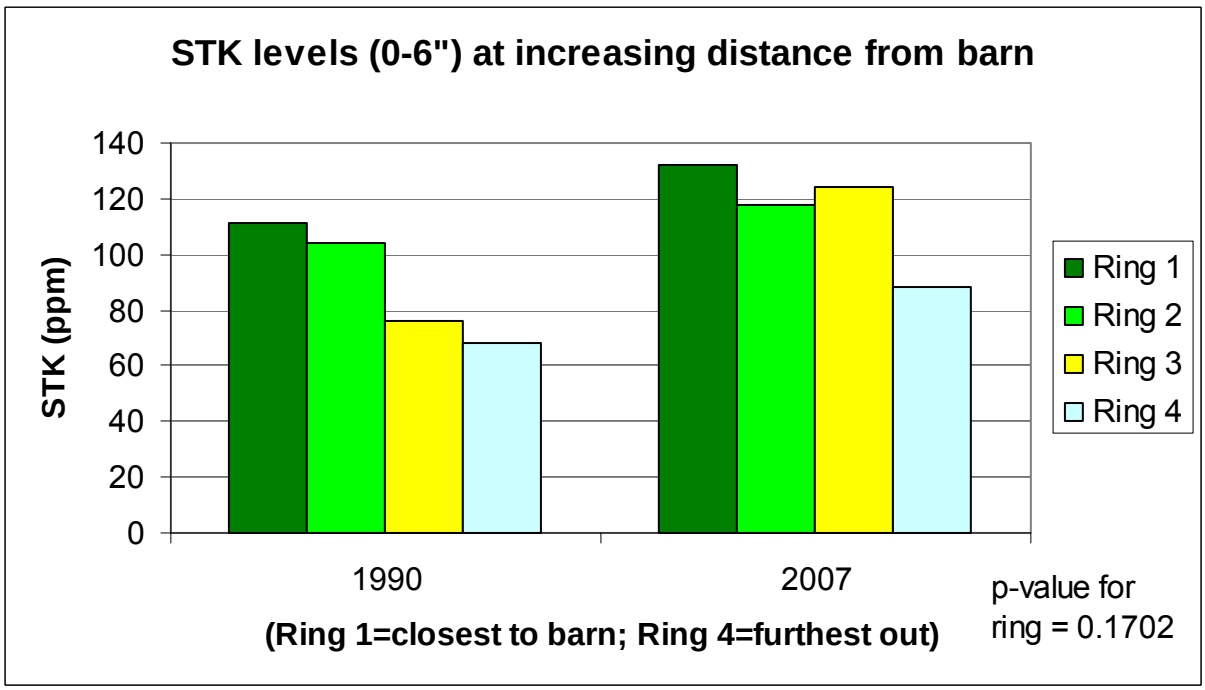


Fig. 10b



RECYCLING MANURE NUTRIENTS:
Linking Farms Project and Grass Ley Experiment

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Effects of Dairy Manure and Weed Management on Weed Communities in Corn on Wisconsin Cash-Grain Farms

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A reason given by cash-grain farmers for not using manure from neighboring livestock operations is that manure may cause greater field weediness. To address this concern, trials were established in corn on 11 cash-grain farms, in which manure from six nearby dairy farms was spread for the first time in at least 10 yr. A split-plot design was used in which manured and nonmanured treatments were established as whole-plots, and split-plot treatments were either with or without the farmer's regular weed control. In the multisite analysis, weed seedling density at the time of corn emergence was not greater in the manured vs. nonmanured treatments. At 7 to 8 wk following planting, weed density was not greater in the manured plots. Just before corn canopy closure, weed biomass also did not differ between manured and nonmanured treatments. Although neither weed species richness nor species diversity differed significantly between manured and nonmanured treatments, these measures did have significant environment-by-manure interactions, indicating that weed species distributions responded differently to manure across the different trial environments. However, farmers' weed control practices were highly successful in both the manured and nonmanured plots. Large portions (280 m^2) of all whole plots were visually inspected for introduced weed species after all weed control practices had been completed. The manured treatments did not differ significantly in the set of species observed, suggesting that manure did not introduce new weed species. Thus, this exploratory study showed that, contrary to some farmers' concerns, an application of dairy manure neither increased field weediness nor required alterations in the farmers' weed control programs.
Nomenclature: Corn, *Zea mays* L.
Key words: On-farm research, weed density, weed biomass, weed species richness, weed species diversity, introduced species, Hill's numbers.

Wisconsin dairy farmers are expanding their herds more quickly than they are acquiring new land, resulting in higher animal stocking rates (Anonymous 1997; Saam et al. 2005). At the same time, increasingly stringent nutrient management regulations, such as the Natural Resources Conservation Service's Nutrient Management Standard 590, are directing Wisconsin dairy farmers to decrease their manure application rates so that applied N and P do not exceed crop requirements (Anonymous 2005). As a result, many farmers are looking beyond their own land for areas to spread manure. One alternative is to transport and apply manure to nearby cash-grain farms. Although many Wisconsin grain farmers acknowledge the nutrient and soil conditioning values of manure, some have concerns that adding manure to their fields may increase weed infestation or introduce new species, thus requiring them to alter or intensify their weed management programs.

Dairy manure has been shown to contain variable amounts of viable weed seeds (Cudney et al. 1992; Mt. Pleasant and Schlather 1994). Feed is often identified as a major source of weed seed in manure; for example, Katovich et al. (2005) hypothesized that velvetleaf (*Abutilon theophrasti* Medik.) migrated into Wisconsin and Minnesota by the importation of contaminated feeds from other states. Weed seed could also enter manure via straw (Duchoň 1948, as cited in Šarapatka et al. 1993) or corn-stalk bedding, or it might be wind-blown into open storage pits. Although feed-pellet processing (Cash et al. 1998), feed ensiling (Blackshaw and Rode 1991; Takabayashi et al. 1979), ruminal digestion (Atkeson et al. 1934; Harmon and Keim 1934; Oswald 1908), anaerobic digestion of manure (Šarapatka et al. 1993), and composting manure (Cudney et al. 1992; Eghball and Lesoing 2000; Rupende et al. 1998; Takabayashi et al. 1979; Wiese et al. 1998) have been shown to reduce the numbers of viable weed seed in manure, potentially high concentrations of viable weed seed may still remain. For example, the viable weed seed load in manure from 20 New York dairy farms ranged up to 424,000 seeds per 1000 kg manure (Mt. Pleasant and Schlather 1994). Less work has been done in estimating weed seed content in slurry or liquid manure.

In addition to introducing weed seed into a field, manure may enhance weed growth by improving soil quality, increasing essential and trace nutrient availability (Eghball and Power 1999; Eghball et al. 2002; Safley et al. 1986), and increasing microbiological activity (Fraser et al. 1988). In addition, organic matter may increase, leading to improved water-holding capacity and aggregate stability (Anderson et al. 1990; Culley et al. 1981). Alternatively, there is evidence that immature compost with high levels of volatile organic acids could suppress weed emergence and growth (Ozores-Hampton et al. 1999, 2002). Even well-composted swine manure with relatively low concentrations of volatile organic acids has been shown to control growth of certain weed species (Menalled et al. 2005).

There is growing evidence that both larger and more diverse weed communities can cause greater losses in crop yield (Davis et al. 2005a; Davis et al. 200b). Previous studies have shown that different agronomic practices, including crop

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rotations (Westerman et al. 2005), tillage, chemical weed control (Davis et al. 2005a; Jeschke and Stoltenberg 2003; Mulugeta and Stoltenberg 1997), and combinations of these factors (Kümmel et al. 2005; Liebman and Mohler 2001; Stevenson et al. 1997; Swanton et al. 2006) can impact weed species richness and diversity. Different weed species demonstrated varying emergence and growth patterns in response to composted swine manure applications (Liebman et al. 2004; Menalled et al. 2005). Thus, manure may also influence the breadth and distribution of weed communities, impacting yields.

The purpose of this study was to address grain farmers' immediate concerns about the overall impact of manure on weediness in fields under conventional management. Specifically, the study objectives were (1) to characterize field weediness in response to manure additions; (2) to test the effectiveness of the farmers' weed control programs in the presence of manure applications; and (3) to measure whether manure introduced new weed species into farmers' fields.

Methods and Materials

To address the issues of the effects of manure on field weediness, efficacy of current weed control practices, and the introduction of new species, 11 on-farm trials were conducted. The 11 site–yr combinations were termed "environments" and deemed a random factor to better convey the range of soil types, weather, and management unique to each site, as well as to allow inferences to a larger population of farms. At each environment, the experimental design was a split plot with the manure treatments (a fixed factor) in whole plots in a randomized complete-block design, and the weed control treatments (also a fixed factor) in the split plots. Blocks were replicated two or three times within each environment, depending upon the amount of land the farmer had available for the experiment. Except for inclusion of a sampling error term in this project, the resulting mixed-effects model was the same as the one for which McIntosh (1983, table 4) listed the sources of variation and gave the appropriate error terms for testing the fixed effects. These tests were done using SAS 8.2 PROC MIXED software (SAS 1999). The same software was used to perform chi-square, likelihood-ratio tests of the environment (a random variable) by fixed-effect interactions, where the corresponding variance components were large, according to the procedures in Littell et al. (1996). Some of the observations did not adhere to the statistical assumptions of homogenous variance and normality, so they were log-transformed for the analyses, according to the following equation:

$$y = \log(x + 1) \quad [1]$$

In such observations, the means reported are from the nontransformed data, whereas statistical significance was based on the transformed analyses. Because of the exploratory nature of this study, the probability level of making a Type I error was set at $\alpha = 0.10$.

Five experiments in 2004 and six in 2005 were superimposed on corn fields in south and central Wisconsin. Manure was supplied by six different dairy farms over the 2 yr. Four of the six dairies were large operations (> 200 lactating cows) that used free-stall barns and maintained nearly 100% animal confinement. The other two dairy farms milked approximately 55 cows and housed the animals in stanchion barns. Five of the six farms used a slurry or semisolid manure storage system, and one dairy farm stored manure as a solid stack. All farms were well-managed, high-producing operations typical for Wisconsin, with rolling herd averages of at least 9,520 kg per cow per year. Manure application, tillage, and weed control programs for each site are summarized in Table 1.

Large whole plots were used to better account for the spatial heterogeneity of weed seedbank communities (Mickelson and Stougaard 2003; Mulugeta et al. 2001) and the nonuniformity of manure (Davis et al. 2002; Dou et al. 2001), as well as to facilitate commercial manure applications. Whole plots (the manure treatment) were between 9.1 and 18.3 m wide and 61 to 152 m long. These dimensions were determined according to manure application machinery width as well as corn planting and harvesting equipment. Split plots (the weed control treatment) consisted of 1-m^2 quadrats, and three quadrats of each weed control treatment were placed within each whole plot. The without-weed-control quadrats were established by placing 1.2 by 1.2 m tarps over each quadrat just before PRE and POST herbicide applications.

At five sites, manure was spread in the late summer or early fall following wheat (*Triticum aestivum* L.) harvest, and at four sites, manure was spread after soybean [*Glycine max* (L.) Merr.] harvest in the fall. Manure was spread at two sites in the spring just before corn planting. Slurry was used at eight sites, and solid manure (bedding pack and barnyard scrapings) at three sites. At six sites, the manure was injected or incorporated within 3 d of application. Farmers fall-tilled two sites, did no fall tillage at two sites, and used fall strip tillage at one site. Manure samples were taken at the time of spreading and analyzed for nitrogen, using total Kjeldahl N. Estimated first-year nitrogen credits from manure (as cited in Bundy et al. 1994 and Kelling et al. 1998) ranged from 33 to 179 kg N/ha, with a median of 120 kg N/ha.

The farmers were responsible for most agronomic decisions, including hybrid selection, planting population, planting date, herbicides, and starter fertilizer. In the spring, before side-dressing, a soil-nitrate test (Magdoff et al. 1984) was used to gauge plant-available nitrate, and farmers based their nitrogen side-dressing rates on University of Wisconsin Extension fertilizer recommendations (Bundy et al. 1994). Total fertilizer nitrogen applied (excluding the organic grower) on the nonmanured treatment ranged from 34 to 223 kg N/ha, with a median of 106 kg N/ha, and on the manured treatment, fertilizer nitrogen additions ranged from 0 to 186 kg N/ha, with a median of 57 kg N/ha.

To measure manure weed density at the time of corn emergence, weed counts were made when corn was between VE and V2 at three sites in 2004. This weed count was not repeated in 2005. Weeds in all quadrats were counted and identified as either broadleaves or grasses (including sedges).

Weed density and species richness were collected between 7 to 8 wk after planting (WAP), near the corn V6 stage. Weeds were primarily counted and identified by species level, except

Table 1. Information on site manuring, soil disturbance, and weed control.

Site	Region	Manure type, rate	Manure application	Soil disturbance (tillage, mechanical weed control, fertilizer application)		Chemical weed control
				Fall	Spring	
						kg ai/ha
1	South central	Slurry, 112,000 L/ha	August 2003, after wheat harvest incorporated[a]	Chiseled, disked, dragged	Field cultivated	PRE: dimethenamid (0.84); POST: pendimethalin (1.39), dicamba (3.36) + diflufenzopyr (1.43)
2	South central	Slurry, 108,000 L/ha	October 2003, after soybean harvest	Strip-tilled	Interrow cultivated, UAN[b] cultivated in	PRE: metolachlor (1.72) POST: dicamba (0.28)
3	South central	Solid, 70,000 kg/ha	August 2003, after wheat harvest incorporated	Deep chiseled	Field cultivated	POST: nicosulfuron (0.04), flumetsulam (0.04) + clopyralid (0.11)
4	Central east	Solid, 22,000 kg/ha	June 2004, before corn planting	None	Zone-tilled	Burndown: glyphosate (rate unknown); PRE: mesotrione (0.13) + atrazine (0.85)
5	Central east	Semisolid, 34,000 kg/ha	June 2004, before corn planting	Unknown	Field cultivated, rotary hoe (1×), cultivate (2×)	None (organic farm)
6	South central	Semisolid, 112,000 L/ha	September 2004, after wheat harvest incorporated	Chiseled	Field cultivated (2×)	PRE: dimethenamid (0.84) + simazine (0.51)
7	South central	Slurry, 112,000 L/ha	November 2004, after soybean harvest	None	Field cultivated, dragged, UAN cultivated in	PRE: metolachlor (1.72) flumetsulam (0.05) + clopyralid (0.14)
8	South central	Slurry, 112,000 L/ha	November 2004, after soybean harvest	Subsoiled, manured plots disked	Field cultivated, UAN cultivated in	PRE: metolachlor (1.87) + mesotrione (0.19)
9	South central	Slurry, 112,000 L/ha	October 2004, after soybean harvest incorporated	Aerway rolled (manure incorporation)	Zone-tilled, UAN injected	PRE: metolachlor (2.1) + mesotrione (0.21); POST: clopyralid (spot-spraying)
10	South central	Slurry, 112,000 L/ha	October 2004, after wheat harvest incorporated	Aerway rolled (manure incorporation)	Field cultivated, UAN injected	PRE: metolachlor (2.1) + mesotrione (0.21)
11	South east	Slurry, 112,000 L/ha	September 2004, after wheat harvest injected	Chiseled	Field cultivated, UAN cultivated in	POST: glyphosate (0.90)

[a] Incorporated, manure was incorporated with field equipment immediately after application.

[b] UAN, 28% urea ammonium nitrate.

for closely related species, which were grouped within genus. Aboveground weed biomass was harvested between 8 and 10 WAP. Broadleaf weeds and perennial grasses were separated by individual species, except for very small or rare weeds, which were combined as "miscellaneous." All annual grass species were combined. Weeds were oven-dried at 60 C for 5 d and weighed.

Species richness and diversity were determined using Hill's numbers N0 and N1 (Ludwig and Reynolds 1988) on the 1-m^2 quadrants. Species richness is the total number of weed species in a community. Hill's number N1 for species diversity (Equation 2) incorporates both species richness and evenness (the proportionate distribution of individuals in each species). Shannon's index, H' (Equation 3), where n_i represents the number of individuals of the ith species, and n represents the total number of individuals in the sample. H' is a measure of the "uncertainty" in predicting to which species an individual randomly chosen from a community of species will belong.

$$N1 = e^{H'} \quad [2]$$

$$H' = -\sum[(n_i/n)\ln(n_i/n)] \quad [3]$$

As the number of species increases and the distribution of individuals in each species becomes more evenly distributed, H' increases. The benefit of Hill's number N1 is that the units are actually in terms of species, such that N1 represents the number of abundant species in a community.

To address whether manure may effectively introduce new weed species even in fields treated with the farmer's regular weed control program, large portions of the whole plots were visually inspected for mature weeds. Scouting took place after all weed control practices had been completed. The areas scouted were either 61 m long and six rows wide, or 91 m long and four rows wide, equaling 280 m^2. This area was deemed large enough to include more than 90% of all weed species present in each whole plot (Mulugeta et al. 2001). All species in the scouted areas were identified.

Results and Discussion

Nontreated Weed Densities. Weed densities in the non-manured, no-weed-control quadrats were used to measure the underlying weediness of the sites. Overall, the cooperating farmers had excellent control of grass weeds in their fields, with an average of only 5.9 ± 1.2 (SE) grass weeds/m^2 at the 10 conventionally managed sites. In comparison, Wagner (1992) found an average grass seedling density of 390 plants/m^2 in his 1990 to 1991 study of 37 nonherbicide-treated field corn and 12 nontreated sweet corn sites in southern and central Wisconsin.

Broadleaf weed-density numbers were typically greater than grass weed densities, with an average of 28.5 (± 4.5) broadleaf weeds/m^2 found at the 10 conventionally managed sites, which is also lower than the 115 broadleaf weeds/m^2 observed by Wagner (1992). In this study, velvetleaf, common lambsquarters (*Chenopodium album* L.), and dandelion (*Taraxacum officinale* Weber in Wiggers) occurred in high numbers at several farms. Wagner (1992) also frequently found common lambsquarters and velvetleaf, as well as redroot pigweed (*Amaranthus retroflexus* L.) as dominant broadleaf weeds. By and large, it appears that historic weed control had been good, and the weed pressure potential before applying manure was considerably lower than that found in the Wagner (1992) study.

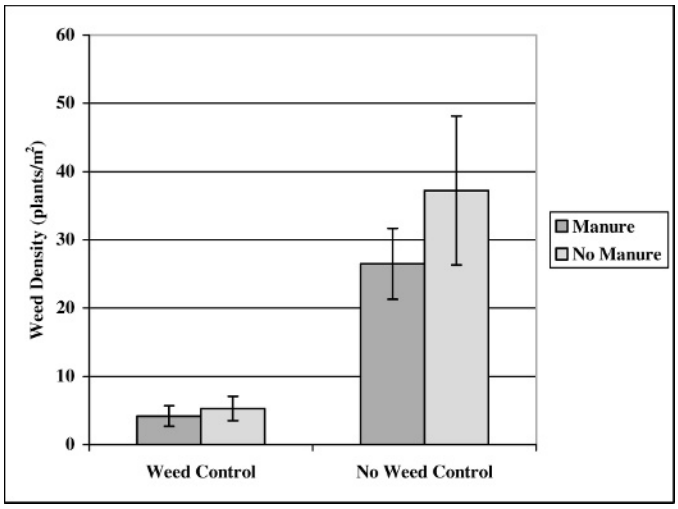

Figure 1. Weed density means, 7 to 8 wk after planting, with standard errors (n = 10).

Manure Effects on Weed Seedling Density at Corn Emergence. In the analysis of weed density at VE to V2 stage in 2004 (2.5 WAP, n = 3), total weed density did not differ between manured and nonmanured treatments (data not shown). There were no significant interactions between environment and manure or between environment and weed control. When the early season total weed density count was divided into grasses and broadleaves and analyzed, results were similar to the total weed density analysis. This early density count suggests that manure did not accelerate weed germination by the time of corn emergence.

Manure Effects on Midseason Weed Density and Biomass. Figure 1 summarizes the weed density means from the four treatments. There were no significant differences in weed density between the manured and nonmanured plots, whereas weed control was highly significant in suppressing weed density (Table 2). There was no interaction between the treatments, indicating that farmers' weed control practices were equally successful in the manured and nonmanured plots. These findings are similar to those of Stevenson et al. (1997), who also showed that plots receiving liquid manure did not contain greater weed density than plots treated with N fertilizer. Not surprisingly, the effect of environment was significant, as weed density did vary by location. This was most likely because of variation in the soil weed seedbanks across the different locations and not the manure sources because there was no interaction between locations and manure application. The interaction between environment and weed control was significant, indicating differences in weed management history among the sites. At some sites,

Table 2. Weed density results from fixed and random effects.[a]

Source	P < F
Manure	0.4694
Weed control	< 0.0001
Manure × weed control	0.7984
Environment	< 0.0001
Environment × manure	0.5000
Environment × weed control	< 0.0001

[a] Fixed effects (manure, weed control, manure × weed control) were analyzed using *F* tests, and random effects (environment, environment × manure, environment × weed control) were analyzed using chi-square likelihood-ratio tests in SAS 8.2 PROC MIXED (Littell et al. 1996).

Table 3. Weed species richness results from fixed and random effects.[a]

Source	P < F
Manure	0.9987
Weed control	< 0.0001
Manure × weed control	0.6764
Environment	0.2398
Environment × manure	0.0534
Environment × weed control	0.0024

[a] Fixed effects (manure, weed control, manure × weed control) were analyzed using *F* tests, and random effects (environment, environment × manure, environment × weed control) were analyzed using chi-square likelihood-ratio tests in SAS 8.2 PROC MIXED (Littell et al. 1996).

there was low weed density both with and without weed control, and in others, weed densities were much higher in the no-weed-control treatments.

Similar results were found for weed aboveground biomass across the 11 environments (data not shown). The main effect of manure was not significant. Again, weed control was highly significant across all environments, and there was no interaction between manure and weed control, again demonstrating that farmers' weed control remained as effective in the manured treatment as in the nonmanured treatment. Environment was again significant, indicating the variation in weed species and maturity that led to higher biomass at some sites. No significant interaction was found between environment and manure, although there was an interaction between environment and weed control, which, again, was likely because of the relative differences in weed control efficacy among sites.

Manure Effects on Weed Species Richness and Diversity. More than 35 weed species were identified across all sites (data not shown). The most common broadleaf weeds (those found at the most sites) included velvetleaf, common lambsquarters, dandelion, redroot pigweed, smooth pigweed (*Amaranthus hybridus* L.), and eastern black nightshade (*Solanum ptycanthum* Dun.), and the most common grasses included giant foxtail (*Setaria faberi* Herrm.), yellow foxtail [*Setaria glauca* (L.) (Beauv.)], and wheat.

Data collected between 7 and 8 WAP were combined to analyze the effects of manure on species richness and diversity across all 11 environments. Because the raw data of richness and diversity largely adhered to assumptions of normality and equal variance, they were not transformed. Species richness did not differ significantly between the manured and nonmanured treatments (Table 3). There was no manure-by-weed-control interaction, indicating that manure did not impact the range of species controlled by the weed control programs. Means of species richness from the four treatments are shown in Figure 2.

Results from the analysis of species diversity were the same as for species richness, with no main effect of manure, a highly significant effect of weed control, and no manure-by-weed-control interaction (data not shown). Thus, the number of species or their relative abundance was not affected by manure. Stevenson et al. (1997) also found that species richness and species diversity remained unchanged between manured and nonmanured plots.

Although environment was not significant, species richness and species diversity did have significant interactions in environment by manure. However, when sites that had received manure from the same dairy were grouped and compared, no clear patterns in richness numbers occurred within the same groups (data not shown). Additionally, there were significant interactions between environment and weed control, which seem to have been a result of the varying success of weed control across the sites.

Introduction of New Weed Species. Contrary to the researchers' primary concern, no influx of new weed species was apparent in the manured treatment compared with the nonmanured treatment. Although some weed species were found only in the manured treatment of a site (designated as "exclusively manure" species), others were found only in the nonmanured treatment ("exclusively nonmanure" species). Three sites had more "exclusively manure" species; five sites had more "exclusively nonmanure" species; and in three sites there was a tie between "exclusively manure" and "exclusively nonmanure" species. When a sign test was applied, no significant difference was found between sites having more "exclusively manure" species and "exclusively nonmanure" species (P = 0.727). These results indicate that manure did not introduce new species of weeds. It should be noted,

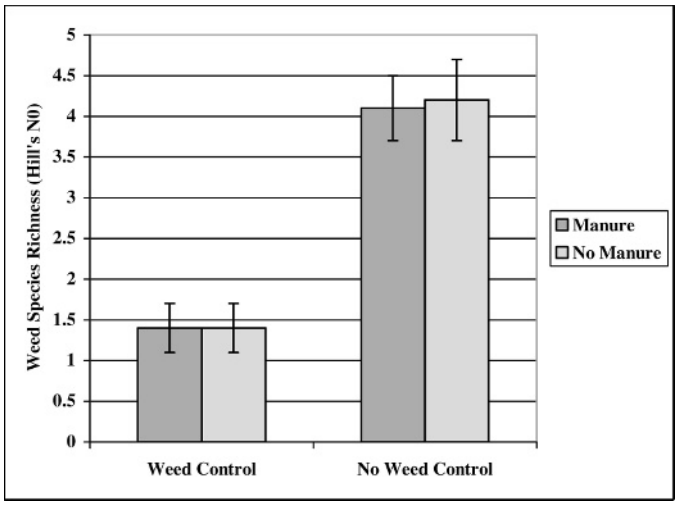

Figure 2. Weed species richness means, 7 to 8 wk after planting, with standard errors (n = 11).

however, that frequent manure applications in the same field could have effects on the weed community over time.

The results from this study indicate that one application of manure did not affect weed density at the time of corn emergence and did not affect weed density or biomass in these well-managed corn-production systems. Manure also did not affect weed species richness or species diversity in the first season after manure applications. However, significant interactions were found between environment and manure, as well as environment and weed control in these two indices of weed communities. The weed control strategies already employed by the farmers were as effective in the manured treatments as in the nonmanured treatments. Results from a visual inspection indicate that manure did not introduce new weed species.

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EFFECT OF DAIRY SLURRY APPLICATION ON SOIL COMPACTION AND CORN (*ZEA MAYS* L.) YIELD IN SOUTHERN WISCONSIN

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EFFECT OF DAIRY SLURRY APPLICATION ON SOIL COMPACTION AND CORN (*ZEA MAYS* L.) YIELD IN SOUTHERN WISCONSIN

ABSTRACT

As stocking rates on Wisconsin dairy farms continue to increase, one possible nutrient management solution is to haul slurry to nearby grain farmer's fields. Although the nutrient and soil building benefits of manure are well known, many grain farmers are hesitant to apply manure on their fields due to potential soil compaction. Studies were initiated to evaluate the effects of tanker-applied slurry on soil compaction and corn (*Zea mays* L.) yield. An on-station trial was established to address the issues of compaction caused by manure tankers, repeated traffic associated with field headlands, and the possible ameliorating effect of manure itself on corn yield. In addition, 15 replicated on-farm trials were established to evaluate the impact of single pass manure applications on soil compaction and yield. These predominately fall applications were conducted when the host farmer felt that the soil would support tanker traffic. Due to its portability and instrument sensitivity, compactness was evaluated with a data-logging hand held penetrometer.

Results from the on-station trial indicate that multiple passes did increase compactness above single-pass traffic and the check. The slurry itself did not attenuate the effect of traffic on soil compaction, nor on yield. Despite yield reductions estimated from in-track samples in both years of 6% (1-pass traffic) and 22% (6-pass traffic) in this study, whole plot corn yields were not reduced due to compaction. The on-farm trials indicated that manure application technique does affect compaction patterns; with broadcast application resulting in less area trafficked by the tanker than injection application, and therefore less area compacted. The narrower gauge truck tires used at some sites led to significantly higher penetrometer readings compared to the control, but this was not the case at sites with wider tractor tires. As in the on-station work, although compaction led to higher penetrometer readings, whole plot corn yields in compacted plots were not adversely affected compared to the control. These results suggest that, in the first year after slurry application, on predominantly prairie derived soils; well-timed applications of dairy slurry do not cause extensive soil compaction nor a reduction in corn yields. This study did not look at the potential residual effects that may positively (> soil organic matter) or negatively (residual soil compaction) impact subsequent crops.

Key Words: Soil compaction, Manure application, Corn yields, Penetrometer, On-farm trials

INTRODUCTION

Due primarily to higher stocking rates and increasingly stringent nutrient management regulations, many Wisconsin dairy farms are looking beyond their own land for areas to spread manure. One possibility is to transport and apply manure on nearby cash grain farmers' land. However, many grain farmers are hesitant to include slurry in their cropping system because they fear soil compaction in their fields and headlands out weighs the nutrient content of manure. Their concerns are not unfounded as manure tankers commonly range from 15 to 28.5m^3 capacity and can weigh from 8 to 20Mg per axle.

Soil compaction is generally broken into two categories: topsoil, or, surface compaction (compaction within the depth of normal tillage) and sub-soil, or, deep compaction (beyond the depth of normal tillage). Håkansson et al. (1988) report that the variables responsible for compaction in the plow layer are soil moisture content (most important), number of traffic passes, equipment weight, wheel configuration (singles or duals etc.), tire-inflation pressure, and speed. Subsoil compaction is primarily related to axle load, soil moisture content and number of passes by the vehicle. A number of researchers (Koger et al. 1985, Guo and Schuler 1992, Daum 1996) have shown that on recently loosened soils, one traffic pass with a loaded axle causes the majority of soil deformation and that after four passes additional trips have little effect on soil compactness.

Because compaction in the plow layer is largely a function of contact pressure, research has been conducted to evaluate the effect of different running gear on soil properties. Bédard et al. (1997) found that oversized tires slightly reduced surface soil compaction on a heavy clay soil in Quebec based on cone index (CI) readings, but had a larger lateral influence on soil compaction (approximately 1.3 times the tire width). In a similar study McBride et al. (2000) reported that floatation tires (28L-26) were preferable to both standard truck tires (445/65R22.5) and tracks. In their study, floatation tires were found to decrease fuel consumption, drawbar draft, wheel rut depth and dry bulk density.

While surface compaction can often be alleviated by natural processes and tillage, compaction beyond the plow layer, in spite of annual freezing, may last for a long time. Lowery and Schuler (1991, 1994) working on two soils in Wisconsin found that elevated cone penetrometer resistances persisted after four years and extended deep into the subsoil (46cm). Håkansson and Reeder (1994) reported that deep sub-soil compaction may cause long term (> 10 years) reductions in yield of up to 5%. There appears to be general consensus in the literature that axle weights greater than 10Mg almost always lead to some sub-soil compaction (Lowery and Schuler 1991, 1994, Håkansson et al. 1987, 1988, Håkansson and Reeder 1994).

Compaction has often resulted in crop yield reductions. While both sub-soil and surface compaction contribute to these reductions, the most severe crop responses are likely the result of compaction in the plow layer (Håkansson et al. 1987). It appears that compaction can affect crop yields by limiting root growth (Dexter 1986, Ehlers et al. 1983), decreasing soil hydraulic conductivity and air movement (Håkansson et al. 1988),

increasing nitrogen loss through denitrification (Motavalli et al. 2003), decreasing nutrient uptake, and providing an environment conducive to the development of plant pathogens (Grath and Håkansson 1994). In the first year of a four-year study, Lowery and Schuler (1991), after compacting the entire plot, reported corn yield reductions ranging from 4 to 14% (Rozetta silt loam) under 8 and 12.5Mg axle loads respectively. First year corn yield reductions of 14 to 43% were found using the same protocol on a less permeable Kewaunee silty clay. Yield reductions however, do not always accompany compaction. Lal and Ahmadi (2000) working on forest derived silt loam soils at two locations in Ohio re-compacted the soil every year for eleven years. They observed approximately a 15% yield reduction in compaction treatments (7.5Mg axle weight over the entire plot) in only two out of eleven seasons. In both years, rainfall was below the long-term average of 987mm by 27% in 1988 and 15% in 1998.

Critical CI readings associated with crop yield reductions are hard to define because of the strong correlation between penetrometer readings and soil moisture. Ehlers et al. (1983) working with Alfisols in Germany reported 3600kPa as limiting to root growth in conventionally tilled topsoil. Dexter (1986), in laboratory experiments, reported similar findings for subsoil compaction and concluded that the CI should not exceed 3000kPa for the production of wheat. In field studies from Wisconsin (Rozetta and Kewaunee silt loams), Lowery and Schuler (1991) report average peak CI readings associated with corn yield reductions on two soils of approximately 3447kPa and 5171kPa for an 8Mg and 12.5Mg axle load respectively. Taylor et al. (1965), in a growth chamber study, found that 2500kPa penetration resistance completely stopped root growth in medium to fine textured soils. Data from studies conducted on Wisconsin silt loam soils suggests that compacted treatments generally differ from check treatments between 10 and 25cm depth (Lowery and Schuler 1991, 1994). This zone may therefore serve as a useful "diagnostic" horizon for identifying soil compaction in the field.

Although a significant amount of research has addressed compaction issues, many of these studies have been conducted under extreme conditions of high soil moisture and full-plot traffic, and few have been conducted in combination with manure applications. These differences could be important for grain farmers. For example, due to the growing demand for land on which to spread manure, and the greater speed associated with custom nutrient haulers, grain farmers could expect that slurry applications would be limited to drier soil conditions. The potential penalty for the dairy farmer could be loss of this land in future seasons. In addition, during field applications of slurry, with the exception of headlands, tanker tire tracks can cover as little as 17% (broadcast application) to a maximum of 50% (injection) of the field. The addition of organic matter in the form of livestock manure may also serve to ameliorate compaction or its adverse effects on yield through increased microbial activity, water stable aggregation, porosity, and organic carbon (Bissonnette et al. 2001, Soane 1990, and Sommerfeldt and Chang 1985).

To address the concerns of grain farmers and their reluctance to include dairy slurry in their crop rotations, a series of on-station and on-farm trials were undertaken. The following questions were addressed:

1) Does normal or repeated tanker traffic under conditions of moderate soil moisture result in soil compaction in cash grain rotations?
2) If so, does the resulting compactness affect first year corn yields?

And…

3) If compaction alone depresses yields, do the soil building and fertility effects of dairy slurry offset this yield reduction?

METHODS AND MATERIALS

On-station Trial

To address the issues of compaction caused by field application of dairy slurry using tankers, repeated traffic on headlands, and the possible ameliorating effect of manure itself on corn yield, an augmented 2 by 2 factorial trial was established at the University of Wisconsin Research Station in Arlington (43º18'8.54"N, 89º20'46.01"W). The trial was conducted in 2005 and 2006 in different fields following soybeans and corn respectively. Both sites were on soils classified as Plano Silt Loams (Fine-silty, mixed, superactive, mesic Typic Argiudolls). Soil morphological, physical and chemical data can be seen for the 2005 and 2006 sites in tables 1 and 2 respectively. The factorial array consisted of two crop nutrient sources (dairy slurry or commercial fertilizer) plus two levels of slurry tanker traffic (one-pass or six-passes), which were augmented with a farmers' check plot (commercial fertilizer with no tanker traffic). Thus, the five treatments were: farmers' check (f), one-pass with manure (m1), one-pass compaction but without manure (c1), six-passes with manure (m6), and six-passes compaction without manure (c6).

Dairy slurry was broadcast each spring using a tractor pulled slurry tank, when the soil was at approximately 80 to 85% of field capacity (23-25% gravimetric moisture 0-30cm). Axle weight in 2005 was 11.2Mg and 10.7Mg in 2006. In both years 28L-26 tires inflated to 228kPa were used. Compaction treatments without manure were made by driving across the plots with a loaded slurry tanker one time (c1) or six times in the same tracks (c6). Manured treatments were applied by driving across a plot one time while spreading (m1), or five times without spreading and then spreading on the sixth trip across the plot (m6). Slurry was applied at a rate of $103 m^3\ ha^{-1}$ (11,000 gal/a) and incorporated (with a chisel plow ~15cm) at both sites within 72 hours of its application. Average total nutrient content was 4.25, 1.55, and $3 kg\ m^{-3}$ for N, P_2O_5 and K_2O respectively. In both years a full season corn hybrid was planted by May 3rd and all plots received starter fertilizer at planting ($112 kg\ ha^{-1}$ of 5:14:42). Due to high soil test levels no further P and K were added. The Pre-sidedress Nitrate Test (PSNT) was used to estimate side dressing N-needs for all the treatments (Andraski and Bundy 2002). In 2005 the manured plots received an additional $12.5 kg\ ha^{-1}$ N as 32% urea ammonium nitrate (UAN) while the non-manured plots received $130 kg\ ha^{-1}$. In 2006, no additional nitrogen was applied to manured plots while the non-manured plots received $178 kg\ ha^{-1}$ N as 32% UAN.

Shortly after corn emergence, three random sampling stations were established in each plot to evaluate change in grain yield with distance from the tanker-tire track. Each station was 1.5m in length parallel to the direction of corn planting, and included three corn rows. The first row was located as near as possible to the center of a tire track (0cm), with additional rows at 76 and 152cm from the track. Prior to machine harvesting, the individual rows in the stations were hand harvested. Individual row hand harvests were taken at the sampling station and shelled with a power-take-off-driven sheller, while whole plots were harvested with a combine.

On-Farm Trials

To further examine the issues of compaction caused by manure tankers and the possible ameliorating effect of manure, three of the on-station treatments were tested on commercial grain farms (on-farm trials). Fifteen on-farm trials were established in total. Trials were established in the fall of 2004 (n=6) and in the spring (n=2) and fall (n=7) of 2005. All the fields were located within a 4-mile radius of one of the five cooperating dairy farms that supplied the slurry and application equipment. Soil morphological, physical, and chemical data for each of the 2005 and 2006 season on-farm trials is presented in tables 1 and 2 respectively. The trials were set up as a randomized complete block design (RCBD) with three blocks and one replicate per block. The treatments were: the farmers' current corn production practices without manure (f), the same production system but including dairy slurry (m1), and a treatment where a loaded slurry tanker was driven across the plot but no slurry was applied (c1). At all of the sites where an injection toolbar was used to apply slurry the application equipment was engaged (though slurry was not spread) while applying the c1 treatment. Tillage regime following application of treatments varied by environment (Table 3), but was generally limited to the upper 12cm. Nitrogen inputs, other than starter fertilizer, were again based on the PSNT and were generally the same for the farmers' check (f) and the compaction only treatment (c1). On average, manured plots (m1) received 41kg fertilizer N ha^{-1} at sidedress and the compaction-only (c1) and farmers' check (f1) plots received 94kg fertilizer N ha^{-1} at sidedress. Plots were dimensioned to accommodate farm equipment and averaged 0.08ha in area. An overview of manure spreading equipment and some agronomic details for each of the fifteen on-farm environments is presented in Table 3.

Penetrometer Measurements: On-Station Trial

In this study a data logging hand-held penetrometer that recorded applied pressure in kilopascals at 2.54cm increments was used to determine CI to a depth of 46cm. Penetrometer readings were accompanied by soil moisture measurements (gravimetric) from 0-15cm and 15-30cm (Tables 1 & 2). In the on-station trial, penetrometer readings were taken when the corn was at the V3 stage (approximately 40 days after the application of treatments) at 38cm increments moving away from the tire track across the three rows at the hand harvest stations in each plot (Figure 1a). Soil moisture at the time of penetrometer measurements was approximately equal to moisture at the time of treatment application (24% to 27% gravimetric).

Penetrometer Measurements: On-Farm Trials

To accompany the yield measurements, penetrometer readings were taken at eleven of the fifteen on-farm sites with the same instrument used in the on-station trial. Readings were taken in mid-May when the corn was in the V3 stage. Transects began in the middle of the plot and extended 4.6m perpendicular to the plot axis toward the outer plot edge**.** Penetrometer readings were taken at 0.3m spacings to a depth of 46cm, for a total of 16 compaction profiles per transect (32 per plot). These transects were subsequently divided into "edge of plot" readings (Strips 1 & 3) and "center of plot" readings (Strip 2) (Figure 1b).

Statistical Analysis

All analyses were made using PROC MIXED of SAS Software version 9.1.3 (SAS Institute 2004). The main effects of traffic and manure treatments were evaluated using the ESTIMATE statement in PROC MIXED.

Statistical Analysis: Penetrometer Readings - On-Station Trial

The median value for each point (distance from the tire track) and depth (2.54cm increments to 46cm) combination was taken from the three random sampling stations within a plot. Median values were used as an unbiased method to reduce the influence of outliers (rocks, macro pores etc…) in our analysis. In this model, point (distance from the tire track) is considered a classification variable and evaluation of treatment/point combinations were made at each depth increment (0 to 46cm). Block is considered a random effect, and both treatment and point are treated as fixed effects. Initial model fitting indicated that the REPEATED MEASURES statement was not required to account for spatial correlation between points within a sampling station.

Statistical Analysis: Penetrometer Readings - On-farm Trials

For the on-farm penetrometer analysis, the eleven sites were considered to be random environments (environment encompassing: soil type, drainage, slope, weather, crop management). Based on findings in the literature for similar soils (Lowery and Schuler, 1991, 1994) and experience from the on-station trials, the median penetrometer value between 10 and 25cm depth for each point within a transect was used for this analysis, resulting in 16 data points per transect, or 32 points per plot. This appears to be the depth range where the greatest differences occur between compacted and non-compacted soils within our zone of measurements. Sampling transects in each plot were sub-divided into 3 strips. Strip 2 consisted of the middle 3.7m of each plot and was made up of the first six penetrometer readings from each transect. This is the area in which the slurry tanker traffic would occur for plots that were broadcast spread. Strips 1 and 3 consisted of the outer 3m (outer 10 readings from each of the two transects) and were traversed, as was the center of the plot, only in those sites where the manure was injected (See Figure 1b). Most of the remaining agricultural machinery traffic was down the center of the plot. Treatment and strip were both treated as fixed effects in this model, while environment and block within environment and their interactions are treated as random effects. To account for spatial correlation between adjacent median penetrometer readings the

autoregressive covariance structure (TYPE = ar(1)), which has homogeneous variances and correlations that decline exponentially with distance, was used (Littell et al. 1996).

Statistical Analysis: Hand Harvest Yields - On-Station Trial

Hand harvest yields (kg m^{-2}) were compared for specific positions (distance from the tire track) between treatments as well as between positions within a treatment. Seasons 2005 and 2006 were analyzed together. In this model, treatment and position are considered fixed effects, with season, block, treatment by block within season, and sampling station as random effects. As with the on-station penetrometer analysis, initial model fitting indicated that the REPEATED MEASURES statement was not required to account for spatial correlation between positions within a sampling station.

Statistical Analysis: Whole Plot Yields - On-Station Trial

Combined analysis was done on whole plot yields for the 2005 and 2006 growing seasons. In this model, treatment is the only fixed effect with season, block and their interaction terms treated as random effects.

Statistical Analysis: Whole Plot Yields - On-Farm Trials

For this analysis, the fifteen site-year combinations were considered to be random environments (environment encompassing: soil type, drainage, slope, weather, crop management). Environment, block within environment and environment by treatment were all treated as random effects in order to consider the results of the analysis as valid for an inference zone of south-central Wisconsin. Best linear unbiased predictors (BLUP's) were used to evaluate the random interaction of environment by treatment (Littell et al. 1996).

RESULTS

Penetrometer Readings: On-Station Trial

In 2005 the overall effect of treatment was significant at each depth between 8cm ($p = 0.0247$) and 13cm ($p = 0.0015$) depth while the point effect was significant at each depth between 0cm ($p = 0.0258$) and 20cm ($p = 0.0006$), indicating the attenuation of penetrometer readings with distance from the tire track. In 2006 the overall effect of treatment was significant at each depth between 10cm ($p = 0.0019$) and 31cm ($p = 0.0084$) depth and distance from the tire track was significant at each depth between 13cm ($p = 0.0125$) and 31cm ($p = 0.0212$). Thus, the compaction treatments in 2006 affected soil resistance to a depth twice that of 2005.

When looking at the main effect of number of trips in the tire track itself**,** the penetrometer readings significantly increased with more traffic passes (Figures 2 & 3). In both years, six passes resulted in significantly higher CI readings in the plow layer than the check. This effect was attenuated by 20cm in 2005, but continued deeper into the subsoil in 2006. One pass with the manure spreader resulted in higher levels of compactness than the check in 2005 (8 to 20cm) but this was not the case at the 2006 site. The main effect of manure on compaction was not significant in either year (data not shown). Along a horizontal plane, the impact of the slurry equipment at both one and six

passes was primarily observed in the plow layer (0 to 20cm) up to 76cm from the track; but the impact was negligible beyond 76cm in both years.

Penetrometer Readings: On-Farm Trials

The type of equipment used for manure application on-farm depended on the cooperating dairy operation. Manure was broadcast applied from tanks that were 1) truck-mounted (n=4), 2) tractor-pulled (n=3) or 3) injected from tractor pulled tanks (n=8). Actual axle weights ranged from 9 to 14.4Mg (Table 3). For broadcasting tanks the slurry width ranged from 9 to 14m and tanker traffic was limited to the middle 3.6m of each plot. Injected slurry was applied in 3.7m strips and tanker traffic covered 47% of the plot. Soil moisture at the time of spreading averaged 21% (gravimetric) across all environments and was considered by the cooperating grain farmer to be appropriate for heavy equipment traffic. At the eleven sites where penetrometer readings were taken, the soil texture class was silt loam or silty clay loam, no hardpan was present, organic matter content averaged 3%, and the beginning of the glacial till was below 91cm at all but two of the sites.

Because of the two distinct traffic patterns at the on-farm sites, the CI analysis was conducted separately on sites with broadcast and injection slurry. The use of repeated measures with the first-order autoregressive covariance structure resulted in a lower Akaike Information Criterion (AIC) than the model in which repeated measures methodology was not used (30241.5 vs. 30323.1) and was therefore considered appropriate for use in this analysis. At the on-farm sites where manure was broadcast applie d, the main effect of strip (1,2 or 3) and the treatment by strip interaction were both significant ($p < 0.0001$ and $p = 0.0073$ respectively). Not surprisingly, Strip 2 (center of the plots) in the manured (m1) and compaction-only (c1) treatments showed greater CI readings in the diagnostic horizon than the plot edges (Strips 1 & 3) as well as the center (strip 2) of the control (f) plots (Figure 4). This difference from strip two of the control was only significant ($\alpha = 0.05$) in the compaction-only (c1) treatment. As might be expected, where the slurry was injected and the tanker trafficked the entire plot (strips 1, 2 & 3) there was no difference in median CI readings between sampling strips in either the compacted or manured plots - and interestingly they were not different than the check plots (Fig. 5) Although actual axle weights were higher at the injected sites, overall, median readings averaged 481kPa lower. At four of the seven broadcast environments where truck mounted tanks were used, tires were 28cm wide and inflated to approximately 450kPa, while at the rest of the environments tires were 71cm wide and inflated to 241kPa.

The effects of tire pressure and tire width was further confirmed when the two modes of broadcasting were evaluated: truck mounted and tractor pulled broadcast tanks. Despite the somewhat heavier axle weights associated with tractor drawn broadcast tanks CI readings at these environments were 370kPa lower on average than those at the truck mounted environments. In addition the center strip (2) at the truck mounted environments was significantly more compacted in the compaction treatment (c1) than it was in either the manured (m1) or farmers' check (f) plots when compared to the edge of

plot strips (1&3). This was not the case at the tractor-pulled broadcast sites where plot strips did not significantly differ from each other in any of the three treatments.

Hand Harvest Yields: On-Station Trial

Results from the combined 2005 and 2006 yield analysis indicated no significant treatment difference overall. Distance from tire track (in-track, 76cm, 152cm) however was highly significant ($p < 0.0001$). In-track yields were significantly reduced in all the compaction treatments but not in the farmers' check plot. This trend was significantly greater ($p = 0.002$) for the six-pass treatments (c6 & m6) than for the one-pass treatments (c1 & m1) as can be seen in Figure 6. In track yields were reduced on average by 6% ($p = 0.06$) and 22% ($p = 0.006$) for the one-pass (c1 & m1), and six-pass (c6 & m6) treatments respectively.

Whole Plot Yields: On-Station Trial

No significant treatment differences were found for whole plot corn yields in the combined season analysis. Contrasts for the main effects of manure and traffic were also non-significant. Yields were: 10.9, 11.0, 11.0, 11.2, 11.7Mg ha^{-1} for the manure-1-pass (m1), compaction-only-1-pass (c1), manure-6- pass (m6), compaction-only-6-pass (c6), and the farmers' check (f) treatments respectively.

Whole Plot Yields: On-Farm Trials

Corn harvest data from the on-farm trials indicated that treatment was highly significant across all environments ($p=0.0248$). Manure (m1) yielded significantly higher than both the compaction-only (c1) ($p=0.044$) and farmers check (f) ($p=0.0095$) plots by approximately 0.4Mg ha^{-1} (Figure 7), despite receiving 52kg ha^{-1} less fertilizer N on average by following PSNT recommendations. The broadcast-slurry environments, where compaction was limited to the middle of the plot, yielded significantly better ($p<0.0001$) than the injected-slurry sites where tanker traffic covered 47% of the plot area. However, tanker traffic alone (c1) did not negatively impact yields compared to the farmers' check (f) within either grouping of environments. Unexpectedly, within the broadcast–slurry sites, those sites that spread with truck mounted tanks yielded significantly better ($p=0.0033$) overall than those spread with a tractor pulled tank. Again however, tanker traffic alone (c1) did not impact yields compared to the farmers check (f) within groupings (Table 4).

DISCUSSION

Penetrometer Readings

Penetrometer readings on station showed that multiple passes (in this case six) did compact the soil and that the more common single pass with a tractor pulled tanker significantly increased compactness in one of the two years compared to the no-tanker check. In 2006 peak CI was higher than in 2005 (1800kPa vs. 1400kPa) and compaction extended deeper into the subsoil (40cm vs. 20cm). The different compaction patterns between years may partially be attributed to the tillage history of the sites. The 2005 experiment was conducted on a field that had been in a no-till system since 2000 while the 2006 site had been in conventional tillage system. No-till cropping systems have

been shown to increase water stable aggregation and aggregate quality compared to conventional tillage systems (Blanco et al. 2005, Shukla et al. 2003). It is possible that better soil structure, combined with a more consolidated surface horizon at the 2005 site attenuated the impact of slurry tanker compression in the plow layer and prevented deep transmission of this soil stress. Despite the classification of both soils as Plano silt loams, the argillic horizon in 2006 (silty clay loam) extended from 25cm to 46cm (Table 2) while the argillic horizon in 2005 began at 39cm depth and had a lower overall clay content (silt loam)(Table 1). In addition to the effects of tillage history, we hypothesis that because the argilic horizon comprised a greater proportion of the 46cm profile in 2006 and that because the clay content of that horizon was higher, deep transmission of soil stress was significantly more pronounced than it was in 2005 (Figures 2 and 3). This is consistent with the findings of Lowery and Schuler (1991) who worked on two Wisconsin soils of varying clay content. Soil moisture in 2005 and 2006 did not differ greatly at the time of spreading (25.5% vs. 26.5%) and was likely of less importance in these CI differences. Manuring in this study did not diminish the effects of compaction, but it must be noted that the manuring effects in this study are only reported for the first year crop. Repeated or multiple additions over time may contribute beneficially to overall soil health (Bissonnette et al. 2001, Soane 1990, and Sommerfeldt and Chang 1985). It is important to note that, although heavy equipment was used in the spring (axle weight about 11Mg), the CI readings also taken in the spring on moist soils were generally low in this trial, almost never reaching the 2500 to 3000kPa threshold that is commonly cited in the literature. In comparison, Lowery and Schuler (1991) reported CI readings as high as 5500kPa on a Kewaunee silty clay.

Penetrometer results from the on-farm sites serve as a useful guide for some of the differences in the pattern and relative level of compactness that grain farmers could anticipate in their fields when manure is spread on relatively dry ground ($\leq$ 21% gravimetric moisture content). As would be expected, penetrometer readings in the center of the plots (strip 2) were significantly higher than both plot border strips (1 and 3) when broadcast equipment was used. On the other hand, no difference was observed at the sites with manure injection due to more passes across the plot. When looking at just the subset of sites where manure was broadcast, four were applied with a truck-mounted tanker and three with a tractor drawn tanker. Significantly higher CI readings were found in the truck applied plots despite the fact that soil clay content at theses sites (3, 4, 10, and 11) was consistently lower than at those sites where tractor-drawn tankers were used (1, 2, and 9) (Tables 1 and 2). Additionally, the highest recorded on-farm soil moisture at the time of manure spreading (26.4% gravimetric) was observed at one of the latter (9). The greater CI readings are therefore most likely because the truck-mounted tanks were equipped with 28cm wide tires inflated to approximately 480kPa, for road efficiency while the tractor pulled spreaders were all equipped with 71cm wide tires inflated to 220kPa. Because compaction in the upper 30cm is largely a function of tire inflation pressure (Håkansson et al. 1988), we assume that the floatation tires served to avert the effects of compaction at these tractor-applied sites. Although we reported median CI readings in a diagnostic horizon (10-25cm), maximum CI readings were, as in the case of the on-station trial, almost always below a threshold level of 2500 to 3000kPa. As a

result, in this set of eleven sites, although manure was applied, crop-limiting compaction did not occur.

Corn Grain Yields

Although the hand harvests indicated that yields were depressed in the manure tanker track, whole plot yields were not reduced due to compaction in either the on-station or on-farm experiments. The manure treatment yielded as well (on-station & n = 11 on-farm) or better (n = 4 on-farm) overall than the conventionally fertilized farmers' check and compaction treatments in both sets of trials. Yield differences between broadcast and injected sites were most likely due to poorer growing conditions in SE Wisconsin where cooperating dairies 3 & 4 with the injection equipment were located, and not the result of differences in application equipment (Table 3).

CONCLUSIONS

Grain farmers in Wisconsin are concerned about the effect of including manure in their crop rotations because the application equipment could increase soil compactness sufficiently to reduce yield. Results were consistent in both the on-station and on-farm trials and showed that manure application equipment does cause quantifiable changes in soil compactness. Multiple passes increased CI readings over a single pass, slurry application techniques affected the extent of wheel traffic in a field, and narrow gauged truck tires generally led to higher CI readings. In spite of the increased compactness, application of dairy slurry with heavy equipment did not reduce corn grain yields in either the on-station or on-farm trials and in fact resulted in significantly higher yields at four of the fifteen on-farm environments. In addition, corn yields in the compaction-only treatments were not significantly different than the farmers' check plot in either study. These results suggest that on fine-textured soils, under normal spreading conditions, although some soil compaction may occur, the equipment used to apply dairy slurry does not cause a reduction in first year corn yields.

ACKNOWLEDGEMENTS

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Table 1. 2005 On-Station and On-Farm Soil Characteristics

Site	Soil Series	Classification	*Profile Description*						*OM*[1] *(%)*	*pH*[2]	*%Moisture*[3]	
			Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture Class			0-15cm	15-30cm
2005 RS[4]	Plano	Typic Argiudolls	Ap	0-20	9	70	21	Silt Loam	3.80	7.07	23.7	23.9
			A	20-29	5	71	24	Silt Loam				
			AB	29-39	4	71	25	Silt Loam				
			Bt1	39+	5	68	27	Silt Loam				
1	Virgil	Udollic Endoaqualfs	Ap	0-20	7	64	29	Silty Clay Loam	2.82	5.87	22.0	23.1
			Btg1	20-46	7	56	37	Silty Clay Loam				
2	Plano	Typic Argiudolls	Ap	0-20	7	68	25	Silt Loam	3.45	6.43	22.0	21.2
			A	20-30	7	64	29	Silty Clay Loam				
			BA	30-41	5	66	29	Silty Clay Loam				
			Bt1	41+	5	64	31	Silty Clay Loam				
3	Plano	Typic Argiudolls	Ap	0-23	13	68	19	Silt Loam	3.70	6.93	22.6	23.0
			BA	23-33	9	68	23	Silt Loam				
			Bt1	33-46	9	64	27	Silt Loam				
4	Plano	Typic Argiudolls	Ap	0-22	21	58	21	Silt Loam	3.95	6.35	22.3	22.2
			AB	22-30	21	56	23	Silt Loam				
			Bt1	30-44	21	54	25	Silt Loam				
			Bt2	44+	15	52	33	Silty Clay Loam				
5	Rotamer	Typic Argiudolls	Ap	0-20	47	34	19	Loam	2.57	7.58	--	--
			Bt1	20-33	47	32	21	Loam				
			Bt2	33+	59	24	17	Sandy Loam				
6	Theresa Kidder	Typic Hapludalfs Typic Hapludalfs	Ap	0-20	43	40	17	Loam	2.23	7.15	--	--
			Bt1	20-39	47	22	31	Sandy Clay Loam				
			Bt2	39+	51	18	31	Sandy Clay Loam				
7	Kidami	Oxyaquic Hapludalfs	Ap	0-20	21	58	21	Silt Loam	1.28	7.10	--	--
			Bt1	20-41	19	54	27	Silt Loam				
			2Bt2	41+	45	22	33	Sandy Clay Loam				
8	Kidami	Oxyaquic Hapludalfs	Ap	0-25	17	62	21	Silt Loam	2.62	6.73	--	--
			Bt1	25-43	13	54	33	Silty Clay Loam				
			2Bt2	43+	35	32	33	Clay Loam				

[1] Organic Matter (0-15cm): determined by weight loss on ignition at 360ºC
[2] pH (0-15cm): determined in water using a 1:1, soil:solution ratio.
[3] At time of penetrometer readings: applies only to the on-station trials and the on-farm sites where penetrometer readings were taken
[4] Research Station Field: 2005

Table 2. 2006 On-Station and On-Farm Soil Characteristics

Site	Soil Series	Classification	*Profile Description*						*OM*[1] *(%)*	*pH*[2]	%Moisture[3]	
			Horizon	Depht (cm)	Sand (%)	Silt (%)	Clay (%)	Texture clas			0-15cm	15-30cm
2006 RS[4]	Plano	Typic Argiudolls	Ap	0-18	15	69	16	Silt Loam	3.78	7.21	24.8	25.6
			AB	18-25	12	68	20	Silt Loam				
			Bt1	25-46	9	60	31	Silty Clay Loam				
9	Plano Kegonsa	Typic Argiudolls Mollic Hapludalfs	Ap	0-18	14	62	24	Silt Loam	2.78	6.90	22.5	25.1
			AB	18-25	13	62	25	Silt Loam				
			Bt1	25-46	10	60	30	Silty Clay Loam				
10	Plano	Typic Argiudolls	Ap	0-20	10	75	15	Silt Loam	3.84	5.73	29.1	25.8
			A	20-30	12	69	19	Silt Loam				
			AB	30-41	12	67	21	Silt Loam				
			Bt1	41+	7	68	25	Silt Loam				
11	Plano	Typic Argiudolls	Ap	0-23	13	70	17	Silt Loam	3.11	5.90	24.6	26.2
			A	23-41	7	70	23	Silt Loam				
			AB	41+	12	71	17	Silt Loam				
12	Theresa[5]	Typic Hapludalfs	Ap	0-20	28	42	30	Silt Loam	2.41	7.20	20.3	20.3
			E	20-25				Silt Loam				
			BE	25-36				Silt Loam				
			Bt1	36-46				Silty Clay Loam				
13	Kidami	Oxyaquic Hapludalfs	Ap	0-25	17	62	21	Silt Loam	2.28	6.72	21.8	22.6
			Bt1	25-43	13	54	33	Silty Clay Loam				
			2Bt2	43+	35	32	33	Clay Loam				
14	Plano St. Charles Troxel	Typic Hapludalfs Pachic Argiudolls Typic Argiudolls	Ap	0-30	15	70	15	Silt Loam	2.49	5.52	17.2	19.5
			A	30+	15	66	19	Silt Loam				
15	Plano	Typic Argiudolls	Ap	0-23	12	73	15	Silt Loam	3.49	6.76	27.5	25.8
			A	23-37	9	67	24	Silt Loam				
			AB	37+	7	71	22	Silt Loam				

[1] Organic Matter (0-15cm): determined by weight loss on ignition at 360ºC
[2] pH (0-15cm): determined in water using a 1:1, soil:solution ratio.
[3] At time of penetrometer readings: applies only to the on-station trials and the on-farm sites where penetrometer readings were taken
[4] Research Station Field: 2006
[5] Profile description and particle size distribution from the USDA Official Soil Series Description. http://www2.ftw.nrcs.usda.gov/osd/dat/T/THERESA.html.

Table 3. Manure application and previous crop information: On-farm Trials

Cooperating Farmer							Tillage		Fertilizer Nitrogen Rate (kg ha^{-1})[3]	
Dairy Code	Grain Site	Slurry Applied	Slurry Rate (m^3 ha^{-1})	Tanker Type[1]	Axle Wt. (Mg)	Previous Crop[2]	Fall	Spring	m1	c1 & f
1	**1**	2004-11-03	103	TPB	11.1	s	none	field cultivator	56	67
1	**2**	2004-11-03	103	TPB	11.1	s	none	field cultivator	0	80
1	**9**	2005-11-21	98	TPB	11.1	s	disk	field cultivator	45	115
2	**3**	2004-10-14	103	TMB	9.0	s	Aerway[4]	zone till[5]	50	92
2	**4**	2004-10-14	103	TMB	9.0	s	Aerway[4]	field cultivator	0	11
2	**10**	2005-10-03	112	TMB	9.0	s	none	field cultivator	50	185
2	**11**	2005-10-03	112	TMB	9.0	w	none	field cultivator	67	179
3	**5**	2005-04-27	112	TPI	14.4	a	none	soil finisher[6]	0	30
3	**6**	2004-10-09	112	TPI	14.4	w	none	soil finisher[6]	0	19
3	**12**	2005-10-07	112	TPI	14.4	s	strip till[5]	none	19	28
4	**7**	2005-04-18	150	TPI	12.0	c	none	field cultivator	169	169
4	**8**	2004-09-20	112	TPI	12.0	w/clov	chisel	field cultivator	45	45
4	**13**	2005-10-06	112	TPI	12.0	s	none	field cultivator / soil finisher[6]	0	135
5	**14**	2005-09-02	103	TPI	11.9	w	Aerway[4]	field cultivator	0	135
5	**15**	2005-09-30	112	TPI	11.9	s	Aerway[4] / chisel	disk	117	117

[1] TPB: Tractor-pulled tank, broadcast applied, TMB: Truck-mounted tank, broadcast applied, TPI: Tractor-pulled tank, injected.
[2] a = alfalfa, c = corn, clov = red clover, s = soybeans, w = wheat
[3] On average 6.6 kg N ha^{-1} was added as starter fertilizer prior to corn planting.
[4] Manure incorporated with and Aerway® roller-bar. http://www.aerway.com
[5] tillage limited to strips: ~18cm tilled stips spaced 76cm center to center
[6] implement generally comprised of a row of discs, multiple rows of field cultivator shanks, and a final finshing attachment (i.e. rolling basket).

Table 4: On-Farm Yield Results: By Environment and Treatment within Environment

	Group	Environmental Mean (Mg ha^{-1})	N	Contrast for Environment[1]	p > F	Treatment[2]	Treatment Mean (Mg ha^{-1})	Treatment Contrasts	p > F
All Environments (n = 15)	**Broadcast applied slurry**	12.9	7	Broadcast vs. Injected	<0.0001	**c1**	12.6	c1 vs. f	0.4590
						f	12.4	m1 vs.c1	0.0670
						m1	13.1	m1 vs. f	0.0167
	Injected slurry	10.6	8			**c1**	10.6	c1 vs. f	0.8385
						f	10.5	m1 vs.c1	0.3762
						m1	10.8	m1 vs. f	0.2786
Broadcast Applied Environments (n = 7)	**Truck-mounted tanks**	13.0	4	Truck broadcast vs. Tractor broadcast	0.0033	**c1**	13.0	c1 vs. f	0.9561
						f	13.0	m1 vs.c1	0.7808
						m1	13.1	m1 vs. f	0.7488
	Tractor-pulled tanks	12.2	3			**c1**	12.0	c1 vs. f	0.3404
						f	11.6	m1 vs.c1	0.0224
						m1	13.1	m1 vs. f	0.0029

[1] Evaluated using best linear unbiased predictors (BLUP's). Littell et al. 1996
[2] c1 = compaction-only 1pass, f = "farmers' check", m1 = manure 1pass.

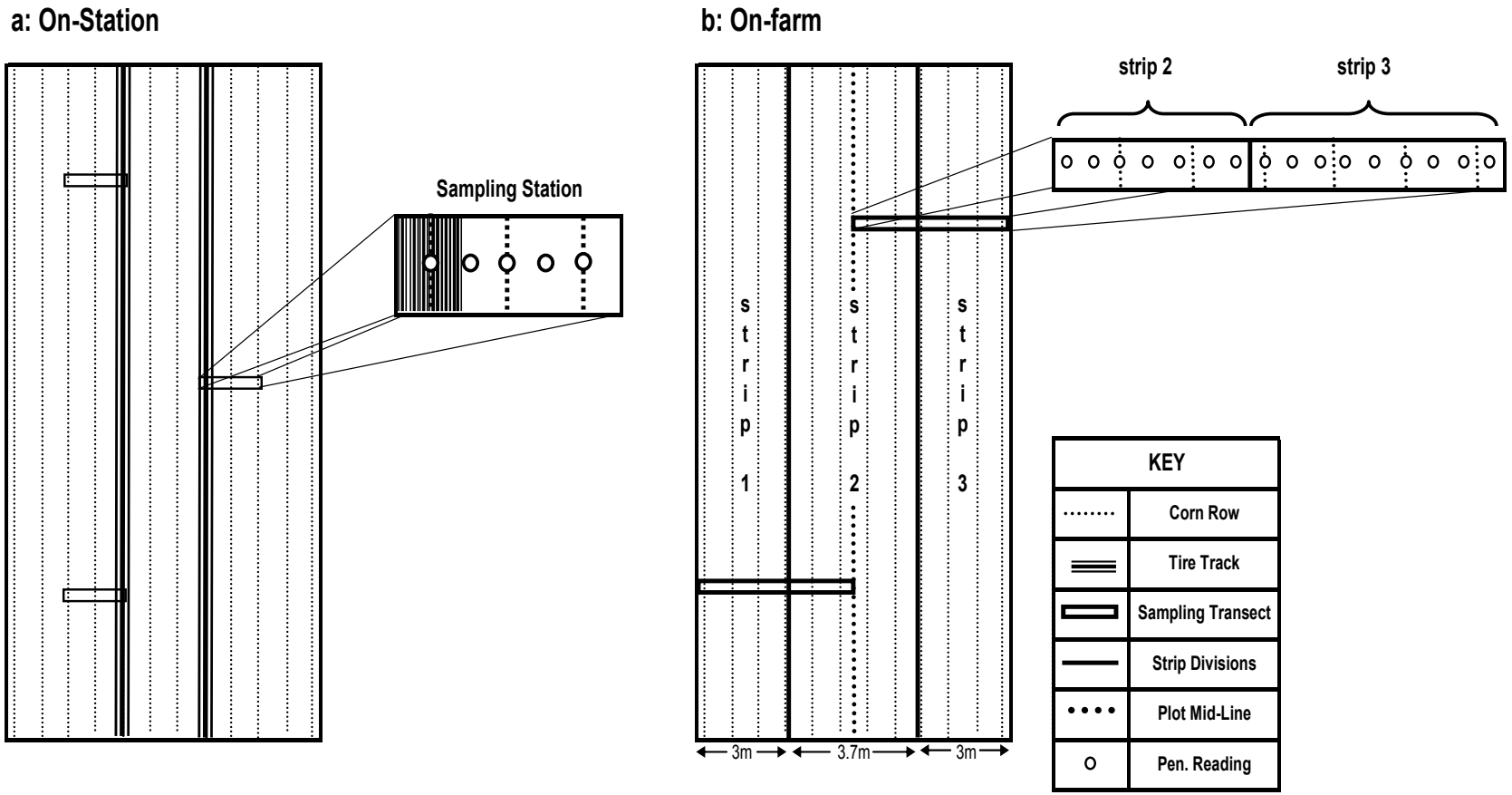

Figure 1. Cone penetrometer sampling design

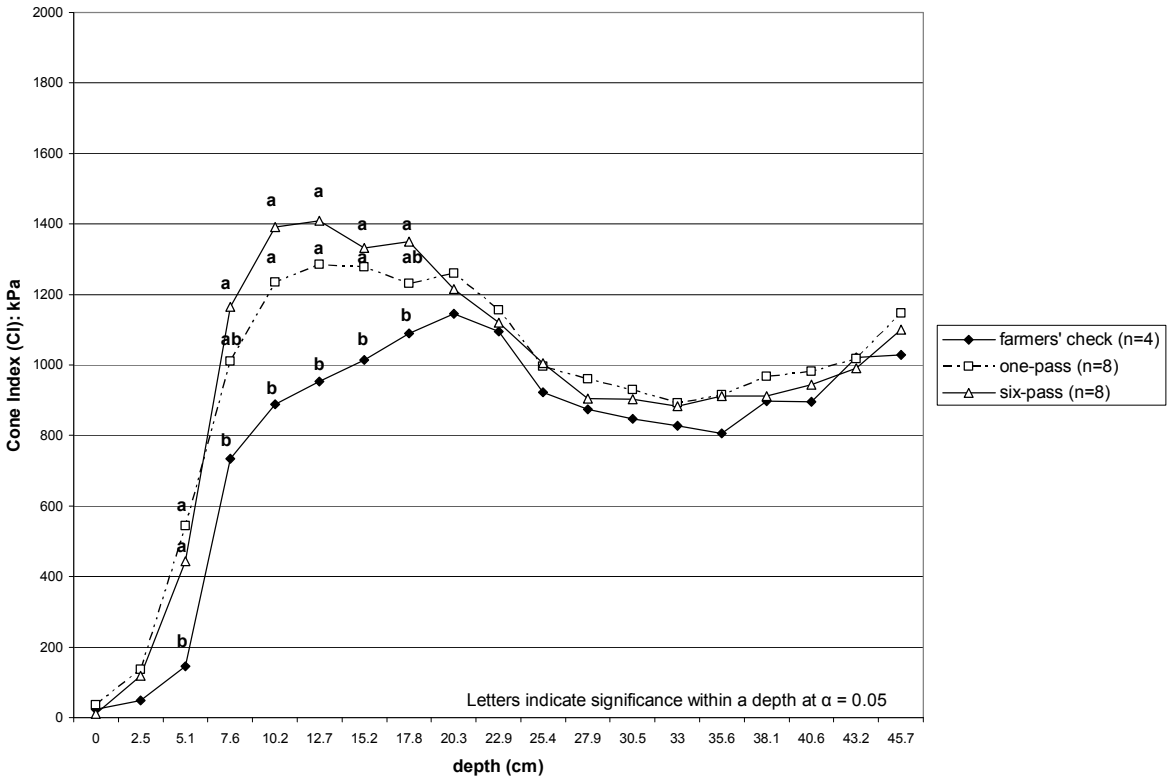

Figure 2. Main effect of traffic in 2005 on-station trial: In-track median cone index (CI) readings by depth.

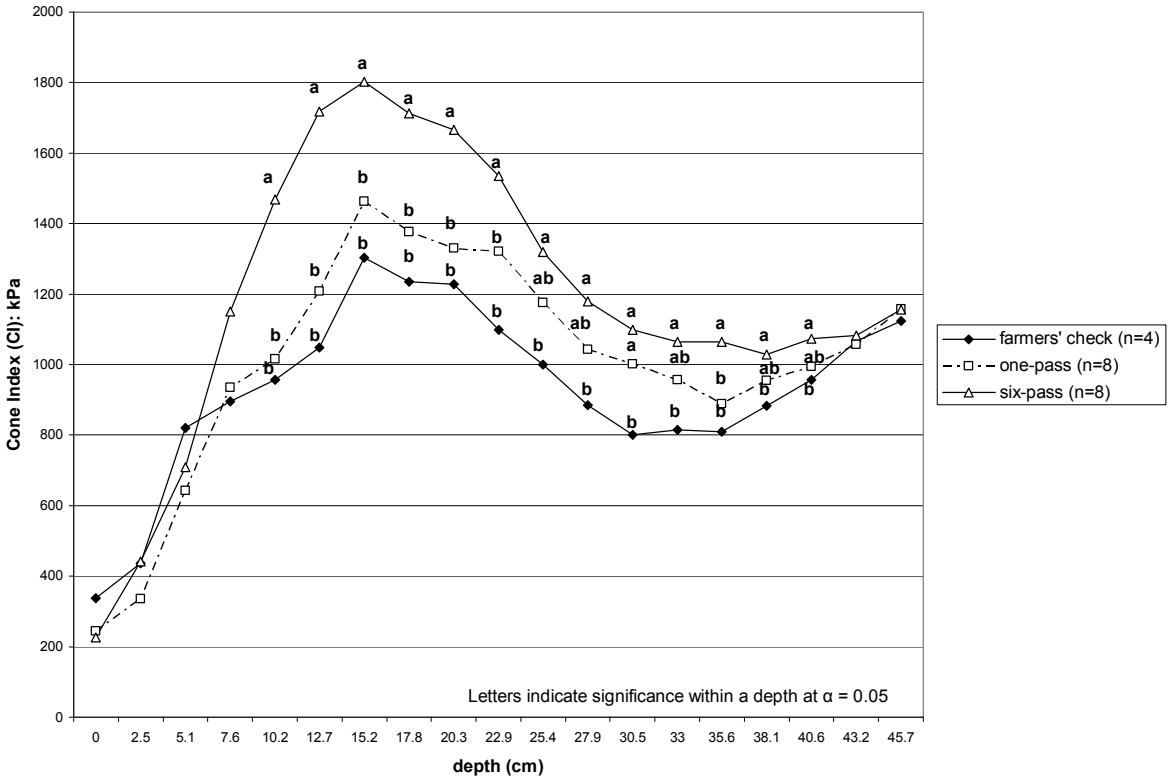

Figure 3. Main effect of traffic in 2006 on-station trial: In-track median cone index (CI) readings by depth.

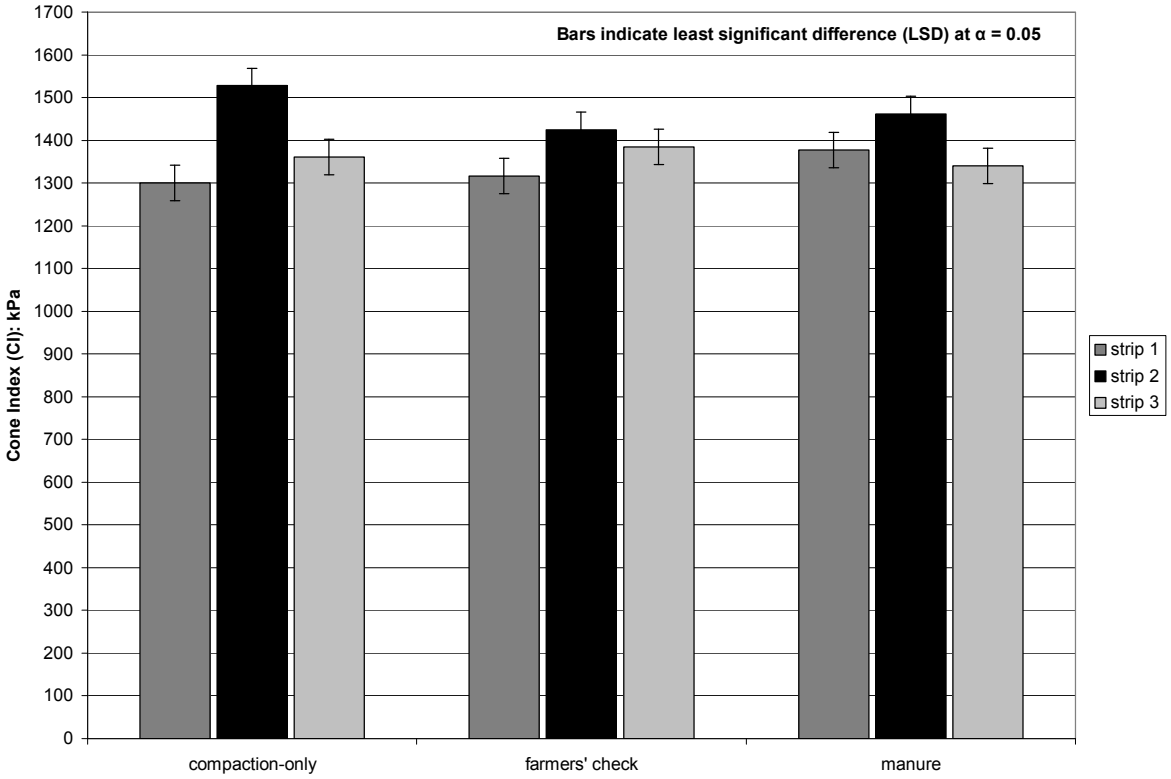

Figure 4. Median CI readings (10-25cm depth) from on-farm plot center and edges: Broadcast applied slurry (7 environments).

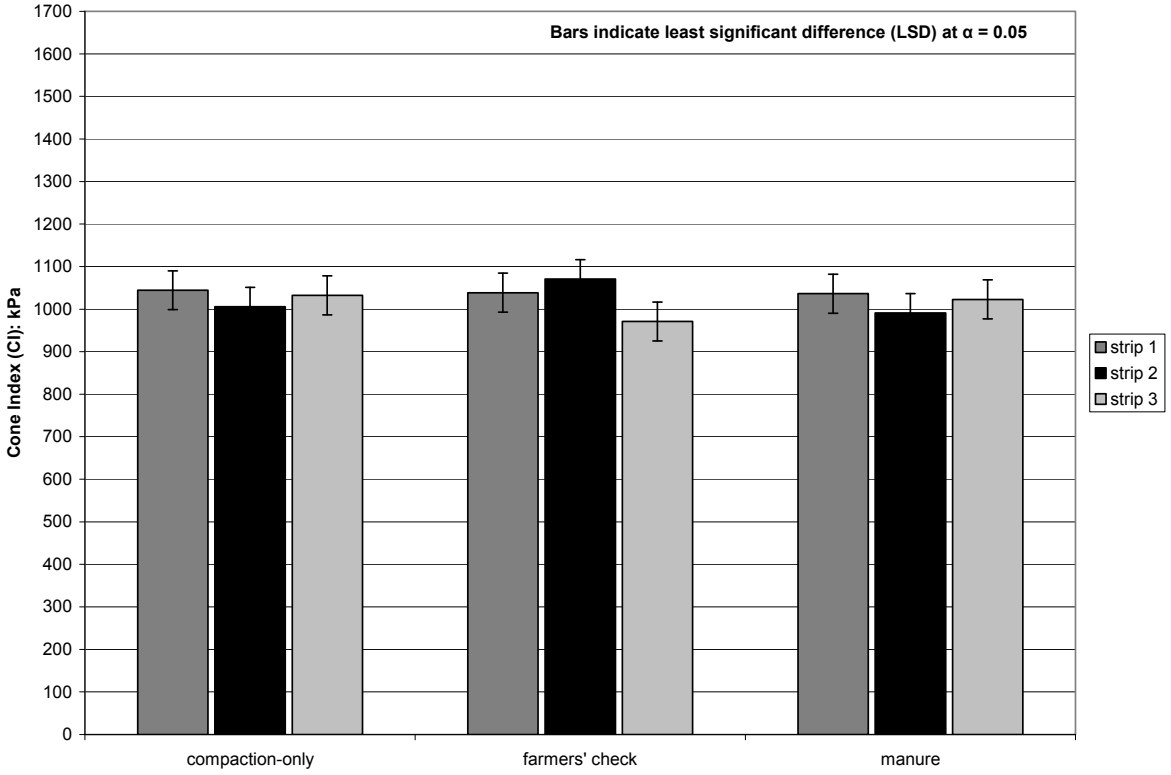

Figure 5. Median CI readings (10-25cm depth) from on-farm plot center and edges: Injected slurry (4 environments).

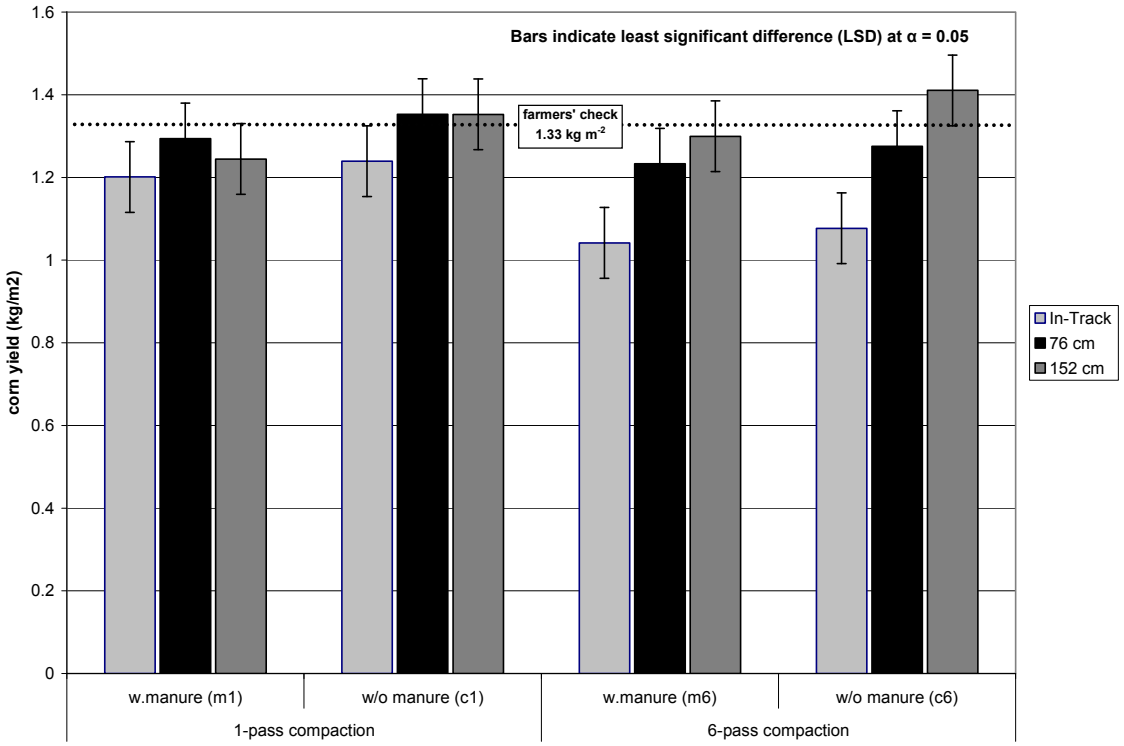

Figure 6. Combined (2005 & 2006) on-station corn grain hand harvest (kg m^{-2}).

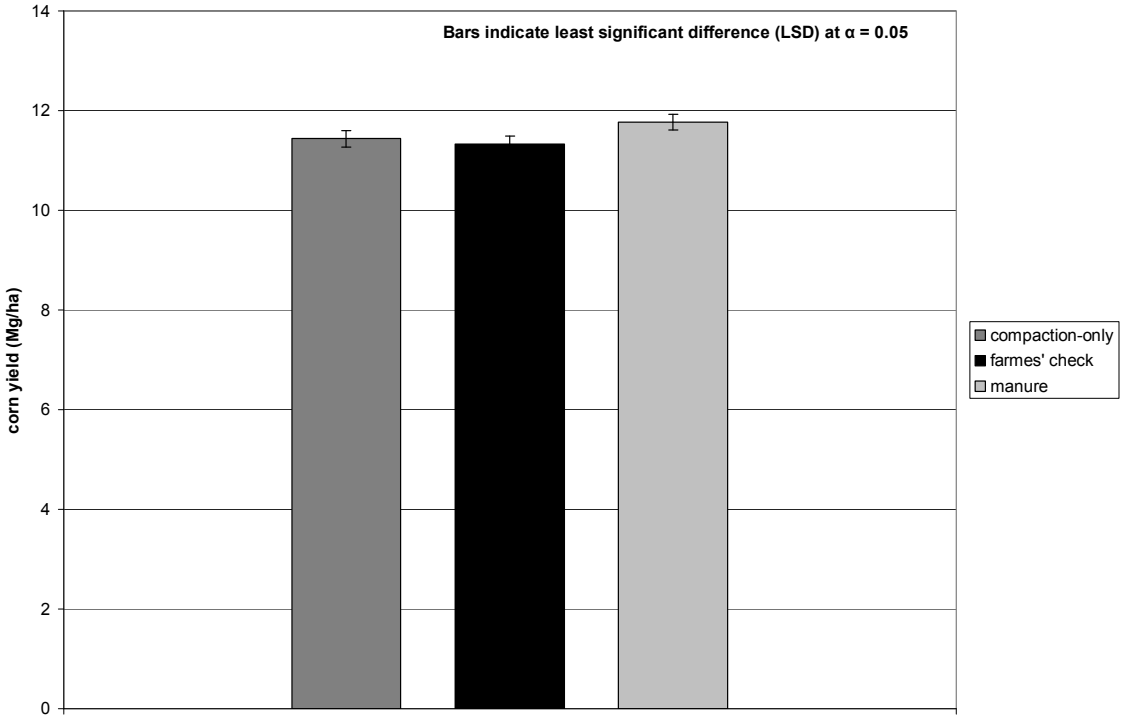

Figure 7. Combined (2005 & 2006) corn grain yields (Mg ha^{-1}) - 15 on-farm environments.

ALTERNATIVE CROPPING SYSTEMS FOR IMPROVED MANURE MANAGEMENT: THE GRASS LEY

Janet Hedtcke, Josh Posner, Rick Walgenbach, John Hall, and Gregg Sanford

INTRODUCTION

Most dairy farms in the North central and Northeastern U.S.A. continue to grow most of their feed and recycle the manure nutrients on the farm. However, to remain economically viable, many dairy farms are increasing herd size and importing more feed nutrients onto the farm. The trend in Wisconsin and throughout the upper Midwest is an increasing number of cows per farm. By 2005, farms with more than 200 animals housed 32% of the state herd and accounted for 34% of the milk production (USDA-NASS, 2006a). It has been found that these larger farms have higher stocking rates (Saam et al., 2005), exacerbating the problems of nutrient management.

Most manure is applied to the corn-alfalfa rotation on dairy farms. However, this rotation leaves the farmer with few spreading windows and nitrogen-efficient opportunities for manure application (Sutton et al., 1979). Even moderate application rates of manure on legumes are not recommended because of salt toxicity and/or crown damage that can occur with slurry and the heavy tanker traffic (Kelling and Schmitt, 2003). The most practical window to apply manure in this rotation is just prior to corn or a new seeding of alfalfa. WICST data shows however, that fall nitrate levels were excessively high and most at risk for leaching in corn following manured alfalfa (WICST 10th Technical Report, p. 31). These findings have been confirmed by other authors. (Beiebly et al., 1973; Sanford et al., 2008). Furthermore, because spreading is limited to primarily the fall and spring in the corn-alfalfa rotation, many dairymen are required to invest in large concrete holding pits to store manure, often for 6 or12 months.

In this project we propose an alternative approach--promoting the use of grass leys on dairy farms to improve nutrient cycling, facilitate manure management, and reduce nutrient leaching and run-off. The term grass ley is European and refers to land that is planted to grass for a few years then followed by annual crops. The grass may be grown for pasture, hay, silage, or green chop. The addition of a nitrogen-demanding grass crop to the rotation would have several advantages while providing feed for the herd. It would permit manure application on a growing sod crop that would minimize the risks of surface runoff and groundwater contamination (Heathwaite et al. 1998; Simmelsgaard, 1998; Schmitt et al., 1999; Webster et al., 1999, Kanneganti and Klausner, 1994). Because of their shallow fibrous root system, grasses are known for their high nutrient absorption levels, especially N. For example, in Great Britain, researchers added 200 lb N/a as liquid slurry in spring and measured only 10 lb N/a leached and by increasing the applications to four times per year (800 lb N/a), nitrate losses were only 15-30 lb N/a. In addition to improved nutrient management, grass sod has practical advantages such as being available earlier for spreading when other ground may be too wet for traffic. An unknown effect of frequent slurry applications however, is cattle acceptance/rejection level of the forage. This issue was examined in a concurrent feeding trial and will be reported on in another paper in this technical report (‘Effects of Land Applying Dairy Slurry on the Subsequent Voluntary Intake of Orchardgrass Hays by Growing Dairy Heifers’).

The goal of this agronomic study is to test the effectiveness of a grass ley system in helping dairy farmers expand their options for spreading manure. In particular, the Grass Ley Project focuses on the following objectives:

- To test the efficacy of the grass ley system in recycling manure nutrients, especially nitrogen and phosphorus, as compared to a "typical" forage system featuring corn for silage;
- To produce abundant, good quality forage.

MATERIALS & METHODS

Design and Treatments. Research plots were laid out in 2003 (Start I) and again in 2004 (Start II) at each of two locations: 1) the USDA Dairy Forage Research Center (DFRC) in Prairie du Sac; and, 2) at Michael Fields Ag Institute (MFAI) in East Troy. This combination of two starts and two locations results in four environments.

The two locations were comparable in baseline soil fertility. According to UW soil test recommendations (Kelling et al., 1998), the average soil test phosphorus (STP) was 'high' at both locations (32 ppm at DFRC; 43 ppm at MFAI) but neither location had a long history of manuring, where STP is often well above 100 ppm. Like STP, soil test potassium (STK) was in the 'high' category (123 ppm at DFRC; 107 ppm at MFAI) but again showing no long history of manuring. Organic matter levels at the DFRC and MFAI were 3.4 and 2.4% respectively. The former location was on a St. Charles/Richwood silt loam while the latter was on a Fox silt loam and both were fairly-well drained.

Plot size (600 sq ft at DFRC and 1200 sq ft at MFAI) was determined by manure spreading equipment as well as the width of the corn planter and drill. In a RCB design, five repetitions (six reps at MFAI Start I) included four treatments:

1) Orchardgrass (*Dactylis glomerata* L.) with manure (OG+M)
2) Orchardgrass with commercial fertilizer (OG+F) –mostly N but also P and K per soil test levels;
3) Corn silage *(Zea mays* L.*)* with manure (CS+M); and
4) Corn silage with commercial fertilizer (CS+F).

Orchardgrass was chosen for its quick establishment, winterhardiness, good drought tolerance, and high yield (compared to brome, perennial ryegrass and reed canarygrass). Corn silage served as the 'standard' system since it is commonly a heavily manured forage option. Manure or fertilizer was applied prior to establishment as well as after each cut of orchardgrass (3-5x per season) and prior to corn planting. Each start consisted of 3 years plus a 4th residual year. In the orchard grass rotation it was a seeding year plus two hay years, and in the corn silage rotation, three years of corn silage. In the 4th year the plots were all planted to corn to quantify residual soil fertility.

Establishment and Agronomy. Start I was established late August 2003 with manure applications on OG+M and CS+M treatments and a 12 lb/a seeding rate of 'Elsie' orchardgrass. But due to poor establishment at both locations due to dry fall conditions (45-60% of normal rainfall from August to October) along with heavy volunteer small grain pressure from the previous crop, the grass was reseeded in April 2004. Likewise, the Start II fall seeding failed at

both locations for the same reasons and was replanted in April 2005. Undersander's study (2006) on fall planting dates for several grasses, including orchardgrass, showed that delaying seeding beyond August not only increased the risk of establishment failure but also reduced yield of the stand the next year by 1 ton/a. Plots were no-till at DFRC (manure surface applied; weeds sprayed with herbicide according to BMP's) and the MFAI location, under low-input management, relied on mechanical tillage for weed control and manure incorporation.

Inputs. First-year nutrient credits from manure are shown in Table 1. The two locations of the study utilized different dairy manure, both in terms of type (slurry and solid bedding pack) and nutrient content (dilute and concentrated). The slurry from DFRC was generally very watery and nutrient-poor, often containing only 50% of the expected nutrient load. The pit design did not allow complete agitation when full, so solids settled to the bottom, leaving nutrient-poor "dirty water" on top. This lower concentration led to high spreading rates (12,000 gal/a) or 'topping off' with commercial fertilizer to meet the desired nutrient input level. The slurry was applied on the surface in one pass with a 2000 gal 'Nuhn' research manure tanker. Over time, due to 'controlled traffic' on the same place in the plot, surface compaction and the resulting thinning of the stand was evident.

The manure at MFAI was from dairy cattle pen-pack with straw bedding that was semi-composted and in windrows. It tended to crust over and shed rainfall, thus helping to retain nutrients. This manure was applied with a box spreader with rear beaters at 16 tons/a on the grass and 30 tons/a on the corn. Manure at this location was incorporated prior to planting corn but was left on the surface in the OG+M treatment after each cut. This resulted in uneven distribution with large clumps of manure lying on and sometimes smothering the grass sod.

Nitrogen fertilizer was either urea or ammonium nitrate to the grass (OG+F) to equal that of the manure of around 50 lb N/a per cut. For the corn silage, N was applied either preplant or as a sidedressing to total 160 lb N/a. As shown in Table 1, the dilute manure on CS+M treatment at DFRC needed a top-off of N fertilizer. Potash was applied according to soil test levels as potassium chloride.

Sampling. When grass was about 15" tall, it was harvested with a sickle bar mower from the center of the plots in a 60-75 sq ft area at 3" stubble height. It was weighed fresh and a grab sample was collected to determine water content. All samples were dried in a 55 °C forced-air oven for one week and yields are reported on dry matter (DM) basis. Dry samples were ground through a 1-mm screen in a Wiley hammer mill and analyzed at the University of Wisconsin Soil and Forage Analysis Laboratory (Marshfield) with NIRS and wet chemistry.

A composite of 5 soil cores (3/4" diameter) were sampled from the middle of each plot from 0-6" depth for routine fertility prior to the trial and each fall following crop harvest. Soil samples were analyzed for pH, organic matter (OM), available P, and extractable K by the University of Wisconsin Soil and Plant Analysis Laboratory (Madison) using the procedures of Schulte *et al*. (1987). Soil organic matter was estimated from weight loss on ignition at 360 °C for 2 h. Soil pH was measured in water with a glass electrode pH meter. Available P and extractable K were analyzed in Bray P-1 extracts. Phosphorus was determined colorimetrically and K was determined with flame photometry. To measure post-harvest nitrate-N (hereafter referred to as fall nitrates), a tractor-mounted hydraulic probe was used to collect two 3-foot deep cores (1 ¼ or

2” diameter, the bigger probe used at the more stony MFAI location) from the center of each plot. These cores were then bulked in each plot.

Statistical analysis. Nutrient budgets were made by summing nutrient input from manure and fertilizer, then subtracting nutrient off-take by each crop. Analysis of variance procedures using proc mixed, proc univariate, and proc means of SAS 8.2 software (SAS 2004) were used to analyze yields, quality, nutrient budgets and profile nitrates. Regression was used to evaluate trends in soil test P and K over the rotations. Statistical analyses were made on an individual-location basis primarily because of the different manure types used at each.

RESULTS & DISCUSSION

Forage Yields. Across locations, corn silage had nearly double the yield of orchardgrass (Table 2). Corn silage yields were lower than expected at MFAI somewhat due to heavy weed pressure and mediocre stand density resulting from the mechanical tillage used as the only method for weed control. However, due to repeating in-season harvesting, the orchardgrass stands were fairly weed-free even without herbicide. Across environments, total orchardgrass yields reflect a seeding year of roughly 2.3 tons/a while the established grass yielded 4.2 tons/a/yr with each cut yielding an average of 0.9 tons/a (data not shown). Though there was a trend for the manured treatments to have higher yields than those fertilized with commercial fertilizer, there were no significant differences due to nutrient type. These results for corn are similar to a past study of comparing yields of fertilized, manured corn to corn plots that were only fertilized (Jokela, 1992).

Forage Quality. Though lower in yield than corn, orchardgrass had higher feed quality (Table 3). Protein levels were 2-3x higher in orchardgrass than corn silage and were excellent for growing cattle. Likewise, the digestibility, as measured by NDF-D, was significantly higher (~20%) for orchardgrass. However, NDF levels, with high levels reducing intake, were lower (and more desirable) in corn silage primarily due to the grain component of that forage. As a result of higher NDF in the orchardgrass, the relative feed value (RFV) was lower than that of corn. The high NDF value of the orchardgrass may limit it as sole forage for high producing dairy cows because of the reduced intake-reduced milk effect. But because the orchardgrass NDF was more digestible than the corn silage, milk per ton (lbs of milk per ton forage) was higher for the orchardgrass. Therefore, blending orchardgrass with other forage would be a good option for feeding it to cows in peak milk or as the sole source of forage for late-lactation cows, dry cows or growing heifers. Like yield, nutrient type within species level had little effect on quality.

Nutrient budget. By computing annual nutrient offtake (yield x nutrient concentration) of each treatment and subtracting that from the annual nutrient input, we estimated the net nutrient levels for P2O5 and K2O (Table 4). At DFRC, all treatments had a net drawdown of P2O5 except OG+M, which, as expected due to the repeated manure applications, had a modest surplus. For K2O, both manured treatments had a positive net balance at DFRC while OG+F had the largest decline in K2O. At MFAI with its more nutrient-rich manure source, we saw a positive balance of P2O5 and K2O for both OG+M and CS+M while the non-manured treatments showed a negative balance for each nutrient. Knowing that the soils at both sites had similar buffering capacities of 18 lb/a P2O5 to change STP by 1 ppm and 7 lb/a K2O to change STK by 1 ppm,

our nutrient budgets reflect the highest change in STP and STK under OG+M at both locations. This is expected to be provide the residual effect in the 4th-yr corn phase.

Soil test trends. Because soil test values were in the 'high' category for both P and K at both locations, we were in a good position to maximize yields without applying much P or K to start. As shown by regression analysis in Figs. 1 and 3, the initial STP levels (intercept of the regression equations) were 32 ppm at DFRC and 45 ppm at MFAI. In general agreement with the annual nutrient budget estimations in Table 4, OG+M had the largest change in STP of +5.4 ppm/yr at DFRC and +7.3 ppm/yr at MFAI (slopes different from zero at $p<0.0001$). Likewise, OG+F had the largest decline in STP of -4.5 ppm/yr at DFRC (slopes different from zero at $p<0.0001$) and -4.3 ppm/yr at MFAI (slopes different from zero at $p<0.0001$). The soil test trends for STK paralleled those of STP for each location with slopes similar to those estimated in the nutrient budget in Table 4.

Fall Nitrates. Fall soil nitrogen levels can be highly influenced by weather. Cold, wet soils can delay mineralization in the spring and heavy rains or snow melt can cause leaching of nitrates out of the rooting zone. Further, lower than expected yields (i.e. due to drought or disease) can lead to unused N. Therefore, fall nitrates levels are more of an annual phenomenon that a cumulative one so we present it as means for each treatment by year and then averaged over years (Figs. 5-8). For DFRC there was no treatment x year interaction or main year effect but the main effect of treatment was significant ($p<0.0937$; Fig. 6). Not surprising, the non-manured orchardgrass, with its fibrous root system and perennial nature, had significantly lower profile nitrates than the corn treatments at both locations, most likely due to the fact that the orchardgrass was still photosynthesizing and utilizing nitrogen into the late fall. Somewhat impressive was that OG+M with its multiple manure applications did not have nitrates any higher than either corn treatment. In fact, the OG+M at MFAI, was very close to background levels found in non-agricultural areas. These conclusions are supported by other studies that tested nitrate leaching on grass/sod crops. Eriksen et al (1999) tested nitrate leaching in four cropping systems where manure was applied, and found the lowest level of leaching occurred in the first year of a grass/clover system. A second group had similar results, with the second-lowest leaching losses in their cropping system experiment from a perennial ryegrass ley (Thomsen et al., 1993). A Cornell team found that following annual manure applications, orchardgrass recovered large quantities of liquid manure and solid manure N (Kanneganti and Klausner, 1994).

Practical issues. In the process of running this trial, we have made a number of practical observations.

1. We did not succeed with our fall seeding of orchardgrass and feel it must be done in August, or in the early spring;
2. It was a challenge after each cutting to get the grass off the plots rapidly, before regrowth began and manure application could burn the newly emerging leaves;
3. University vets have suggested to us that the heavily manured forage should be ensiled vs. hayed because the fermentation process kills bacterial that can cause health issues (i.e. Johnne's disease);
4. Pit agitation and manure hauling is expensive and time consuming so hauling several times a summer following each cut might be prohibitively expensive and time consuming. With rapid, smaller volume trucks (e.g. 4000 gal husky), it can require two

passes to reach application rates of 12,000 gals/a resulting in more traffic and potential sod kill.

CONCLUSIONS

Although somewhat challenging to establish orchardgrass in the fall following small grains, once established, the grass was easy to manage (no tillage or herbicides) and produced high quality feed with reasonable yields. The orchardgrass sod provided windows for in-season manure spreading. It did accumulate P and K over time which is expected to provide residual nutrients for the following crops that can be managed to drawn down residual fertility levels. In addition, the ley system was very efficient in absorbing manure nitrogen as evidenced by the low fall nitrate levels. The next step is to test this system on-farm on a larger scale to determine how it fits into a dairy farmer's current system.

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TABLES/FIGURES

Table 1. Average manure nutrient input per year (1st yr available) at DFRC and MFAI							
		Grass (4 applications/yr)			Corn (1 application/yr)		
		N	P2O5	K2O	N	P2O5	K2O
		lb/a					
DFRC	Start I	219	122	536	56	32	133
	Start II	226	119	560	61	30	137
	Average	**223**	**121**	**548**	**59**	**31**	**135**
MFAI	Start I	209	215	652	91	69	186
	Start II	176	215	582	123	119	289
	Average	**193**	**215**	**617**	**107**	**94**	**238**

- DF average total nutrient content (N:P2O5:K2O) 16:4:14 lbs/1000 gals with 2.5% DM
- MF average total nutrient content (N:P2O5:K2O) 11:6:13 lbs/ton with 25%DM

Table 2. Mean annual forage yield across starts, reps, and years		
	DFRC (n=30)	MFAI (n=33)
	Tons DM/a	
OG+M	3.96b	3.68z
OG+F	3.42b	3.23z
CS+M	8.22a	6.04x
CS+F	7.58a	4.98y
P- value	0.0013	0.0006
DFRC = 5 reps x 3 yrs x 2 starts = 30 MFAI = Start I: 6 reps x 3 yrs =18 + Start II: 5 reps x 3 yrs = 15 for a total of 33		

Table 3. Mean annual forage quality across starts, reps, cuts, and years							
Location	Treatment	%CP	%NDF-D	%NDF	RFQ	RFV	MILK lbs/ton
DFRC (n=120)	OG+M	18.7a	74.4a	53.0a	180a	117c	3615a
	OG+F	17.9a	72.4a	52.9a	174b	116c	3530a
	CS+M	6.8b	57.5b	43.6b	n/a	148b	2893b
	CS+F	6.7b	58.1b	43.4b	n/a	154a	2955b
	p- value	0.0001	0.0001	0.0001	0.0760	0.0001	0.0001
MFAI (n=132)	OG+M	14.3x	72.2x	55.1x	169x	111y	3503x
	OG+F	13.8x	69.8x	55.0x	161x	110y	3403x
	CS+M	6.0y	58.1y	46.2y	n/a	151x	2817y
	CS+F	6.4y	58.8y	46.0y	n/a	160x	2851y
	p- value	0.0001	0.0007	0.0007	0.1115	0.0001	0.0084

n/a: RFQ for corn silage not reported by lab

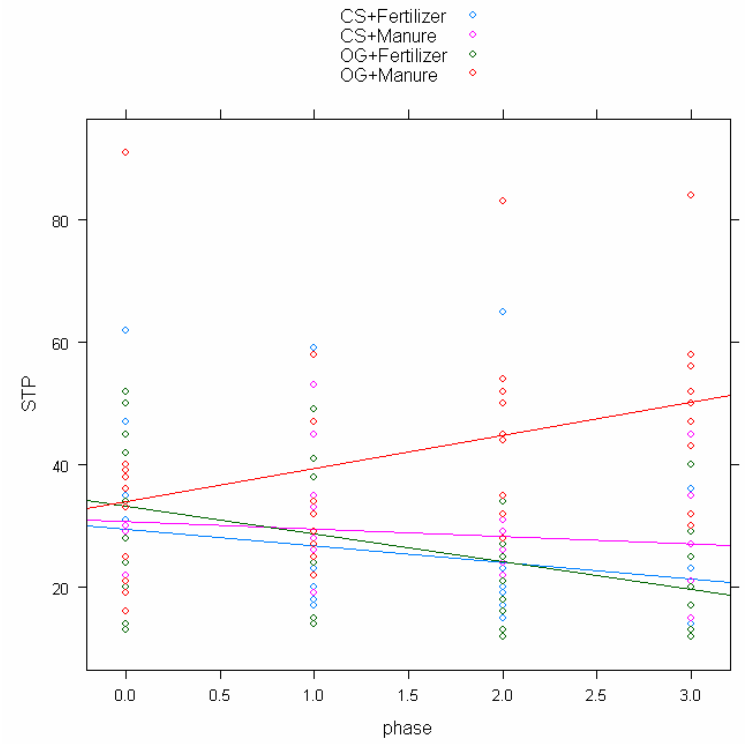
Table 4. Estimated annual nutrient budget (1st yr available) and corresponding change in soil test values.[1]

		Net P2O5	Change in STP	Net K20	Change in STK
Location/ manure type	Treatment	lb/a/yr	ppm/yr	lb/a/yr	ppm/yr
DFRC Slurry	OG+M	+54a	+3	+222a	+32
	OG+F	-58c	-3	-170d	-24
	CS+M	-16b	-1	+64b	+9
	CS+F	-52c	-3	-57c	-8
MFAI Solid	OG+M	+155a	+9	+375a	+54
	OG+F	-49c	-3	-143c	-20
	CS+M	+50b	+3	+138b	+20
	CS+F	-44c	-2	-38c	-5

The soils at both locations have soils with similar buffering capacity. It takes 18 lb/a P2O5 to change STP by 1 ppm, and 7 lb/a K2O to change STK by 1 ppm (A2809)

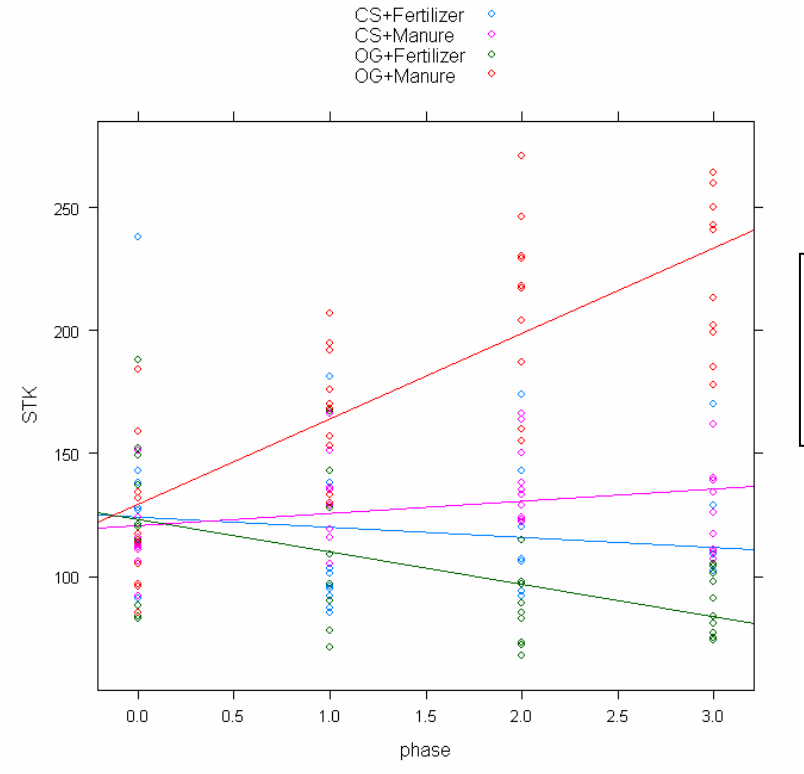
[1] Net= (Average 3-yr nutrient input – average 3-yr annual offtake)/3

Fig. 1. STP trends with regression equations at DFRC (*= slope significant different than zero)



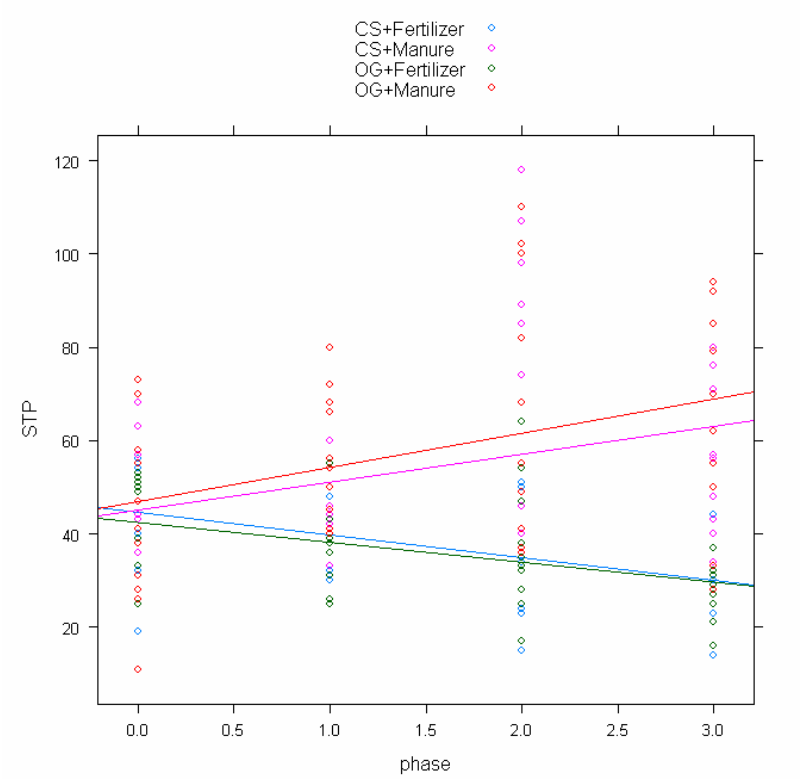
OG+M: y = 34 + 5.4x**
OG+F: y = 33 – 4.5x**
CS+M: y = 31 – 1.2x
CS+F: y = 30 – 2.7x

Fig. 2 STK trends with regression equations at DFRC (*= slope significant different than zero)



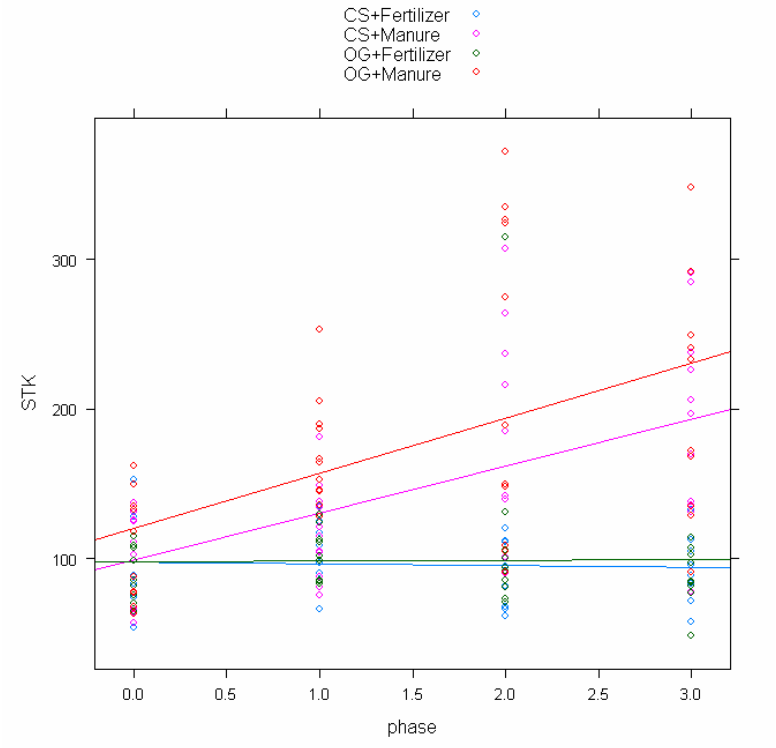
OG+M: y = 129 +34.7x**
OG+F: y = 123 -13.2x*
CS+M: y = 121 +4.9x*
CS+F: y = 124 – 4.1x

Fig. 3 STP trends with regression equations at MFAI (*= slope significant different than zero).



OG+M: y = 47+7.3x**
OG+F: y = 43-4.3x*
CS+M: y = 45+6.0x**
CS+F: y = 45-4.8x*

Fig. 4 MF STK trends with regression equations at MFAI (*=slope significant different than zero).



OG+M: y = 121+36.7x**
OG+F: y = 98+0.4x
CS+M: y = 99+31.4x**
CS+F: y = 98-1.3x

Fig. 5. Average soil profile nitrates over time at DFRC (averaged over reps and starts)

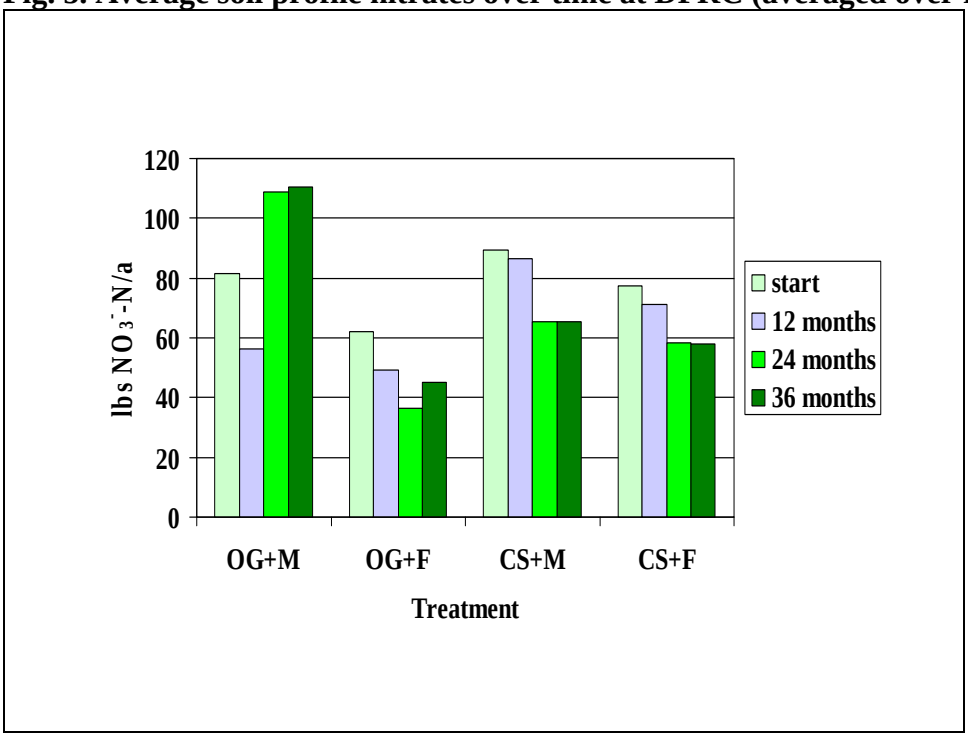


Fig. 6. Average soil profile nitrates at DFRC (averaged over reps, years and starts)

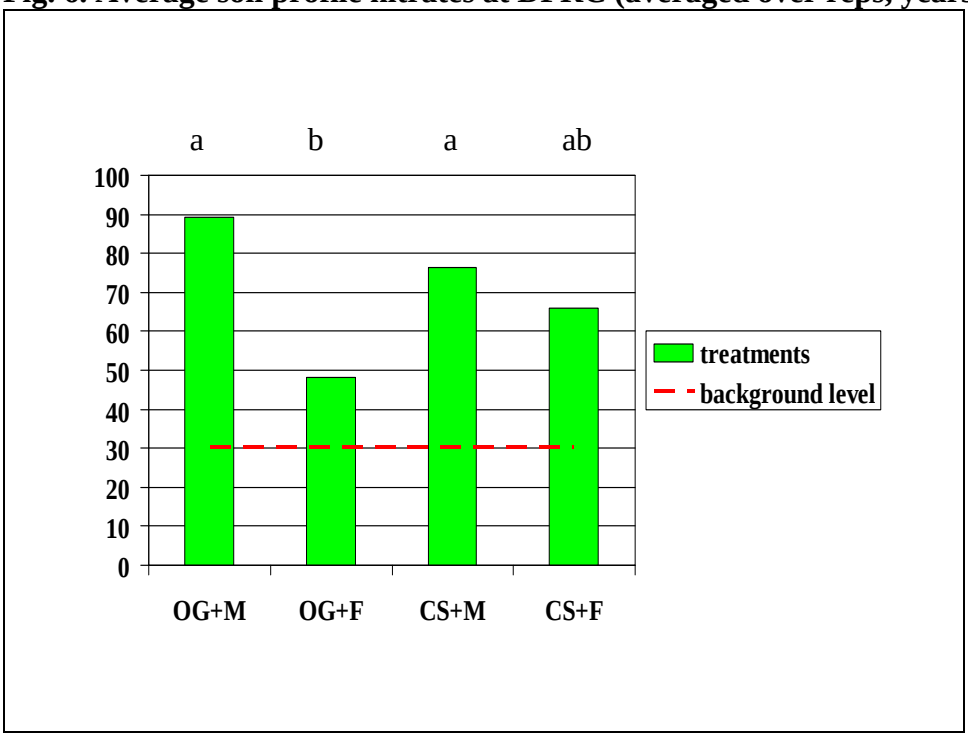


Fig. 7. Average soil profile nitrates over time at MFAI (averaged over reps and starts).

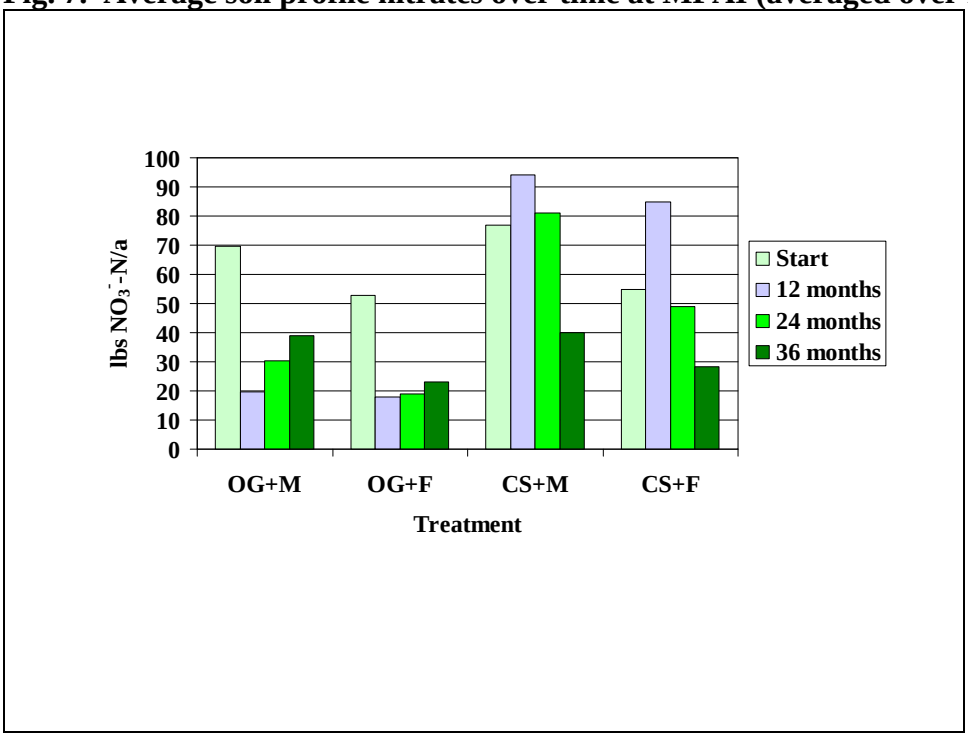
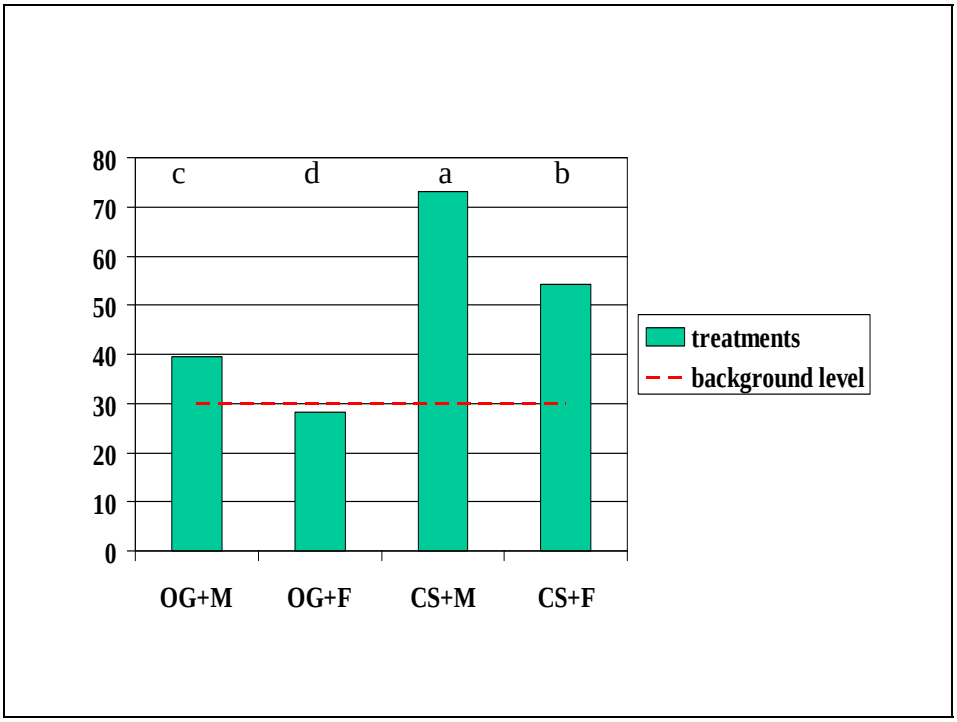


Fig. 8. Average soil profile nitrates at MFAI (averaged over reps, years and starts)



Effects of Land Applying Dairy Slurry on the Subsequent Voluntary Intake of Orchardgrass Hays by Growing Dairy Heifers

W. K. Coblentz, J. A. Davidson, R. P. Walgenbach, J. L. Posner, and J. L. Hedtcke

INTRODUCTION

Many dairy operations have a critical need for available sites to land apply dairy slurry after spring planting, and throughout the summer months. This is especially problematic when dairy producers have large proportions of their acreage planted to corn and alfalfa. One possible way to alleviate this problem is to use perennial grass sods as a summer site for receiving dairy slurry. This approach is attractive because grass sods are harvested as hay or silage numerous times throughout the summer, thereby allowing multiple opportunities for spreading. In addition, the applied nutrients can be utilized by a growing forage crop that does not already fix nitrogen. However, this management strategy is only viable if the voluntary intake of these forages by livestock is not negatively affected. Our objectives were to compare voluntary intakes by growing dairy heifers for orchardgrass hays that were fertilized with either dairy slurry or a commercial N fertilizer (ammonium sulfate) and harvested during late spring (1st cutting) or mid summer (3rd cutting).

METHODS

Field Management. 'Elsie' orchardgrass was established during 2004 at the US Dairy Forage Research Farm, near Prairie du Sac, WI. The 8.5 acre field was divided into two parts: a manured half and a fertilizer-only half. After each cut dairy slurry was applied to the manured portion of the field and ammonium sulfate and potash, if necessary, to the fertilized portion. Two cuts were taken during the seeding year and four cuts during the first hay year. During 2006, approximately 93,500 L/ha (10,000 gal/a) of dairy slurry was applied to half of the orchardgrass acreage on 11 April. This application rate was calculated to provide ≈56 kg N/ha as a first-year credit for plant growth. Similar applications also were made following the 1st and 2nd cuttings. The remaining half of the orchardgrass acreage was fertilized with ammonium sulfate at a rate of 84 kg N/ha on 15 April, and at 56 kg N/ha after each subsequent cutting. Other nutrients were applied as needed to meet the soil-test recommendations of the University of Wisconsin. Hays were harvested at the early heading stage of growth (14 May) and as vegetative regrowth (3rd cutting, 14 July). All hays were packaged as 1.2 x 1.5-m round bales with a John Deere 457 baler. Each bale was secured with net wrap, and then stored under roof until the initiation of the voluntary intake trial. Immediately prior to offering the hays to dairy heifers, each bale was shredded to an approximate 9-cm particle length with a Valmetal 5500 tub grinder. A total of four experimental hays with a 2 x 2 factorial arrangement of treatments were evaluated for voluntary intake; these included two fertilization strategies (commercial, dairy slurry) and two harvest dates (14 May, 14 July).

Animal Procedures. Eight pregnant Holstein dairy replacement heifers (483 ± 37.6 kg) were used in a 2 x 2 replicated Latin Square design. During the trial, each heifer was housed in tie-stalls with fresh water and a trace mineral block available continuously. All procedures associated with the care and feeding of the dairy heifers were approved by the University of Wisconsin College of Agriculture and Life Sciences Animal Care and Use Committee. Heifers were assigned to one of the two squares based on their voluntary intake of a common grass hay diet during a 14-d preliminary adjustment period. On this basis, one square was designated as a high-intake square (23.5 ± 0.63 g/kg BW), and the other a low-intake square (20.0 ± 1.53 g/kg

BW). After the adjustment period, heifers were offered experimental hays at 1.1 times the intake from the previous day; hays were offered twice daily in approximately equal proportions, and orts (i.e. refused/uneaten feed) were collected and weighed the following morning. Subsamples of hays and orts from each heifer were obtained each day, dried to constant weight at 50°C, and retained for analysis of nutritive value and mineral composition. The experiment included four 18-d experimental periods, each divided into 9 d of adaptation and 9 d of data collection.

Laboratory Analysis. All dried forage and ort samples were ground through a Wiley mill (Arthur H. Thomas, Philadelphia, PA) equipped with a 1-mm screen, and then analyzed for neutral detergent fiber (NDF), crude protein (CP), whole-plant ash, K, P, Ca, and Mg. The neutral-detergent solution contained both sodium sulfite and heat-stable α-amylase. Additionally, the four experiment hays were evaluated for 48-h in vitro NDF digestibility (NDFD), which was used subsequently to provide an estimate of energy density (TDN) for all hays (University of Wisconsin Soil & Forage Testing Laboratory, Marshfield, WI). Mineral composition was determined by atomic absorption spectroscopy.

RESULTS & DISCUSSION

Composition of Hays. Although the initial characteristics of nutritive value for the four experimental hays were not compared statistically, some general trends were observed (Table 3). Of these, most were related to harvest date, rather than fertilization strategy. Hays harvested on 14 July (3rd cutting) exhibited numerically greater concentrations of NDF (61.4 vs. 57.8%), but lower concentrations of NDFD (67.1 vs. 72.5% of NDF) and TDN (61.6 vs. 64.2%) than hays harvested on 14 May. Hays harvested on 14 July also exhibited greater concentrations of CP (16.4 vs. 13.4%); an advantage of comparable magnitude (16.3 vs. 13.5%) also was observed for hays receiving dairy slurry compared to commercial fertilizer. Major differences in mineral composition also were associated primarily with harvest date (Table 4). Mean concentrations of K (2.19 vs. 1.84%), Ca (0.25 vs. 0.16%), and Mg (0.20 vs. 0.14%) were numerically greater on 14 July than on the 14 May harvest date.

Voluntary Intake. No fertilization strategy x harvest date x square interaction ($P \geq 0.112$) was observed for any response variable, thereby indicating that intake responses were consistent across low- and high-intake squares. Voluntary intakes of dry matter (DM) and organic matter (OM, DM corrected for ash) were affected only by harvest date ($P \leq 0.021$; Table 5); in each case, intakes of hays harvested on 14 May were greater than observed for 14 July. For DM and OM, these differences were equal to 0.13 and 0.15% of BW, respectively. Intakes of NDF were virtually identical across treatments (1.19% of BW), exhibiting no differences due to fertilization strategy ($P = 0.693$) or harvest date ($P = 0.937$). The greater concentrations of CP in hays fertilized with dairy slurry or harvested on July 14 were reflected in voluntary intakes of CP by dairy heifers. Intakes of CP were greater for hays receiving dairy slurry (1696 vs. 1360 g/d; $P < 0.001$) and for hays harvested on 14 July (1626 vs. 1429 g/d; $P = 0.014$).

Intakes of K (Table 6) also were greater for hays receiving dairy slurry (216 vs. 193 g/d; $P = 0.002$) or harvested in mid-July (216 vs. 193 g/d; $P = 0.002$), but no interaction of these effects was observed ($P = 0.206$). Similar responses were observed for Mg, but only a harvest date effect was observed for Ca ($P = 0.001$), in which intake of Ca was greater for hays harvested on 14 July (20 vs. 14 g/d). Intake of P was not affected by any aspect of treatment ($P \geq 0.607$).

CONCLUSIONS

Generally voluntary intakes of hays receiving dairy slurry were not affected adversely by this fertilization strategy, nor was there evidence that broadcast applications of these soil amendments interacted with harvest date. Intakes of DM and OM for hays harvested on 14 May were greater than those observed for 14 July; this occurred even though hay was harvested in May at the early heading stage of growth, but was comprised of only vegetative regrowth in July. However, these intake responses were consistent with the slightly greater concentrations of NDF for July hays, and the greater concentrations of NDFD for hays harvested in May. While these responses appear to contrast with normal expectations relating advancing plant maturity and reproductive development with intake and digestibility, they are consistent with the expected effects of temperature on fiber development. Intakes of CP were greater for hays receiving dairy slurry and for those harvested in July, which reflected the greater concentrations of CP observed initially for these hays. Concentrations of K were >2.0% for forages harvested in July, and K intakes also were increased by application of dairy slurry. This may be problematic for incorporation into diets of dry cows or heifers nearing calving. Overall, voluntary intake of hays was affected only marginally by the application of dairy slurry.

TABLES/FIGURES

Table 1. Concentrations of organic matter (OM), neutral-detergent fiber (NDF), 48-h neutral-detergent fiber digestibility (NDFD), crude protein (CP), and total digestible nutrients (TDN) for four orchardgrass hays offered to pregnant Holstein dairy heifers.

Harvest	Fertilization	OM	NDF	NDFD	CP	TDN
		---------- % of DM ----------				
14 May (early heading)	Commercial	90.3	57.0	72.7	12.5	63.5
	Dairy Slurry	89.9	58.5	72.3	14.2	64.9
14 July (vegetative)	Commercial	88.8	62.9	67.0	14.4	63.0
	Dairy Slurry	88.6	59.8	67.1	18.4	60.1

Table 2. Concentrations of K, P, Ca, and Mg for four orchardgrass hays offered to pregnant Holstein dairy heifers.

Harvest	Fertilization	K	P	Ca	Mg
		---------- % of DM ----------			
14 May (early heading)	Commercial	1.80	0.33	0.13	0.12
	Dairy Slurry	1.88	0.33	0.18	0.16
14 July (vegetative)	Commercial	2.06	0.37	0.25	0.19
	Dairy Slurry	2.32	0.34	0.25	0.21

Table 3. Intakes of dry matter (DM), organic matter (OM), neutral detergent fiber (NDF), and crude protein (CP) by pregnant Holstein heifers offered diets of orchardgrass hay.

Treatment	------- DM ------		------- OM -------		------ NDF ------		---------- CP ---------	
	kg/d	% BW	kg/d	% BW	kg/d	% BW	g/d	% BW
Fertilization								
Commercial	10.2	1.98	9.2	1.78	6.11	1.19	1360	0.26
Dairy Slurry	10.5	2.02	9.4	1.81	6.21	1.20	1696	0.33
Harvest								
14 May (early heading)	10.7	2.07	9.7	1.87	6.16	1.19	1429	0.28
14 July (vegetative)	10.0	1.94	8.9	1.72	6.15	1.19	1626	0.31
SEM	0.20	0.034	0.19	0.032	0.118	0.022	49.6	0.009
Effects	---------- P > F ----------							
Fertilization (F)	0.331	0.390	0.437	0.461	0.556	0.693	< 0.001	< 0.001
Harvest (H)	0.021	0.015	0.010	0.006	0.980	0.937	0.014	0.010
Interaction (F x H)	0.885	0.870	0.894	0.861	0.138	0.111	0.151	0.136

Table 4. Intakes of K, P, Ca, and Mg by pregnant Holstein heifers offered diets of orchardgrass hay.

Treatment	K	P	Ca	Mg
	---------- g/d ----------			
Fertilization				
Commercial	193	34	16	15
Dairy Slurry	216	33	18	18
Harvest				
14 May (early heading)	193	33	14	14
14 July (vegetative)	216	33	20	19
SEM	4.3	1.2	1.1	0.5
Effects				
Fertilization (F)	0.002	0.883	0.084	0.002
Harvest (H)	0.002	0.941	0.001	< 0.001
Interaction (F x H)	0.206	0.607	0.072	0.063

ORGANIC RESEARCH

USE OF A RYE COVER CROP FOR WEED MANAGEMENT IN AN ORGANIC REDUCED TILLAGE GRAIN ROTATION

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INTRODUCTION

Organic agriculture is of growing importance in the US as consumer demand for organic products increases. Since 1997, organic crop acreage has grown 72% in the upper Midwest, and currently there are 287,520 acres of organic grain crops, primarily corn, soybean and wheat (ERS 2006). However, organic management comes with its own set of challenges compared to conventional agriculture. A national survey of 1200 certified organic farmers reported that weed management is the largest general constraint to transitioning to organic management (Walz 1999). Another concern among organic producers is the frequency of tillage and cultivation required for mechanical control of weeds. Such heavy reliance on tillage is associated with intensive fuel and labor demands (Hedtcke et al. 2002; Posner 1990-2004), soil loss (RUSLE, Watershed Protection Processes Research Unit 2006) and reduced soil structure (STIR index, USDA-NRCS 2005) as well as decreased soil quality over time (Post et al. 2004; Matson et al. 1997; Villamil et al. 2006). A possible solution is the use of rye (*Secale cereale* L.) as a fall cover crop and then as a mulch during the soybean (*Glycine max* L.) phase. This system could, theoretically, help reduce soil erosion, increase soil organic matter and aggregation, trap excess nitrogen, and suppress weeds without cultivation, (Bowman et al., 1998; Hartwig and Ammon, 2002; Ruffo et al., 2004). This literature review will focus on two issues:

- The ecology of rye and management for weed suppression.
- The effects of using an organic, no-tillage rye mulch regime on weed communities.

Rye ecology and management for weed suppression:

a. Background: Rye is a cool season annual, initially cultivated in northern Europe (Stoskopf 1985). Historically it has been grown in the upper Midwest for use as a feed or forage crop for the dairy industry. Today however, rye is primarily used as a cover crop to protect against erosion at construction and roadway sites, planted following potato harvest on sandy soils, and following corn silage and manure application. In many organic operations it is also used as a green manure crop. It is planted in the late summer to early fall, and begins vegetative growth before becoming dormant in the winter. Due to its cold hardiness, vegetative growth continues as long as temperatures are above 38 $^{\circ}$ F (Bowman et al. 1998; Stoskopf 1985).

b. Seeding rates and planting dates: Although recommendations for planting rye for grain are about 100 lbs/acre, when planted as a cover crop, rye should be planted at a higher rate, 100-300 lbs/acre, depending on prior seedbed preparation, planting date and planting method (Stoskopf 1985). It is sensitive to planting depth, and should be planted no deeper than 2 inches, but, in fact, can germinate even on the soil surface, thus easily adapting to overseeding methods which would allow earlier planting and greater fall growth. The challenges in using rye as a cover crop in an organic system in the upper Midwest are fitting the rye into the growing window between corn, (*Zea mays* L.) harvest

and soybean planting, method of killing the rye in the spring, and ryes' possible depletion of soil moisture prior to soybean planting, (Westgate et al., 2005).

Research conducted in Canada indicates that a range in fall planting dates for rye can have an affect on time of heading. This study found that rye seeded in August through early September headed in early June, whereas rye seeded late September through late October headed in late June (Fowler 1982). Rye varieties tested in Wisconsin (planted in early October) show a range in maturity (Kaeppler et al. 2007), but begin anthesis by June 1 (Robert Foresberg, personal communication, 2007). This is not surprising since, according to Bowman et al (1998), rye initiates flowering in response to daylength longer than 14 hours (around May 1 in Wisconsin), and temperatures above 40 ° F. As a result, it is not clear if there would be much range in date of anthesis among commercially available rye varieties due to planting date or varietal differences.

c. Timing and Method of Killing: Conventional farmers often use herbicide to kill a rye cover crop (Ateh and Doll 1996) while organic farmers use tillage. Both of these methods are effective and can be done regardless of growth stage. However, in organic systems, incorporating fresh organic matter just prior to planting soybeans can result in poor stands due to increased pressure from seed corn maggots (*Delia platura* Meigen) (personal observation). If the rye is being killed mechanically, then the physiological stage is important in determining the success of killing the rye. If the rye is still in a vegetative stage, it will regrow and compete with the next crop. However, once rye becomes reproductive, mechanical kill methods are much more successful. This phenomena has been documented by Ashford and Reeves (2003) in Alabama using a roller crimper to kill the rye, and by De Bruin et al. (2005) in Iowa, and Wilkins and Bellinder (1996) in New York, both using a sickle-bar mower. Westage et al. (2005) had similar results in Iowa using a corn stalk chopper. All of these studies concluded that mechanical kill was most successful at or after anthesis. Sickle-bar mowing is an effective method of killing rye (Wilkins and Bellinder, 1996), but studies from Wisconsin have shown that these mowers are not well adapted to the weed management system (Jerry Doll, personal communication 2007; personal observation 2006). Rotary mowers are not effective since rye residues may be unevenly distributed in windrows or clumps throughout the field, resulting in hair pinning of residues that can clog the planter, or leaving the soil exposed, allowing rapid germination and growth of weeds. Another problem with rotary mowing is that the residue is cut into small pieces which decompose very quickly, reducing the benefits of the residue mulch to prevent weed growth (Creamer and Dabney, 2002). A more promising method of killing rye is rolling or roller-crimping. Rolling lays the residue flat on the ground in one direction, making planting through the residue easier. Roller-crimping crimps (kills) the rye while rolling it flat. In addition, Ashford and Reeves (2003) noted that the energy requirements of a roller are ten times less than that of a rotary mower. In the studies reviewed for this paper, rye biomass at the time of mechanical killing ranged from 3.6 to 4.4 tons of dry matter per acre (Ashford and Reeves 2003; Wilkins and Bellinder 1996).

d. Rye's allelopathic effect: As a dead mulch, rye is both a physical barrier that shades weed seeds and it produces allelochemicals that suppress weed germination, (Singh et al.,

2003; Weston and Duke, 2003). The main allelochemicals are BOA [2-(3H)-benzoxazolinone] and DIBOA [2,4-dihydroxy-1,4-(2H)-benzoxazine-3-one], which are cyclic hydroxamic and phenolic acids, (Singh et al., 2003). These chemicals are toxic to small seeded annual dicots and grasses, but less harmful to crops with large seeds like corn or soybean, (Weston and Duke, 2003; Burgos and Talbert, 2000; Dhima et al., 2006). The larger-seeded crops can avoid the allelochemicals since they are planted deeper than the zone with the highest concentration near the surface. The allelochemicals are released from both living plant parts and dead rye residues. BOA is biotransfrormed by soil bacteria into AZOB [2,2'-oxo-1,1'-azobenzone], which is more toxic than either BOA or DIBOA, (Singh et al., 2003). Thus soil conditions such as moisture and temperature can have an affect on toxicity of decomposing rye residues. Allelopathic affects of rye residues occur until the residues have decomposed. For this reason, the size of the pieces of residue and the C:N ratio, both of which affect rate of decomposition, will affect the effectiveness of rye a weed-suppressing mulch.. Singh et al. (2003) found the greatest allelopathic affects of rye to occur shortly after killing. Price et al. (2006) reported that in no-herbicide plots, rye provided more effective weed control than black oat and wheat based on visual ratings and weed biomass. Moonen and Barberi (2004), reported that plots with a rye cover crop had the lowest species richness, and also the lowest weed biomass compared to other cover crops and crop residues.

e. Cultivar selection: Although no breeding work has been done for the rye-mulch systems, the amount of allelochemicals produced by root and shoot biomass has been shown to differ significantly between cultivars (Burgos et al. 1999). This study indicates that breeding of rye cultivars for use as a cover crop could improve the effectiveness of the rye in suppressing weeds. In addition to the production of allelopathic compounds, rapid growing and early timing of anthesis are characteristics of rye cultivars that would permit a timelier planting of soybeans.

f. **Water use in rye:** A potential constraint of using rye as a cover crop preceding soybeans is the depletion of soil moisture delaying soybean germination and slowing early crop development, (Westgate 2006). Blevins et al. (1971), for example, found that when a rye cover crop was planted prior to no-tillage corn, soil moisture was lower in the early spring. In a set of more recent studies, early killed rye had significantly higher soil moisture than late killed rye during drier springs, however no-tillage plots had higher soil moisture contents than conventional tillage plots later during the season due to reduced evaporation (Munawar et al. 1990; Westgate et al. 2005). While evaluating the roller-crimper, Ashford and Reeves (2003) found a linear relationship between increased percent kill of the cover crop and higher soil water content at 2 weeks after crimping. The residue mat created by the roller crimper resulted in greater soil water conservation by reducing total evaporation, despite water loss through transpiration of rye regrowth.

A study conducted in Ontario concluded that while rye will drawn down soil moisture levels, a rainfall event of 15 mm or greater would recharge the 0-10 cm layer of soil to field capacity, thus allowing soybean germination (Wagner-Riddle et al. 1994). It is estimated that a plano silt loam will need 19 mm of rainfall to recharge the top 10 cm of the soil (Soil Survey Staff 2007). An analysis of precipitation history from Arlington,

Wisconsin from 1971-2000, indicates that in the months of May and June, a precipitation event greater than 13 mm occurred an average of 2.3 and 2.5 days per month respectively (Midwest Regional Climate Center 2000-2007). This analysis suggests that the surface soil would rewet, permitting soybean germination relatively quickly after a late May/Early June planting.

g. **The effect of a rye cover crop on yield**: The use of a rye cover crop has variable effects on soybean yield. Rye has been found to increase, have no effect, and decrease yield in conventional soybean production systems. Soybean yields in Minnesota during a two-year study were comparable between treatments including and not including rye as a mowed cover, however economic returns were lower in the rye system due to the cost of the rye seed (De Bruin et al. 2005). Reddy et al. (2003), working in Mississippi, had similar findings in a study comparing soybean yield in treatments with a rye cover crop plowdown to no cover crop. Ruffo et al. (2004) in a study of different crop rotations in Illinois found no difference in yields between soybeans from the conventional corn-soybean rotation and other rotations which included rye cover crops. Singer and Kohler (2005) however, found that soybean yields were lowered in the plowed rye plots due to poorer soybean stands. On the other hand, Price et al. (2006) working in Alabama found that soybean yields were higher or equal in the rye treatments (killed with glyphosate and then roller-crimped) two years out of three compared to other cover crops and to no cover crop. During the three years studied, yield was 350%, 125%, and 0% higher than the soybean yield without a cover crop, and the increase was attributed to the decrease in weed competition, along with the soil quality benefits associated with conservation practices. Overall, rye affected soybean yield through its effect on weed biomass, by competing with the soybean crop, by depleting or conserving soil moisture, and by reducing soybean stand establishment.

The effect of agronomic practices on weed communities:

a. Effect of tillage: The greatest impact of tillage compared to no-tillage, is in the depth and distribution of weed seeds throughout the soil profile. Tillage will distribute weed seeds evenly throughout the soil, whereas weed seeds in a no-tillage system tend to accumulate near the soil surface, (Cardina et al. 2002). Cardina et al. (2002) in Northern Ohio found that conventional tillage favors weed species which prefer to be buried like sheperd's-purse (*Capsella bursa-pastoris* (L.) Medicus), broadleaf plantain (*Plantago major* L.), and annual bluegrass (*Poa annua* L.). On the other hand, species which die easily if left on the surface of the soil are reduced in no-tillage systems. No-tillage however, creates a niche for species that are more competitive on the surface of the soil, like common lambsquarters (*Chenopodium album* L.), yellow woodsorrel (*Oxalis stricta* L.), redroot pigweed (*Amaranthus retroflexus* L.), and giant foxtail (*Setaria faberi* L.), (Cardina et al. 2002). Mulugeta et al. (2001) in Wisconsin found that species richness was as much as two times greater in long term no-tillage plots than in short term no-tillage or tilled plots, and that species richness is influenced by the duration of no tillage.

b. Effect of herbicide use: Research from Finland (Hyvonen et al. 2003) has shown that the main affect of farming organically is that herbicide susceptible species like common lambsquarters accumulate in these low input systems. They also found that in organic

fields, there is greater species diversity because there are more weeds. Menalled et al. (2001) in Michigan studied a corn-soybean-wheat rotation under organic and conventional management and concluded that organic management favored perennials and dicot weed species, especially common lambsquarters, whereas farming with herbicides favored annual and monocot species. When analyzing the weed seedbank, Menalled et al. (2001) found that although the weed seedbank under organic management was greater than that under conventional management, the organic seedbank declined over the six years, whereas the conventional seedbank increased.

c. Effect of rye: Most of the research published on rye as a cover crop is from conventional systems, and compares plowed rye cover crops to not using a cover crop or to using herbicide for weed control. When compared to fallow, rye plow down reduced weed species density by 25-73%, (Reddy et al., 2003; Moonen and Barberi, 2003). Westgate et al. (2005) reported that the weed suppresion ability of rye increased with rye biomass at the time of killing. However, it has been reported that a rye cover crop did not provide adequate weed control where weed populations were high (De Bruin et al., 2005).

Some weed species are more susceptible to the rye than others, showing that rye has the potential to shift the weed community, (Reddy et al. 2003; Moonen and Barberi 2004). Singh et al. (2003) found that rye inhibited common lambsquarters, large crabgrass, and ragweed. Burgos and Talbert (2000) found that in culture dish bioassays, small-seeded weeds were more susceptible to aqueous extracts of BOA and DIBOA. Barnyardgrass (*Echinochloa crus-galli* L.), goosegrass (*Eleusine indica* L.), large crabgrass, and Palmer amaranth (*Amaranthus palmeri* S.) were also found to be susceptible. Similar results were found in plots with a rye cover crop in a 7-year field study in Italy of cover crop effects on weed seedbanks, (Moonen and Barberi, 2004).

In addition to the direct effect of rye on weed populations, the use of rye as a mulch may promote weed seed predation which can be a significant source of weed mortality, (Menalled et al. 2007). Weed seed predators include vertebrates such as mice and birds, as well as invertebrates such as crickets (families Gryllinae and Numobiinae) and carabid beetles, (Menalled et al. 2007; O'Rourke et al. 2006). Lundgren et al. (2006), compared the effect of intensity of crop rotation (vegetables versus row crops versus forage) used during transition to organic on granivorous invertebrate communities. They reported the highest density of granivores in the low intensity forage crop rotation. Menalled et al. (2007) studied carabid populations in no-till, organic and conventional fields. They found the highest number of weed seed predators in the no-till fields, and the greatest diversity of predators in both no-till and organic fields. They confirmed that both tillage and herbicides reduced carabid populations. Hartwig and Ammon (2002), in a study of cropping systems found that the number of ground beetles were highest in the rye cover crop system suggesting that this was due to reduced tillage and increased ground cover.

CONCLUSION

Weed control within organic grain production is a priority research theme. The development of a reduced tillage, high residue organic weed control system would help

reduce soil erosion and degradation and save farmers labor and fuel, while improving soil organic matter and water retention. A rye cover crop is a tool that might be able to fill that niche, but not without difficulties. In the upper Midwest it is difficult to fit rye into the already short growing season, difficult to effectively kill rye without using herbicide or tillage, and risky to use in a dry spring. The previous research shows mixed results as to the effect of rye on weeds, soil moisture and finally soybean yield. Future research however, on rye variety selection, rye killing techniques and soybean planting specifically for the upper mid-west would allow farmers to evaluate this system under best management practices. Rye remains a promising tool to use to control weeds in an organic grain rotation in the upper Midwest, but may or may not prove suitable as a reduced-tillage cover crop.

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Table 1. Effect of rye cover crop on weed pressure in soybean.

Authors	Year Published	Location	Treatments	Rye effect on weeds
Ashford & Reeves	2003	Alabama	C.C.: rye, black oat, wheat; Time of kill: flag-soft dough; Method of kill: herbicide vs. crimper	Increased biomass related to increased weed suppression
Moonen & Barberi	2004	Italy	CT vs. NT; N rate; C.C.: rye, subterranean clover, crimson clover	reduced seedbank density in CT; lowest species richness; lowest weed biomass
Price et al.	2006	Alabama	C.C.: black oat, rye, wheat; Herb: no, PRE, POST	In no herb plots, rye and black oat provided most weed control, greater than fallow
Reddy et al.	2003	Mississippi	C.C.: rye or crimson clover; Tillage: NT or CT; Herb: no, PRE, POST	Rye suppresses weeds 25-73%; Weed biomass lowest in rye plots
Westgate et al.	2005	Iowa	Method and growth stage of rye kill	Later kill and higher biomass led to lower weed densities
Wilkins & Bellinder	1996	New York	Stage of rye and wheat c.c. at mow-kill	rye biomass should be> 4000 kg/ha to suppress weeds

Table 2. Effect of rye cover crop on soybean yield.

Authors	Year Published	Location	Treatments	Rye effect on yield
Moonen & Barberi	2004	Italy	CT vs. NT; N rate; C.C.: rye, subterranean clover, crimson clover	lowest yield in rye plots
Price et al.	2006	Alabama	C.C.: black oat, rye, wheat; Herb: no, PRE, POST	In no herb plots, higher yields with rye c.c.than if fallow
Reddy et al.	2003	Mississippi	C.C.: rye or crimson clover; Tillage: NT or CT; Herb: no, PRE, POST	No effect
Ruffo et al.	2004	Illinois	Rotation: C/S, HV-C/R-S, R-C/R-S, HV+R-C/R-S; N rate	No effect
Singer & Kohler	2005	Iowa	Method and growth stage of rye kill	Lower yield in rye plots

EVALUATION OF SEED TREATMENTS FOR ORGANIC CORN: 2006

Janet Hedtcke, Bill Stangel, Gregg Sanford, John Hall

INTRODUCTION

In 2003, to comply with the National Organic Program (NOP) standards, we started using certified organic seed (untreated, non-GMO) for our organically managed systems on the WICST plots. In both organic systems (CS3 & CS5), the corn phase followed a plowdown legume, typically tilled the previous fall. Even with delayed planting we consistently had poor stands at emergence (refer to 'Addressing Organic Corn and Soybean Plant Populations in the WICST Trial' paper in this report). Not only did we suffer severe yield decline on these plots but we also had increased weed pressure resulting in increasing weed seedbank numbers.

The rule of thumb is that corn needs 110 GDD (base 50°F) from planting to emergence. Typically in southern WI, we get wet and cool weather in early to mid-May delaying corn emergence for 2-3 weeks and sometimes halting field operations all together. The long-term minimum soil temperature data at 2" depth at Arlington shows that mid-May is the average time when soil temperatures reach 50°F (Fig. 1) yet the variability over years is significant. From Fig.1, one can see that there are many years with minimum soil temperatures falling below 50°F even into late May. Most organic farmers don't consider planting corn until the third week of May to reduce their risk of cold soil, particularly if they are on soils less well drained than those at Arlington.

A common practice among organic farmers is to plant corn seed when soil temps have warmed to average of at least 50°F to allow for rapid germination and emergence (ideally emerging in less than one week). Delayed planting allows for early weed flushes to be managed with tillage while also allowing soil temperatures to warm. While delayed planting allows for improved weed control and reduces the risk of untreated seed loss (from insects and disease), it has been shown to negatively impact yields with each day beyond May 15 (Fig. 2). By missing early planting windows, farmers can miss timely planting and be forced to plant late, forcing them to switch hybrids, or change crops altogether. Unlike conventional corn that can be treated with tested fungicide and insecticide, these options are unavailable to the organic producer.

The objective of this trial was to evaluate seed treatments approved for organic corn production on their effect of stand density and yield and to determine if seed treatment is effective in early planting situations.

METHODS

In 2006, a trial was established at two locations in southern Wisconsin – Arlington and East Troy. At each location corn was planted at two dates – early and late May. The combined location-planting date gave us 4 environments to test the following seed treatments:

- Untreated
- Natural II ™
- T-22 Planter Box™
- Cinnamon oil (East Troy only)

Natural II has been tested in a number of locations in the upper Midwest with varying results (Delate et al., 2005, 2006 in IA; Vigue and Clayton, pers. comm. 2006 in IL; Albert Lea

Seedhouse in MN, 2005). T-22 planter box has been on the market for several years and is thought to be beneficial in warmer soils not excessively high in nitrate-N (Gries and Blackmer, 2002). Cinnamon oil has shown promise in laboratory experiments at Iowa State (Christian, pers comm. 2005). Details of each treatment are shown in Table 1.

The plots were laid out in a RCB design with 3-4 treatments/rep and 4 reps by planting date (Fig. 3). At both locations, field-sized equipment was used (6 row planter, cultivator, combine, all based on 30" spacing) so plots were large at approximately 0.10 a (15' x 300'). The corn hybrid used in the trial was Blue River 48F27, a 102-d maturity. Seeding rates were between 34,500 and 38,000 seeds/a across the environments. Plant density data was collected from the 4 inner rows (4 stations of 17'5" length; 1 station/row) in each plot. Yield was measured on all 6 rows with a weigh wagon. The agronomic information for each location is reported in Appendix 1 and 2.

RESULTS

Agronomic Performance. Due to the cold and wet conditions that prevailed in early May of 2006, the early-planted environments were under substantially unfavorable conditions. Figure 4 shows that it took nearly three weeks for the corn to emerge in the 'Arlington early' environment vs. just 5 days in the late environment. As a result, the stands across all treatments were poor with less than half of the seed planted emerging (Table 2). Seed corn maggot was observed at the Arlington location and was thought to be the main cause of the extremely low stand counts. It appears that Natural II provides some protection from cold, wet soils and perhaps has some insecticidal qualities as well. At both locations, Natural II had improved stands over the other treatments by 1.5-2x and higher yields by about 50 bu/a (Tables 2 and 3). In the later planting, there were less stand and yield differences observed at Arlington but at East Troy, Natural II had 30% higher yields than the other treatments (Tables 2 and 3). The cinnamon oil treatment may have damaged the seed or somehow contributed to seed death (dessication, pest attractant?) as it performed worse than the untreated check (Tables 2 and 3). T-22 planter box was inconsistent across environments.

The earlier planted corn due to relatively poor corn stands allowed in-row weeds to emerge and all treatments had heavy weed populations (general observation). In addition to affecting yield, these weeds added to the weed seedbank, potentially affecting following crops in the rotation.

Economics. With a market price of $5 for each bushel of organic feed corn, an additional 1-2 bushels is all that is need to get a return on the investment of these seed treatments. Natural II seed treatment gave a clear advantage over all the other treatments but T-22 paid for itself in the early planting at the East Troy location.

SUMMARY

Early and late planting dates represented dates to capture weather variability in a typical May -- 17 days to emergence in early planting (May 5) and only 5 days to emergence in late planting (May 23). The early planting at each location had poor stands across treatments but the Natural II was 1.5-2x higher than the others and was the highest yielding in the early planting environments. Due to the warm conditions for the late planting, there was no treatment effect

observed at Arlington but Natural II yielded best at East Troy in the late planting. At a nominal fee, some seed treatments are worth the cost if only for insurance.

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Fig. 1.

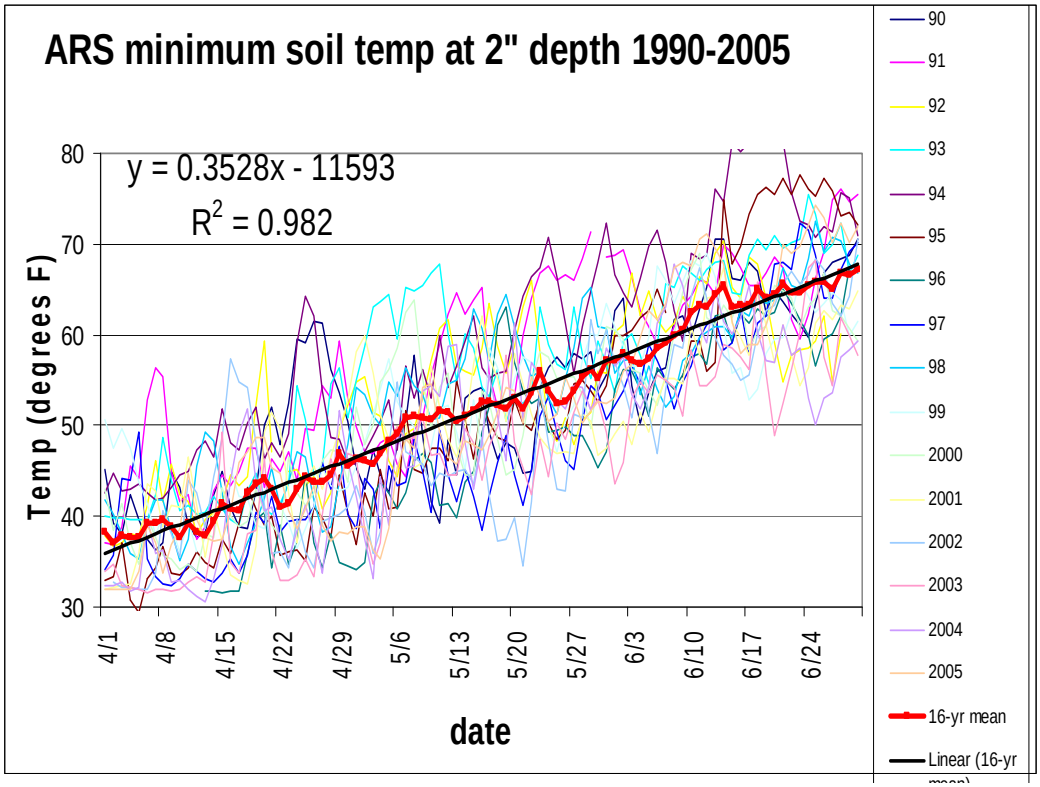
ARS minimum soil temp at 2" depth 1990-2005
y = 0.3528x - 11593
R2 = 0.982
Temp (degrees F)
80
70
60
50
40
30
4/1
4/8
4/15
4/22
4/29
5/6
5/13
5/20
5/27
6/3
6/10
6/17
6/24
date
90
91
92
93
94
95
96
97
98
99
2000
2001
2002
2003
2004
2005
16-yr mean
Linear (16-yr

Fig. 2

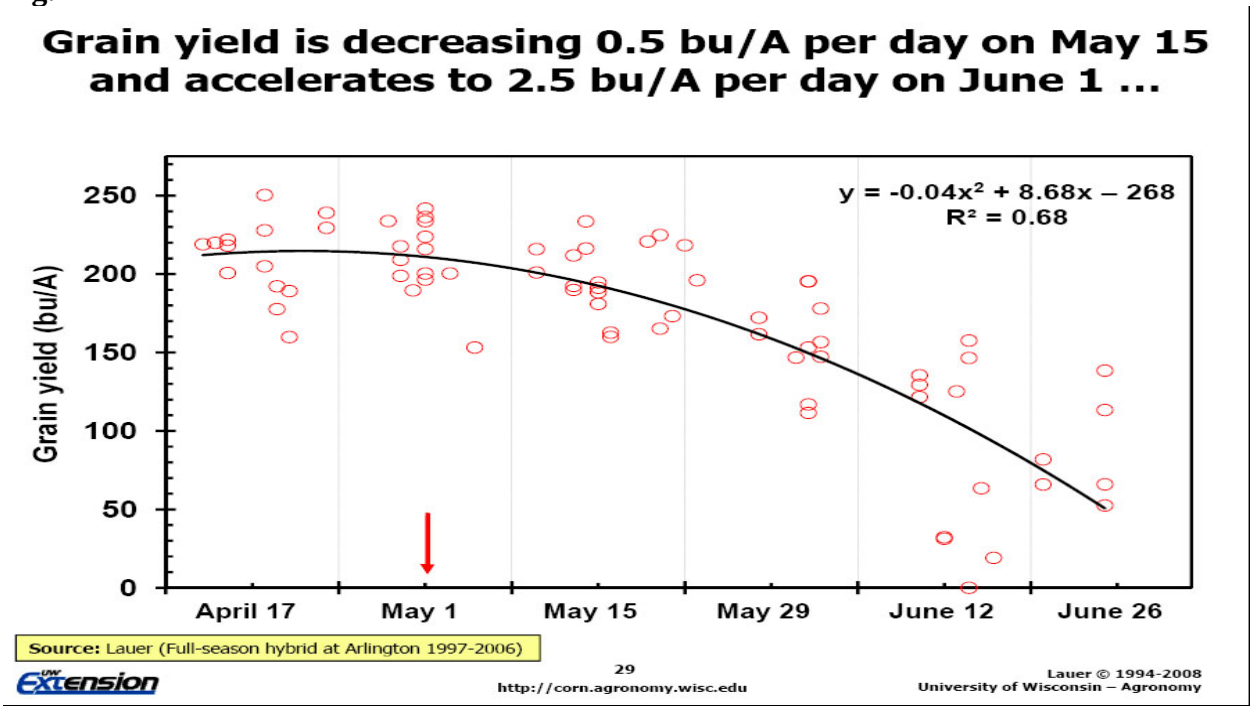
Grain yield is decreasing 0.5 bu/A per day on May 15 and accelerates to 2.5 bu/A per day on June 1 ...
y = -0.04x² + 8.68x – 268
R² = 0.68
Grain yield (bu/A)
250
200
150
100
50
0
April 17
May 1
May 15
May 29
June 12
June 26
Source: Lauer (Full-season hybrid at Arlington 1997-2006)
UW Extension
29
http://corn.agronomy.wisc.edu
Lauer © 1994-2008
University of Wisconsin – Agronomy

Table 1. Treatment descriptions and costs					
Treatment	**Supplier**	**Coat ingredient**	**Method of application**	**Application rate**	**$ / 80,000 kernels**
Control	--	untreated	--	--	--
Natural II ™	AgriCoat LLC.	*Actinomyces spp.* etc…	Seed film coating	Pre-treated 3oz / 80,000 kernels	$12.00 (~$6/a)
T-22 ™	Bioworks Inc.	*Trichoderma harzianum*	Planter box	2oz / 80,000 kernels	$11.40 (~$5.70/a)
Cinnamon Oil	USDA ARS: Iowa State	*Cinnamomum zeylanicum* Oil	Planter box	5 oz / 80,000 kernels	$3.31 (~$1.65/a)

Fig. 3. Visual of the field layout of the RCB design at Arlington

EARLY PLANTING DATE	LATE PLANTING DATE
REP 1	REP 1
REP 2	REP 2
REP 3	REP 3
REP 4	REP 4

Fig 4.

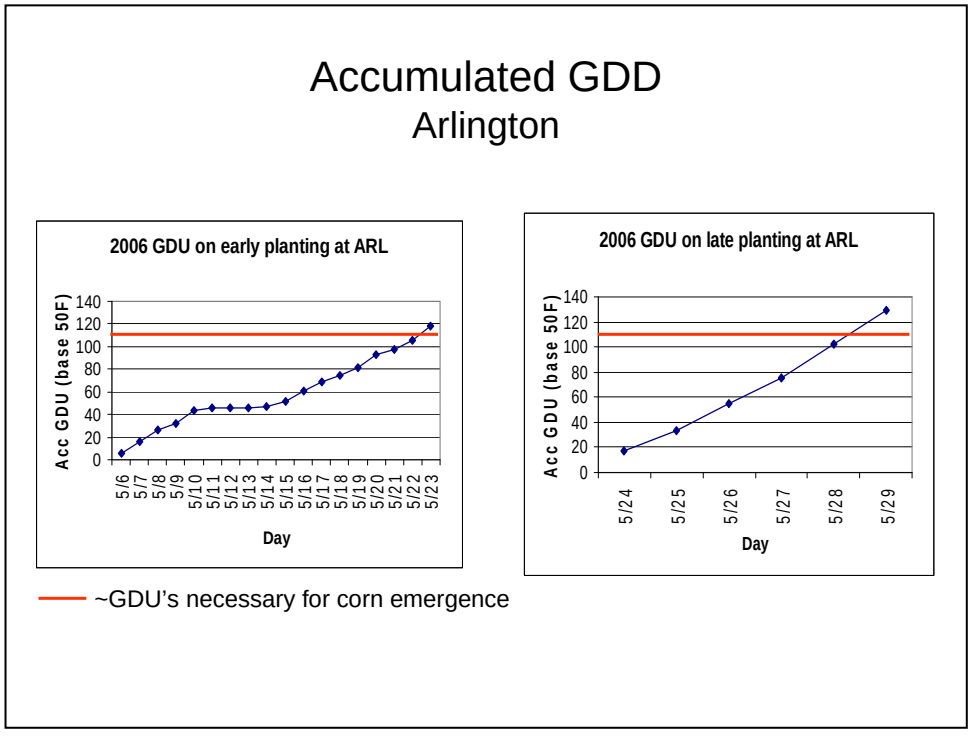

Table 2. Corn stand density in four environments in 2006.				
	Arlington		East Troy	
	Planting date			
Treatment	Early	Late	Early	Late
	----------Plants/acre at V5 stage----------			
Untreated check	8,930b	30,601a	16,625c	28,677
Natural II™	15,754a	29,330a	28,496a	29,076
T-22 Planter Box™	8,131b	27,152b	18,912b	27,987
Cinnamon oil	n/a	n/a	11,507d	25,918
p-value	*0.0001*	*0.0092*	*<0.0001*	*<0.1204*

Table 3. Corn yield in four environments in 2006				
	Arlington		East Troy	
	Planting date			
Treatment	Early	Late	Early	Late
	----------bu/a----------			
Untreated check	125.6b	173.4	97.7c	98.5b
Natural II™	168.8a	179.1	149.3a	146.4a
T-22 Planter Box™	114.1b	180.0	117.6b	100.9b
Cinnamon oil	n/a	n/a	92.9c	102.6b
p-value	*<0.0002*	*0.6308*	*<0.0001*	*<0.0001*

Appendix 1. Agronomic calendar for the Arlington site, 2006		
Previous crop	Alfalfa	
Fall '05 practices	Manured (6,000 gal/a) October 11, 2005 (surface applied)	
Area of field	Early planting (North ½ of field)	Late planting (South ½ of field)
Spring '06 Practices	Chisel w/sweeps and prepared seedbed on April 27th, disked April 27th, soil finished May 4th	
Variety **Date** **Rate**	Blue River BR48F37 May 5, 2006 34,500 seed/a	Blue River BR48F37 May 23, 2006 38,000 seed/a
Rotary Hoe	5-13-06, 5-23-06	5-31-06, 6-3-06
Tine Weed	Tried 5-20-06, pulled out	None
Cultivation	5-26-06, 6-20-06	6-20-06 (disk hiller)
Scout/data	Took aerial photos, stand counts and yield comparisons	
Harvest	October 9, 2006	
Fall Practices	No fall tillage due to slope length and channels in field	

Appendix 2. Agronomic calendar for the East Troy site, 2006		
Previous crop	Wheat	
Area of field	Early planting (North ½ of field)	Late planting (South ½ of field)
Spring '06 Practices	Manured (poultry manure) May 4, 2006 at 3 tons/a (box spreader); Mulchmaster 3x to incorporate wheat and manure; field cultivator May 8 and May 23 for seedbed preparation	
Variety **Date** **Rate**	Blue River BR48F37 May 8, 2006 35,600 seed/a	Blue River BR48F37 May 23, 2006 35,600 seed/a
Rotary Hoe	None	None
Tine Weed	5-25-06, 6-3-06	6-3-06
Cultivation	1x	1x
Scout/data	soil erosion in late May, heavy weed pressure, stand counts and yield comparisons	
Harvest	November 8, 2006	
Fall Practices	No fall tillage	

FLAME WEEDING CORN ON THE WICST PLOTS

Janet Hedtcke, Gregg Sanford, Bill Stangel, John Hall

INTRODUCTION

Good weed control is crucial in organic systems. However, erosion is a concern with the high tillage intensity inherent to organic row crop production. It's also known that tillage and cultivation can bring up buried weed seed and stimulate weed seed germination. A lower disturbance option for controlling weeds is to combine mechanical weed control with flame weeding with propane. This remains a relatively new option in organic corn production in Wisconsin and the consequences on yield have not been well documented. The purpose of this study was to determine the effect on weeds and corn yield from flaming at various stages of corn growth.

METHODS

2006. *Trial I.* The study was superimposed on the organic grain system of WICST (CS3: corn-soybean-wheat) at the Arlington Research Station in the spring of 2006. Plots were 15' (6 corn rows) x 170'. A 2-row flamer with four burners (2 per row) positioned directly over the row about 7" above ground level passed over the corn at 5 mph. Three treatments randomized and replicated 4x were applied to organic corn in early June: 1) Control (no flaming); 2) Flaming at V1 (one leaf collar visible) and V3 (3 leaf collars visible); 3) Flaming at V1/cultivating at V3. All treatments received the normal mechanical weed control passes (1 rotary hoe, 1 tine weeding and 2 row cultivations except the 2-time flaming treatment which had one less cultivation).

2007. *Trial II.* In 2007 we investigated the impact of flame weeding corn in both organic systems on WICST – CS3 (described above) and CS5 (corn-oats/alfalfa-alfalfa). The main difference between the two systems was the weed community. The organic grain system was dominated by annual grass weeds (mostly giant and yellow foxtail) while CS5 had a high component of quackgrass. Both systems had similar annual broadleaf pressure. In contrast to 2006, we did not flame at V1 (due to time constraints) but flamed at V3 of corn development (~ mid-June) and instead of burning directly on the row as in 2006, the four burners were angled towards the base of the two corn rows in 2007. Speed was again 5 mph. This was compared to a no flaming treatment. In CS5 plot sizes were 15' x 510' with treatments randomized to the east vs. west edge of the main plot across 4 reps; and in CS3 plot sizes were 15' x 30' (plot length was shorter than CS5 due to other trials in place on this system) and were stacked on the west edge of the 4 reps. Aside from the treatments in this year, all plots received 2 (CS5) or 3 (CS3) rotary hoeings, 1 tine weeding and 1 (flamed) or 2 (non-flamed) row cultivations.

In-row weeds were counted in 3-ft lengths in 2006 and 5-ft lengths in 2007 in 3 different areas of each plot in mid-July. Stand data was collected from each plot and corn yield was measured in late October.

RESULTS

2006. *Trial I.* Immediately after the first flaming, the corn leaves wilted but recovered quickly. Flaming at V3 was more severe on the corn as recovery took longer and the

corn remained shorter than the other treatments for most the season. Plants per acre were not different between treatments but the average stand was poor at only14,000 plants/acre (goal is 30,000 plants/acre for maximum yield). 2x-flaming reduced grass weeds compared to the other treatments but broadleaf control was variable. Yields were greatly impacted by the 2x-flaming with yield loss of 28 bu/a compared to the control. Flaming 1x had equal yields and similar weed pressure as the no-flame control.

2007. *Trial II.* Stands were much better in 2007 due to a warm dry spring which allowed for quick corn emergence. There were no differences in stand density between the flamed and control treatments (35,000 plants/acre) even though the flamed corn looked rough after the flaming. Because we missed our V1 flaming, the weeds were much larger at the V3 flaming but broadleaf weeds were reduced at alpha=0.10 level with flaming. This was probably due to the height of the burner which was at about 4" from the ground and closer to the growing point of the broadleaf weeds.

Michigan State conducted a study with flame weeding V3 corn and at or just before soybeans emergence (Taylor-Hill et al 2008 poster at UMOFC in La Crosse). In corn they found that flaming (weeds 0.25-to-2") was not as effective at reducing weeds as the rotary hoe. In soybeans, they reported that flaming weeds <0.25" followed by a rotary hoeing was most effective/economical compared to either flaming or rotary hoeing alone. Crop yield was not reported.

Table 1. Trial 1: Effect of flaming over row on corn yield and weed pressure in 2006.

		Weeds	
Treatment	Corn yield	Grass	Broadleaf
	Bu/a	----------# plants/3 ft of row----------	
Control	151.7a	21.7a	12.6b
Flame 2x (V1, V3)	123.9b	4.7b	11.7b
Flame 1x (V1)	145.5a	11.4a	21.8a
p-value	*0.1156*	*0.0008*	*0.0921*

Columns with different letters are statistically different at alpha=0.10.

Table 2. Trial II. Effect of flaming at base of corn in 2 organic systems in 2007.

		Weeds	
Treatment	Corn yield	Grass	Broadleaf
	Bu/a	----------# plants/5 ft of row----------	
CS3 corn			
Control	158.7	38.8	4.2
Flame 1x at V3	159.9	37.5	2.6
p-value	*0.8031*	*0.8912*	*0.0951*
CS5 corn			
Control	193.4	n/a	n/a
Flame 1x at V3	196.1	n/a	n/a
p-value	0.1842		

n/a = not available

DISCUSSION

Flaming directly over the row at V1 and V3 reduced grass weed pressure but severely affected corn yields while flaming only at V1 was not especially effective on broadleaf weeds. Combining information from both trials (2006 and 2007), it appears that a first flaming over the row at V1 would be recommended for early weed control followed by flaming at V3 with burners angled at base of corn so not to burn off all the corn leaves. Our data also suggests that this second pass with the flamer could replace a cultivation. We currently see three components to continuing research in this area:

1. To insure we are getting the best use from flaming, we need to address combined burner orientation (over row, at base of corn), burner height, flaming speed, and BTU intensity for good weed control.
2. We need to measure how we can use flame weeding to reduce mechanical weed control while maintaining good yields.
3. We need to look at the economics of flaming vs. mechanical weed control

Flaming could replace the rotary hoe or tine weeder early when the corn is vulnerable to mechanical tillage or when field conditions are too wet for mechanical operations. Flame weeding would have the advantage of not disturbing the soil and may reduce weed flushes typically seen with tillage operations. It may also be a tool to suppress quackgrass that tillage can sometimes hasten.

APPENDIX

Appendix I. 2005 Agronomic Calendar for WICST (Fld 440)

ARLINGTON RESEARCH STATION

Corn rotations					
CROP-2005 Rotation Treatment #	**CORN CS1 + prairie 1**	**CORN CS2 3**	**CORN CS3 6**	**CORN CS4 7**	**CORN CS5 12**
Plot #'s	109,204,306,412, 501,504,508	101,214,303,401	102,212,313,407	111,209,305,409	103,213,314,410
Primary Tillage	Chisel plow 11-16-04	None	Chisel plow w-sweeps 11-16-04	Chisel plow 11-16-04	Chisel plow w-sweeps 11-16-04
Secondary Tillage	Field cultivator 2x 4-28-05	None	Field cultivate 2x 4-28-05	Field cultivator 2x 4-28-05	Field cultivate 2x 4-28-05
Variety Planting Date Rate	Growmk FS4453 4-29-05 32,000 seeds/a (has Poncho 250 seed trt)	Growmk FS4453 4-29-05 32,000 seeds/a (has Poncho 250 seed trt)	NC+ 42A32 5-18-05 34,500 seeds/a	Growmk FS4453 4-29-05 32,000 seeds/a (has Poncho 250 seed trt)	NC+ 42A32 5-18-05 34,500 seeds/a
Starter Fertilizer	100 lb 5-14-42	100 lb 5-14-42	None	100 lb 5-14-42	None
Fertilizer	120 lb N/a (28%) based on PSNT	113 lb N/a (28%) based on PSNT	102 & 313 = 200 lb/a K_2SO_4 5-3-05	None	213 & 410 = 200 lb/a & 103 & 314 =400 lb/a K_2SO_4 on 5-3-05
Manure	None	None	None	20 ton-a 11-16-04	15 ton-a 11-16-04
Pesticides-Herbicides	Pre-emerge: Force 3G (4.4 lb/a) 5-5-05 Dual II Magnum (1.5 pt/a) Post-emerge: 6-8-05 Buctril (1.14 pt/a)	Prozap zinc phosp. in furrow (6 lb/a); Pre-emerge 5-5-05: Roundup WMax (13 oz/a) burndown; Dual II Magnum (1.3 pt/a) + AMS; Post-emerge: 6-8-05 Buctril (1.14 pt/a) 6-17-05 Distinct (4.0 oz/a) +AMS, NIS	None	Pre-emerge: 5-5-05 Dual II Magnum (1.5 pt/a) Post-emerge: 6-8-05 Buctril (1.14 pt/a)	None
Rotary Hoe-tine weed	None	None	RH: 5-10, 5-18, 5-24 TW: 6-2, 6-8 2x	None	RH: 5-10, 5-18, 5-24 TW: 6-2, 6-8 2x
Cultivation	None	None	6-14, 6-24 (2x)	None	6-14, 6-24 (2x)
Harvest & Yield	10-19-05 197.3 bu/a	10-19-05 210.2 bu/a	10-19-05 102.2 bu/a	10-19-05 231.4 bu/a	10-19-05 128.3 bu/a
Fall Practices	Chop stalks Chisel plow with twisted shank 11-14-05	11-14-05 100 lb/a 0-0-60 on 101 & 401	Chop stalks Moldboard plow 11-15-05	Chop stalks Manure 9000 gal-a 11-10-05, Chisel plow with twisted shank 11-14-05	Chop stalks Manure 9000 gal-a 11-10-05, Moldboard plow 11-15-05
Crop 2006	**Corn**	**Soybean**	**Soybean**	**D.S. Alfalfa**	**Oats-Alfalfa**

Appendix I (cont'd). 2005 Agronomic Calendar for WICST (Fld 440)

Soybean and Wheat Rotations			
CROP-2005 Rotation Treatment #	**NR Soybean CS2 2**	**WR Soybean-Wheat CS3 5**	**Wheat-Red Clover CS3 4**
Plot #'s	108, 206, 310, 408	106, 202, 307, 411	104, 201, 301, 402
Primary Tillage	None	Chisel plow 11-16-04	Field cultivator 1x 10-6-04
Secondary Tillage	None	Field cultivator (2x) April 28 then rotary hoe 5-10 and 5-18	None
Planting Date	5-10-05	SB: 5-18-05 WW: 10-4-05	WW: 10-6-04 Red clover: 4-9-05 with NT drill Berseem clover-oats: 8-17-05, NT drill
Variety Rate	'Cropland RT 2089' 225,000 seeds/a (2675 sd/lb)	Sb: 'IA 1008' (food grade) 170,000 seeds/a (2550 sd/lb) WW: 150 lb/a ('Arapahoe' Hard Red)	'Patriot' Hard Red: 180 lb/a 'Arlington' red clover: 12 lb/a Berseem-oats: l0 and 140 lb/a
Fertilizer	None	None	None
Pesticides-Herbicides	Post-emerg: 5-16-05 Roundup-WMax (13 oz/a); Synchrony (0.25 oz/a) + AMS & Crop oil; 6-17-05 Roundup-Wmax (22 oz/a); Pursuit DG (0.72 oz/a) + Speedway; 7-29-05 Warrior (2.5 oz/a); Lorsban 4E (12 oz/a)	None	None
Rotary Hoe-tine weed	None	RH: 5-24 TW: 6-2 (2x), 6-8 (2x)	None
Cultivation	None	6-14-05	None
Harvest & Yield	10-4-05 59.0 bu/a	10-4-05 24.6 bu/a	Wheat: 7-13-05 49.8 bu/a Straw: 7-15-05 0.65 ton dm-a
Fall Practices	None	Field cultivator 1x to prep for wheat planting Planted wheat 10-5-05	After wheat harvest, dug quack with field cultivator (2x each date) on 7-28, 8-1, 8-17. Planted berseem-oats 8-17-05 No fall tillage-spring chisel
Crop 2006	**Corn**	**Wheat - Red Clover**	**Corn**

Appendix I (cont'd). 2005 Agronomic Calendar for WICST (Fld 440)

Forage rotations						
CROP-2005 Rotation Treatment #	**D.S. Alfalfa CS4 10**	**Estab. Alfalfa I CS4 9**	**Estab. Alfalfa II CS4 8**	**Oats-Alfalfa CS5 11**	**Estab. Alfalfa I CS5 13**	**Pasture CS6 14**
Plot #'s	107, 205, 309,404	105, 203, 308,406	113, 210, 311,414	110, 208, 304,413	114, 211, 312, 403	112, 207, 302, 405
Primary Tillage	Chisel plow 11-16-04	None	None	Chisel plow 11-16-04	None	None
Secondary Tillage	Soil Finisher 2x 4-14-05	None	None	Soil Finisher 2x 4-14-05	None	None
Variety Planting Date	'Magnum V' 4-14-05	-	-	'Magnum V' alf, 'Forage +' oats, trapper peas 4-14-05	-	'Arlington' Red clover & annual ryegr fenceline* 4-9-05
Rate	12 lb/a			Alf - 12 lb/a oats 50 lb/a Peas – 50 lb/a		12 lb/a
Fertilizer	None	6-6-05 200 lb/a 0-0-50	6-6-05 200-400 lb/a 0-0-50	6-6-05 (110, 413) 400 lb/a 0-0-50	6-6-05 (not 211) 360 lb/a 0-0-50	None
Manure	20 ton-a 11-11-04	None	None	15 ton-a 11-11-04	None	Grazing to Nov 1st
Pesticides-Herbicides	**Herbicide** Post-emerge: 6-10-05 Raptor (4 oz/a) + NIS & AMS **Insecticide** 6-10-05 Warrior (2.25 oz.a)	**Insecticide** 7-14-05 Warrior 2.56 oz/a	**Insecticide** 7-14-05 Warrior (2.56 oz/a) **Herbicide** 10-29-05 2,4-D (16oz/a); Express XP (0.125 oz/a); Glystar Plus (39 oz/a), Citron + NIS	None	None	Spot sprayed thistles (stinger 0.25 fl oz-gal water)
Harvest & Yield (Ton DM-a)	7-8-05= 0.28 8-17-05=1.36 Total = 1.64	6-2-05= 1.59 7-8-05= 1.42 8-17-05=1.07 10-18-05=0.55 total = 4.63	6-2-05 = 1.03 7-8-05 = 0.75 8-17-05 =0.90 10-18-05=0.42 total = 3.11	Oatlage: 7-12-05 =3.02 total = 3.02	6-2-05 = 1.65 7-8-05 = 0.85 8-17-05 =0.93 10-18-05=0.45 total = 3.88	5-23-05 =0.96 6-28-05 =0.54 8-19-05 =1.11 total = 2.61
Fall Practices	None	None	Manured 6000 gal-a 11-10-05, Chisel plow with twisted shank 11-14-05	Seeding failed; Dug quack 2x on 7-28,8-1,8-17. Reseeded untrt WL346 LHR 8-17	Manured 6000 gal-a 11-10-05, Moldboard plow 11-15-05	Clipped
Crop 2006	**Alf I**	**Alf II**	**Corn**	**Alf I**	**Corn**	**Pasture**

***seed ryegrass @ 15 lb/a along fenceline where water cup-tub is located. Just one pass (5' width) with drill.**

Appendix I (cont'd). 2005 Agronomic Calendar for WICST (Fld 440), cont'd

Satellite – Chemlite plots			
CROP-2005 Rotation Treatment #	**Corn (cs3 w-chemical inputs)**	**WR Soybean-Wheat (cs3 w-chemical inputs)**	**Wheat-Red Clover (cs3 w-chemical inputs)**
Plot #'s	SAT B, F	SAT A, E	SAT C, D
Primary Tillage	Chisel plow w-sweeps 11-16-04	Chisel plow 11-16-04	Field cultivator 1x 10-6-04
Secondary Tillage	Field cultivator 2x 4-28-05	Field cultivator 2x 4-28-05	None
Planting Date	5-3-05	SB: 5-18-05 WW: 10-5-05	WW: 10-7-04 Red clover: 4-9-05 Berseem clover: 8-5-05 (used no-till drill)
Variety Rate	Growmk FS4453 32,000 seeds/a (has Poncho 250 seed trt)	SB: Dairyland DSR-184-RR 170,000 seeds/a (3075 sd/lb) WW: Pioneer 25R47 180 lb/a	Pioneer 25R37: 180 lb/a Arlington red clover: 12 lb/a Berseem clover: 10 lb/a
Fertilizer	100 lb starter (5-14-42) 80 lbs N-a (28% sidedress)	None	4-11-05 110 lb N-a
Pesticides-Herbicides	Full rate banded over row Pre emrg -1 pass: 5-12-05 Camix (callisto+Dual) (1.2 qt/a); Princep (0.5 pt/a)	Broadcast at half rate Post ermg: 7-15-05 Roundup Wmax (22 oz/a) + Speedway; 7-29-05 Warrior (2.5 oz/a); Lorsban 4E (12 oz/a); 9-6-05 Poast Plus (24 oz/a) + Crop oil & AMS	None
Rotary Hoe	None	5-10-05	None
Cultivation	6-9-05, 6-14-05	6-9-05, 6-14-05, 6-22-05	None
Harvest & Yield	10-19-05 201.5 bu/a	10-4-05 54.4 bu/a	Wheat: 7-14-05 79.3 bu/a Straw: 7-15-05 1.18 T dm-a
Fall Practices	Chop stalks Chisel plow with twisted shank 11-14-05	Field cultivator Planted wheat 10-5-05	After wheat harvest, plowed up red clover (by mistake); FC 2x on 7-28, 8-3 and replanted berseem 8-5; no fall tillage
Crop 2006	**WR Soybeans**	**Wheat - Red Clover**	**Corn**

Appendix II. 2005 Agronomic Calendar on the Organic Grain Plots (Arl 403)

Crop 2005	ALFALFA/ ORCHARDGRASS	WINTER WHEAT & OATS	CORN	SOYBEANS
Strip #	1	2	3	4
Plot	A, B	C (wheat), D (oats)	E, F	G, H
STK '04 (ppm)	98, 100	78, 104	107, 129	108, 125
Primary Tillage	NONE	C: disked 10-11-04 D: field cultv 4-14-05	Chiseled w/sweeps, then planted oat cover crop 9-22-04	Chisel plow w/sweeps 12-1-04
Secondary Tillage	NONE	C: Cultimulcher 10-12-04	Field digger 2x 5-2-05, rotary hoe: 5-10, 5-18	Field digger 2x, 5-2-05 Rotary hoe: 5-10, 5-18
Variety **Plant Date** **Rate**	8-18-04 8 lb/a 'Hardy' alf, 4 lb/a 'Potomoc' grass	'Patriot' HR winter wheat in plot C (IH drill) 10-16-04 at 180 lb/a; 'Esker' oats plot D at 96 lb/a on 4-15-05	NC+ 42A32 5-18-05 34,500 sd/a 1.5" deep	Sb: IA 1008 (food grade) 5-18-05 175,000 sd/a 1.25" deep
Manure	NONE	NONE	NONE	NONE
Rotary Hoe/ **Tine Weed**	NONE	NONE	RH: 5-24-05; TW: 6-2-05, 6-5-05	RH: 5-24-05; TW: 6-2-05, 6-5-05
Cultivation	NONE	NONE	6-9-05, 6-20-05, 6-27-05	6-9-05, 6-20-05, 6-27-05
Handweed/ **scout**	Note: Shepherd's purse prevalent last fall in new alf/grass seeding; winterkill on south end of plot B -- reseeded	NONE; vol. winter rye throughout plot	6-23-05 to 7-13-05: 14.5 man hrs/a	6-23-05 to 7-15-05: 75 man hr/a (30 hrs on 6-29 alone)
Plant Popln.	N/a	D: 100,800 plants/acre	F: 27,167 plants/acre	H: 116,200 plant/acre
Harvest	6-02-05: 1.64 t dm/a 7-08-05: 0.92 t dm/a 8-25-05: 0.93 t dm/a	D: 7-27-05: 112 bu/a (after cleanout); 74 bu/a (wheat var trial mean) 0.75 t dm/a oat straw	11-3-05: 181.5 bu/a	10-4-05: 64.1 bu/a
Market	RFV = 147-185; Protein: 19-22% $140/ton	Food-grade wheat: $4.50/bu; 62 lb/bu; Oats: 4% cleanout; protein: 14.5%, TW=32.5 lb/bu	Feed-grade Protein: 9.5% $5/bu	Feed-grade Protein: 40%; 6% splits, 3% smalls (Delong). $12/bu
Fall Soil test 0-6" on 11-3-05 **STP** **STK**	 73, 50 74, 70	 64, 87 71, 69	 61, 64 78, 61	 70, 117 83, 131
Fall Practices	None: Chisel w/sweeps in spring '06	Field digger 2x; Plant 'Viking 357' alfalfa/'Calibra' per. ryegrass mix 8-17-05	None: Chisel in spring '06	Plant 'Arapahoe' HR winter wheat 10-5-05 @ 140 lb/a
Crop 2006	CORN	ALFALFA/ PER. RYEGRASS	SOYBEANS	WINTER WHEAT

Alleys seeded to winter rye in September '05 with no-till drill

Appendix III. 2005 Agronomic Calendar on the Organic Grain Production Plots (MFAI)

CROP-2005	CORN	ALFALFA/ ORCHARDGRASS	SOYBEANS	WINTER WHEAT or OATS
Strip #	1	2	3	4
Plot	A, B*	C,D	E*, F	G, H*
STK '04 (ppm)	176, 114	153, 123	87, 77	50, 60
Primary Tillage	JD 726 Mulch finisher (2 passes) 4-26-05	Chisel plow 9-2-04	JD 726 Mulch finisher (2 passes) 5-5-05	JD 726 Mulch finisher 10-13-04
Secondary Tillage	Mulch finisher 5-16-05	Field cultivator 9-7-04 Cultipacker 9-8-04	Mulch finisher 5-23-05	Mulch finisher 2nd pass 10-14-04
Variety Plant Date Rate	NC+48F37 5-16-05 31,000 seeds/a	'Hardy' Alf, 'Elsie' Og 9-8-04 15lbs/a alf & 4lbs OG no-till drilled same mix on 4-3-05	Vinton 81 5-23-05 170,000 seeds/a	HRW Patriot Wheat 10-14-04
Manure Rate & Date	18 ton/a 4-26-05	16 ton/a 9-2-04	None	None
Rotary Hoe/ Tine weed	RH 5-23-05 RH 5-27-05 TW 6-8-05	None	RH 5-27-05 RH 6-2-05 TW 6-8-05	None
Cultivation	6-14-05	None	6-14-05	None
Handweed/ Scout – man-hr/a	None	None	Yes Aprox. 2hr/a	None
Plant popln.	19,750	N/a	256,400	N/a
Harvest date & yield	10-28-05 158 bu/a at 18% moisture	5-27-05 6-30-05 8-12-05 10-24-05	10-4-05 28 bu/a	7-18-05 62 bu/a
Market	$5.25/bu field harvest (uncleaned) at 18% moisture	went to neighboring dairy	$14/bu field harvest (uncleaned)	$8/bu cleaned and bagged and delivered; 13-14% moisture
Soil test 0-6" on 11-18-05 **PH:** **STP** **STK**	 6.4, 6.1 120, 107 196, 173	 5.8, 5.7 81, 61 83, 103	 5.7, 6.0 38, 59 88, 96	 6.4, 6.1 47, 40 83, 83
Fall Practices	Chisel plowed 11-2-05	Undercut with chisel plow with sweeps on 11-23-05	JD 726 Mulch finisher (2 passes) and planted to Winter Rye on 10-24-05	Spread manure- 14t/a - 8-12-05, JD 726 Mulch finisher, planted 'Viking 357' alfalfa/'Calibra' per. ryegrass (12&4lbs) 8-15-05
Crop 2006	SOYBEANS	CORN	WINTER RYE	ALFALFA/ PER. RYEGRASS

* variety trials in B, E, H

Appendix IV. 2006 Agronomic Calendar for WICST (Fld 440)

ARLINGTON RESEARCH STATION

Corn rotations					
CROP-2006 Rotation Treatment #	**CORN CS1 + prairie 1**	**CORN CS2 2**	**CORN CS3 4**	**CORN CS4 8**	**CORN CS5 13**
Plot #'s	109,204,306,412, 501,504,508	108,206*,310,408	104,201,301,402	113,210,311,414	114,211,312,403
Primary Tillage	Fall chisel plow 11-14-05	None	Spring chisel plow 4-27-06	Fall chisel plow 11-14-05	Fall MB plow 11-15-05
Secondary Tillage	Field cultivator 4-27-06	None	Field cultivator 5-4-06, 5-22-06	Field cultivator 4-27-06	Field cultivator 5-4-06, 5-22-06
Variety Planting Date Rate	Dekalb 5878 Bt 4-28-06 34,000 s/a	Dekalb 5878 Bt 4-28-06 34,000 s/a	Viking 5305 (NII) 5-23-06 38,000 s/a	Dekalb 5878 Bt 4-28-06 34,000 s/a	Viking 5305 (NII) 5-23-06 38,000 s/a
Starter Fertilizer	100 lb/a 5-14-42	100 lb/a 5-14-42	120 lb/a 0-0-50 in starter box	100 lb/a 5-14-42	None
Fertilizer	140 lb N/a (28%) per PSNT 6-15-06	120 lb N/a (28%) per PSNT 6-15-06	None	None	None
Manure	None	None	None	6000 gal/a 11-10-05	6000 gal/a 11-10-05
Pesticides	Force 4.4 lb/a in planter 4-29-06 tank mix: Dual II Magnum (24 oz/a), Hornet WDG (4 oz/a)	4-29-06 tank mix: Dual II Magnum (24 oz/a), Hornet WDG (4 oz/a), Mirage + (30 oz/a); spot sprayed 206*	None	4-29-06 tank mix: Dual II Magnum (24 oz/a), Hornet WDG (4 oz/a)	None
Rotary Hoe/tine weed	None	None	RH: 5-31-06 TW: 6-7-06	None	RH: 5-31-06 TW: 6-7-06
Cultivation	None	None	6-13-06 ('Wil-rich') 6-23-06 (disk hiller)	None	6-13-06 ('Wil-rich') 6-23-06 (disk hiller)
Hand weed	No	No	2 man-hr/a (7/6/06)	No	2 man-hr/a (7/7/06)
Harvest & Yield	10-24-06 192.7 bu/a	10-24-06 190.6 bu/a	10-24-06 144.8 bu/a	10-24-06 217.7 bu/a	10-24-06 189.0 bu/a
Fall Practices	Chop stalks 10-27 chisel plow 11-30	none	Chop stalks 10-27 MB plow 11-26	Chop stalks 10-27, 12,000 gpa manure 11-24, chisel plow 11-30	Chop stalks 10-27 8,000 gpa Manure 11-24, chisel plow 11-30
Crop 2007	**Corn**	**Soybean**	**Soybean**	**D.S. Alfalfa**	**Oats/Alfalfa**

* due to missing corn from ground squirrels, plot 206 was replanted 6/16/06 and spot sprayed on 6/23/06 with Distinct (4 oz/a), Accent ST (0.5 oz/a), NIS (1 qt/100), AMS (3 lb/a). Stand did not recover so plot data was omitted. Plot 211 cultivated on 6-9-06 for quack control in low area at center of plot.

MISC:

N/S Alleys: Spray in spring; till throughout summer; July 10, Aug E/W alleys replanted August

Border rows in CS3 and CS5: Hand weeded. Spot sprayed thistles in prairie and pasture in June

Appendix IV (cont'd). 2006 Agronomic Calendar for WICST (Fld 440)

Soybean and Wheat Rotations			
CROP-2006 Rotation Treatment #	**NR Soybean CS2 3**	**WR Soybean/Wheat CS3 6**	**Wheat/Berseem Clover+oats CS3 5**
Plot #'s	101, 214, 303, 401	102, 212, 313, 407	106, 202, 307, 411
Primary Tillage	None	Fall MB plowed 11-15-05	Fall field cultivator 1x after soybeans 10-5-05
Secondary Tillage	None	Field cultivator 5-4-06, 5-22-06	None
Planting Date	May 10, 2006	SB: May 23, 2006 WW: October 9, 2006	WW: 10-5-05 Berseem clover/oats: No-till drilled Aug 11, 2006
Variety Rate	Renk 253 RR 225,000 seed/a (3000 sd/lb) inocul = cell tech	Sb: Viking 1832 (feed grade) 190,000 seeds/a; (2700 sd/lb) inocul = cell tech WW: untrt Pioneer 25R47, 1.6 million viable seed/a	Arapahoe HR WW: 150 lb/a Berseem/oats: l2 and 40 lb/a
Fertilizer	11-14-05 plots 101 and 401 100 lb/a 0-0-60	102 and 212 got 120 lb/a 0-0-50 in starter box	None
Pesticides	6-1-06, 6-29-06 Mirage + (32 oz/a), speedway 1 qt/100 gal (= 3.2 oz/a)	None	None
Rotary Hoe/tine weed	None	RH: 5-31-06 TW: 6-2-06, 6-7-06, 6-20-06	None
Cultivation	None	6-13-06 ('Wil-rich') 7-17-06 (disk hiller)	None
Hand weed	None	2 man-hours/acre	None
Harvest & Yield	10-25-06; 63.8 bu/a	10-6-06; 58.7 bu/a	Wheat: 7-18-06; 66.6 bu/a Straw: 7-19-06; 1.04 bu/a
Fall Practices	None	Leveled ridges with disc; then soil finisher; then drilled (no-till) wheat 10-9-06;	7-20, 7-28 Quack digger; 8-11 chisel, disk, cultipack (1x each) before summer seeding berseem clover/oats
Crop 2007	**Corn**	**Wheat / Berseem Clover-Oats**	**Corn**

Appendix IV (cont'd). 2006 Agronomic Calendar for WICST (Fld 440)

Forage rotations						
CROP-2006 Rotation Treatment #	**Dir. Sd. Alfalfa CS4 7**	**Estab. Alfalfa I CS4 10**	**Estab. Alfalfa II CS4 9**	**Oats/Alfalfa CS5 12**	**Estab. Alfalfa I CS5 11**	**Pasture CS6 14**
Plot #'s	111, 209, 305, 409	107, 205, 309,404	105, 203, 308,406	103, 213, 314, 410	110, 208, 304,413	112, 207, 302, 405
Primary Tillage	Fall chisel plow 11-14-05	None	None	Fall MB plow 11-15-05	None	None
Secondary Tillage	Soil Finisher 2x 4-5-06	None	None	Soil Finisher 2x 4-5-06	None	None
Variety Planting Date	Magnum V 4-6-06	------	------	'Forage Plus' oats, 'WL346 LH' alf, 4-6-06	------	'Elgon' per. Ryegrass, Red clover 3-29-06
Rate	12 lb/a			62 and 12 lb/a		4 and 10 lb/a
Fertilizer	None	0-0-60	0-0-60	None	250-500 lb/a 0-0-50	June 50 lb N/a, 250 lb/a 0-0-60 on 302
Manure credit	9,000 gal/a 11-10-05	None	None	9,000 gal/a 11-10-05	None	Graze May 2-Oct 27
Pesticides	**Herbicide** Post-emerge: 6-1 Raptor 4 oz/a, AMS, NIS **Insecticide** 6-1, 6-7 Warrior 2 oz/a	**Insecticide** 7-15 Warrior 2 oz/a	**Insecticide** 7-15 Warrior 2 oz/a **Herbicide**10-6 Mirage plus 2 pt/a; Express XP 0.125 oz/a, 2,4-D 1 pt/a	None	None	Spot sprayed thistles with Stinger in June
Harvest & Total yield	July 7 Aug 1 Sept 1 2.81 ton DM/a	June 1 June 30 July 30 Sept 1 4.32 ton DM/a	June 1 June 30 July 30 Sept 1 3.85 ton DM/a	June 16 July 21 Sept 1 4.62 ton DM/a	June 9 July 7 Aug 1 Sept 8 4.39 ton DM/a	June 1 July 20 Aug 28 Oct 20 5.80 ton DM/a
Fall Practices	None	None	4,000 gpa Manure 11-24 and fall chisel (disk ripper) 1-3-07	None	4,000 gpa Manure 11-24 and Fall MB plow 11-26-06	None
Crop 2007	**Alf I**	**Alf II**	**Corn**	**Alf I**	**Corn**	**Pasture**

Appendix IV (cont'd). 2006 Agronomic Calendar for WICST (Fld 440)

Satellite – Chemlite plots			
CROP-2006 Rotation Treatment #	**Corn (cs3 w/chemical inputs)**	**WR Soybean/Wheat (cs3 w/chemical inputs)**	**Wheat/Red Clover (cs3 w/chemical inputs)**
Plot #'s	SAT C, D	SAT B, F	SAT A, E
Primary Tillage	Spring chisel plow, 4-16-06	Fall chisel plowed 11-14-05	Fall Field dug 1x prior to planting wheat, 10-5-05
Secondary Tillage	Field cultivator 4-27-06	Field cultivator 4-27-06 and 5-4-06	None
Planting Date	4-28-06	SB: 5-23-06 WW: 10-9-06	WW: 10-5-05 Red clover: 3-29-06
Variety **Rate**	Dekalb 5878 Bt 34,000 seeds/a	IA-1008 (non-organic) 170,000 seeds/a (2450 sd/lb) inocul = cell tech	Pioneer 25R47, 150 lb/a 'Marathon' RC, 12 lb/a
Fertilizer ***(see map for rates*****)**	100 lb/a 5-14-42 80 lbs N/a (28%) 6-15-06	none	60 lb N/a (urea) 4-7-06
Pesticides	4-29-06 tank mix (half rate broadcast): Dual II Magnum (12 oz/a), Hornet WDG (2 oz/a)	Post emrg 6-23-06: Raptor 2.5 oz/a broadcast	None
Rotary Hoe **Tine Weed**	None	5-31-06 6-2-06, 6-7-06	None
Cultivation	6-13-06 ('Wil-rich') 6-23-06 (disk hiller)	6-13-06 ('Wil-rich') 7-17-06 (disk hiller)	None
Harvest	10-24-06; 199.8 bu/a	10-6-06; 54.2 bu/a	Wheat: 7-18-06; 109.7 bu/a Straw: 7-19-06; 1.13 ton DM/a
Fall Practices	Chop stalks 10-27 Chisel plow with twisted shank 11-30-06	Leveled ridges with disc; then soil finisher; then drilled (no-till) wheat 10-9-06	Disk ripper on clover 11-30-06
Crop 2007	**WR Soybeans**	**Wheat / Red Clover**	**Corn**

Appendix V. 2006 Agronomic Calendar on the Organic Grain Plots (Arl 403)

Crop 2006	CORN	ALFALFA-PER RYE	SOYBEANS	WHEAT/ALFALFA
Strip #	1	2	3	4
Plot	A, B*	C, D	E, F*	G, H
STK '05 (ppm)	74, 70	71, 69	78, 61	83, 131
Primary Tillage	Spring chisel w/sweeps April 19; disk April 27	None	Spring chisel w/twisted shank April 25th; disk April 27	None
Secondary Tillage	Field cultivate May 8 and May 23	None	Field cultivate May 8 and May 23	None
Variety Plant Date Rate	Viking 5305 May 23, 2006 38,000 seed/a	Planted Aug 17, 2005	Viking 1832 May 23-24, 2006 190,000 seed/a + cell tech inoculant	Planted Oct. 7, 2005
Manure credit	April 19, 2006 (4800 gal/a)	None	None	None
Fertilizer	None	500 lb/a K_2SO_4, split	none	None
Rotary Hoe**	5-30-06, 6-3-06	None	5-30-06	None
Tine Weed**	None	None	6-7-06, 6-17-06	None
Cultivation	6-16-06, 6-30-06 plot B only	None	6-20-06, 7-17-06	None
Handweed/ Scout (# man-hours/plot)	Allow 75 minutes on center 36 rows	None	Allow 75 minutes on center 24 rows	None
Plant Popln	31,000 plants/a	n/a	n/a	n/a
Harvest Date & Yield	November 9, 179.8 bu/a	June 3 July 6 Aug 1 4.72 tons DM/a	October 9, 65 bu/a	July 18 82 bu/a
Market	$4.75/bu local dairy	fed on-farm	$12/bu Cashton	$5/bu Cashton
Fall soil test 0-6" on 11-20-06 STP ppm STK ppm	74, 69 105, 119	56, 83 116, 130	59, 66 146, 137	66, 77 137, 179
Fall Practices	spring till	spring till	No-till 'Pion 25R47' winter wheat and 'Esker' spring oats	12,000 gpa manure then summer seeded alfalfa 'Pion. 54H91'
Crop 2007	SOYBEANS	CORN	SMALL GRAINS	ALFALFA

* corn and soybean variety trials in plots B and F
Alleys seeded to winter rye in September '05 with no-till drill
Cropped North-South alleys with 30" soybeans (Blue River var 2.2 RM planted June 12, 2006); west alley left for winter rye seed production.

Appendix VI. Soil test P (0-6” depth) on WICST at Arlington Ag. Research Station (1992-2006).

	SOIL TEST PHOSPHORUS (ppm)														
System/plot#	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**
CS1 trt 1 109,204,306,412	93	84	91	88	91	83	82	80	76	85	91	79	83	87	70
CS2 trt 2 108,206,310,408	79	65	68	67	66	61	59	75	69	70	77	63	77	71	61
CS2 trt 3 101,214,303,401	89	78	89	72	83	72	75	62	53	57	59	52	55	59	74
CS3 trt 4 104,201,301,402	69	64	68	65	66	55	55	46	43	48	45	36	48	44	39
CS3 trt 5 106,202,307,411	- -	57	63	52	57	56	47	67	49	55	64	49	61	61	48
CS3 trt 6 102,212,313,407	- -	53	57	49	49	48	45	52	51	51	59	54	51	50	48
CHEMLITE trt 4 C, D	- - -	- - -	- - -	57	- - -	- - -	- - -	59	61	64	62	56	55	58	48
CHEMLITE trt 5 A, E	- - -	- - -	- - -	56	- - -	- - -	- - -	56	50	53	58	45	46	51	32
CHEMLITE trt 6 B, F	- - -	- - -	- - -	40	- - -	- - -	- - -	47	53	48	57	45	52	44	33
CS4 trt 7 111,209,305,409	94	85	99	84	90	90	90	81	80	95	111	85	93	98	91
CS4 trt 8 113,210,311,414	105	81	92	93	94	81	91	93	81	81	101	97	95	93	95
CS4 trt 9 105,203,308,406	- -	62	65	74	91	72	66	79	78	80	83	80	90	92	72
CS4 trt 10 107,205,309,404	77	71	72	67	77	76	63	66	74	86	84	73	91	94	79
CS5 trt 11 110,208,304,413	103	88	93	91	96	82	90	81	75	95	103	83	93	107	90
CS5 trt 12 103,213,314,410	72	67	72	64	72	66	59	68	60	65	80	70	70	75	58
CS5 trt 13 114,211,312,403	- -	73	83	78	76	71	66	68	71	77	80	74	86	82	71
CS6 trt 14 112,207,302,405	- -	82	84	75	74	73	64	68	64	73	54	69	78	76	90
Prairie corn 501, 504, 508	- - -	- - -	- - -	- - -	- - -	- - -	67	63	61	75	75	65	63	73	56
High div. prairie 502, 506, 509	- - -	- - -	- - -	- - -	- - -	- - -	67	68	60	70	74	61	69	70	54
Low div. prairie 503, 505, 507	- - -	- - -	- - -	- - -	- - -	- - -	62	65	65	68	69	59	61	69	58

values are an average of 3 samples/plot across 4 reps for a total of 12 obs.

Appendix VII. Soil test K (0-6” depth) on WICST at Arlington Ag. Research Station (1992-2006).

	SOIL TEST POTASSIUM (ppm)														
System/plot#	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**
CS1 trt 1 109,204,306,412	219	295	228	241	257	254	229	217	203	194	202	225	227	246	244
CS2 trt 2 108,206,310,408	239	229	183	182	214	178	184	197	169	153	179	172	177	194	180
CS2 trt 3 101,214,303,401	198	264	214	208	230	224	212	164	128	126	131	138	154	148	161
CS3 trt 4 104,201,301,402	189	251	182	175	209	166	180	124	104	109	95	102	125	113	128
CS3 trt 5 106,202,307,411	- - -	226	171	164	191	172	150	174	145	136	140	152	154	165	163
CS3 trt 6 102,212,313,407	- - -	201	142	149	155	136	131	149	130	110	133	132	125	133	155
CHEMLITE trt 4 C, D	- - -	- - -	- - -	183	- - -	- - -	- - -	144	142	140	133	127	137	145	130
CHEMLITE trt 5 A, E	- - -	- - -	- - -	190	- - -	- - -	- - -	152	123	127	130	116	95	113	100
CHEMLITE trt 6 B, F	- - -	- - -	- - -	138	- - -	- - -	- - -	101	136	112	124	112	123	117	110
CS4 trt 7 111,209,305,409	175	216	171	157	180	212	200	168	116	127	146	131	122	158	178
CS4 trt 8 113,210,311,414	203	170	154	184	189	153	166	179	128	96	142	156	112	124	169
CS4 trt 9 105,203,308,406	- - -	170	128	160	228	143	115	134	133	107	91	153	135	131	149
CS4 trt 10 107,205,309,404	189	224	155	153	196	205	141	133	137	163	111	124	153	180	175
CS5 trt 11 110,208,304,413	198	236	172	185	201	153	154	135	95	108	122	98	115	126	118
CS5 trt 12 103,213,314,410	181	210	144	127	143	128	98	110	87	75	103	121	89	127	106
CS5 trt 13 114,211,312,403	- - -	211	173	180	174	153	153	130	120	110	101	117	117	132	134
CS6 trt 14 112,207,302,405	- - -	186	157	176	208	210	180	202	148	153	163	175	174	165	180
Prairie corn 501, 504, 508	- - -	- - -	- - -	- - -	- - -	- - -	182	130	160	155	168	156	145	164	191
High div. prairie 502, 506, 509	- - -	- - -	- - -	- - -	- - -	- - -	230	163	151	178	183	165	156	161	193
Low div. prairie 503, 505, 507	- - -	- - -	- - -	- - -	- - -	- - -	203	170	168	139	169	154	151	158	190

Values are an average of 3 samples/plot across 4 reps for a total of 12 obs.

Appendix VIII. Fall nitrates in the top 3-ft of soil at Arlington Research Station in 1991-2006.

Crop	Sys	Phase	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06
			lbs NO_3^--N/acre															
Corn	CS1	**Cont. Corn**	48	97	102	154	179	164	115	148	87	130	79	110	110	82	116	67
	CS2	**After Soybeans**	41	105	105	166	141	170	128	100	77	107	68	55	59	77	91	76
	CS3	**After Red Clover**	- -[1]	67	83	100	145	45	129	112	83	61	81	44	96	70	66	56
	CS4	**After 3 yrs. Alf**	- -	- -	142	164	184	94	229	121	153	189	171	140	187	142	148	170
	CS5	**After 2 yrs. Alf**	- -	101	118	150	202	82	180	145	173	121	154	121	142	151	160	139
Soybean	CS2	**Narrow-row**	42	74	100	71	145	73	143	100	94	81	101	71	108	61	83	74
	CS3	**Wide-row**	25	66	89	83	140	76	127	98	71	68	53	64	100	55	76	99
Wheat	CS3	**Wheat / Red Clover**	26	48	65	48	85	38	90	76	51	57	53	37	46	45	39	52
Alfalfa	CS4	**Dir-seed Alfalfa**	32	61	80	77	117	59	114	100	75	69	101	96	101	75	89	84
	CS4	**Alfalfa Hay I**	27	49	55	46	117	62	112	111	74	65	85	66	93	69	64	78
	CS4	**Alfalfa Hay II**	- -	60	69	46	105	61	141	92	69	98	83	87	58	87	54	81
	CS5	**Alfalfa with Oats**	- -	- -	103	67	101	65	97	81	62	65	72	77	98	69	96	77
	CS5	**Alfalfa Hay**	- -	- -	84	67	107	51	116	72	63	70	71	57	79	56	54	85
Pasture	CS6	**Rotational Grazing**	- -	- -	91	58	98	90	100	88	62	60	50	50	76	88	78	86
Check			26	28	-	72	108	31	209	158	50	38	26	19	33	31	27	63

[*] staggered start - soil nitrates not tested until after first season in the rotation.

[2] prairie plots established in 1999 which were then used as the check. Previous years, the check was the North fenceline, adjacent to a neighboring field which received hog manure.

Starting in 1998, soil was sampled to a 3-ft depth for every plot using Giddings probe from Soils Dept.

3rd foot nitrate levels from 1993 to 1997 estimated using various regression equations (see previous WICST Technical Reports): Source: Ehrhardt, P.D. and L.G. Bundy. 1995. Predicting Nitrate-N in the two- to three-foot soil depth from nitrate measurements on shallower samples. J. Prod. Agric. Vol. 8, no. 3.

Appendix IX. Manure nutrient analysis from the Arlington Research Station[1]

Year	DM%	Total N	Total P205	Total K20
		lbs/ton		
1990 [2]	19.4	11.9	7.1	10.1
1991	17.0	13.2	7.4	12.9
1992 [2]	17.0	10.7	7.5	16.0
1993 [3]	-	-	-	-
1994	12.1	8.9	4.5	11.3
1995	15.6	10.6	5.8	10.4
1996	15.3	9.8	7.2	9.8
1997	11.7	9.2	3.6	8.8
1998	14.3	10.3	3.7	9.9
1999	16.8	11.1	3.8	7.1
2000	13.2	11.6	3.1	6.8
2001	11.8	13.2	4.8	11.4
2002	14.6	9.6	3.2	6.0
2003	16.1	7.9	3.6	7.1
2004	13.8	8.6	4.2	7.2
2005	23.6	49.0	21.8	37.7
		lbs/1000 gal		
2006[4]	9.6	31.7	11.9	27.1

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.

Appendix X. Weighted Relative feed values on WICST forage systems at Arlington, 1992-2006.

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	**trial avg**
CS4																
Direct seed alfalfa	184	152	160	126	150	123	140	153	141	164	165	179	158	151	167	**154**
Haylage I	128	138	156	147	126	152	154	128	154	155	161	148	152	172	133	**147**
Haylage II	134	141	143	151	155	144	164	141	162	148	183	160	148	179	140	**153**
CS5																
Oatlage (1st crop)	124	missing[1]	103	116	103	116	96	95	95	115	90	112	90	120	120	**107**
Oat/alf haylage (2nd, 3rd crop)	143	missing[1]	149	103	116	141	111	104	125	155	183	-	125	-	117	**132**
Haylage I	142	139	141	132	147	143	148	141	149	147	177	124	110	166	157	**144**
CS6																
Pasture	128	134	125	101	143	134	137	127	101	112	131	127	128	118	122	**124**

[1] missing data because oats harvested as grain not oatlage or haylage.

formula for weighted RFV = [(Y1*RFV1) + (Y2*RFV2) + (Y3*RFV3) + (Y4*RFV4)]/(Y1+Y2+Y3+Y4)
* pasture is not weighted average

Appendix XI. WICST Fall Legume Nitrogen from Plowdown Crop Preceding Corn Phase at Arlington (1991-2006).

Year	Crop System	Crop[1/]	Foliage		Roots		Total
			lb DM/a	%N	lb DM/a	%N	lb N/a
1991	3	Red Clover	1853	3.24	2604	2.63	129
1992	3	Red Clover	2102	2.89	1816	2.72	110
1992	4	Alfalfa	2697	2.03	1767	2.27	95
1992	5	Alfalfa	2090	3.43	3352	2.29	148
1993	3	Red Clover	2811	2.81	1314	3.18	121
1993[2/]	4	Alfalfa	1866	2.91	1233	3.36	96
1993[2/]	5	Alfalfa	1613	4.05	1443	2.18	97
1994 [3/]	3	Hairy Vetch	4325	3.29	134	3.24	147
1994[2,4/]	4	Alfalfa	2242	3.50	1233	2.50	109
1994	5	Alfalfa	500	3.41	2327	2.04	65
1995	3	Red Clover	2460	2.90	948	3.09	101
1995	4	Alfalfa	163	3.18	1235	2.51	36
1995	5	Alfalfa	308	3.59	2345	2.32	65
1996	3	Red Clover	3213	3.01	(1453)	(2.72)	136
1997	3	Hairy Vetch	1343	4.66	767	(2.72)	83
1998	3	Red Clover	3229	2.36	1229	(2.72)	110
1998	4	Alfalfa	1283	3.83	2582	(2.45)	119
1998	5	Alfalfa	1635	3.50	2328	(2.25)	121
1999	3	Red Clover	5354	4.00	2253	2.27	265
1999	4	Alfalfa	889	3.05	3026	2.16	92
1999	5	Alfalfa	1104	3.44	3069	2.34	110
2000	3	Red Clover	5974	2.53	1414	2.53	187
2000	4	Alfalfa	1180	4.47	2774	1.91	106
2000	5	Alfalfa	1260	3.98	2780	1.89	103
2001	3	Red Clover	6521	2.18	1370	2.90	182
2001	4	Alfalfa	326	2.58	3730	2.47	101
2001	5	Alfalfa	681	2.54	3216	2.46	96
2002	3	Red Clover	3723	2.11	1640	2.70	118
2002	4	Alfalfa	462	3.07	624	2.33	63
2002	5	Alfalfa	0	0.00	(2607)	(2.25)	59
2003	3	Red Clover	816	3.43	(1453)	(2.72)	68
2003	4	Alfalfa	1545	3.00	(2007)	(2.45)	96
2003	5	Alfalfa	1060	2.94	(2607)	(2.25)	90
2004	3	Red Clover	5893	2.04	(1453)	(2.72)	160
2004	4	Alfalfa	1349	3.08	(2007)	(2.45)	91
2004	5	Alfalfa	1055	2.86	(2607)	(2.25)	89
2005	3	Berseem Clover/oats	4842	1.73	2009	0.93	103
2005	4	Alfalfa	0	0.00	5719	2.20	126
2005	5	Alfalfa	0	0.00	6493	2.20	143
2006	3	Berseem Clover/oats	2587	2.12	1273	0.99	67
2006	4	Alfalfa	1664	3.28	2726	1.68	100
2006	5	Alfalfa	1447	4.00	2228	1.81	98

[1/] Starting in 2003, botanical separations were done on all treatments (legume, straw, weeds, oats) and were part of the plowdown N credit.
[2/] Spring seeded with red clover because of severe winterkill to alfalfa in 1993.
[3/] Hairy vetch planted after wheat harvest because of thin stand of red clover.
[4/] Values in parentheses are estimates using used trial averages since no root samples were taken.

Appendix XII. List of publications involving WICST over the duration of the trial (1990-2006).

2006

Theses:

Cook, Amy. Jan. 2006. Lessons From Linking Farms: Effects of Dairy Manure on Corn Production, Nutrient Accumulation and Weed Pressure on Wisconsin Cash-Grain Farms [MSc Thesis]. Madison, WI. University of Wisconsin 163 Pp

Sanford, Gregg. Jan. 2007. Dairy Slurry in Corn Based Systems: Impacts on Profitability and Soil Compaction. [MSc Thesis]. Madison, WI University of Wisconsin. 80 Pp

Abstracts:

Baldock, J., J. Posner, J. Hedtcke. 2006. Evolving Soil Test P and K Levels on the Wisconsin Integrated Cropping Systems Trial. [Abstract] 98th ASA-CSSA-SSSA International Annual Meetings (November 12-16, 2006, Indianapolis, Indiana) CD-ROM Abstract 154-8.

Baldock, J., J. Posner, J. Hedtcke. 2006. Understanding Organic Corn and Soybean Yields: The Importance of Weed Pressure. [Abstract] 98th ASA-CSSA-SSSA International Annual Meetings (November 12-16, 2006, Indianapolis, Indiana) CD-ROM Abstract 245-9.

Hedtcke, J., J. Posner, J. Baldock. 2006. Evaluation of forage-Based Cropping Systems: Data From WICST. [Abstract] 98th ASA-CSSA-SSSA International Annual Meetings (November 12-16, 2006, Indianapolis, Indiana) CD-ROM Abstract 55-6.

Hedtcke, J., G. Sanford, A. Cook, J. Posner, J. Hall, and J. Baldock. Including Manure in Cash-Grain Rotations: Lessons From on-Farm Trials in Wisconsin. [Abstract] 98th ASA-CSSA-SSSA International Annual Meetings (November 12-16, 2006, Indianapolis, Indiana) CD-ROM Abstract 53-5.

Mueller, D., B. Stangel, D. Frye, J. Hedtcke, J. Posner, J. Hall. 2006. Developing an Organic Crop Research Program at the University of Wisconsin Arlington Agricultural Research Station. [Abstract] 98th ASA-CSSA-SSSA International Annual Meetings (November 12-16, 2006, Indianapolis, Indiana) CD-ROM Abstract 150-5.

Sanford, G., J. Posner, J. Hedtcke, R. Schuler, J. Baldock. 2006. Manure Spreading and Its Effects on Soil Compaction and Corn Yield in Southern Wisconsin. [Abstract] 98th ASA-CSSA-SSSA International Annual Meetings (November 12-16, 2006, Indianapolis, Indiana) CD-ROM Abstract 154-9.

Journal Articles:

Betcher, J., G. Hadley, J. Posner, G. Sanford. 2006. Linking Farms: A Financial Solution. *In* Proceedings of the 2006 Wisconsin Fertilizer, Aglime, and Pest Management Conference. Vol 45. P 189. Jan. 17-19, 2006. Madison, WI

Cook, A.R., J.L. Posner, J.O. Baldock. 2007. Effects of Dairy Manure and Weed Management on Weed Communities in Corn (Zea Mays) on Wisconsin Cash-Grain Farms. Weed Technology. 21(2): 389-395.

Hedtcke, J., J. Posner, M. Rosemeyer. 2006. Using Cattle to Reduce Oak Savanna Understory Shrub Abundance: Stocking Rates and Weight Gains. *In* Proceedings of the 19th North American Prairie Conference. Aug 8-12, 2004. Madison, WI: University of Wisconsin–Madison.

Osterhaus, J.T., L.G. Bundy, and T. W. Andraski. 2006. Evaluation of the Illinois Soil Nitrogen Test and Soil Organic Nitrogen Fractions for Predicting Corn Nitrogen Needs. Submitted to Soil Sci. Soc. Am J.

Osterhaus, J.T., and L.G. Bundy. 2006. Using the Illinois Soil Nitrogen Test to Predict Optimum Nitrogen Rates for Corn in Wisconsin. *In* Proceedings of the 2006 Wisconsin Fertilizer, Aglime, and Pest Management Conference. Vol 45. P 61. Jan. 17-19, 2006. Madison, WI.

Sanford, G. J. Posner, R. Schuler. 2006. Manure Spreading Effects on Soil Compaction and Crop Yield. *In* Proceedings of the 2006 Wisconsin Fertilizer, Aglime, and Pest Management Conference. Vol 45. P 192. Jan. 17-19, 2006. Madison, WI

Wagner, T. and J. Posner. In Review. Manure Management on A Township Scale: Using A Land Evaluation Approach in Wisconsin. Submitted to the Journal of Renewable Agriculture and Food Systems 2006.

2005

Thesis:

Wagner, T. January 2005. Manure Management: Using A Land Evaluation Site Assessment Approach. [MSc Thesis]. Madison, WI: University of Wisconsin. 120 Pp.

Osterhaus, Jeffery. Dec. 2005. Evaluation of the Illinois Soil Nitrogen Test in Wisconsin Cropping Systems. [MSc Thesis]. Madison, WI University of Wisconsin. 100 Pp

Abstracts:

Cook, A.R., J.L Posner, J.L. Hedtcke, J.O. Baldock, J. Doll, H. Kummel 2005. Measuring differences in weed pressure on manure-applied corn fields. Poster presentation, American Society of Agronomy 97th International Mtg., Salt Lake City, UT. Nov 6-10, 2005.

Kummel, H., J. Doll, J. Posner, J. Hedtcke, J. Baldock, and A. Cook. 2005. Weed seed bank changes in chemical-free corn production systems of the upper Midwest: Results from the first 15 years of WICST. Poster presentation, American Society of Agronomy 97th International Mtg., Salt Lake City, UT. Nov 6-10, 2005.

Journal Articles:

Saam, H., J.M. Powell, D.B. Jackson-Smith, W. Bland, J. Posner. 2005. Use of Animal Density to Estimate Manure Nutrient Recycling Ability of Wisconsin Dairy Farms. Agricultural Systems. 84:343-357.

2004

Theses:

Avila-Segura, M. June, 2004. Soil Acidification Processes in Agroecosystems. [PhD Thesis]. Madison: University of Wisconsin. 150 Pp

Mariola, M. August 2004. Who Is A Farmer? The Identity Crisis in Modern Agriculture. [MSc Thesis]. Madison, WI: University of Wisconsin 139 Pp

Meyer, J. August 2004. The Vertical Distribution of Phoshorus at the Wisconsin Integrated Cropping Systems Trial. [MSc Thesis]. Madison, WI: University of Wisconsin. 134 Pp

Simonsen, C. June 2004. Investigations of Composition, Germination, Structure and Physiognomy in Three Southern Wisconsin Tallgrass Prairies. [MSc Thesis]. Madison, WI: University of Wisconsin. 183 Pp

Abstracts:

Avila, M., P. Barak, J. Posner, D. Laird. 2004. Comparative Rates of Acidification of Midwestern Agricultural Systems. [Abstract] 96th Annual Meeting of American Society of Agronomy (Oct 31-Nov 4, Seattle, WA) CD-ROM Abstract S-11 6317.

Baldock, J., J. Posner, J. Hedtcke. 2004. Soil Test P and K Trends in Alternative Cropping Systems: Data From WICST. [Abstract] 96th Annual Meeting of American Society of Agronomy (Oct 31-Nov 4, Seattle, WA) CD-ROM Abstract S-04 5935.

Baldock, J., J. Posner, J. Hedtcke. 2004. Does Diversification Reduce Yield Variability?: Data from WICST. [Abstract] 96th Annual Meeting of American Society of Agronomy (Oct 31-Nov 4, Seattle, WA) CD-ROM Abstract C-03, A-08, C-01 5902.

Hedtcke, J., J. Posner, and K. Albrecht. 2004. Using Managed Grazing to Restore Oak Savanna Structure: Impact on Cattle. [Abstract]. North American Prairie Conference. (August 8-12, Madison, WI. Conference Proceedings Pg 66.

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