# The Wisconsin Integrated Cropping Systems Trial
# Tenth Report - 2003 & 2004

Compiled by Janet Hedtcke and Josh Posner, December 2005
http://www.cias.wisc.edu/wicst/

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# PROLOGUE

This is the tenth 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 thirteen production years (1990 – 2002). In this report, we discuss the results of the 2003 & 2004 growing seasons. This is the twelfth 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 2004, all the treatments of the Cropping Systems had completed at least three full cycles of their respective rotations. Also included in this report are research results of satellite trials conducted both on-farm and adjacent to the WICST core trials.

Funding for the project continues to come primarily from the USDA-ARS pilot project on Integrated Farming Systems. Other grants important to the success of the project come from the Wisconsin Fertilizer Research Council, USDA-National Research Initiative, USDA-Sustainable Agriculture Research and Education Fund, as well as Hatch funds managed by the College of Agricultural and Life Sciences.

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We also acknowledge with many thanks, the contributions to this project of those who assisted at the research stations in managing the crops and animals –Darwin Frye, Paul Bergum, and Tim Patchin at Arlington.

# 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.**

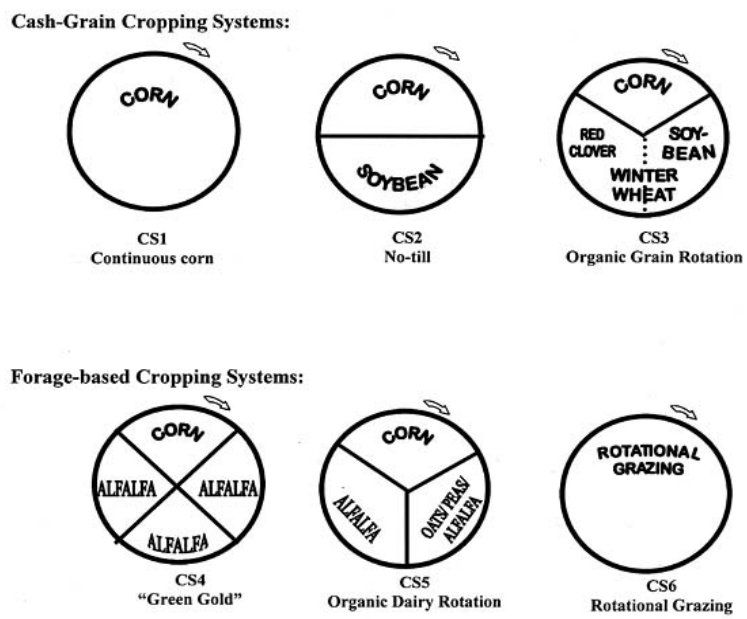


**Figure 1b. Schematic diagram of the cropping systems of the WICST experiment.**

**Table i.. Productivity, Economic, and Environmental Comparisons Between Rotations. Wisconsin Integrated Cropping Systems Trial 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<br>Alachlor 2 lb | Counter 1.4 lb | 4.1 |
| **$R_2$ Drilled Soybean Corn** | 55 bu<br>160 bu | 12,510 | 1788 | 6.9 | 104 | 110 | Bladex 2.5 lb<br>Alachlor 2.5 lb<br>Sencor 0.5 lb<br>Treflan 1.5 lb | 0 | 4.0 |
| **$R_3$ Row soybean Wheat Corn** | 40 bu<br>60 bu/2t straw<br>120 bu | 10,010 | 763 | 12.6 | 50 | 0 | 0 | 0 | 2.9 |
| **$R_4$ Seeding alfalfa Hay I Hay II Corn** | 3t dm<br>5t dm<br>5t dm<br>160 bu | 10,710 | 1188 | 13.7 | 110 | 10 | Eptam 2.9 lb<br>Bladex 2.0 lb<br>Alachlor 2.5 lb | Lorsban 1.0 lb | 1.9 |
| **$R_5$ Oats/alfalfa Hay I Corn** | 60 bu/2t dm<br>4t dm<br>120 bu | 9,440 | 811 | 18.2 | 45 | 10 | 0 | 0 | 1.6 |
| **$R_6$ 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. Growing season rainfall (inches) at the Wisconsin Integrated Cropping Systems Trial site at Arlington.[1]**

| Month | 2004 | (*) | 2003 | (*) | 30-year average 1971 - 2000 |
|---|---|---|---|---|---|
| April | 1.92 | -1.32 | 2.06 | -1.18 | 3.24 |
| May | 10.36 | 6.93 | 3.85 | 0.42 | 3.43 |
| June | 4.11 | 0.07 | 3.36 | -0.68 | 4.04 |
| July | 4.35 | 0.49 | 3.26 | -0.6 | 3.86 |
| August | 3.12 | -1.12 | 1.85 | -2.39 | 4.24 |
| September | 0.56 | -3.08 | 4.00 | 0.36 | 3.64 |
| October | 3.32 | 0.89 | 1.35 | -1.08 | 2.43 |
| Growing Season Total | 27.74 | | 19.73 | | 24.88 |
| Yearly Total | 35.75 | | 29.09 | | 32.80 |

* Deviation from 30-year average

**Figure 2. Rainfall graph from Arlington 2003 and 2004 vs. the long-term norm.**

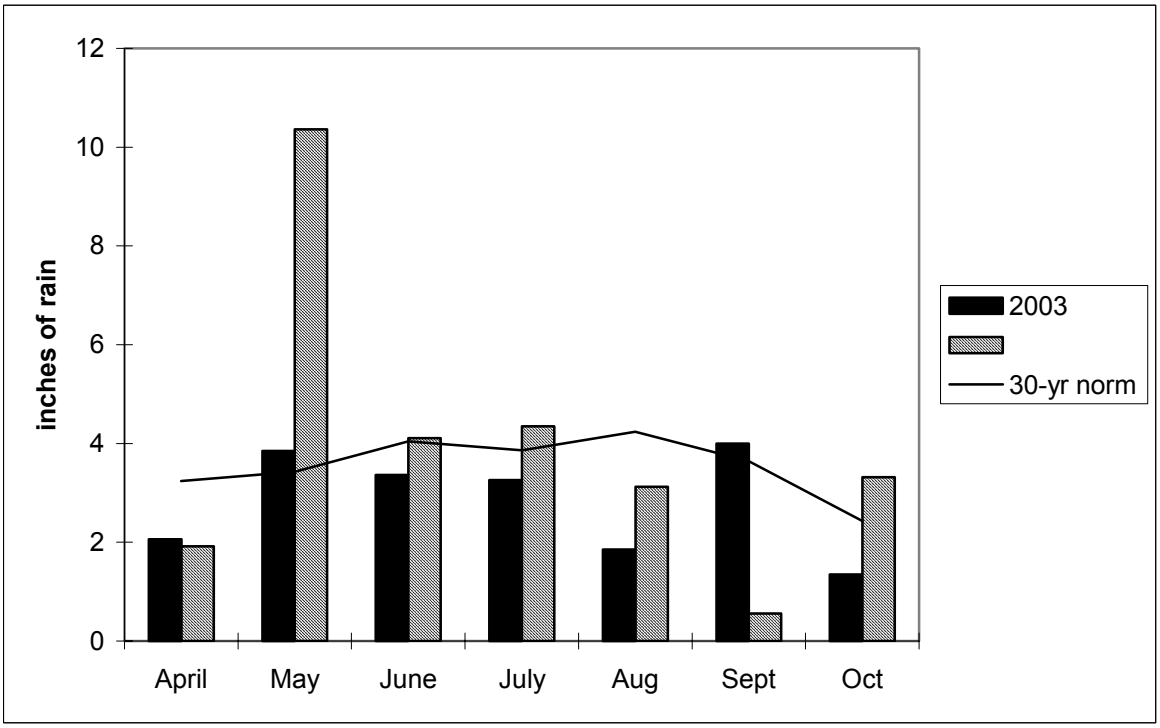

**Figure 3. Growing Degree Days at Arlington (2004 vs. norm)**

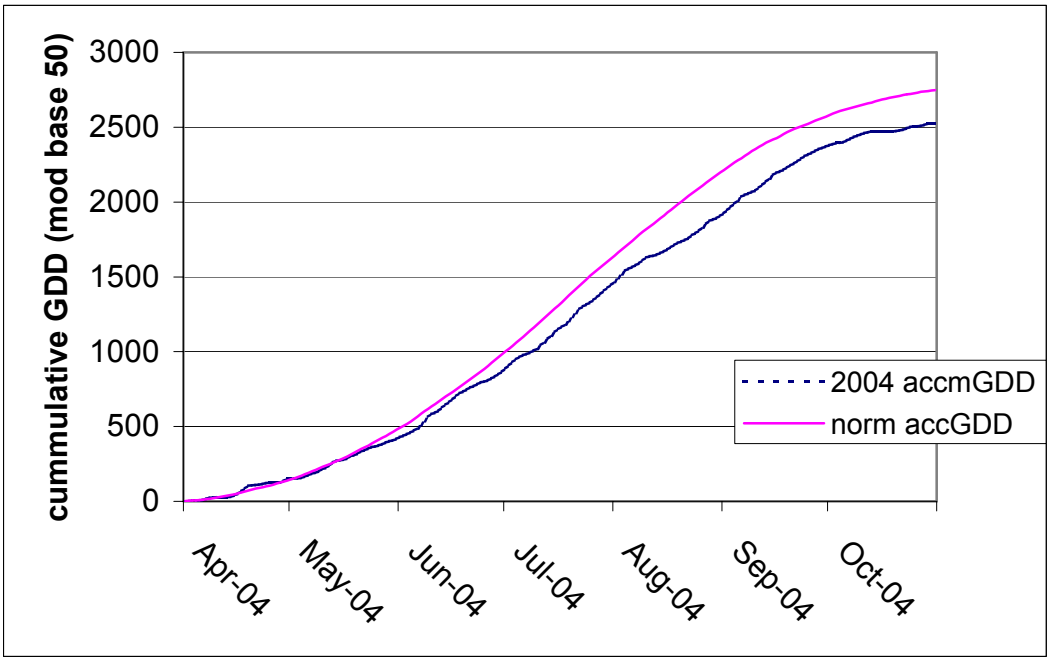


**Figure 4. Growing Degree Days at Arlington (2003 vs. norm).**

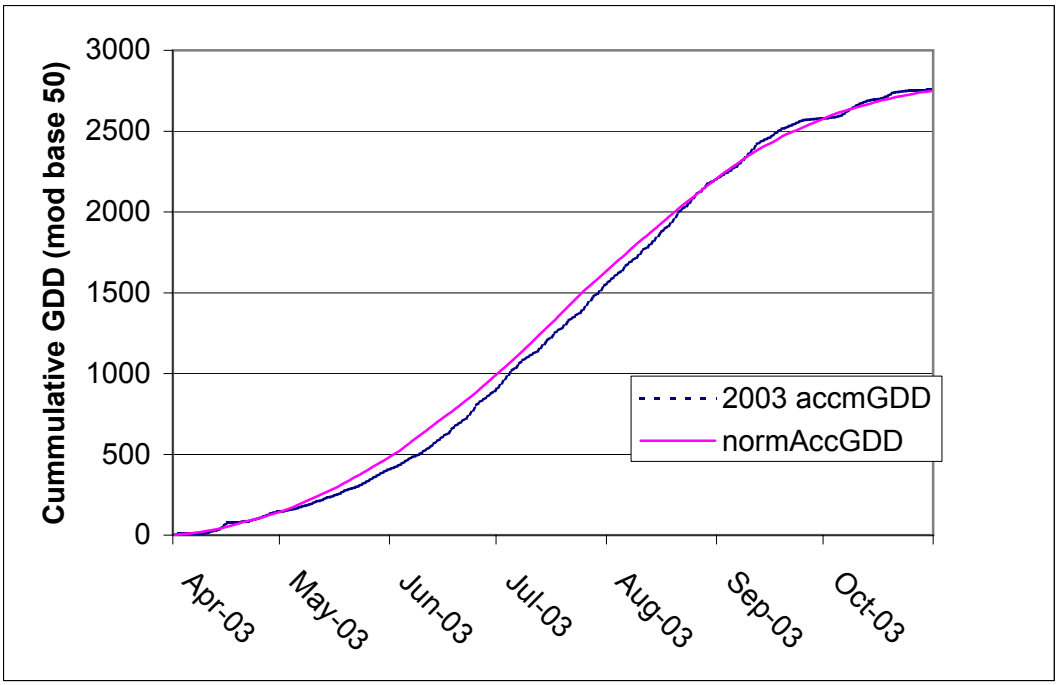

**Table 2. Yields from WICST at Arlington Agric. Research Station, 1992-2004.**

| | **Corn** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ----------bu/acre---------- | | | | | | | | | | | | |
| $CS_1$ | Continous corn | 144.0 | 123.7 | 178.1 | 143.1 | 131.5 | 128.6 | 196.2 | 170.4 | 161.6 | 193.6 | 192.2 | 175.0 | 193.9 |
| $CS_2$ | After sb (No Till) | 150.1 | 129.8 | 190.2 | 167.7 | 140.0 | 157.4 | 212.6 | 162.9 | 162.9 | 207.7 | 159.0[1] | 176.5 | 189.0 |
| $CS_3$ | Org. 3-crop | 99.2 | 87.1 | 188.4 | 155.6 | 83.4 | 147.6 | 197.8 | 155.6 | 132.8 | 155.5 | 157.8 | 110.0 | -[2] |
| $CS_4$ | 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 |
| $CS_5$ | After 2-yrs alf (org) | 112.0 | 119.1 | 198.8 | 157.1 | 153.6 | 155.3 | 205.1 | 181.9 | 135.2 | 181.2 | 174.1 | 149.7 | -[2] |
| *LSD (P<0.05)* | | *12.6* | *7.4* | *12.6* | *11.6* | *16.0* | *10.0* | *12.3* | *14.7* | *24.5* | *18.3* | *21.1* | *18.0* | *5.1* |
| | | | | | | | | | | | | | | |
| | **Soybeans** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** |
| | | ----------bu/acre---------- | | | | | | | | | | | | |
| $CS_2$ | Drilled – No till | 30.1 | 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 |
| $CS_3$ | Org. 3-crop | 38.0 | 53.3 | 44.4 | 63.3 | 60.2 | 48.8 | 51.9 | 31.0 | 40.9 | 35.4 | 51.0[1] | 32.5 | 33.6 |
| *LSD (P<0.05)* | | *NS* | *NS* | *NS* | *2.20* | *NS* | *NS* | *NS* | *1.5* | *4.5* | *15.6* | *NS* | *1.6* | *10.47* |
| | | | | | | | | | | | | | | |
| | **Wheat** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** |
| $CS_3$ | Grain (bu/a) | 45.2 | 28.6 | 60.9 | 68.1 | 45.4 | 54.4 | 57.7 | 56.9 | 41.7 | 54.8 | 70.5 | 53.6 | 34.9 |
| $CS_3$ | Straw (ton DM/a) | 0.34 | 1.44 | 1.44 | 1.22 | 1.55 | 0.97 | 0.58 | 0.63 | 0.83 | 0.71 | 1.43 | 0.40 | 0.54 |
| | | | | | | | | | | | | | | |
| | **Seeding yr. Forage** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** |
| | | ----------ton DM/acre---------- | | | | | | | | | | | | |
| $CS_4$ | Direct seeded | 3.59 | 3.27 | 3.21 | 3.19 | 1.57 | 3.56 | 2.63 | 2.27 | 2.59 | 3.21 | 2.96 | 2.91 | 1.85 |
| $CS_5$ | Oats/peas/alf | 2.60 | NA | 3.37 | 3.21 | 2.68 | 4.66 | 5.67 | 4.69 | 4.14 | 4.53 | 3.56 | 2.30 | 4.35 |
| *LSD (P<0.05)* | | *0.49* | *0.51* | *NS* | *NS* | *0.90* | *NS* | *0.67* | *0.34* | *0.24* | *1.27* | *NS* | *NS* | *1.06* |
| | | | | | | | | | | | | | | |
| | **Estab'd Forage** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** |
| | | ----------ton DM/acre---------- | | | | | | | | | | | | |
| $CS_4$ | Hay I | 3.46 | 3.93 | 4.56 | 4.02 | 4.16 | 5.08 | 4.30 | 4.49 | 5.44 | 5.89 | 5.18 | 4.83 | 5.08 |
| $CS_5$ | Hay I | 5.17 | 4.65 | 5.30 | 4.89 | 4.42 | 4.99 | 4.47 | 5.49 | 5.86 | 5.29 | 5.10 | 5.94 | 4.88 |
| $CS_4$ | Hay II | 3.99 | 3.25 | 3.68 | 2.24 | 3.77 | 4.50 | 4.13 | 4.06 | 5.31 | 5.53 | 4.50 | 3.37[4] | 5.15 |
| CS6 | Pasture[5] | 2.81 | - | - | - | - | - | - | - | - | - | - | - | 5.48 |
| *LSD (P<0.05)* | | *1.20* | *1.15* | *0.42* | *0.36* | *0.59* | *NS* | *NS* | *0.35* | *0.32* | *0.52* | *0.50* | *0.86* | *0.69* |

[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.
[4] Only 3 cuts taken on CS4 Hay II (4 cuts taken on CS4 Hay I and CS5 Hay I).
[5] Hay was mechanically harvested as a comparison with CS4 and CS5.

Org = organically managed

# Arlington Agricultural Research Station – 2003 Report

Janet Hedtcke, Dwight Mueller, and Paul Bergum

The 2003 season's soil moisture started well below normal due to low precipitation during previous fall and winter. Rain plus snow from November through April was only 50% of the longterm average. May and June rainfall was about average but then the summer became very dry with only a total of 2" from July 15-Sept 10. Finally, rain came in November and December totally more than 7 inches.

In 2003, 2 different trials were superimposed on the border rows of the grain systems. On the western 6 rows of the corn phase of CS1 and CS2, Larry Bundy set out a study to compare the amino sugar N test with the pre-sidedress N test. On the eastern 6 rows of the corn phase of CS1, CS2, and CS3, 11,000 gal/a of slurry was applied in the spring (April 21st) as part of graduate student, Amy Cook's, research project of importing manure from dairy to cash grain systems.

**Corn Phase**

Corn in CS1, CS2, and CS4 were all planted on April 29th at 32,000 seeds/A with a 105-day corn, Pioneer 35R58 Bt. The organically managed corn (CS3, CS5) was planted into a stale seedbed that had been worked with a field digger in late April and again just before planting on May 23rd at 34,500 seed/A with a 101-day corn, NC+ 100A2. Deep nitrate soil tests (PPNT) were taken for the CS1 and CS2 plots. As a result of the tests, a side-dress application of 80-120 lbs N/a was applied on CS1 plots and 80 lbs N/a on CS2 plots on June 19th. Legume and manure credits were taken in the other systems and no additional synthetic fertilizer was needed on the manured grain plots (eastern 6 rows of cs1 and cs2). Starter fertilizer (5-14-42) was used on CS1, CS2, and CS4 at 100 lb/a.

Weed control worked well with the high-input corn, although there was some quackgrass creeping in on the border rows. The border rows were treated with Accent but this expenditure was not 'charged' against CS1. The organically managed systems had medium-to-heavy weed pressure. We continue to struggle to find the appropriate tool for shallow tillage in preparing the stale seedbed. In addition, we didn't succeed in allowing flushes of weeds to germinate between seedbed preparation and planting. Once planted, two rotary hoeing were done followed by 3 cultivations in CS3. Still, CS3 had heavy foxtail pressure but broadleaf weeds were moderately well controlled. No hand labor was spent on pulling weeds because it would have been too costly.

Ground squirrels are still causing severe problems in CS2. Areas of two plots (303, 401) were so destroyed that they had to be replanted with the planter using Renk 232 (85 d) corn. Hand baiting of zinc phosphide pellets was done but after the damage was done. We will try adding this poison in-furrow next year at planting. Plant population and yield data don't however, reflect the ground squirrel damage caused in CS2 vs. CS1.

Corn yields averaged 181 bu/a for the high input systems, above average from the trial average of 171 bu/a. Corn yields were more variable in the low input systems from 110 on CS3 to 150 on CS5, both lower than the trial mean. Corn on CS3 had very heavy weed pressure and looked N deficient, especially when comparing it to the eastern 6 rows which had received 11,000 gal/a slurry this spring. CS1 and CS2 yields were very similar at 175 and 177 bu/a respectively, vs.

191 bu/a on CS4. This demonstrates the significant benefit of rotating corn with leguminous crops and manure.

**Soybean Phase**

Asgrow 2001 (RR) was planted at 250,000 seeds/A in 7" rows for the CS2, no-till rotation on May 22nd. A food-grade variety (IA2053) was planted at 190,000 seeds/A in 30" rows for the CS3 rotation on May 23rd. The CS2 soybeans were no tilled into high residue cover (approximately 75% cover) with a John Deere no-till drill. For CS2, a burndown treatment of Round Up Weathermax helped control early weeds. A second application of Round-up Weathermax on the round-up ready beans took care of the post-planting weeds. Weed control for the rest of the growing season was excellent in the CS2 rotation. Narrow-row beans were sprayed for aphids in early August.

The organically managed beans were planted into a seedbed that had been worked with a field digger in late April and again just before planting. After planting, two rotary hoeings and 3 cultivations were done on CS3 beans. Hand weeding of the organic bean plots was done on July 2, spending about 2 man-hours/acre. Yields of both systems were only about 70% of the trial average because of the summer drought conditions. CS3 beans were taken to DeLong for grading; cleanout (splits, off-color, off-shape) was minimal (~ 5%).

**Wheat/Red Clover Phase**

Wheat (var, 'Kaskaskia') had been planted on October 10th, 2002 following soybean harvest tillage at a seeding rate of 180 lbs/a. The wheat hardly got out of the ground (~1") before a cold November set in. Winterkill was a concern, but eventually the stand started to greenup in late April. There was a moderate weed population of yellow foxtail and lambsquarter beneath the wheat canopy. The wheat yield averaged 54 bu/a, right on pace with the trial average but straw yields were low at 0.40 tons DM/a, partly due to the high cutting height to avoid weeds and red clover. Red Clover was seeded on April 2, 2003 at 12 lbs/a, with a John Deere no-till drill. Wheat stubble and weeds were clipped/removed in early September to prevent weeds from setting seed. The stand of red clover was doing well under the wheat but yields were rather poor with less tan half a ton DM at the end of the growing season because of no rain for most of the summer.

**Forage Phases**

The new seedings in CS4 and CS5 systems were planted with Magnum V on April 14th. CS5 was planted with a mix of alfalfa, bay oats, and Trapper field peas to help with forage yield and quality and weed control. CS5 seeding was taken off as silage on June 27th but the second crop was all weeds so it was clipped and blown back on the field. CS4 alfalfa seeding established well and was harvested 3x during the season. All the established plots were harvested 4 times during the season except plowdown phase of CS4, which was sprayed out. July cuttings got rained on for all phases of each system. Seasonal yields were very comparable to the trial average. Relative feed value was similar to past years and was highest on CS4 and lowest on oats/peas/alfalfa phase of CS5. CS5 established plots had a lot of quackgrass present. Pasture (CS 6) was quite productive until mid-August when rain deficit reduced growth and hay had to be supplemented to the heifers for the remainder of the season.

# Arlington Agricultural Research Station – 2004 Report

Janet Hedtcke, Dwight Mueller, and Paul Bergum

2004 will be remembered as a very cool season with ample moisture. Although the winter and early spring were again below average in precipitation, rainfall in May was record breaking (3x the norm at 10.3"). The weather conditions were difficult on crop establishment (there was standing water on the Northeast end of the trial well into June), but once established most crops yielded well. Growing degree units were well below normal, particularly in July and August (see Fig. 3), which impacted corn maturity in some cases but fortunately the weather was abnormally warm in September.

The 2 superimposed trials on the border rows of the grain systems continued this season. On the western 6 rows of CS1 and CS2, Larry Bundy and graduate student Jeff Osterhaus continued to monitor corn yields and soil nitrates to improve their amino sugar N test. On the eastern 6 rows of CS1, CS2, and CS3, ~ 11,000 gal/a of slurry was applied the previous fall (November 2nd) with the 'Calumet' tanker as part of graduate student Amy Cook's research project of importing manure from dairy to cash grain systems. Manure was incorporated (with the chisel plow) on CS1 and CS3 and surface applied on CS2.

**Corn Phase**

Corn in CS1, CS2, and CS4 were all planted on May 5th at 32,000 seeds/A with a 105-day corn, LG2533. Starter fertilizer (5-14-42) was used on CS1, CS2, and CS4 at 100 lb/a. Potash was applied on some of the plots in CS4 and CS2. In June PSNT samples were taken from both manured and non-manured plots in CS1, 2, and 3. As a result of the test, the recommended full rate of N fertilizer (160 lb N/a) was applied on CS1 and CS2 corn on June 21th. The PSNT did not pick up the approximately 100 (?) pounds of N added in the 11,000 gals/a of slurry added to the manured strips.

Although it never reached 90 °F during the season, corn yields in the conventional systems were excellent reaching a max of 224 bu/a (i.e. Chemlite). However, corn moistures were high, still in the upper 20's in mid-November. In recent years, CS2 yields advantage over CS1 has been diminishing. This year, CS1 corn yield was significantly higher that CS2 by 5 bu/a. One possible reason for the general convergence of yields is the problem with ground squirrels in CS2. They have caused considerable stand damage in some plots. However, yearly stand counts have not been statistically different between the systems. Although we hand bated 'Prozap' (zinc phosphide) pellets, some areas were replanted. New insecticide boxes have been purchased that are split so regular insecticide can be put on one side and the prozap on the other. This will allow better calibration/effectiveness in 2005. It is also likely that the cool, wet conditions this spring delayed emergence in the no-till system more so that in CS1, and thus reduced CS2 yields.

There were more challenges than usual this year with corn in the chemfree systems (CS3 and CS5). Plots had a lot of volunteer alfalfa, quackgrass and red clover from last fall's plowdown. The first spring tillage didn't occur until mid-May when plots were disked and field dug but then a wet period delayed any further seed bed preparation and planting until late May. For reasons unclear to us, the corn on the WICST plots had a very poor stand when it emerged but the same variety planted the same day on the 403 plots has an excellent stand. Corn was replanted to an 85-day variety (Brunner OR8403) on June 16th, but, the GDD units were way below average and the corn did not develop fully. By the first killing frost (Oct 5), the CS3 and CS5 corn had not

dented. Because the corn was too wet for grain harvest, but we did not want the field full of volunteer corn next year, and harvesting as silage would markedly affect the long term nutrient budgets, snaplage (kernels+husk+cob) was harvested using a custom chopper.

It is interesting to look at the corn yield trends from the first 6 years (1993-1998) compared to the last 6 years (1999-2004). Among the high-input systems, the largest increase has been in CS1 with a 31 bu increase, followed by CS4 with a 20 bu increase, and lastly CS2 with a 10 bu/a increase. Both low-input systems had lost 1 bu in the latter period, with CS3 and CS5 averaging 142 and 164 bu/a, respectively, in the last 6 years. The increase in the high input is attributed to improved varieties. The lack of change in the low-input systems may be a combination of improved variety but offset by increasing weed pressure. The weed seed bank continues to build up in the CS3 and CS5 plots, particularly giant foxtail and quackgrass, respectively. In April, we collected soil samples from each system and grew them out in the greenhouse. Later in the season, as part of Amy Cook's weed id study, we counted and id'd weeds in all corn phases of each system using 1-$m^2$ quadrats.

**Soybean Phase**

Soybeans were planted on May 17 and May 27 for CS2 and CS3 respectively. A Roundup Ready (RR) variety was used on CS2 (KB241) and an organically grown food-grade variety was planted in CS3 (NC+1F61). We used a non-RR variety for Chemlite (Latham 250). Another result of the cool weather was reduced aphid pressure; so much so that beans did not need to be treated with insecticide. Beans were dry in time for wheat planting by October 5th. Yields were modest for CS2 at 50 bu/a and markedly lower in CS3 due to heavy giant foxtail pressure. Even after 2 rotary hoeings and 3 row cultivations, giant foxtail was still severe in the CS3 beans. We spent about 8 man-hr/acre hand weeding broadleaf weeds from the chemfree soybean plots.

**Wheat/Red Clover Phase**

Growing conditions in the fall of 2003 allowed good wheat stands and there was little to no winterkill on the plots. However, the cool wet weather of May and June also set the stage for head scab on wheat all across Wisconsin. The WICST plots were no exception where both 'Patriot' and 'Pioneer 35R37' had significant damage (20-30%) and heavy dockage at the elevator. To improve the quality, combines were set to blow light kernels out the back so volunteer wheat was very common. Hence, yields were about half the average at 35 bu/a.

**Forage Phases**

The new seedings in CS4 and CS5 systems were planted with Magnum V on April 4th. CS5 was planted with a mix of alfalfa, 'Forage Plus' oats, and Trapper field peas. Emergence was timely but due to the wet field conditions this spring, the new seedings had reduced vigor. The alfalfa in CS4 was stunted and chlorotic. 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. Roots were likely infected with disease. Two cuts were taken from the new seedings and 4 cuts were taken on the established forage in CS4. This year, we set up exclusion areas within each pasture and mechanically harvested from the area throughout the season. Yields and quality were comparable to the established alfalfa systems. Heifer performance was excellent averaging 1.92 lb/head/day. We plan to continue monitoring pasture productivity mechanically and with weekly hand sampling.

# GROSS MARGINS OF THE WICST CASH-GRAIN SYSTEMS: 2003 and 2004

Janet Hedtcke[1] and Josh Posner2

## INTRODUCTION

Profitability is one of the key factors that drive management decisions. Farming is no exception. Successful commodity farming, i.e. cash-grain production, is dependent upon producing and marketing large volumes of grain as efficiently as possible. Large acreage, large machinery, and large debts are all part of the business. However, growing interest in organic production uses another strategy: producing food/feed in an ecologically balanced way and usually on a smaller scale. In this approach, the idea is to promote natural or biological synergies that exist in crop rotations and through a combination of lower input costs and price premiums, more than compensate for reduced returns from lower yields, lower volume and higher labor inputs[2]. The economics of producing corn and soybeans under 3 different cropping system will be addressed in this paper.

## MATERIALS AND METHODS

The WICST cash-grain systems are compared in this paper. The WICST forage system analyses can be found in 'WICST Forage Systems Comparison: Production, Milk Models and Gross Margins' of this technical report. To review, cropping system 1 (CS1) is continuous corn with a high input level. Cropping system 2 (CS2) is a no-till corn-soybean rotation with medium inputs. Cropping system 3 (CS3) is a 3-yr rotation of corn-soybean-winter wheat/red clover with low inputs (chemical free). Although managed organically, it is not 'certified organic' due to constraints of the trial. CS1 and CS2 are scaled up from 0.7-acre plot size to 1200-acre farms while CS3, being managed without chemicals, has been scaled up from 0.7-acre plots to 600-acre farm size. Reducing the size of a farm in the CS3 rotation was based on an informal survey of organic farmers and inspectors who reported few single-family organic grain farms surpassed 600 acres. The primary reason for this was that mechanical tillage sets an upper limit on the size of a farm entirely in row/annual crops, unless most of the work can be custom hired.

Gross margins were calculated using Agriculture Budgeting Calculation Software, (ABCS; Frank and Gregory, 2000). Gross margins represent the dollars available to cover the overhead costs of capital, land, labor and management. The way to interpret the adequacy of the gross margin is to estimate the amount of dollars needed per acre to cover those overhead costs. Project economists estimate that a cash grain farmer would need approximately $35-$40 per acre to cover labor and management, $80 to $140 per acre for rent, and approximately $40-$60 per acre to cover the depreciation and interest cost associated with machinery and drying facilities owned on the farm. This adds up to approximately $155 to $240 per acre (or on average ~ $200/acre) to be covered by gross margins. Therefore, we are considering the break-even point as ~ $200/acre.

Input and output prices for each system were recorded each year. Commodity corn and soybean prices for conventional grains are taken from WI Ag Statistical Service October price. To not

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[2] repeated mechanical tillage and hand weeding

inflate the potential premiums for the organic grains, organic feed grade prices were collected from various elevators marketing organic grains (Table 1) to livestock producers. Since WI Ag Statistics Service no longer tracks wheat prices, cash price at time of harvest was used. No storage or futures options are included in the analysis; grain is sold 'right off the combine'. Trucking was charged against CS1 and CS2 at $0.04/bu and against CS3 at $0.11/bu per 100 miles and because commodity grain elevators are closer and more widespread than organic grain elevators. Corn drying costs were at $0.03/point/bu down to 15% moisture.

**Table 1. Price comparison: Conventional (CBOT) and organic feed-grade prices.***

| | Conventional $/bu | | Organic feed grade $/bu | |
|---|---|---|---|---|
| | 2003 | 2004 | 2003 | 2004 |
| corn | 2.08 | 2.25 | 3.75 | 4.00 |
| soybean | 6.50 | 5.71 | 8.75 | 12.50 |
| wheat | 3.13 | 1.52 | 3.75 | 3.50 |

* organic prices quoted from Delong, Cashton, Sunrich, Clarkson, Peavy, Didion, American Health & Nutrition

In addition to grain prices, labor requirements are an important issue when comparing conventional and organic production systems. Table 2 shows the wage for a field worker according to National Agricultural Statistic Service's Lake Region (includes Wisconsin, Minnesota and Michigan) averaging April and October rates for the course of the trial. Labor costs were included for such things as handling/hauling grain in both conventional systems and hand weeding the organic soybeans, and other miscellaneous tasks. In the 8th WICST Technical Report (1999-2000) it was determined that CS3 had labor requirements (planting, rotary hoeing, cultivating, harvesting) in both the spring and fall that would make it very difficult for a family to manage a 1200-acre farm. As a result, we decided to reduced farm size to 600 acres, and to lessen the spring workload, we assigned rotary hoeing (after two hoeings) and cultivation (after one cultivation) to be custom hired. Since farm size was reduced from 1200 to 600 acres, it was decided that the operator could harvest soybeans and plant wheat himself instead of custom hiring it done. Neither 2003 nor 2004 actually used any custom hire because rotary hoeing and cultivation were minimal. Custom rates are typically based on survey results compiled by USDA WI Ag Stats 'Wisconsin's 200X Custom Rate Guide'.

**Table 2. Field worker wage ($/hr) across years in the Lake Region of the Midwest.**

| 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5.35 | 6.01 | 5.94 | 6.47 | 6.64 | 7.29 | 7.35 | 7.43 | 7.84 | 8.21 | 9.28 | 9.28 | 9.17 |

Still, gross margin analysis is a blunt tool to compare systems with different labor requirements because owner/operator labor is not charged as a production cost, but rather must be recovered in the gross margin. Table 3 shows the estimated labor/acre that is done by the operator himself or family member, and not covered in hired labor.

| **Table 3. Owner/Operator labor for cash grain systems.** | | |
|---|---|---|
| | 2003 | 2004 |
| System | Number of hours per acre | |
| **CS1** | **1.38** | **1.30** |
| | | |
| CS2 corn | 0.91 | 0.91 |
| CS2 soybean | 0.45 | 0.45 |
| **CS2 mean** | **0.68** | **0.68** |
| | | |
| CS3 corn | 1.62 | 1.25 |
| CS3 soybean | 1.63 | 2.03 |
| CS3 wheat | 0.76 | 0.76 |
| **CS3 mean** | **1.34** | **1.35** |

## RESULTS

### Yields

Yields from the cash-grain systems are in Table 4. In 2003, corn yields were not different between CS1 and CS2 ($p<0.05$); however, CS3 corn yields were lower because they suffered from heavy weed competition as well as a later planting date. Soybean yields were slightly higher in CS2 ($p<0.05$) but both systems suffered from the dry summer weather that year. Heavy giant foxtail pressure in CS3 limited soybean yields to 33 bu/a. Wheat grain in 2003 was comparable with the trial average but straw yields were particularly low, partly due to the high cutting height to avoid contamination by the tall red clover beneath.

In 2004, CS1 and CS2 yields were not significantly different, both yielding very well in a cold growing season. However, CS3 corn was considered a failure. System 3 was replanted in mid-June because of poor initial emergence, but due to a cold growing season, grain did not reach blacklayer by the killing frost. It was decided to custom harvest as snaplage (ear + husk) because corn silage removal would result in an unusually heavy nutrient removal and no harvest would result in heavy infestation of volunteer corn in next year's soybeans. Soybean yields were also much better in CS2 vs. CS3 due to heavy weed pressure in CS3. And finally, the scab in wheat hurt yields and quality as the infected kernels were blown out the back of the combine. Straw yields continue to be very low.

| Table 4. Crop yields from WICST cash-grain systems. | | |
|---|---|---|
| | **2003** | **2004** |
| **Corn (bu/acre)** | | |
| Continuous corn (CS1) | 175.0 | 193.9 |
| After sb (No-till system) (CS2) | 176.5 | 189.0 |
| Org. 3-crop (CS3) | 110.0 | -[2] |
| *LSD (0.05)* | *17.3* | *6.9* |
| | | |
| **Soybean (bu/acre)** | | |
| After corn (No-till system) (CS2) | 35.6 | 49.8 |
| Org. 3-crop system (CS3) | 32.5 | 33.6 |
| *LSD (0.05)* | *1.6* | *10.5* |
| | | |
| **Wheat** | | |
| Org. 3-crop (CS3) grain (bu/acre) | 53.6 | 34.9 |
| Org. 3-crop (CS3) straw (tons DM/a) | 0.40 | 0.54 |

[2] Corn harvested as snaplage valued at $37/ton 'as fed' yielding on average 3.3 tons/acre, 'as fed'

**Production Costs**

The largest variable expenses incurred by the grain farmer are fertilizer, seed, pesticides and corn drying costs (Table 5). Continuous corn (CS1) incurs higher fertilizer costs than CS2 because of annual starter and nitrogen fertilizer inputs necessary for the production of corn; CS2 corn also enjoys legume credits from the soybean phase, which results in less N input needed. Furthermore, CS1's drying costs are higher than the other two systems since 100% of its acres are in corn vs. half or a third of the farm acreage in CS2 or CS3. For example, in 2003, CS1 farm wide drying costs averaged $54/a vs. $30/a for CS2 and only $11 for CS3. In 2004, corn moisture was very high at harvest, and with the high price of natural gas, drying costs were quite extraordinary at nearly $90/a for CS1. Although no pesticides are used in CS3, hand weeding is charged to the soybean phase and capped at $50/acre. The organic system (CS3) does incur higher trucking costs because organic markets are generally not as close as commodity markets and organic grain requires special tracking to maintain their identity. Diesel fuel usage serves as a proxy of operator labor. During the last two years, fuel has been highest for CS1 at around $14/acre. , Fuel costs are slightly higher for CS3 than CS2 because of repeated tillage in the former and no tillage in the latter but both are about half the cost of CS1. It is interesting to find that fuel cost isn't higher for CS3 with its heavy demand on mechanical weed control, but rotary hoeing and cultivation don't use as much horsepower than say, chisel plowing. Also, during the wheat phase, fuel costs are reduced significantly lowering the system average. The inputs costs for growing organic corn and beans are about half that of conventional corn and beans so even though organic yields are not as high as conventional ones, lower input costs result in similar or better gross margins. For example, in both 2003 and 2004, CS3 variable expenses were less than half that of CS1 and about 33% less than CS2.

| Table 5. Variable costs of the cash-grain cropping systems on WICST, 2003 & 2004. | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **Crop Phase** | **Fertilizer** | **Seed** | **Corn Drying** | **Herbicide & Insect.** | **Diesel fuel** | **Total Var. Expenses[1]** |
| | | ----------$/acre---------- | | | | | |
| 2003 | **CS1 – corn** | **29.65** | **54.00** | **54.06** | **31.13** | **13.89** | **227.42** |
| | | | | | | | |
| | CS2- corn | 32.94 | 54.00 | 59.54 | 32.07 | 9.68 | 235.82 |
| | CS2-sb | 0 | 45.00 | 0 | 15.55 | 5.84 | 95.21 |
| | **CS2-average** | **16.47** | **49.50** | **29.77** | **23.81** | **7.76** | **165.52** |
| | | | | | | | |
| | CS3- corn | 0 | 47.30 | 33.78 | 0 | 9.70 | 136.78 |
| | CS3-sb | 0 | 24.81 | 0 | 0 | 9.94 | 72.48 |
| | CS3-wheat/rc | 0 | 72.24 | 0 | 0 | 4.30 | 106.34 |
| | **CS3-average** | **0** | **48.11** | **11.26** | **0** | **7.98** | **105.20** |
| | | | | | | | |
| 2004 | **CS1 – corn** | **47.88** | **48.60** | **88.54** | **28.25** | **15.81** | **276.84** |
| | | | | | | | |
| | CS2- corn | 55.85 | 48.60 | 91.71 | 16.35 | 11.16 | 272.98 |
| | CS2-sb | 0 | 30.00 | 0 | 15.22 | 6.73 | 78.97 |
| | **CS2-average** | **27.93** | **39.30** | **45.86** | **15.79** | **8.95** | **175.98** |
| | | | | | | | |
| | CS3- corn | 0 | 80.41 | --[2] | 0 | 10.40 | 165.60 |
| | CS3-sb | 0 | 33.27 | 0 | 0 | 13.56 | 125.35 |
| | CS3-wheat/rc | 0 | 54.64 | 0 | 0 | 5.19 | 79.10 |
| | **CS3-average** | **0** | **56.11** | **0** | **0** | **9.72** | **123.35** |

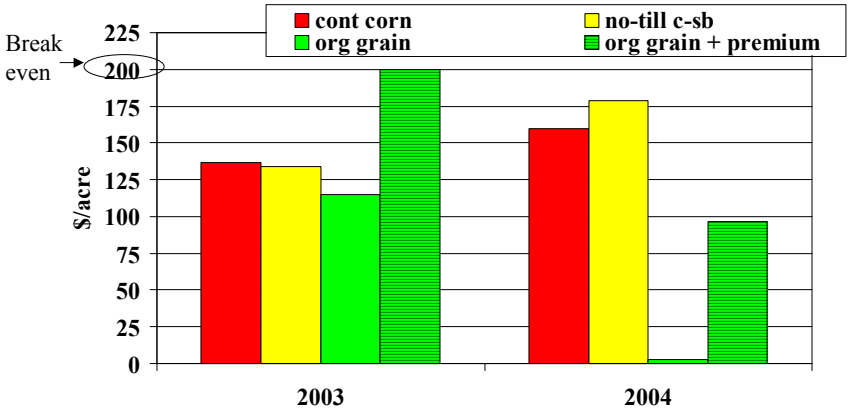
[1] Total variable expenses includes other items than just those in the table (e.g., scouting, trucking, repair & maintenance, etc.)
[2] Corn harvested as snaplage

**Gross Margins**

Gross margins without government payment were all below the break-even mark of $200/acre in both 2003 and 2004 (Fig. 1). Low commodity prices and mediocre soybean yields due to mid-summer drought were to blame in 2003. However, adding an organic feed grade premium in 2003 to CS3 boosted profits up to the break-even level. Custom rates for snaplage processing in 2004 were quite high at $52/acre. As the Fig. 1 shows, the failed corn stand along with scab problems on the wheat severely impacted gross margins for CS3. No organic premium was given to the snaplage and the already low yielding wheat was heavily docked for damaged kernels. 2004 was the first time in the history of the trial that the corn crop has failed and the

wheat was a disaster in CS3. On a real farm, an alternative crop would likely have been planted instead of replanting corn in late June of such a cold and wet spring.

**Fig. 1. Gross margins of the cash-grain systems 2003 and 2004**




*Government payments not included in analysis

Organic feed grade premiums have been holding steady for the last 6 years (Table 6) and look to stay there as organic dairy farms increase the market for organic feed.

**Table 6. Organic prices for crops sold directly from the field -feed grade for c, sb, w.**

| Year | corn | soybean | wheat |
|---|---|---|---|
| | ----------$/bu---------- | | |
| 1999 | 3.75 | 9.00 | 5.00 |
| 2000 | 3.67 | 8.00 | 4.50 |
| 2001 | 3.67 | 7.50 | 4.50 |
| 2002 | 3.67 | 7.50 | 4.50 |
| 2003 | 3.75 | 8.75 | 3.75 |
| 2004 | 4.00 | 12.50 | 3.50 |

prices quoted by Delong, Cashton, Sunrich, Clarkson, Peavy, Didion, American Health & Nutrition

## CONCLUSIONS

Generally speaking, 2003 and 2004 were difficult years for profitable grain production. While production was high for conventional systems, especially in 2004, prices were low and variable costs were high. In the organic grain system, production was modest in 2003 and largely a failure in 2004, but low input prices and feed premiums resulted in the system having highest gross margins in 2003 and modest margins in 2004. In appears due to the expansion of the organic livestock market in the upper Midwest, that feed grade premiums will remain good for the near future and the harder to attain food grade premiums will be excellent. This coupled with

lower costs, will make organic grain production competitive with conventional production. However, improved weed control will be necessary to maintain good yields and increase gross margins.

## CITATIONS

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# WICST FORAGE SYSTEMS COMPARISON:

## a. Production, Milk Models and Gross Margins

Janet Hedtcke[1], Jon Baldock[2] and Josh Posner[3]

## INTRODUCTION

Forages play a major role in Wisconsin agriculture. Over 3 million acres of Wisconsin cropland are in alfalfa, grass and clover hay and pasture, similar to the acreage in corn production (WI Ag Stats, 2004). They play a major role in dairy and beef rations as well has horse diets, providing 50 to 100% of the dry matter intake. Furthermore, cropping systems that include forages and manure result in better corn yields vs. strictly cash-grain systems (WICST data not shown). Additional benefits come from the perennial characteristic of forages such as permanent ground cover and thus little soil erosion, expanded wildlife habitat, and aesthetic beauty of a varied landscape. This paper summarizes the three forage systems of WICST comparing forage yield and quality, milk production and gross margins.

## MATERIALS AND METHODS

Historical trial data are presented from both the Arlington Research Station (ARL) and Lakeland Ag Complex (LAC) through 2002. There is no data beyond 2002 for LAC as WICST was no longer conducted at that site. System four (CS4) is a high input forage ration with 3 years of alfalfa followed by one year of corn. The alfalfa is sole seeded and herbicides are used to control weeds. Dairy manure is applied with a slinger spreader at the rate of 20 tons/acre before and after the corn phase. During the alfalfa phases, the established alfalfa is on an intensive cutting schedule with 4 cuts to be taken before Sept 15. System five (CS5) is a chemical free system of alfalfa seeded with oats and peas, a production year of alfalfa, followed by a year of corn. Dairy manure is spread at a rate of 15 tons/acre before and after the corn phase. The last cut of the plowdown alfalfa in CS5 is taken during late September to promote winterkill. The pasture (CS6) is a management-intensive rotational grazing system using dairy heifers to harvest their forage and spread their manure. Starting in 2004, exclusion areas (10' x 20') were set up in each pasture plot and mechanically harvested on a haying schedule for a yield comparison to the mechanically harvested alfalfa plots in CS4 and CS5. For more details on the grazing system, see 'Rotational Grazing with Dairy Heifers on WICST: b. Pasture and Heifer Productivity' in this report.

Forage quality was analyzed by UW Soil and Plant Analysis Lab using NIRS technology. In the last few years, relative forage quality (RFQ) has been used, which more accurately reflects the feeding value than relative feed value (RFV) when the forage contains a lot of grass that has a more readily digestible fiber fraction. Milk91 (Howard et al, 1991) was used to summarize 1992-2002 data and Milk2000 (Shaver et al, 2000) was used for 2003 and 2004 where digestibility values were included in the forage analysis reports. MILK91 uses the forage analysis (crude protein, acid detergent fiber (ADF), and neutral detergent fiber (NDF)) to calculate an approximation of a balanced ration using National Research Council (NRC) values. MILK2000 uses forage analyses (crude protein, NDF, *in vitro* NDF digestibility, starch, and non-

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fiber carbohydrate) to estimate energy content and DM intake to predict milk production per ton of forage DM.

The economic analysis is based on the concept of gross margins. Gross margins equal the dollars available to cover the costs of capital, land, and the operator's labor and management once the variable cost of production (seed, fertilizer, chemical, fuel, repairs, etc.) have been paid.. Gross margins were calculated using Agriculture Budgeting Calculation Software (ABCS) (Frank, 2000). We would estimate that a dairy farmer would need approximately $35-$40 per acre to cover labor and management, $80 to $140 per acre for rent, and approximately $40-$60 per acre to cover the depreciation and interest cost associated with machinery and drying facilities owned on the farm. This adds up to approximately $155 to $240 per acre (or on average ~ $200/acre) to be covered by gross margins. Therefore, our hypothetical the break-even point is ~ $200/acre. However, $200/acre is probably an over estimate for CS6 because of the less capital, depreciation, labor, etc. associated with this system vs. the mechanically harvested systems.

Gross revenue for CS4 and CS5 is based on the actual yield and market price based on forage quality or Relative Feed Value (RFV) during the forage phases, and grain prices during the corn phase. For example, RFV of 140 is used as the base since it is the minimal quality necessary for early lactation, high producing dairy cows (Undersander et al., 1992). This 140 RFV was assigned a price of $80 per ton of dry matter and any deviations in RFV from 140 were used to adjust the forage price by adding or subtracting $1 per RFV point. Each cutting from each plot were summed to give an annual gross margin estimate. The machinery complement was dimensioned for a 150-acre farm for both systems

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). An informal survey and recent newspaper articles revealed that custom grazing heifer raisers are getting from $0.85 to $1.50 per head per day (Agriview, Aug. 18, 2005). The price differential reflects who pays for supplemental feeding, breeding and vet costs. In our analysis, heifer income was based on a rate of $1.18/hd/d (average of $0.85 and $1.50) because we charged supplemental feed to the system but not 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. Stocking density was about 1.2 Animal Units/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 Animal Unit). It should be realized that the gross margins analysis for CS6 only pertain to the time spent on pasture and not during the off-season when cattle must be fed stored feed. Three difference scenarios are presented to show the effect on grazing GMs when days on pasture, cost of grain supplement, and amount of grain fed are varied.

## RESULTS

### HAY PRODUCTION

*New Seeding.* Forage production in the new seedings has differed between systems and years. In 2003, direct seeded alfalfa phase of CS4 produced significantly higher yields and quality than the oat-pea-alfalfa seeding in CS5 (Table 1). This can be explained because 3 cuts were taken from CS4 vs. just 1 cut taken in CS5. Weeds were a problem in that year in CS5 seeding and the

later cuts were mostly weeds and therefore removed and disposed of. Although lower quality than CS4, forage from the seeding year of CS5 produced forage suitable for many classes of livestock including far-off dry cows, unbred heifers, beef cows, horses and other livestock at maintenance nutritional requirements. Due to high potassium in the CS5 forage, particularly the oatlage, it has limited value as a sole-source forage for the transition diet of dry cows because of problems such as milk fever associated with high potassium diets.

Unlike 2003, in 2004, CS4 alfalfa seeding produced significantly less yield (albeit higher quality forage) than the CS5 oat-pea-alfalfa seeding (Table 1). Both systems were harvested two times but record rainfall (3x the norm for May) likely reduced seedling vigor by hastening root disease in the sole-seeded alfalfa. At the same time, the oats and peas in CS5 responded favorably to high moisture and produced over 2 ton/acre of forage. Pasture forage was not compared since there is not a newly seeded phase in that system.

**Table 1. Seeding year hay yield and quality at ARL 2003 and 2004.**

| | System | Yield (T dm/a) | RFV | RFQ | Protein % |
|---|---|---|---|---|---|
| 2003 | CS4 (c-**a**-a-a) | 2.91a* | 186a | 208a | 22.4a |
| | CS5 (c-**o/p/a**-a) | 2.30a | 112b | 147b | 16.7b |
| | | | | | |
| 2004 | CS4 (c-**a**-a-a) | 1.85y | 166y | 172y | 21.0y |
| | CS5 (c-**o/p/a**-a) | 4.35z | 107z | 145z | 13.9z |

*Different letters within column for each year are statistically different at $p<0.01$

*Established Alfalfa.* In 2003, alfalfa yield produced in CS4 was significantly lower than in CS5 (Table 2). Though, CS5 alfalfa was lower in forage quality than CS4 alfalfa, it was still very good quality even for high producing dairy cows. Protein levels were all above the minimum of 16.5% recommended for lactating dairy cows (NRC of dairy, 2001).

In 2004, forage yields were similar across systems (Table 2). With plenty of rainfall and soil moisture this spring, established forages thrived. Four cuts were taken from CS4 and 3 cuts from CS5 and the pasture. Impressively, pasture quality was better than the alfalfa in CS5 and it could have been higher if it were harvested on a grazing vs. a haying schedule.

**Table 2. Established year hay yield and quality at ARL 2003 and 2004.**

| | System | Yield (T dm/a) | RFV | RFQ | Protein % |
|---|---|---|---|---|---|
| 2003‡ | CS4 (c-a-**a**-a) A1 | 4.83b* | 166a | 186a | 21.1a |
| | CS4 (c-a-a-**a**) A2 | 3.37c | 162a | 181ab | 19.8b |
| | CS5 (c-o/p/a-**a**) A1 | 5.94a | 150c | 173b | 19.6b |
| | | | | | |
| 2004§ | CS4 (c-a-**a**-a) A1 | 5.08z | 157a | 175a | 22.5a |
| | CS4 (c-a-a-**a**) A2 | 5.15z | 155a | 173a | 21.9a |
| | CS5 (c-o/p/a-**a**) A1 | 4.88z | 110c | 127c | 17.2c |
| | CS6 (pasture) | 5.48z | 132b | 156b | 19.4b |

*Different letters within column for each year are statistically different at $p<0.01$

‡ CS4 2nd yr hay was only cut 3 times vs. other systems which were cut 4 times.

ESTIMATED MILK PRODUCTION

Estimated milk production is a function of dry matter production and quality. Milk production in 2003 was higher for CS4 seeding vs. CS5 seeding due to higher yield and quality (Table 3). In the established plots, milk production was similar between systems except that the final year of CS4 alfalfa was lower because only 3 cuts were taken vs 4 cuts in the other plots.

In 2004, greater yield with average quality produced 2.5 times more milk from CS5 oats-peas-alf than the pure alfalfa seeding in CS4 (Table 3). In the established phases, one less cut in CS5 resulted in lower milk production compared to CS4. Excellent pasture quality and yields produced abundant milk.

**Table 3. Milk 2000 model for WICST forage systems at ARL (2003, 2004).**

| | 2003 | 2004 |
|---|---|---|
| | Milk production (lb/acre) | Milk production (lb/acre) |
| CS4 new alf seeding | 9,162x | 5,444z |
| CS5 oat/alf seeding | 7,052y | 13,809y |
| | | |
| CS4 1st prod yr of hay | 14,093a | 15,543 a |
| CS4 2nd prod yr of hay | 10,368b | 15,803 a |
| CS5 1st prod yr of hay | 17,378a | 13,599 b |
| CS6 12th yr of pasture | N/a‡ | 16,752a |

*Different letters within column for each year are statistically different at $p<0.01$

‡ No hay exclosure data in 2003.

Looking at the forage data over the course of the trial, results from the MILK91 analysis showed no significant differences between systems within each site (Table 4).

**Table 4. Milk91 linear contrasts for WICST forage systems at both sites.**

| | Milk production (lb/acre) | |
|---|---|---|
| | ARL (through 2002) | LAC (through 1998) |
| | | |
| CS4 direct seeded alfalfa | 6,150 | 4,740 |
| CS5 oats/peas/alfalfa‡ | 6,200 NS* | 4,350 NS |
| | | |
| CS4 Hay 1 vs. | 9,740 | 8,380 |
| CS5 Hay 1§ | 10,460 NS | 8,810 NS |
| | | |
| CS4 Hay 1 | 9,590 | 8,390 |
| CS4 Hay 2¶ | 8,860 NS | 8,470 NS |

*NS= not significant at $p<0.10$; linear contrasts are for each site (LSMeans)

‡ 1990 first year of data; no data for 1991 and 1993 because oats were harvested as grain.

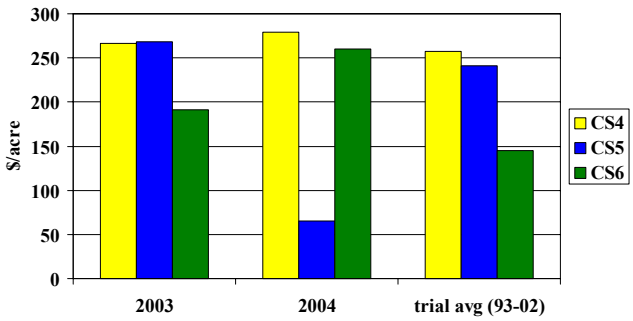
§ 1991-first year of data.

¶ 1992- first year of data.

GROSS MARGINS

Integrating forage yield and quality not only serves to estimate milk production, but it also is the basis to determine gross revenue and therefore gross margins. Figure 1 shows the gross margins in 2003 and 2004 and the trial average for the 3 forage systems. In 2003, gross margins were about equal between CS4 and CS5 averaging $267/acre. However, due to the droughty summer of 2003, supplemental hay had to be fed to heifers for about a month thus reducing CS6 gross margin to $191/acre. However, all three systems were at or above the long-term trial mean in 2003. In 2004, the failure of replanted corn stand in CS5 reduced gross margins to just over $50/acre. The pasture was as profitable as the high-input alfalfa system of CS4 since less capital (machinery, interest, depreciation, etc.) and labor are required in the grazing system. For more information on the calculation of the pasture gross margins, see the WICST 9th Technical Report (2003) on page 35.

**Fig. 1. 2003 & 2004 forage system gross margins vs. 10-yr trial mean at ARL**




SCENARIOS THAT EFFECT GM OF GRAZING

*Days on Pasture.* The average number of days on pasture at Arlington is 135, well short of a full growing season. Table 5 shows the effect on GM by keeping the heifers on pasture for more days of the year. A producer can make about $1.70/day for each day beyond 140 days. Maximizing days on pasture reduces overall yearly feeding costs and manure handling. However, wind and rain protection should be provided if heifers are going to be out on pasture in April or late October when cold, driving rain can negatively impact heifer performance. Further, shade should be available to help alleviate heat stress in the summer.

**Table 5. Effect of 'days on pasture' on gross margins. Staring date: May 1**

| # days on pasture | Removal date | Gross margin per acre |
|---|---|---|
| 140 | Sept 17 | $182 |
| 150 | Sept 27 | $199 |
| 160 | Oct 7 | $216 |
| 170 | Oct 17 | $233 |
| 180 | Oct 27 | $250 |
| assumptions: $1.18/hd/d, 2 # grain/hd/d @ $0.087/lb, 1 hr labor/d @ $10/hr, no hay fed | | |

*Cost of grain.* Another factor that affects GM is the cost of supplemental grain. Grain cost can vary depending on the source of corn. If a grazier has access to corn at close to the costs of production, then the concentrate and mineral mix (including mill charge) is about $0.087/lb. However, if the corn must be purchased, then the cost of grain mix increases to $0.15 to 0.20/lb, depending on market price. In WICST Technical Report #9 (2000 and 2001), the annual purchase price for corn was used for the years 1992-2002. If we assume 170 days on pasture, $1.18/hd/d income, 1 hr labor/d @ $10/hr, and 2 lbs grain fed per hd per day using $0.087/lb and $0.175/lb, gross margins increase from $180 to $233/acre by using the less expensive grain. It would be hard to justify paying higher grain rates if the income was less than $1.18/hd/day. If cheaper corn could not be found, then the grower might think about reducing the amount fed by focusing on feeding at times of high energy needs such as early spring when the weather can be cold and wet.

*Amount of grain fed.* Table 6 shows the effect of reducing the amount of grain fed from 100%, which is 2 lb/hd/day all season. For example, assuming 170 days on pasture, the 50% reduction rate would equal feeding 2 lb/hd/d for all of May and June and 25 days in October, the most obvious times that heifers would need supplemental energy.

**Table 6. Effect of grain supplementation* on GM.**

| Grain fed | Gross margin (per acre) |
|---|---|
| 100% | $233 |
| 75% | $246 |
| 50%* | $259 |
| 25% | $273 |

* grain held at $0.087/pound

## CONCLUSION

Forages are an important component of dairy based agriculture. WICST data has shown that both chemical free forage production (CS5), as well as rotational grazing (CS6) are both highly productive systems with suitable quality forage for many classes of livestock. The alternative systems on WICST could successfully be included on any livestock farm as milk production was shown to be very similar between systems. Good productivity and reduced inputs have made these alternative systems economically competitive with the high input, pure alfalfa system (CS4). Comparing scenarios shows the importance of keeping the animals on the paddocks for a full 170 days and assuring a source of inexpensive corn. Reducing the amount or timing of corn fed to the animals will become a priority if heifer weight gains begin to surpass the target 1.8 lbs/day.

## CITATIONS

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# ROTATIONAL GRAZING WITH DAIRY HEIFERS ON WICST:

## a. Pasture and Heifer Productivity

Janet Hedtcke[1] and Josh Posner[2]

## INTRODUCTION

Whereas more and more of the milk stream is coming from large dairies with more than 1000 animal units (1 AU=1000 lb cow), managed (rotational) grazing is an increasingly important part of the landscape. In a recent study by PATS, researchers reported that managed grazing farms consistently generated more farm income and had lower costs than confinement farms in spite of less milk per cow produced (Krigel and McNair, 2005). Managed grazing is now practiced on 22% of the states' farms with another 21% of dairy farms using some pasture for the milk cow ration. Farmers in the driftless area of Wisconsin have the highest use of grazing (49-74%), primarily on marginal land and south-central WI also has a significant number of dairymen using managed grazing at 26-35% (Kriegl and McNair, 2005). Average farm size for dairy farms using managed grazing in Wisconsin is 245 acres. In this report, we look at the productivity of the grazed paddocks between 1993 to 2004 at Arlington, and 1992-1995 at Lakeland.

## MATERIALS AND METHODS

### Background

Pastures were established at the Lakeland Agricultural Complex (LAC) and 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 seeding dates and rates). At LAC, the forage was mechanically harvested in 1991 and grazing began in 1992. At ARS, severe winterkill of the grasses required reseeding in 1992. Slow establishment due to drought delayed grazing there until the spring of 1993. Red clover was seeded (frost seeded at LAC and drilled at ARS) into the pastures on alternative years through 1995. Thereafter, red clover was seeded at a reduced rate when deemed necessary. Two of the paddocks at LAC (reps 1 and 4) were tilled and reseeded in August of 1996 to repair severe trampling damage, which occurred during the wet weather earlier that summer. The fall seeding of 1996 there failed and there was more reseeding in the fall of 1997. As a result, no grazing or mechanical harvest occurred on the plots at LAC in 1997. The WICST trial ended at LAC after the 2002 growing season.

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**Table 1. WICST pasture seeding dates and rates.**

| | Arlington Ag Research Station | | | Lakeland Agricultural Complex | | |
|---|---|---|---|---|---|---|
| Year | Date | Species | (lb/acre) | Date | Species | (lb/acre) |
| 1990 | 23-Apr | 'Marathon' red clover | 7.0 | 30-May | 'Marathon' red clover | 6.1 |
| | | 'Badger' smooth bromegrass | 8.0 | | 'Badger' smooth bromegrass | 3.0 |
| | | 'Toro' timothy | 4.0 | | 'Toro' timothy | 3.5 |
| 1992 | 30-Apr | Orchardgrass (early) | 6.0 | - | - | - |
| | | 'Badger' smooth bromegrass | 12.0 | | | |
| | | 'Toro' timothy | 6.0 | | | |
| | 31-Jul | Orchardgrass (early) | 4.5 | | | |
| 1993 | 09-Apr | 'Arlington' red clover | 12.0 | 07-Apr | 'Arlington' red clover | 20.0 |
| 1995 | 17-Mar | 'Arlington' red clover | 15.0 | 24-Mar | 'Arlington' red clover | 18.0 |
| 1996 | 26-Apr | 'Arlington' red clover | 6.0 | 09-Mar | 'Arlington' red clover* | 18.0 |
| | | | | 22-Aug | 'Arlington' red clover** | 6.0 |
| | | | | | timothy | 4.0 |
| | | | | | perennial ryegrass | 3.0 |
| 1997 | 05-Apr | 'Arlington' red clover | 6.0 | 21-Aug | reed canarygrass | 8.0 |
| | | | | | Orchardgrass (early) | 3.0 |
| | | | | | 'Arlington' red clover | 8.0 |
| 1998 | - | - | - | 30-Mar | 'Arlington' red clover*** | 15.0 |
| 2001 | 13-April | 'Arlington' red clover | 12.0 | 26-Mar | Arlington' red clover | 6.0 |
| 2003 | 02-April | 'Arlington' red clover | 8.0 | - | - | - |

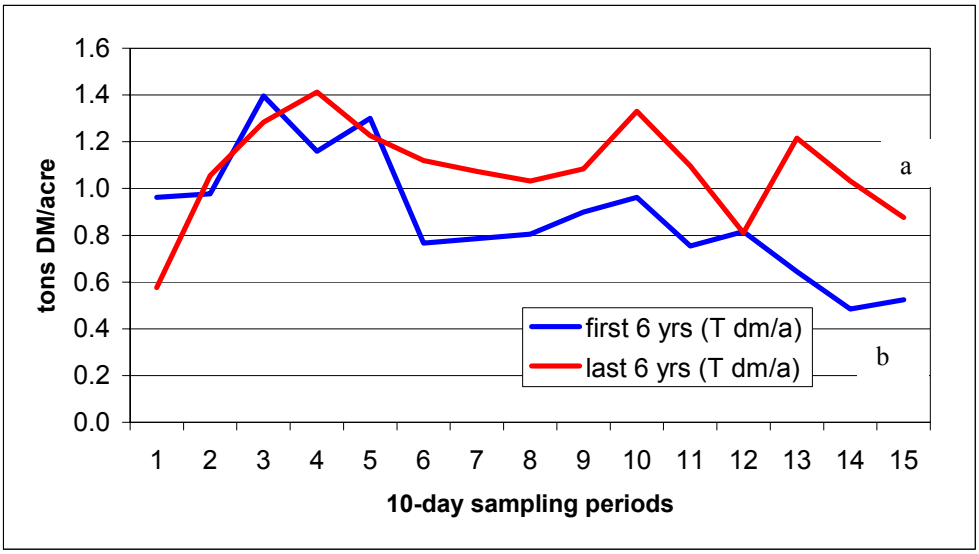
* Seeded with no-till drill; otherwise broadcast seeded except for drilling with 1990 establishment.

* * reps 1 and 2 *** Heavy seeding due to poor pasture conditions

## Pasture Management

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). The most recent, effective and practical was stocking four-to-five heifers on the plots and treating them as a cohort. This has resulted in some haying in the early spring, but the paddocks appear to be in better health (Fig. 1). Grazing pressure is adjusted throughout the season as the rate of forage growth changes. For example, in the hot, dry summer months, when forage regrowth has slowed, heifers will be given a larger area or moved through the paddock at an increased rate to maintain intake and body condition. If necessary, supplemental hay will be fed to allow adequate pasture rest and regrowth. 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, years (1993-2004) replace replicates in the analysis of variance of heifer performance.

**Fig. 1. Dry matter production on pasture plots at Arlington from 1993-98 (first 6 yrs) vs. 1999-04 (last 6 yrs).**




In both 2003 and 2004, 5 heifers at approximately 500# each were placed on the 2.8 acres of pasture for a stocking rate of 1.8 animals/acre. Heifers moved through each paddock in about a-week-to-9 days, allowing each paddock to recover for about 24 days. Since the initiation of the trial pasture *yield* or more correctly *available forage or herbage mass* has been estimated approximately weekly from three to four random quadrats ($0.25m^2$) placed in the next area that animals would be moved to, clipped to ground level (i.e. 1 to 2-in. stubble). This information was graphed by pooling the harvest quadrat data from the 11 years at Arlington. Each point represents the mean of 4-12 sampling dates that fell within the indicated 10-day period across the season. In 2004, we initiated a second measure of productivity, by establishing an exclusion area in each pasture plot, which we mechanically harvested based on a haying schedule (data found in the paper '*WICST Forage Systems Comparison: Milk Models and Economics*' within this technical report).

Forage was dried (in 60°C oven for at least 48 hr) and forage availability is expressed on a dry matter basis. Samples were 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). Relative feed value (RFV) was calculated from NDF and ADF for each sample. Recently available from SPAL is RFQ (relative forage quality), which more accurately predicts quality than RFV because it uses fiber digestibility as an indicator verses 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 bull) using stinger in a backpack sprayer (7ml of stinger/gal water). In 2003 about 0.25 gallons were used in the four plots (2.8a). In 2004 about twice that quantity of spray was used (0.5 gallons). Typically, thistles have been found along the fenceline where the mower can't reach.

*Clipping*. Since 2000, the heifer stocking density has remained constant and therefore excess

spring forage growth has been mechanically harvested as hay, which on a real farm would be used for winter feed or during forage shortages during the growing season. Generally, 2 plots each season are harvested as hay of mediocre forage quality; occasionally a good fall (1994, 1995) allowed an additional hay harvest from one of the paddocks (Tables 2 & 3). Mechanical clipping with a rotary mower (to about 4" stubble height) following a grazing episode has frequently been done through mid-July to remove seed heads and keep weeds in check thus improving the pasture stand and quality.

*Nutrient management.* Nitrogen fertilizer was not added in either 2003 or 2004. It was very dry in 2003 and timing fertilizer application with rainfall proved to be impossible. In 2004, there was so much rainfall and thus lush pasture growth that N fertilizer was unnecessary. Early spring applications of 50 lb N/a were administered at Arlington in 1993, 1994, 1996, and 2000, and in 1993 at Lakeland. In 2004, soil test P and K levels in replicates # 1 and 2 are still 'excessively high'. Rep 2 (plot 207) has historically tested excessively high in STK (388 ppm), probably due to its proximity to the old field road from the dairy barn. However, in replicates #3 and 4, STK is drawing near the replacement category (STK=115) and should start receiving K fertilizer to maintain levels.

### Heifer Management

Grazing details for years prior to 2003 have been reported in each of the previous WICST technical reports (2nd-9th).

*2003.* Five heifers were shrunk, weighed and placed on pasture from May 7th and removed September 24th (139 days on pasture). Five control animals of similar size were weighed at the same time and remained in confinement. Due to a drought during the summer months, pasture grass growth was minimal in August so supplemental hay was fed for 33 days for a total of 1020 lbs (*as fed)*. The cattle were removed earlier than normal from the plots due to lack of feed. Two pounds of grain was fed each day to each heifer.

*2004***.** Five heifers were shrunk, weighed and placed on pasture from April 27th until October 11th (167 days on pasture). Another 5 control animals (confinement) were weighed (recently moved and housed at Marshfield). 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. No supplemental hay was fed, but grain was again fed at 2 lb/hd/day throughout the season.

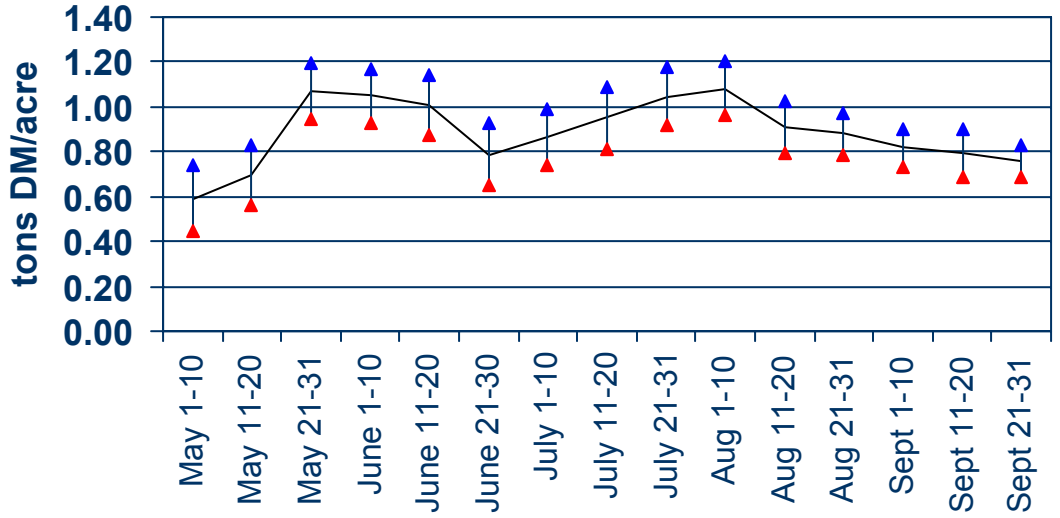
## RESULTS AND DISCUSSION

### Long-term Productivity.

Since the pasture plots were established, they have produced well with about 0.8 to 1.0 tons of available dry matter/acre at Arlington as the heifers moved to new grass, and 0.6 to 1.0 tons at Lakeland (Fig. 2 & 3). The growth curves at each site suggest that our stocking rate is about right so that a relatively constant supply of forage is available in each cycle. At ARS, the growth distribution was a bit more even than at LAC although both sites experienced the 'summer slump', or reduced forage production in late June and July. The flat lay of the paddocks at ARS allows most of the rainfall to infiltrate instead of running off and the excellent water holding

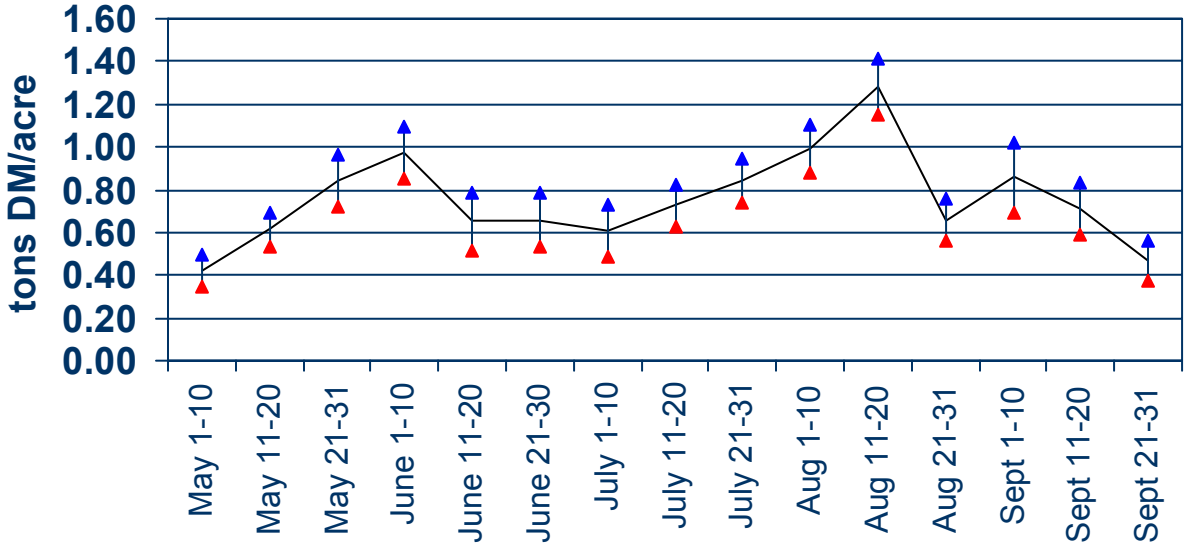
capacity of the soil are partial explanations for the sustained production during the dry summer months. At LAC, reduced summer yields were, in large part due to the fact that the paddocks are on some slope, the soils have slower infiltration rates and during several years, there has been hotter, drier summer weather at this site.

**Fig 2. Pasture forage availability at Arlington over the duration of the trial (the line is the mean for each sample period with 90% confidence interval around each mean).**




1 Data from 1993-2004 except no yield data for 1996.

**Fig 3. Pasture forage availability at Lakeland during the first four years of the trial (the line is the mean for each sample period with 90% confidence interval around each mean).**




1 Data from 1992-1995.

**Table 2. Mechanical hay harvested on pasture plots over the course of the trial at ARS.**

| Year[1] | Date | Yield (tons DM/a) | Plot # | Crude Protein (%) | RFV |
|---|---|---|---|---|---|
| 1993 | June 11 | 0.54 | 112,302,405 | 13.8 | 90 |
| 1994 | May 31 | 1.08 | All 4 plots[2] | 13.3 | 103 |
| | October 21 | 1.10 | All 4 plots[2] | 16.7 | 125 |
| 1995 | June 5 | 0.38 | All 4 plots[2] | 12.1 | 101 |
| | October 9 | 0.99 | All 4 plots[2] | 16.9 | 93 |
| 1997 | June 14 | 1.43 | 405 | - | - |
| 1998 | May 12 | 1.68 | 302 | 19.4 | 145 |
| 2000 | May 16 | 1.15 | 207 | 18.1 | 120 |
| | June 6 | 1.68 | 302 | 9.6 | 82 |
| 2001 | May 25 | 1.52 | 207 | - | - |
| | June 30 | 1.04 | 405 | 10.7 | 89 |
| 2002 | May 6 | 1.20 | 207 | - | - |
| | May 16 | 0.94 | 405 | 18.7 | 132 |
| | June 11 | 0.23 | 405 | 15.5 | 108 |
| 2003 | June 24 | 2.15 | 405 | 12.9 | 102 |
| 2004 | May 25 | 1.75 | 302 | 14.0 | 115 |

[1] No hay harvested in 1996 or 1999. [2] Only partial plot was taken as hay while the rest was grazed.

**Table 3. Mechanical hay harvested on pasture plots over the course of the trial at LAC.**

| Year[1] | Date | Yield (tons DM/a) | Plot # | Crude Protein (% of DM) | RFV[2] |
|---|---|---|---|---|---|
| 1992 | May 30 | 1.43 | 104,314,408 | 16.5 | 136 |
| 1994 | June 16 | 0.39 | All 4 plots[2] | 12.1 | 99 |
| 1995 | May 31 | 0.28 | All 4 plots[2] | 11.6 | 79 |
| | June 23 | 0.32 | 104, 314 | 15.4 | 90 |
| 2000 | June 20 | 1.59 | 408 | 16.6 | - |
| 2001 | July 9 | 0.75 | 408 | 6.6 | 84 |
| 2002 | June 9 | 1.28 | 408 | 13.9 | 102 |

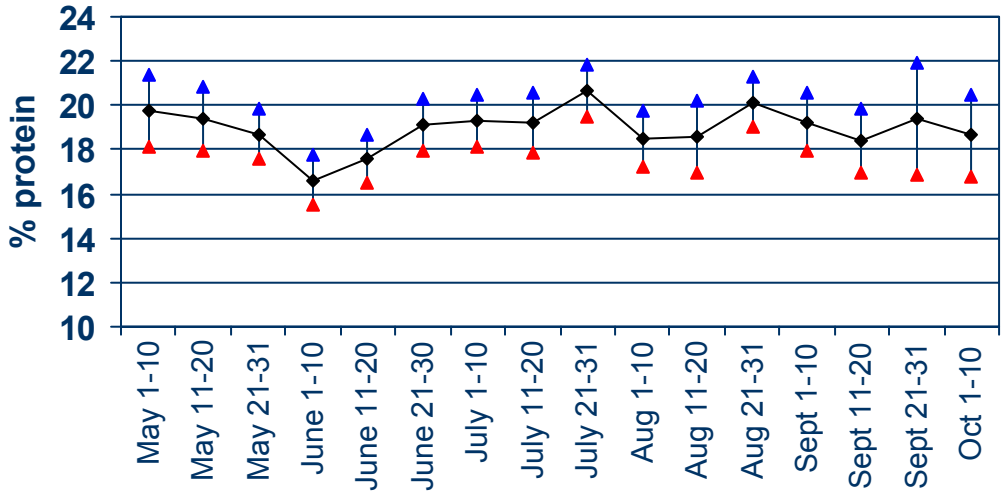
[1] No hay harvested in 1993, 1996-1999. [2] Only partial plot was taken as hay while the rest was grazed.
[2] RFV of 100 = full bloom alfalfa

## Long-term Quality

Forage quality has been very good with protein levels fairly steady within the season. Average crude protein was 18.4% across sites and peaked at 21% when grass regrowth was leafy and legumes were prevalent (Figs. 4 and 5). Generally, protein levels dropped as low as 14% during mid-June as grasses matured. The forage quality in the first week on June is significantly lower than in early May or later in the summer when the grasses are predominately leaves.

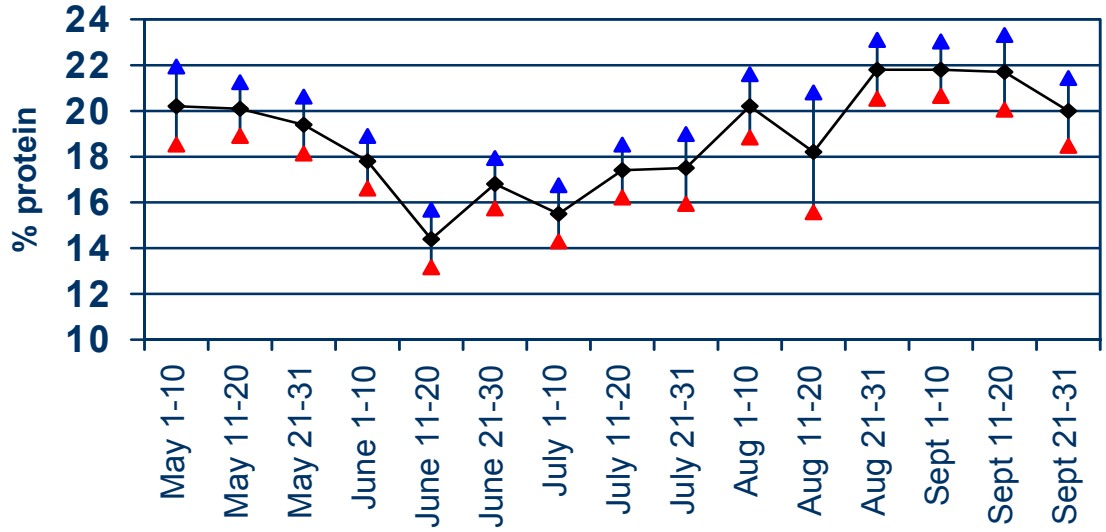
Relative feed value, averaged 123 across sites and years ranging from 100 to 160 (data not shown). (This number underestimates the quality of grass-based forage and in the future the RFQ analysis will be used). Arlington tended to have higher quality grass than LAC at most sampling points perhaps due to a more favorable environment at ARS or better plot management. A RFV between 115 and 130 is considered appropriate for growing heifers between 12 and 18 months like those used in the study.

**Fig 4. Pasture crude protein at Arlington over the duration of the trial (the line is the mean for each sample period with 90% confidence interval around each mean).**




1 Data from 1993-2004 except no yield data for 1996.

**Fig. 5. Pasture crude protein at Lakeland during the first four years of the trial (the line is the mean for each sample period with 90% confidence interval around each mean).**



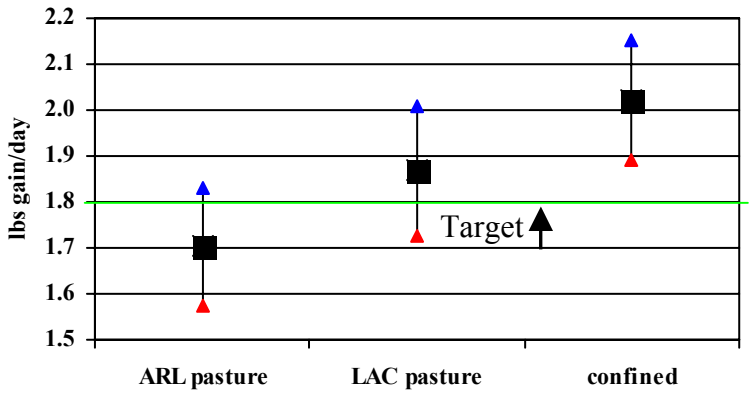

1 Data from 1992-1995.

## Heifer performance

Using years as our replication factor for heifer performance, we had 69 animals on the grazing treatment and 65 animals on the confinement treatment at ARL (12 years of data). Fifty-four animals were on pasture at LAC over the duration of the trial (7 years of data). Using 1.8 lb/day weight gain target, grazing at both sites was not statistically different from the goal as shown by the 90% confidence intervals in Fig. 6. However, the mean of 1.7 lb/hd/d is at the low end of performance and it seems that our minimal grain supplementation will continue to be necessary to provide energy. There was a difference between the confinement group and the pasture group

at ARL with the confinement group having significantly more body condition. This can be explained by their high-energy ration and less exercise compared to the pasture group. In general, confinement animals gained 2.2 lb/d or about 20% faster rate than the heifers on pasture. This is in agreement with a study by Tobert and Linn (2002) who found that feedlot heifers gained 23% more weight per day than pastured heifers. The daily ration fed to the confinement group on per heifer basis is typically 11 # alfalfa haylage (18% CP, 63% DM), 5 # corn silage (7% CP, 38% DM) and 5 # of corn-soybean meal-oat mix (16% CP, 90% DM).

**Fig 6. Heifer performance under managed grazing compared to confinement with 90% confidence interval around each mean.**




## CONCLUSION

On the excellent soils at Arlington and good soils at Lakeland, intensive rotational grazing with modest corn supplementation permits dairy heifers to gain weight at close to the recommended 1.8 lbs/head/day. The economics of the conventional alfalfa based hay vs. rotational grazing is presented in the paper '*WICST Forage Systems Comparison: Milk Models and Economics*' within this technical report. Pastured heifers, harvesting their own forage and spreading their manure can substantially reduce labor and feeding costs compared to confinement. However, one must remember that heifers are only on pasture 6 months of the year, which means stored feed must be on hand for winter feeding and extra labor must be added for manure management and some type of housing or shelter should be available against wind and rain.

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# BENEFITS OF DIVERSIFYING THE CORN-SOYBEAN ROTATION: Data from WICST 1995-2003

Janet Hedtcke[1], Josh Posner[2], and Jon Baldock[3]

## INTRODUCTION

Since the mid-20th century, farmers have become more specialized, resulting in less diverse and higher input cropping systems. However, marginal profits, increasing pest pressure, and growing concern for pollution hazard have renewed interest in diversifying cash-grain rotations. As part of the Wisconsin Integrated Cropping Systems Trial (WICST), we compared 3 cash-grain systems with different levels of crop diversity and inputs for 9 years and compared them in terms of production, profitability and environmental impact.

## MATERIALS AND METHODS

Based on early results from the WICST, which began in 1989, a 'Chemlite' system was initiated in 1995 for comparison to the existing cash grain systems of continuous corn (c-c-c), and a no-till corn-soybean system (c-sb). Chemlite is a corn-soybean-winter wheat with red clover system (c-sb-w/rc) with half the N fertilizer and pesticide inputs as the other systems. The soybeans were drilled in narrow rows in the no-till system and planted in wide rows in Chemlite to allow row cultivation. Red clover was drilled in the wheat in early spring. All plots were 0.7 acre and field-sized equipment was used. Management inputs and outputs, and commodity prices have been recorded each year. Soil fertility levels and soil nitrates were monitored from annual fall soil sampling.

The experiment was set up with two replicates in a randomized complete block. Each phase of each system existed each year during the 9-yr trial to encompass different environments and weather. All effects in the model are fixed except year and replicate, which are random. To compare corn and soybean phases, 95% confidence intervals were calculated.

The Crop Rotations Options Program (CROP) software (Baldock et al., 1998) was used to determine net returns (to labor, capital, and management). Net returns were calculated on a system basis. A 1000-acre farm was used in CROP and yearly input prices (seed, fertilizer, herbicide etc.), yields, and commodity prices (including straw sales) were entered for each system. Harvest-time commodity price (October price without storage option [WI Ag Stats, 2004]) was used across systems without any governmental price supports. We used RUSLE2 at various slope steepness and lengths to compare each system's predicted soil erosion.

## RESULTS

There were no YEAR X SYSTEM interactions for crop yield so system means are presented. Corn and soybean yields were not significantly different among the systems averaging 166.9 and 52.5 bu/a, respectively (Fig. 1). Wheat grain and straw yields in Chemlite were above the local county average (data not shown).

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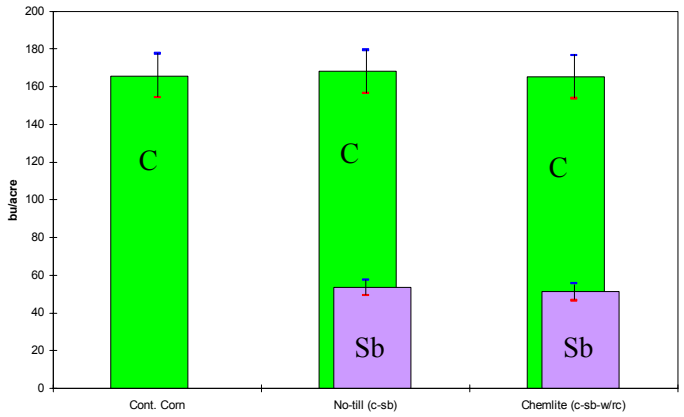
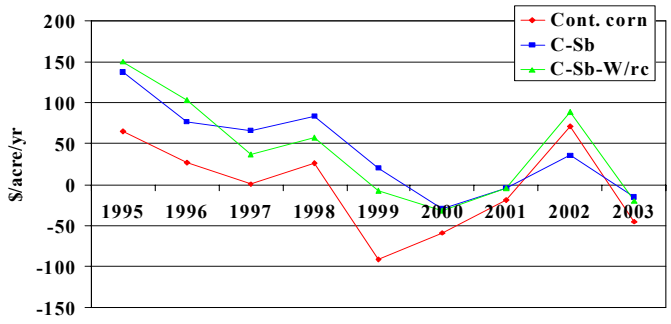
**Fig. 1. Corn and soybean yield comparison across systems with 95% confidence interval (1995-2003 avg.)**




The 9-yr. average net return was very similar between no-till c-sb ($45/a/yr) and Chemlite ($41/a/yr), both significantly higher than continuous corn ($3/a/yr). Note the precipitous trend in net returns for all systems, which was mainly due to declining commodity prices during the time of the study (Fig. 2).

**Fig. 2. Net Returns ($/a/yr) on each system over 9 years.**




Due to the annual use of starter fertilizer, the continuous corn plots had higher STP values (89 ppm) than the other systems (58 ppm). Fall soil nitrates, which could potentially leach into the ground water, were always highest under continuous corn, over twice that of typical

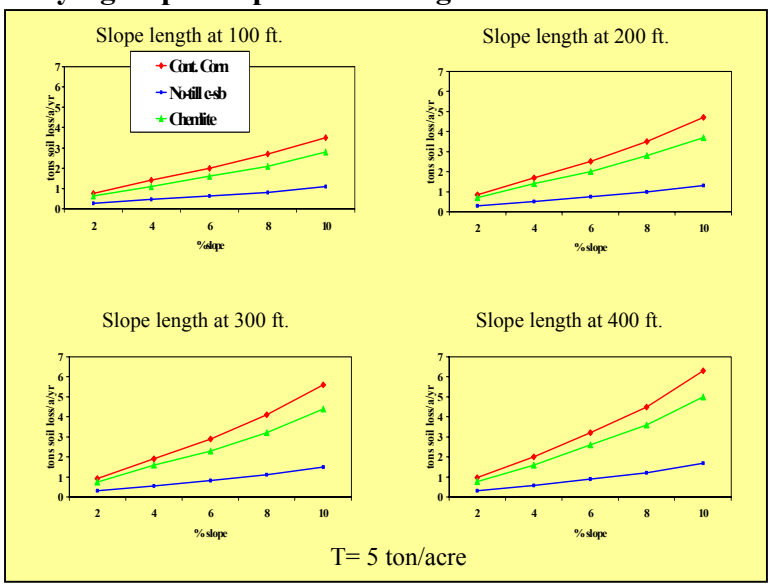
'background' nitrate levels of 50 lb/a to a 3-ft. depth. Chemlite was 41 and 23% lower than continuous corn and no-till c-sb, respectively (Fig. 3). The wheat phase in the fall and winter on a third of the farm helps to hold the nitrate in place. Furthermore, the red clover green manure reduces the use of chemical fertilizer in the following corn phase.

**Fig. 3. Fall soil nitrates in top 3 ft. of soil in each system (1999-2003 avg.)**

| System | lb $NO_3^-$-N/a | 95% CI |
|---|---|---|
| Continuous corn | 107.4 | 89.6 to 125.2 |
| No-till corn-soy | 82.5 | 65.2 to 99.8 |
| Chemlite corn-soy-wheat/red clover | 63.8 | 46.0 to 81.6 |

Soil loss was well under 'T' (T=5 T/a/yr) for the no-till c-sb on all 'farmable' slopes (Fig. 4). However, due to repeated annual tillage, the conventionally tilled systems should not be done on steep slopes longer than 300 ft. because soil loss approaches or exceeds 'T'. The continuous corn system had higher soil loss than Chemlite in all scenarios tested because the wheat and red clover cover crop provided soil protection in a third of the system. No-till methods can be added to Chemlite to further reduce soil erosion on steep slopes.

**Fig. 4. Predicted soil loss by RUSLE2 on the 3 systems at varying slope steepness and lengths.**



## CONCLUSIONS

This research shows that expanding grain rotations beyond monocropping corn is advantageous from economic and environmental perspectives. Net returns were lowest for continuous corn. Soil test P remains excessively high under continuous corn. Soil loss was always CS1>Chemlite>CS2. Increasing from two crops to three also has certain environmental advantages such as reduced nitrates and it is still economically competitive.

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# DOES DIVERSIFICATIONS REDUCE FALL NITRATES: Data from WICST

Josh Posner[1], Janet Hedtcke[2] and Jon Baldock[3]

## INTRODUCTION

Fall soil nitrate-N levels are an indirect measure of the synchrony between nitrogen availability during the growing season and crop nitrogen uptake in agricultural fields. Also, between late fall and the following spring these nitrates can leach below the rooting zone and be lost to the agricultural system. As a result, fall monitoring of soil nitrates is one measure of potential environmental impact of alternative production systems. For this reason we monitored nitrate-N on all 14 phases of the six cropping systems in the Wisconsin Integrated Cropping Systems Trials (WICST) at two locations in southern Wisconsin.

## MATERIALS AND METHODS

In 1990, the trial was initiated at Arlington and Elkhorn, Wisconsin on silt loam soils developed under prairie vegetation. The trial compares three cash-grain systems and three forage based systems. Plots are 0.7 acres in size, all phases are present every year and each system is replicated four times at both locations. In late October/early November, we sampled the plots for fall nitrates. Each sample consisted of six cores that were taken as 3-paired samples across the plot and bulked at 0-12 inches, 13 to 24 inches and 25-36 in depths. Initially (1990-1996) sampling was done by hand with a 1-in. diameter probe and subsequently (1997-2003) with a truck mounted 1.25-in. diameter hydraulic probe. Each year samples were taken from adjacent land to serve as non-agricultural, background checks.

All phases of the six systems were up and running by 1993, and until 1998, the treatments were equivalent at both sites. Shortly thereafter the Elkhorn site was terminated and the trial continues at the Arlington site. Nitrate-N was extracted from the top 3 feet of soil using a 2M KCl extractant and analyzed with a Lachet Flow Injection Analyzer. The SAS ProcMix model was used for this analysis, where year and block where considered random variables.

## RESULTS

When averaged over rotation phases, the ranking of the systems fall soil nitrate-N levels were nearly the same at both locations. Continuous corn (CS1) had the highest levels at both sites, and the rotationally grazed paddocks (CS6) had the lowest levels at Arlington, while the chemical free grain system (CS3) was lowest at Elkhorn (**Fig. 1 and 2**). Somewhat surprisingly, the no-till corn soybean system (CS2) operated under Best Management Practices was very similar in fall nitrates to the two dairy rotations amended with manure (CS4 and CS5). The chemical free grain system (CS3) and the rotational grazing (CS6) were among the lowest at both sites and not significantly different from each other. All six cropping systems left nitrate-N levels that were significantly above the standard background level in Wisconsin of 50 lbs nitrate-N/3 feet (Bundy, 1994).

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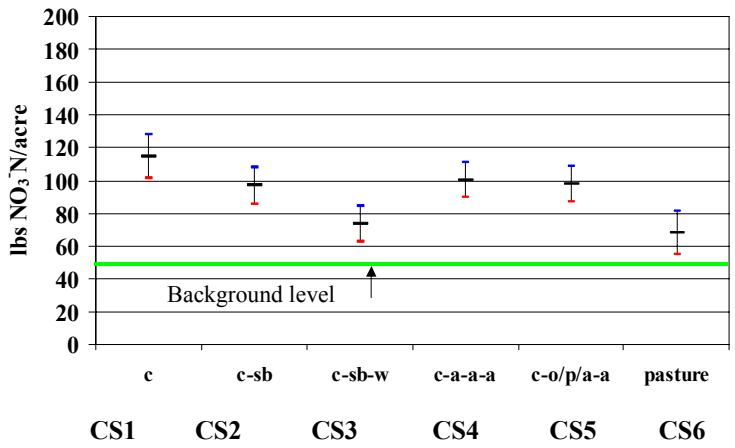
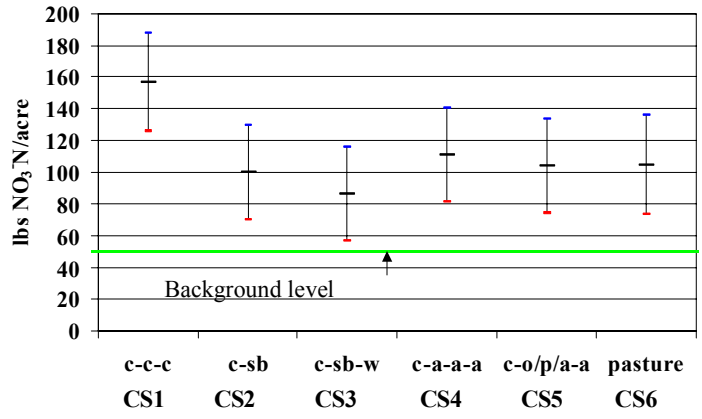
# Fig. 1. Cropping Systems Fall Nitrates

## Mean and 90% Confidence Intervals
## Arlington (1993-2003)




# Fig. 2. Cropping Systems Fall Nitrates

## Mean and 90% Confidence Intervals
## Elkhorn (1993-1996)



Corn was the "hot" phase in the dairy rotations due to the combination of legume credits plus manure **(Fig. 3 and 4)**. In the grain rotations, continuous corn had the highest nitrate-N levels, but the corn and soybean phases of systems CS2 and CS3 were nearly equivalent. The wheat/red clover phase in the chemical free system (CS3) had the lowest mean nitrate-N levels at both sites and it was the only phase that was not significantly different from the background level at both sites. This was probably due to the production of wheat with only soil organic matter mineralization and soybean legume credits and then the vigorous growth of red clover that was only undercut, not incorporated in the late fall. In this system wheat yields averaged 54 bu/a and corn yields were 146 bu/a. (WICST Technical Report, 2003).

**Fig. 3. Crop Phase Fall Nitrates**
**Mean and 90% Confidence Intervals**
**Arlington (1993-2003)**

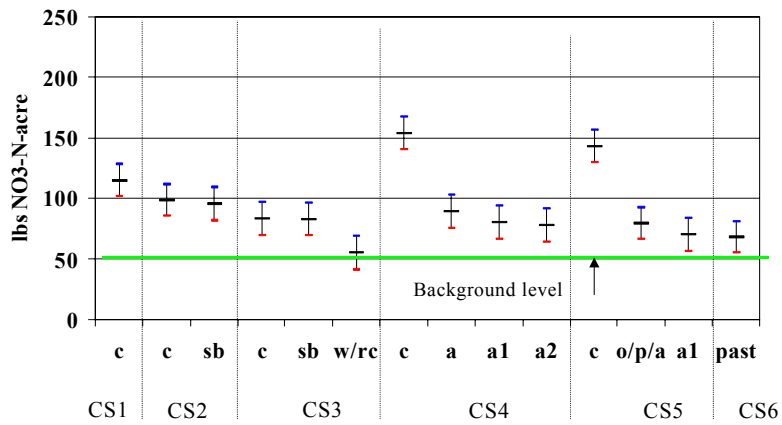
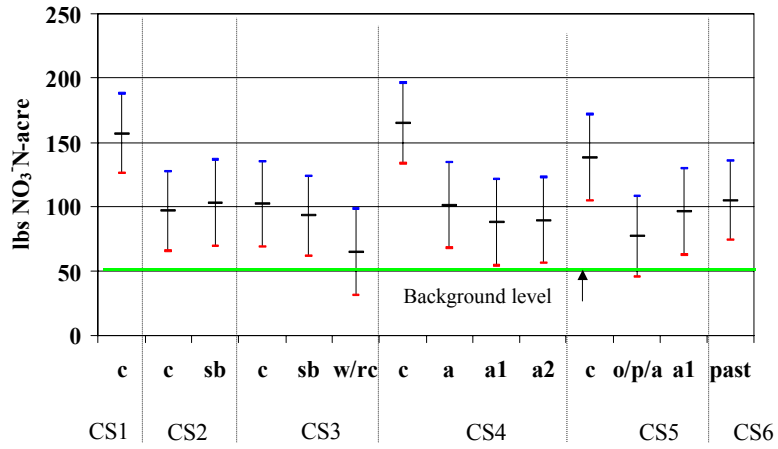



**Fig. 4. Crop Phase Fall Nitrates**
**Mean and 90% Confidence Intervals**
**Elkhorn (1993-1996)**



## CONCLUSIONS

This work suggests that all the agricultural systems studied did have significantly higher levels of fall nitrates than the background level of 50 lbs nitrate-N/3 feet. Also, both the forage based and grain based systems resulted, on average, in equally high levels of fall nitrate-N. The most benign systems were the chemical free grain (CS3) and rotational grazing forage (CS6) systems. The highest fall soil nitrate-N levels were associated with corn production especially when corn received both legume-N and manure-N. With both the grain and forage systems, the lowest fall nitrate-N levels were associated with the most diversified cropping systems.

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# EVALUATION OF THE ILLINOIS SOIL NITROGEN TEST FOR CORN PRODUCTION IN WISCONSIN

J.T. Osterhaus, L.G. Bundy, and T.W. Andraski

## JUSTIFICATION AND STATEMENT OF PROBLEM

Improved nitrogen (N) management in corn production is needed to optimize economic returns to farmers and minimize environmental impacts associated with agricultural N use, specifically, nitrate enrichment of groundwater and hypoxia of the Gulf of Mexico. In recent years, improving nitrogen management has been made through the use of soil nitrate testing in Wisconsin (Bundy and Andraski, 1995; Andraski and Bundy, 2002), although additional improvements in predicting crop N requirements on a site-specific basis are needed. A North Central Regional study (Bundy et al., 1999) showed that preplant (PPNT) and presidedress (PSNT) soil nitrate tests could improve identification of sites where corn would not respond to N fertilization, but the use of soil nitrate tests in cropping systems with substantial amounts of organic N mineralization was less promising and indicated a need to better understand and quantify N mineralization in cropping systems (Bundy et al., 1999). A major obstacle to improve N management is the lack of a reliable technique to estimate the N mineralization component of the crop N supply. A recent test based on measuring the amino sugar content of soils (Khan et al., 2001) shows promise for predicting corn N response where variation in N availability is mainly due to differing levels of N provided by N mineralization. Amino sugars are a structural component of the microbes that result in nitrogen mineralization, therefore measuring amino sugars could be an indirect indication of N-mineralization. Research is needed to evaluate this method (Illinois soil nitrogen test) in a range of soil climates and previous management environments to determine its potential for improving N management in Wisconsin and other locations.

## OBJECTIVE

Calibrate the amino sugar N test method (Illinois soil nitrogen test – ISNT) for predicting corn nitrogen rates in Wisconsin using established experiments with a range in N availability.

## SUMMARY OF PREVIOUS WORK

Amino sugar-N accounts for about 10-15% of the total N in most soils. Recent work in Illinois (Khan et al., 2001; Mulvaney et al., 2001) shows that amino sugar-N content is a good indicator of the need for N fertilization in corn production. In the Illinois research, 11 of 18 corn N response experiments showed no response to additional N fertilizer. Analysis of amino sugar-N in soils from these 18 N response experiments showed a good inverse relationship between the magnitude of corn yield response to N and the amino sugar content of the soil. All of the non-responsive sites had amino sugar-N test values of more than 250 ppm while sites where applied N fertilizer resulted in increased yields test values were less than 250 ppm. These findings indicate that the Illinois soil nitrogen test has the potential to improve N fertilization recommendations for corn on a wide range of soils. This paper will discuss the performance of the Illinois soil nitrogen test alone and in conjunction with soil nitrate-N measurements for predicting corn yield response to N fertilization in southern Wisconsin.

## PROCEDURE

The experiments were located on several of the established cropping systems treatments in the Wisconsin Integrated Cropping Systems Trial (WICST) at the Arlington Agricultural Station. Access to the WICST experimental site is provided through the cooperation of Dr. J.L. Posner, University of Wisconsin-Madison, Department of Agronomy.

Research using the Wisconsin Cropping Systems Trial (WICST):

The Wisconsin Integrated Cropping Systems Trial (WICST) at the Arlington Research Station was initiated in 1990 and includes six cropping systems with a range of crop diversity, management intensity, and external or purchased inputs (Griffith and Posner, 2001). The trial features large individual plot size (0.70 acres) and the cropping systems have been managed uniformly for more than ten years. Two systems were of special interest for the evaluation of the amino sugar N test, specifically, fall plowed continuous corn (CC) and no-till soybean-corn rotation (SC). Nitrogen response experiments were established in each of these two cropping systems using a randomized complete block design with four replications. Nitrogen fertilizer treatments were hand broadcast as ammonium nitrate at rates of 0, 60, 90, 120, 150, 180, and 210 lb N/acre soon after corn planting. Individual plots were six rows wide and 30 ft. long. Corn was planted using an adapted hybrid, 30-inch row spacing, and a target plant density of 28,000-30,000 plants/acre. Corn silage yield by harvesting 6 randomly selected plants from the two center rows. Corn grain yields were determined in each plot by harvesting the two center rows with a plot combine. The N rate structure in the corn sequences allowed determination of corn yield response to N and an estimate of the economic optimum N rate (EONR). Regression analysis was used to establish the relationship between (EONR) for corn and soil N tests.

Soil samples were collected before corn planting from each plot according to the following plan: 1) Preplant soil samples (0-3 ft depth in 1-ft increments) for soil nitrate determinations were taken in April; 2) Soil samples for the amino sugar-N analysis were collected at the same time from the 0-6 and 6-12 inch depths; 3) Pre-sidedress soil samples to one foot depth were collected in early June, at approximately the v-6 stage; and 4) at the end of season (November) soil samples were collected after corn grain harvest (0-3 ft depth in 1-ft increments) to see if any residual nitrate-N remained after the growing season. Preplant soil samples were analyzed for nitrate-N (Bundy and Meisinger, 1994) and amino sugar-N analysis was performed as described by Khan et al. (2001). Nitrate analysis for the pre-sidedress and fall nitrate tests were conducted following the preplant sampling method. The second year experiments in the WICST experiment were moved to a new location within the experiment to avoid any residual effects of the N rate treatments from the previous year.

## RESULTS AND DISCUSSION

Soil nitrate and amino sugar-N content:

In the 2003 growing season, preplant soil profile (0-3 ft) $NO_3$-N contents obtained in April were significantly higher in CC (142 lb/a) than in SC (84 lb/a) and about one-half of this was in the top one foot (Table 1). Pre-sidedress soil $NO_3$-N contents (0-1 ft) obtained in June were not significantly different between previous crops (57 lb/a in CC and 40 lb/a in SC.

During the 2004 growing season, preplant soil profile (0-3 ft) $NO_3$-N contents obtained in April were nearly equal in both CC (44 lb/a) and SC (53 lb/a) resulting in no credit in the CC rotation and only 3 lb/a N-credit in the SC rotation (Table 2). Pre-sidedress soil $NO_3$-N contents (0-1 ft) obtained in June were not significantly different between previous crops (33 lb/a in CC and 26 lb/a in SC),

The preplant samples were also analyzed using the ISNT. The values also show that in both years only the CS rotation in 2003 would have responded to additional N fertilizer based on the critical value of 235 ppm determined by Khan and Mulvaney (Khan et al., 2001). However, this is not the N response that was observed in the field.

In both 2003 and 2004, soil samples were also obtained in approximately 7-day increments from two depths (0-6 and 6-12 in.) from one replication for each of the two previous crops throughout the growing season. In general, little change in ISNT values was apparent over the course of the growing season and the apparent differences over time are likely due to spatial variability. This suggests that the ISNT is measuring a more constant and stable fraction of the soil N pool instead of a variable and plant available N pool.

**Corn silage and grain yield**:

**Corn Silage Analysis**:

The 2003 corn silage yield averaged across N rates for CC and SC was 8.95 and 9.03 tons DM/acre, respectively, and was not significantly different. Silage yield without N fertilizer was 6.90 and 5.90 tons DM/acre for CC and SC, respectively. Regression analysis of the N response data resulted in an economic optimum N rate (EONR) of 175 lb/acre for CC and 156 lb/acre for SC (Table 4). Silage yields at the EONR were 9.70 tons/acre for CC and 9.81 tons/acre for SC.

The 2004 corn silage yield averaged across N rates for CC and SC was 6.60 and 7.26 tons DM/acre, respectively, and was not significantly different. Silage yield without N fertilizer was 5.51 and 5.66 tons DM/acre for CC and SC, respectively. Regression analysis of the N response data resulted in an economic optimum N rate (EONR) of 63 lb/acre for CC and 109 lb/acre for SC (Table 5). Silage yields at the EONR were 5.98 tons DM/acre for CC and 7.64 tons/acre for SC.

**Corn Grain Analysis:**

In 2003, the effect of previous crop on corn grain yield was not significant. Grain yields without N fertilizer were 119 bu/acre for CC and 109 bu/acre for SC. A significant grain yield response to N fertilizer occurred with yield increases of about 55% for CC and 90% for SC at the non-limiting N rate. Similar to silage, grain yield responded to slightly higher N rates in CC compared with SC (Table 6). The EONR for CC was 196 lb/acre resulting in a yield of 184 bu/acre compared with SC which had an EONR of 160 lb/acre with a corresponding yield of 206 bu/acre.

During 2004, the effect of previous crop on corn grain yield was not significant. Grain yields without N fertilizer were 144 bu/acre for CC and 146 bu/acre for SC. A significant grain yield response to N fertilizer occurred with yield increases of about 33% for CC and 36% for SC at the non-limiting N rate. Similar to silage, grain yield responded to slightly higher N rates in CC

compared with SC (Table 7). The EONR for CC was 109 lb/acre resulting in a yield of 188 bu/acre compared with SC which had an EONR of 100 lb/acre with a corresponding yield of 191 bu/acre.

End-of-season soil nitrate:

In 2003, soil profile (0-3 ft) $NO_3$-N contents at the end of the growing season were significantly higher in CC than in SC at all N rates (Table 8). A linear relationship between N rate and soil $NO_3$-N content was apparent for both previous crops. For CC, soil $NO_3$-N values ranged from 21 to 120 lb/acre at the 0 to 210 lb/acre N rate. For the full range of N rates in SC, $NO_3$-N values ranged from 7 to 106 lb/acre.

The 2004 growing season soil profile (0-3 ft) $NO_3$-N contents at the end of the growing season were not significantly different in either rotation all N rates (Table 9). A linear relationship between N rate and soil $NO_3$-N content was apparent for both previous crops. For CC, soil $NO_3$-N values ranged from 33 to 70 lb/acre at the 0 to 210 lb/acre N rate. For the full range of N rates in SC, $NO_3$-N values ranged from 22 to 119 lb/acre.

## SUMMARY

The amino sugar-N content of soil based on the results of the ISNT is not adequate to correctly determine crop N need. The N recommendation based on the ISNT results given the critical value of 235 ppm would have resulted in no additional N application in both 2003 and 2004 except in the 2003 CS rotation, resulting in under application of N.

The 2003 and 2004 growing seasons resulted in very different N recommendations for each year and for each crop rotations. The ISNT values differed very little from one growing season to the next and throughout each of the growing seasons. This shows that the ISNT is measuring a more constant and stable fraction of the soil N pool instead of a variable and plant available N pool.

Nitrogen rate recommendations based on the preplant soil nitrate test (PPNT) would have resulted in below optimum N rates for both CC and SC in 2003, while in 2004 over-application would have resulted in both cropping rotations. Nitrogen rate recommendations based on the presidedress soil nitrate test (PSNT) for the 2003 season underestimated the EONR for both rotations. In 2004, the PSNT resulted in a slight over-application of N fertilizer in both the CC and SC rotation (about 20-30 lb. over-application). Table 10 summarizes the EONR compared UW recommendations and soil nitrate tests. Further research will evaluate whether a combination of soil N tests (i.e. PPNT or PSNT and ISNT) will improve site-specific N rate recommendations.

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Table 1. Effect of previous crop on preplant (April) soil profile $NO_3$-N levels, Arlington 2003.

| | Previous crop † | |
|---|---|---|
| Soil depth | Corn | Soybean |
| | ---------- soil $NO_3$-N, lb/acre ---------- | |
| 0 - 1 | 69 | 36 |
| 1 - 2 | 49 | 32 |
| 2 - 3 | 24 | 16 |
| 0 - 3 | 142 | 84 |

† Previous crop (0-3 ft) $p>f = 0.01$.

Table 2. Effect of previous crop on preplant (April) soil profile $NO_3$-N levels, Arlington 2004

| | Previous crop † | |
|---|---|---|
| Soil depth | Corn | Soybean |
| | ---------- soil $NO_3$-N, lb/acre ---------- | |
| 0 - 1 | 18 | 20 |
| 1 - 2 | 14 | 16 |
| 2 - 3 | 12 | 17 |
| 0 - 3 | 44 | 53 |

† Previous crop (0-3 ft) $p>f = 0.25$.

Table 3. Preplant ISNT values

| Crop Rotation | Sample Depth (ft) | Average ISNT Value (ppm) | |
|---|---|---|---|
| | | 2003 | 2004 |
| Cont. Corn (CS1) | 0-1 | 291 | 252 |
| Soybean Corn (CS2) | 0-1 | 207 | 259 |

Table 4. Economic optimum N rate for corn silage yield following corn and soybean, Arlington 2003.

| Previous crop | n ‡ | Model | $R^2$ | EONR † | Yield at EONR |
|---|---|---|---|---|---|
| | | | | lb/acre | ton/acre |
| | | | | | |
| Corn | 27 | $y = 6.98 + 0.029x - 0.000077x^2$ | 0.42 | 175 | 9.70 |
| Soybean | 20 | $y = 5.83 + 0.049x - 0.00015x^2$ | 0.58 | 156 | 9.81 |

† Based on $0.15/lb N fertilizer and $20/ton corn silage at 70% moisture.
‡ n = 27 and 20 due to the removal of some plots from the experiment due to heavy weed, insect, and rodent damage.

Table 5. Economic optimum N rate for corn silage yield following corn and soybean, Arlington 2004.

| Previous crop | n ‡ | Model | $R^2$ | EONR † | Yield at EONR |
|---|---|---|---|---|---|
| | | | | lb/acre | ton/acre |
| | | | | | |
| Corn | 27 | $y = 5.5443 + 0.00998x - 0.0000492x^2$ | 0.37 | 63 | 5.98 |
| Soybean | 20 | $y = 5.6875 + 0.0321x - 0.00013x^2$ | 0.26 | 109 | 7.64 |

† Based on $0.25/lb N fertilizer and $20/ton corn silage at 70% moisture.
‡ n = 27 and 20 due to the removal of some plots from the experiment due to heavy weed, insect, and rodent damage

Table 6. Economic optimum N rate for corn grain yield following corn and soybean, Arlington 2003.

| Previous crop | n ‡ | Model | $R^2$ | EONR † | Yield at EONR |
|---|---|---|---|---|---|
| | | | | lb/acre | bu/acre |
| | | | | | |
| Corn | 27 | $y = 120 + 0.60x - 0.0014x^2$ | 0.64 | 196 | 184 |
| Soybean | 20 | $y = 108 + 1.17x - 0.0035x^2$ | 0.63 | 160 | 206 |

† Based on $0.15/lb N fertilizer and $2.50/bu corn grain.
‡ n = 27 and 20 due to the removal of some plots from the experiment due to heavy weed, insect, and rodent damage

Table 7. Economic optimum N rate for corn grain yield following corn and soybean, Arlington 2004.

| Previous crop | n ‡ | Model | $R^2$ | EONR † | Yield at EONR |
|---|---|---|---|---|---|
| | | | | lb/acre | bu/acre |
| | | | | | |
| Corn | 27 | $y = 144 + 0.705 - 0.00278x^2$ | 0.84 | 109 | 188 |
| Soybean | 20 | $y = 147 + 0.781x - 0.0034x^2$ | 0.81 | 100 | 191 |

† Based on $0.25/lb N fertilizer and $2.50/bu corn grain.
‡ n = 27 and 20 due to the removal of some plots from the experiment due to heavy weed, insect, and rodent damage

Table 8. Effect of previous crop and corn N rate on end-of-season (October) soil $NO_3$-N levels (0 to 3 ft) following corn, Arlington 2003.

| Previous crop | N rate, lb/acre | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 60 | 90 | 120 | 150 | 180 | 210 | Mean † |
| | ---------- soil $NO_3$-N, lb/acre ---------- | | | | | | | |
| Corn | 21 | 41 | 55 | 79 | 93 | 103 | 120 | 72 a § |
| Soybean | 7 | 19 | 37 | 34 | 66 | 87 | 106 | 51 b |
| Mean ‡ | 16 e | 32 de | 46 cde | 59 bcd | 84 abc | 94 ab | 115 a | |

† Previous crop $p>f = 0.03$.
‡ N rate $p>f = <0.01$. Previous crop x N rate $p>f = 0.97$. CV = 56%.
§ Mean values followed by the same letter are not significantly different at the 0.05 probability level.

Table 9. Effect of previous crop and corn N rate on end-of-season (October) soil $NO_3$-N levels (0 to 3 ft) following corn, Arlington 2004.

| Previous crop | N rate, lb/acre | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 60 | 90 | 120 | 150 | 180 | 210 | Mean † |
| | ---------- soil $NO_3$-N, lb/acre ---------- | | | | | | | |
| Corn | 34 | 33 | 36 | 40 | 47 | 46 | 70 | 44 |
| Soybean | 22 | 26 | 23 | 33 | 33 | 119 | 68 | 46 |
| Mean ‡ | 28 b § | 29 b | 30 b | 36 b | 40 b | 82 ab | 69 ab | |

† Previous crop $p>f = 0.86$.
‡ N rate $p>f = 0.03$. Previous crop x N rate $p>f = 0.23$.
§ Mean values followed by the same letter are not significantly different at the 0.05 probability level.

Table 10. Summary of EONR compared to UW recommendations and soil nitrate tests.

| Growing Season | 2003 | | 2004 | |
|---|---|---|---|---|
| Previous Crop | Sb | C | Sb | C |
| EONR † | 160 | 196 | 100 | 109 |
| UW Recommendation | 120 | 160 | 120 | 160 |
| PPNT ‡ | 86 | 68 | 117 | 160 |
| PSNT § | 103 | 120 | 134 | 127 |

† Economic optimum nitrogen rate (lb/a).
‡ Preplant soil nitrate test recommendation (lb/a).
§ Pre-sidedress soil nitrate test recommendation (lb/a).

# VERTICAL DISTRIBUTION OF PHOSPHORUS UNDER LONG-TERM CROPPING TRIALS

Juliane M. Meyer and Phillip Barak

## INTRODUCTION

Historically, due to its high soil fixation rates and low solubility, phosphorus has not been considered an environmental menace, but years of over-application and the shift in American agriculture from small family farms to large corporate enterprises (McDowell et al., 2001; Sharpley et al., 2001) has led to phosphorus buildup and leaching in many soil types (Eghball et al., 1996; Lucero et al., 1995; Novak et al., 2000; Whalen and Chang, 2001). In addition, phosphorus accumulation in the upper soil profile can be exacerbated by conservation tillage with significant vertical stratification of nutrients occurring (Cruse et al., 1983; Holanda et al., 1998; Howard et al., 1999; Robbins and Voss, 1991; Scheiner and Lavado, 1998; Shear and Moschler, 1969). Because of these issues, the objective of this research was to examine the vertical distribution of phosphorus under the well-managed cropping systems established at the Wisconsin Integrated Cropping Systems Trials (WICST) in an attempt to determine the location of labile phosphorus and assess the potential negative environmental impacts based on the placement of the phosphorus.

## SITE HISTORY

Prior to the establishment of the Arlington Agricultural Research Station in Arlington, Wisconsin, the 28 ha of land that is now the site of the WICST plots was privately held and farmed. Farmsteads were located at various sites near the current day location of the WICST site, but one farmhouse and the accompanying outbuildings occupied the easternmost portion of the site, next to US-51. Research station records for these fields began in 1961, and at that time the acreage was all farmed as alfalfa hay. Over the ensuing years, the land was divided into three fields and planted in a variety of crops including oats, alfalfa, and corn with various phosphorus applications ranging from 0 to 82 kg P $ha^{-1}$. The site also has a history of heavy manure application due to its close proximity to local dairies; however, because manure has often been considered a waste product and not a nutrient source, the application rates were not recorded. The WICST trial was initiated in 1990.

## HYPOTHESES

***Bray-1 phosphorus soil test levels*:** The soil test phosphorus (STP) levels on all the plots were excessively high at the initiation of the trial and one goal in Best Management Practices was to bring these levels to optimum. It was hypothesized that the alfalfa-corn system (CS4) would have the highest levels of STP after 12 years of cropping due to the additions of manure and fertilizer, followed by the continuous corn treatment (CS1) since starter fertilizer, high in phosphorus, was applied annually. The corn-soybean rotation (CS2) would follow since P fertilizer was only added to the corn phase. It was anticipated that the rotational grazing (CS6) would follow due to the lack of added fertilizer, and simple recycling of the grazing and subsequent manure deposition. The rotation with lowest STP values would be CS3, which had no P fertilizer or manure additions, but annual removal of corn, soybeans and wheat + straw. (CS4>CS1>CS2>CS6>CS3).

***Vertical stratification*:** It was anticipated that two factors would be important in P-stratification: tillage and crop harvest. Considering primarily tillage, the greatest stratification would occur in the no-till systems (CS2 and CS6), followed by the high input, conventional tillage systems (CS1 and CS4) and then the low input conventionally tilled CS3. Looking at harvest management, it was thought that the removal of the forage in CS6 would lessen phytocycling compared to leaving the corn and soybean residue on the surface in CS2. By the same token, the alfalfa harvest would reduce P-enrichment of the soil surface compared to CS1 where corn stover was left on the field. (CS2>CS6>CS1>CS4>CS3)

***Soil sorption isotherms*:** It is thought that soils with high levels of STP, or having received high amounts of P inputs, would have lower sorption capabilities and greater soil solution phosphorus, presenting a situation where P leaching could potentially occur. Because of this, the cropping systems that still receive phosphorus inputs (either mineral or manure) would have a greater chance of exhibiting vertical P movement.

## MATERIALS AND METHODS

***Field Sampling***: Duplicate soil cores, 45-mm in diameter (1 ¾") and 1-m depth, were obtained from each plot in five of six cropping systems in the fall of 2002 and again in the springs of 2003 and 2004 in repetitions 1 and 2. The systems sampled include: continuous corn, CS1; corn-soybean, CS2; corn-soybean-winter wheat-red clover, CS3; corn-alfalfa-alfalfa-alfalfa, CS4; and, pasture, CS6. The sampled plots were in the corn phase of each rotation in 2002, with the exception the rotational grazing system, and each followed their rotation sequence in 2003 and 2004. All the plots had been in their respective rotation for 12 years prior to sampling. Two sets of control cores were removed from center of the grass alleyways between plots 112 and 113 in repetition I and plots 206 and 207 in repetition II.

After removal, cores were stored intact in plastic capped liners (Giddings Machine Company Inc., Windsor, Colorado; www.soilsample.com) at 4º C until processing. Cores were processed individually by sectioning into 1-cm intervals for the first 40 cm and then 5-cm intervals for the next 40 cm. The remaining 20 cm of the core were not analyzed. Samples were air-dried and hand-ground for analysis. This resulted in forty-eight samples from each core.

***Laboratory Experiments***: Labile phosphorus was extracted by the Bray P-1 dilute acid extraction (Bray and Kurtz, 1945) as modified by Avila-Segura et al. (2004) for use with a microplate reader and analyzed by the ascorbic acid method (Avila-Segura et al., 2004; Murphy and Riley, 1962).

Soil sorption isotherms were created using the techniques of Graetz and Nair (2000) as modified for a microplate reader by Avila-Segura et al. (2004). Specific samples were chosen by using profiles of the Bray P-1 with depth. Solutions were analyzed by the ascorbic acid method (Murphy and Riley, 1962) and plotted using the Langmuir equation. As soil sorption is nonlinear, the data were fit to this equation using the nonlinear optimizing routine "Solver" (Microsoft Excel 2000) to minimize the sum of squares of the residuals (Barrow, 1978). The fitted data were graphed and inspected to assure that local minima were avoided. Equilibrium P concentration and the P buffer capacity were analytically calculated from the fitted parameters.

## RESULTS AND DISCUSSION

Three or four cores from each plot of the five cropping systems in repetitions 1 and 2, plus a control set were analyzed (i.e., approximately one core per plot per year). The mean P-levels and standard error bars per plot are shown in Figures 1 and 2. The control cores were too dissimilar to simply average, so all four cores are represented in Figure 2b. Because all the samples were analyzed in 1-cm and 5-cm increments, the analytical results were also mathematically combined and then averaged to create "bulk samples". This allowed us to compare cores in a manner consistent with current soil testing procedures, (i.e., samples taken in 15-cm increments).

***Cropping System Cores***: The phosphorus profiles for the various cropping systems (Figures 1 and 2) suggest chromatography columns, with considerable vertical stratification. There is a general trend of high surface phosphorus content decreasing with depth to low mid-range concentrations and then increasing concentration at depths of 40-cm and greater. Initial surface soil (0 to 1-cm depth) P levels range from 35 mg P $kg^{-1}$ soil to 155 mg P $kg^{-1}$ soil and the results from the 15-cm depth range from 20 mg P $kg^{-1}$ soil to 147 mg P $kg^{-1}$ soil.

***Control Cores***: The WICST organizers neither set aside a location for a control nor did they archive sufficient samples to depth at the onset of the trial in 1989, because the intent of the research was to compare cropping systems and not to explicitly track soil changes from their start point in time. In an effort to determine a background phosphorus profile, it was decided that the 2.4-m alleyways between the existing plots were the best potential locations. These grass alleyways are not used for vehicular traffic and spillage of fertilizer is minimal. In order to further reduce edge effects, the chosen locations were adjacent to the pasture plots that only receive depositional manure from the grazing heifers.

Four cores were removed from each of the two locations. Unfortunately, due to the inherent heterogeneity of the site, these profiles were not entirely comparable (Figure 2b); controls B and C had similar profiles that started with approximately 140 mg P $kg^{-1}$ and average plow layer Bray P-1 values from 110 to 140 mg P $kg^{-1}$. Controls A and D had very similar profiles, with surface Bray P-1 levels near 90 mg P $kg^{-1}$ and average plow layer values of approximately 50 mg P $kg^{-1}$ soil. Although the initial P levels differ, both sets of cores have surface phosphorus values that are approximately 30 mg P $kg^{-1}$ greater than the mean of the entire 15 cm plow layer. This type of heterogeneity has been shown to be common in heavily manured fields.

### Bray P-1 Concentrations to Depth

Because current soil testing methods composite soil cores over a greater area with lesser resolution, the values obtained for this study were mathematically averaged to provide a comparison. Table 1 shows the results of the current research for the combined samples (0 to 15 cm, 16 to 30 cm, and 31 to 60 cm) for each cropping system and the difference from the controls. For simplicity, the similar controls were averaged (i.e., A & D and B & C) and the results are shown accordingly.

For the current research, in the 0 to 15 cm plow layer, the mean Bray P-1 levels of all cropping system cores are vary when compared to the control cores with most showing some

drawdown of P. The actual ranking of soil test levels did not exactly match our hypothetical ranking, as there was one difference. Cropping system 4, the corn-alfalfa system, has the highest average phosphorus value (due to heavy manuring), followed by CS1 (continuous corn with high-P starter fertilizer every year), followed by the fertilizer-free CS6 (pasture), CS2 (corn-soybean with high-P fertilizer every other year), and CS3 (corn-soybean-winter wheat-red clover). It was hypothesized that CS2 would be ranked higher than CS6, but that was not the case. It is possible that less phosphorus is removed from the pasture system then the corn-soybean system causing a greater amount of phosphorus to remain in the soil profile.

In the zone below the plow layer, 16 to 30 cm, average P values are still high to excessively high when compared to soil test recommendations for Wisconsin in every system except CS3. In the 31 to 60 cm zone, all soil test phosphorus levels are lower than in the upper profile. The highest value was found in CS2, 35.7 mg $kg^{-1}$, with the control B & C following having a P concentration of 29.7 mg $kg^{-1}$. The level of phosphorus in control A & D at this depth is similar with the other plots, but the P level in control B & C is higher than the remaining systems suggesting that the crop rooting system is extracting P from these depths more consistently than in those check plots.

The second half of Table 1 shows the difference in Bray P-1 concentrations between each system and two controls, with negative values denoting depletion of soil phosphorus. As shown, P levels have been lowered in the upper 15 cm for all five cropping systems studied. This decrease is greatest for CS3, which does not receive any fertilizer and lowest for CS4, which receives manure additions twice throughout each four year rotation. The subsoils (16 to 30 cm) also have been depleted of soil P with the greatest removal again in CS3.

**Table 1. Mean Bray P-1 at three combined depths with the values having been mathematically averaged.**

| **Soil Depth** | **CS1** | **CS2** | **CS3** | **CS4** | **CS6** | **Control** | |
|---|---|---|---|---|---|---|---|
| *Plot Number* | *109 & 204* | *108 & 206* | *102 & 212* | *113 & 210* | *112 & 207* | *A & D* | *B & C* |
| **cm** | | | ------- mg P $kg^{-1}$ ------- | | | | |
| 0-15 | 60.6 | 31.3 | 29.1 | 77.1 | 42.1 | 50.5 | 122 |
| 16-30 | 57.7 | 37.8 | 28.9 | 50.7 | 45.0 | 38.8 | 149 |
| 31-60 | 13.6 | 20.2 | 14.2 | 16.8 | 13.7 | 10.6 | 29.7 |
| *Difference from controls A & D* | | | | | | | |
| 0-15 | 10.1 | -19.3 | -21.4 | 26.5 | -8.4 | – | – |
| 16-30 | 18.8 | -1.0 | -9.9 | 11.9 | 6.2 | – | – |
| 31-60 | 3.0 | 9.5 | 3.6 | 6.2 | 3.0 | – | – |
| *Difference from controls B & C* | | | | | | | |
| 0-15 | -61.6 | -90.9 | -93.1 | -45.1 | -80.1 | – | – |
| 16-30 | -91.1 | -111 | -120 | -98.1 | -104 | – | – |
| 31-60 | -16.0 | -9.5 | -15.5 | -12.9 | -16.0 | – | – |

## Vertical Stratification in the Root Zone

The range of phosphorus concentrations with depth, from high to low to high again, reveals that vertical stratification is present in the majority of cropping systems at the WICST at Arlington. Figure 3 shows the Bray P-1 phosphorus distribution in the upper 30 cm of each plot and Table 2 shows the average concentration of Bray P-1 phosphorus over three different depth

intervals commonly sampled for soil testing for agriculture and environmental purposes. Of the plots sampled, 109 (continuous corn), 113 (corn-alfalfa), 210 (corn-alfalfa), and 112 (pasture) have the greatest stratification, with their surface P concentrations ranging from approximately 75 to 125 mg P $kg^{-1}$ soil and the phosphorus concentrations at 30 cm depth between 15 and 20 mg P $kg^{-1}$ soil. Cropping system one, plot 204 and CS6, plot 207 show stratification to a lesser degree, with surface concentrations between 55 and 70 mg P $kg^{-1}$ soil and the deeper depths again around 15 to 20 mg P $kg^{-1}$ soil. CS6-207 shows most of the stratification for its profile in the upper five centimeters, whereas the other profiles have a more gradual decline in phosphorus levels from the surface to 30-cm deep. Of the stratified systems, CS3 (corn-soybean-winter wheat-red clover) has the least stratification, with the surface soil for both plots containing approximately 35 to 40 mg P $kg^{-1}$ soil and the 30-cm soil containing about 15 mg P $kg^{-1}$ soil. Cropping system 2 (corn-soybean) did not show stratification in the top 20 cm most likely because it was conventionally tilled for the first four years of production. Although not directly associated with vertical stratification, all of the systems show a slight increase of phosphorus between 12 and 14 cm, which is likely a mechanical effect from the old plow layer.

The actual estimates of stratification did not match the hypothetical ranking. It was thought that the no-till systems 2 (corn and soybeans) and 6 (pasture) would have the greatest stratification and the more frequently tilled systems 1 (continuous corn), 4 (corn and alfalfa) and 3 (organic grain) would have the least stratification. In this study when comparing the average stratification for each cropping system using the 0 to 5/5 to 15 cm ratio, the greatest stratification occurred in CS6 followed by CS3, CS4, CS1, and CS2. It is likely that CS2 has the least amount of stratification due to modest P additions and high P off take as corn and soybean grain. This net removal of phosphorous has masked the natural tendency for this no-till system to create a stratified P profile in the soil.

**Table 2. Average Bray P-1 values for three different depth intervals commonly sampled for soil test phosphorus. Max/Min is equal to the maximum P concentration from 0 to 5 cm and minimum equals the lowest concentration from 26 to 30 cm. Mean denotes the average of the plow layer (0 to 15 cm).**

| Core | CS1 | | CS2 | | CS3 | | CS4 | | CS6 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Interval | 109 | 204 | 108 | 206D | 102 | 212 | 113 | 210 | 112 | 207 |
| cm | ---------- mg $kg^{-1}$ ---------- | | | | | | | | | |
| 0 – 5 | 82.0 | 54.9 | 33.1 | 27.1 | 38.0 | 36.4 | 90.3 | 96.6 | 79.0 | 42.3 |
| 5 – 15 | 73.6 | 39.7 | 34.3 | 29.3 | 25.1 | 25.1 | 55.3 | 82.4 | 41.8 | 23.8 |
| 15 – 30 | 32.6 | 18.8 | 14.5 | 18.7 | 14.4 | 11.7 | 22.5 | 22.2 | 21.8 | 19.8 |
| Max/Min | 5.6 | 4.3 | 4.0 | 3.9 | 4.3 | 4.9 | 10.3 | 7.5 | 8.4 | 4.5 |
| Max/Mean | 1.1 | 1.3 | 1.1 | 1.2 | 1.4 | 1.3 | 1.5 | 1.2 | 1.7 | 2.3 |
| 0–5/5–15 | 1.1 | 1.4 | 0.97 | 0.92 | 1.5 | 1.4 | 1.6 | 1.2 | 1.9 | 1.8 |

There are likely causes for the stratification shown in this research: first, the systems are minimally tilled and so P inputs from fertilizer and manure are left to slowly infiltrate the soil profile, and second, these systems leave copious amounts of plant tissue as crop residue on the soil surface after harvest. Upon decomposition, this plant matter releases phosphorus (that was mined from deeper in the soil profile) back into the soil at the surface and so this phytocycling of nutrients will cause greater stratification.

Because this site was under conservation management prior to the beginning of the WICST and vertical stratification was found in the untilled control, this is assumed to be the starting condition. Twelve years of tillage and nutrient extractions have not only maintained the vertical stratification but somewhat amplified it. The original goals of the Wisconsin Integrated Cropping Systems Trials included intentional drawdown of high phosphorus concentrations and reduction of erosion using conventional tillage methods. According to current Wisconsin soil test recommendations, the P levels for the plow layer in each of the cropping systems are still excessively high for corn, alfalfa, wheat, and managed pasture (>30 ppm P) as well as soybeans (>20 ppm P) and red clover (>25 ppm P) (Kelling et al., 1998). These values are based on bulk soil samples for the plow layer, but phosphorus levels in conservation tillage systems are known to become stratified with depth due to the lack of mixing (Cruse et al., 1983; Holanda et al., 1998; Howard et al., 1999; Robbins and Voss, 1991; Scheiner and Lavado, 1998; Shear and Moschler, 1969). It is difficult to compare stratified systems with recommendations based on conventional soil testing methods because the act of taking composite soil samples from a soil that does not display P homogeneity means that the values obtained are highly dependent upon the depth of sampling. In essence, composite sampling on a stratified system gives a weighted average that only truly represents the phosphorus level at one soil depth within the entire sampling zone. In stratified systems, the greatest amount of soil P is at the most vulnerable location for loss by soil erosion and the true P value for crop requirements is not determined. This shows that new testing methods are needed for these systems, to determine both plant nutritional needs and runoff potential.

**Soil Sorption Isotherms**

Phosphorus sorption research was conducted on a subset of soil samples from the larger collection of cores with the depths selected based on inflection points from the Bray P-1 to depth curves (Figures 1-2). Results of the phosphorus sorption/desorption protocol (Avila-Segura et al., 2004; Nair et al., 1984) were fit to a form of the Langmuir equation written as:

$$S - S_0 = k_l S_{\max} \frac{C}{1 + k_l C},$$

where $S$ is the sorbed P, $S_0$ is the initial sorbed P, $k_l$ is the Langmuir constant, $C$ is the soil solution concentration, and $S_{max}$ is the P sorption maximum. Figure 4 and Table 3 show the isotherms and the fitted and calculated parameters for each interval of a selected core from CS1, plot 109. The data for the remaining cores are not presented here.

Values for $S_{max}$ varied among plots (data not shown), but within a core (Table 3), tended to be similar or increase with depth, which is consistent with the findings of Mozaffari and Sims (1994). The largest sorption maximums were located at the deepest soil intervals, for multiple reasons: first, there are more sorption sites in this zone due to lower phosphorus levels; second, clay content is higher in the subsoil and sorption is correlated with the clay content (Mozaffari and Sims, 1994); third, the fitted functions were less precise due to the steepness of slope; and fourth, $S_{max}$ is an extrapolation of the data beyond the range of data points toward a saturating concentration of phosphorus. It is important to note that there was little correlation between the $S_{max}$ values and Bray P-1 phosphorus concentrations, a finding that agrees with results from Eghball et al. (1996), who found no correlation between adsorption maximums and available phosphorus concentrations at different soil depths.

**Table 3. Fitted and calculated parameters using the Langmuir equation for P sorption data for CS1, plot 109.**

| Cropping System | Depth | SSE | $k_l$ | $S_{max}$ | $S_0$ | pH | $C_0$ | $dS/dC\|_{C=C_0}$ | $r^2$ |
|---|---|---|---|---|---|---|---|---|---|
| | cm | | | mg P kg$^{-1}$ | | | mg P L$^{-1}$ | | |
| CS1 – 109 | 6 | 4.78 | 0.50 | 201 | -34.2 | 6.00 | 0.407 | 69.7 | 0.998 |
| | 12 | 5.23 | 0.48 | 189 | -28.4 | 5.33 | 0.367 | 65.7 | 0.997 |
| | 19 | 69.0 | 1.14 | 203 | -31.9 | 6.00 | 0.163 | 165 | 0.974 |
| | 24 | 139 | 1.39 | 205 | -28.8 | 6.32 | 0.117 | 212 | 0.954 |
| | 30 | 857 | 3.00 | 244 | -41.1 | 6.32 | 0.068 | 506 | 0.776 |
| | 40-45 | 337 | 8.32 | 355 | -129 | 6.20 | 0.068 | 1201 | 0.929 |
| | 55-60 | 488 | 9.90 | 384 | -136 | 6.00 | 0.055 | 1588 | 0.899 |
| | 70-75 | 665 | 4.13 | 273 | -57.2 | 5.39 | 0.064 | 707 | 0.841 |

The phosphorus adsorption strength, $k_l$, tended to increase with depth and the equilibrium phosphorus concentrations, $C_0$, defined here as the concentration at which no phosphorus is sorbed or desorbed from solution, decrease with depth within a core. Finally, the buffer capacity of the soil, calculated from the fitted sorption isotherm at the equilibrium phosphorus concentration, i.e., *dS/dC* at $C_0$, increases with depth within each core, particularly below 20 cm. The highest soil solution P values are associated with soil samples with the lowest buffer capacity and the highest Bray P-1 concentrations. There is the potential for leaching within these systems; however, at this time, the deeper soils are fully capable of sorbing the excess P that may slip below the upper root zone, thereby keeping vertical migration to a minimum.

## CONCLUSIONS

The soil profiles presented here all resemble chromatography columns and all the cores within a plot have similar Bray P-1 profiles to depth. These results show the intentional drawdown of phosphorus, starting in 1989, has been successful and continued management will bring the phosphorus levels to optimum for Wisconsin soils (between 10 and 25 mg kg$^{-1}$). The majority of the soil profiles presented did not show phosphorus leaching to depth, but the soil sorption data shows that the potential exists. Phosphorus added at the soil surface, through both fertilizer additions and crop residue decomposition, will slowly infiltrate and migrate downward through the nutrient-rich surface soil, which has limited sorption sites, to the more nutrient-poor soil below where sorption sites are abundant, thereby limiting the leaching potential. Further analysis of these samples using the Hydrus 1-D modeling program will shed more light on the movement of P through both leaching and phytocycling.

Finally, vertical stratification is present in these systems, including the control cores, and the current management practices are amplifying this stratification by adding nutrients at the soil surface without incorporation by tillage. This practice is localizing high concentrations of phosphorus at the soil surface; the area most susceptible to runoff. Because current soil sampling methods composite soil from multiple cores to a depth of 15-cm, a stratified system would give a value for runoff potential that would be lower than the actual P concentration at the surface and so new soil sampling techniques are needed for systems that exhibit vertical stratification.

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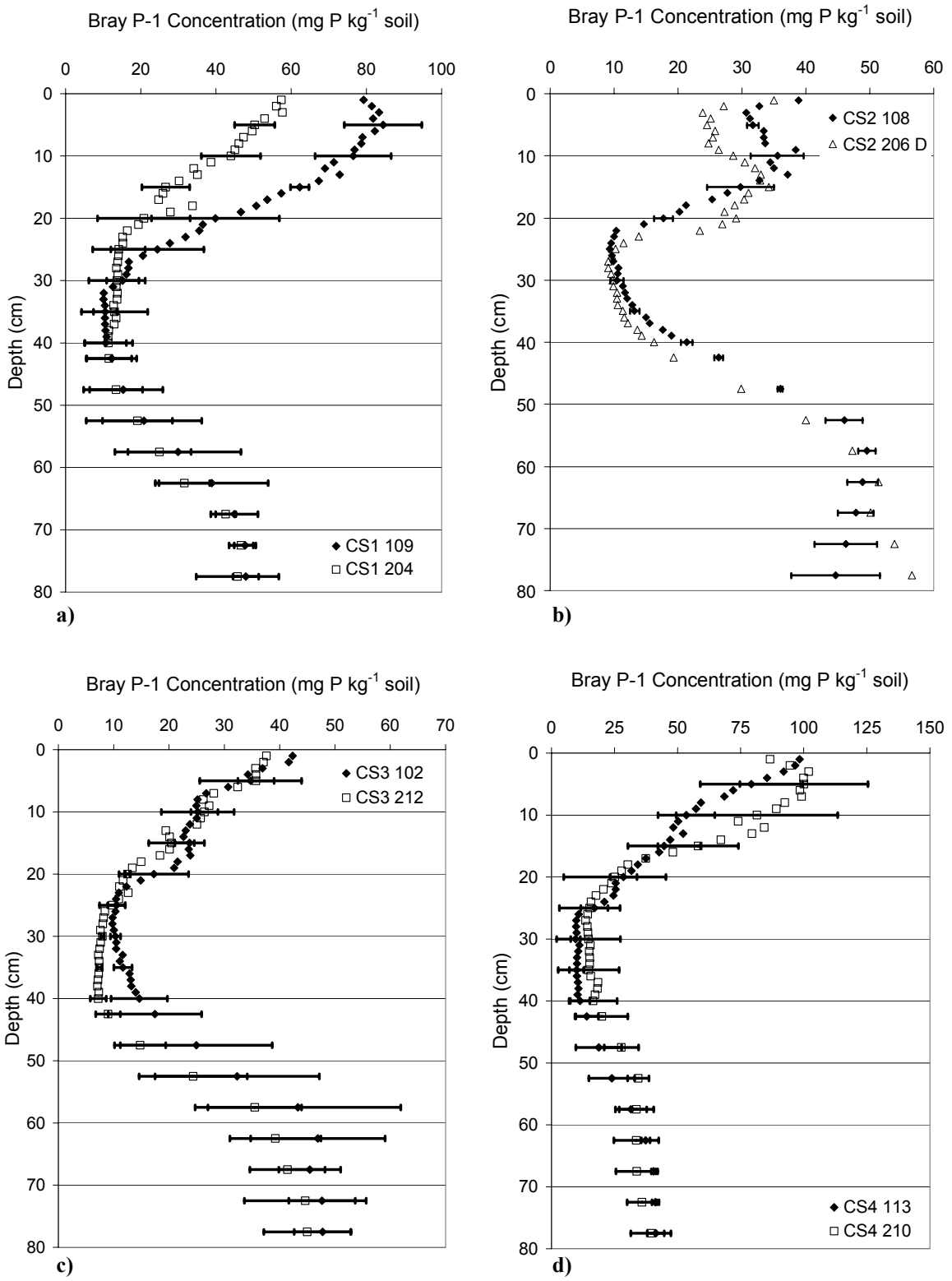


**Figure 1. Average concentrations of Bray P-1 (mg P kg$^{-1}$) to depth for four cropping systems at the WICST Arlington, Wisconsin site: a) CS1, plots 109 and 204; b) CS2, plots 108 and 206; c) CS3, plots 102 and 212; d) CS4, plots 113 and 210. Standard error bars represent the standard deviation from the average of the three cores evaluated for each plot.**

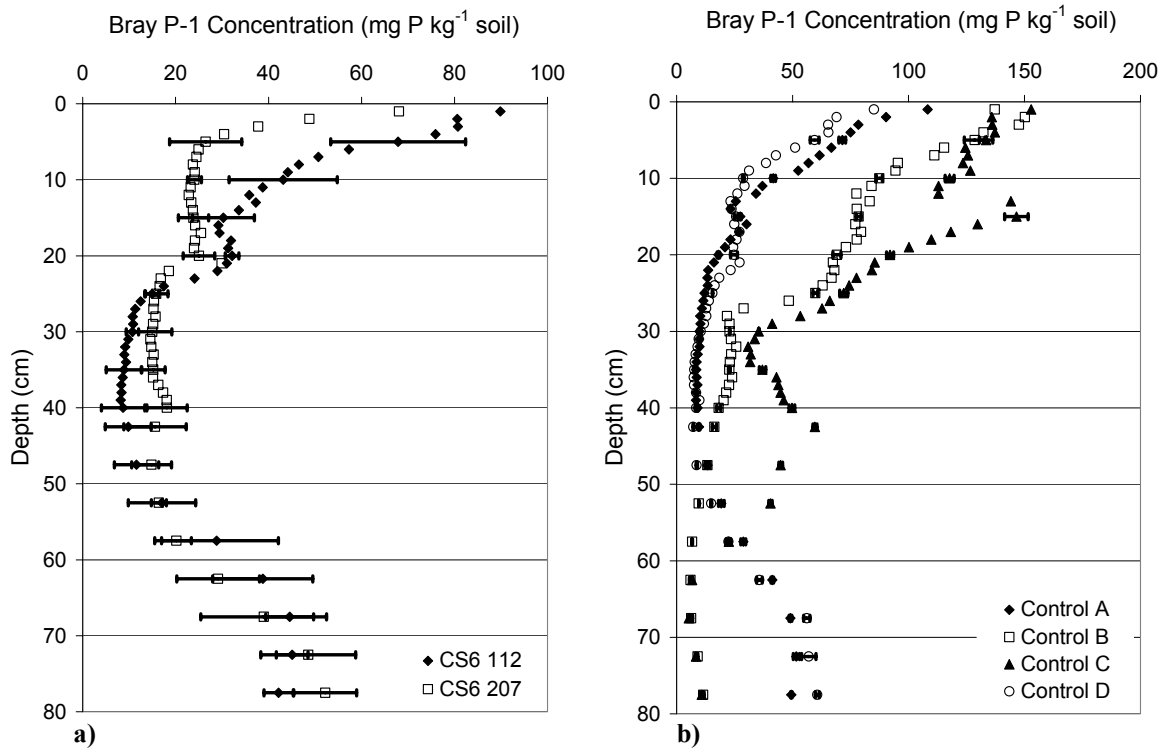


**Figure 2. Average concentrations of Bray P-1 (mg P kg$^{-1}$) to depth for one cropping system and hypothetical control plots at the WICST Arlington, Wisconsin site: a) CS6, plots 112 and 207; b) four control cores removed from the alleyway between existing plots. Standard error bars represent the standard deviation from the average of the three cores evaluated for each plot.**

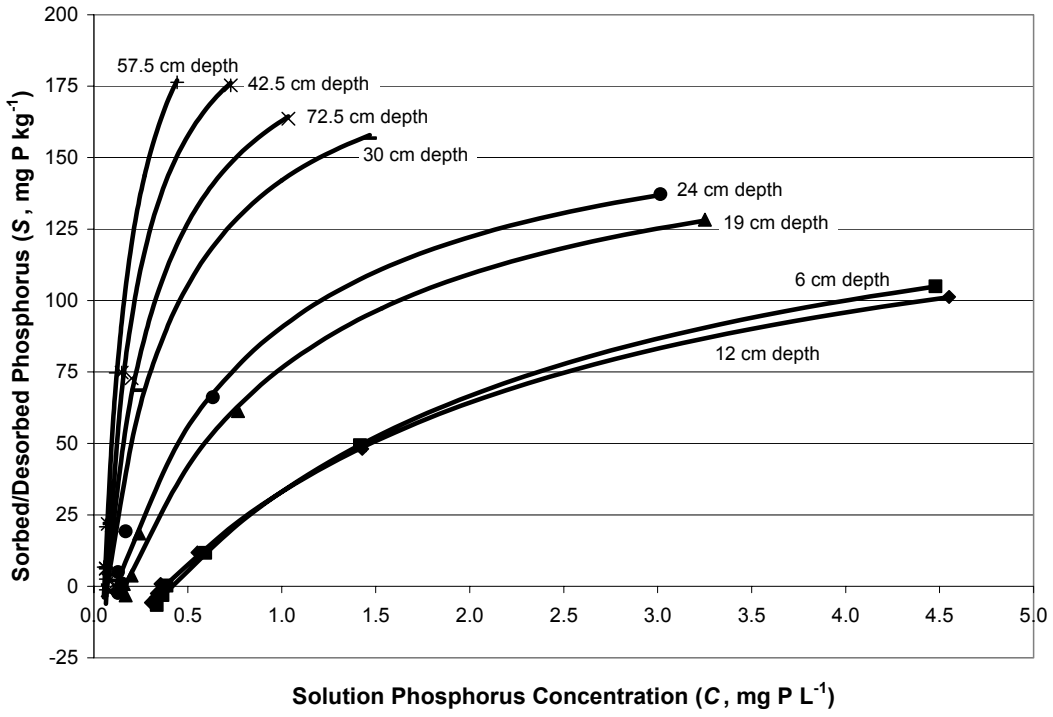


**Figure 3. Langmuir sorption isotherms for CS1, plot 109 at eight depth intervals.**

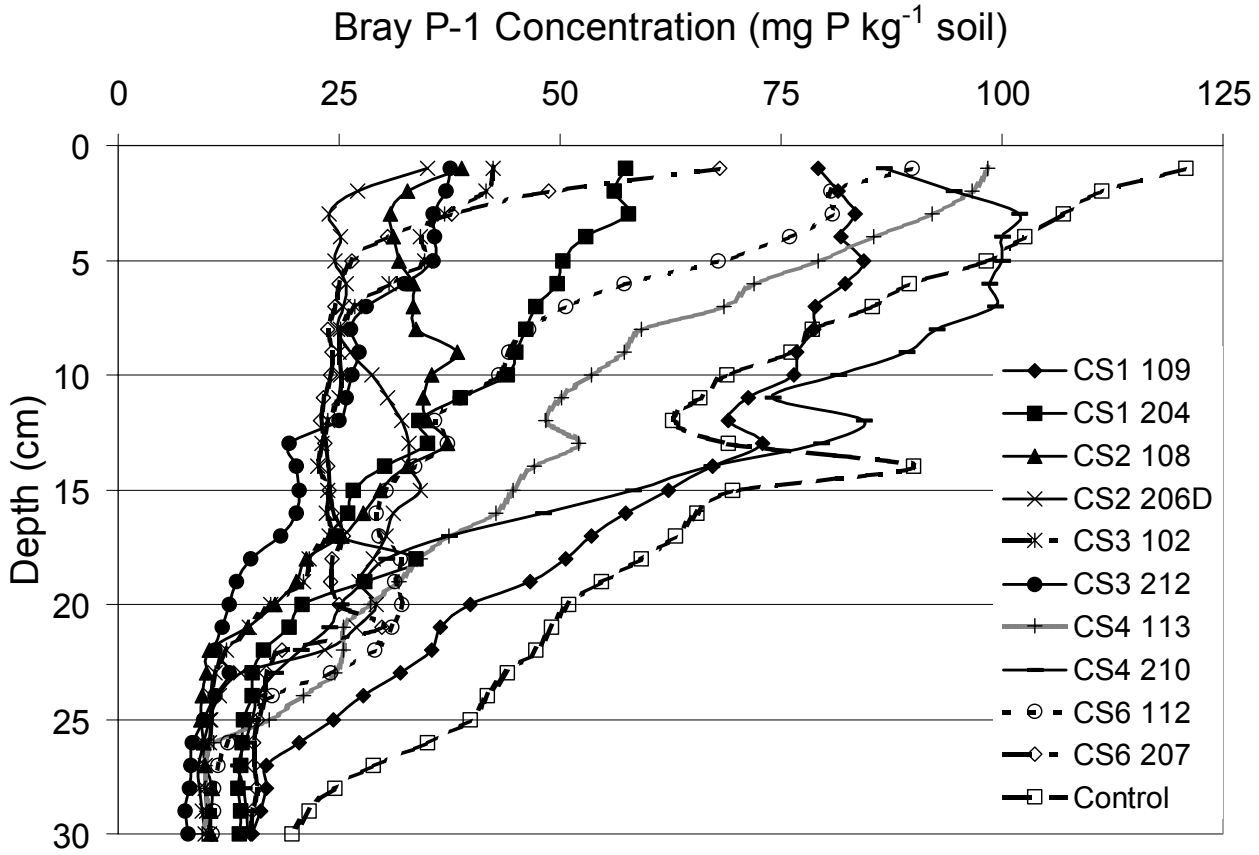


**Figure 4. Vertical phosphorus stratification at the Wisconsin Integrated Cropping Systems Trial as shown by the Bray P-1 concentrations (mg P kg$^{-1}$ soil) to depth.**

# SOIL ACIDIFICATION PROCESSES IN AGROECOSYSTEMS AT WISCONSIN INTEGRATED CROPPING SYSTEM TRIALS

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## ABSTRACT

Soil acidification associated with nitrogen inputs, both as acid-forming fertilizers and biological nitrogen fixation, has been noted in a variety of agroecosystems. Previously reported acidification rates range from 1.1 to 11.4 kmol $ha^{-1}$ $yr^{-1}$, largely associated with crop productivity and nitrate leaching losses. The objective of this research was to determine acidification rates at the Arlington site of the Wisconsin Integrated Cropping System Trials (WICST) for several cropping systems that represent major agroecosystems of the Upper MidWest: continuous corn (CS1), corn/soybean rotation (CS2), and corn/alfalfa/alfalfa/alfalfa rotation (CS4). Average annual acidification rates for these rotations at WICST were 0.8, 1.3, and 6.5 kmol $ha^{-1}$, respectively. The legume phases of CS2 and CS4 were particularly associated with strongly acidifying processes. At WICST, however, 'best management practices' reduced annual acidification rates in continuous corn by the use of pre-plant nitrate tests (PPNT) to judiciously apply nitrogen fertilizer by as much as 5.2 kmol $ha^{-1}$ and by stover return by 3.7 kmol $ha^{-1}$. The use of manure, which also returns plant alkalinity to soil, in CS4 reduced soil acidification rates by as much as 6.0 kmol $ha^{-1}$ $yr^{-1}$.

## INTRODUCTION

It has long been known, since the pioneering work of W.H. Pierre in the 1930s, that use of ammoniacal N fertilizers in excess of crop uptake and removal induces acidification in agricultural soils. This knowledge has been broadened to include legume-derived nitrogen as well. In recent years, estimates of soil acidification rates have been established for various agricultural systems. Legume-based pastures in New Zealand showed acidity inputs of 1.1 to 11.4 kmol $ha^{-1}$ $yr^{-1}$ that were correlated to the rate of biological $N_2$ fixation (BNF; Bolan et al., 1991). Wheat and barley in Canada, fertilized with 90 and 180 kg N $ha^{-1}$ $yr^{-1}$, showed acidity inputs of 1.3 and 5.6 kmol $ha^{-1}$ $yr^{-1}$ (Bouman et al., 1995). In Wisconsin, continuous corn receiving 56, 112 and 168 kg N $ha^{-1}$ $yr^{-1}$ as ammonium nitrate or urea showed net acidity inputs of 1.5, 4.2 and 8.9 kmol $ha^{-1}$ $yr^{-1}$ (Barak et al., 1997). Soil acidification associated with nitrogen inputs has been shown to trigger loss of base cations (Ca and Mg; Bolan et al., 1991; Barak et al., 1997) and manganese toxicities in crops. With acidification, there is also loss of cation exchange capacity and evidence of accelerated soil weathering (Barak et al., 1997).

The Wisconsin Integrated Cropping Systems Trial (WICST), a long-term study with measured nutrient fluxes and archived soil samples, provides an attractive test site for measuring acidity fluxes in Midwestern agroecosystems because of its well-managed, highly productive fields. Of the six cropping systems at the WICST, continuous corn (CS1), corn-soybeans (CS2), and alfalfa-alfalfa-alfalfa-corn (CS4) were studied in this project because of their predominant roles in Wisconsin agriculture and their representation of extremes of cultural practices, ranging

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from monoculture relying on N fertilizer (CS1) to legume-based rotations that rely heavily on biological $N_2$ fixation (BNF; CS2 and CS4). (The WICST nomenclature, i.e., CS1, CS2 and CS4, is used here to facilitate use of our data in the context of current and future research efforts at the WICST.) Furthermore, some of the current practices at WICST have reasonable alternatives, such as harvesting corn stover for biomass instead of returning residue to soil surface for conservation tillage to reduce erosion (as in CS1, CS2, and CS4) or forgoing the use of dairy manure in the corn/alfalfa rotation (CS4); careful analysis of the fluxes of acidity will allow evaluation of these practices in terms of soil acidification without separate long-term experiments.

## MATERIALS AND METHODS

The WICST fields at Arlington (WI) Agricultural Research Station are on a Plano silt loam (fine-silty, mixed, superactive, mesic Typic Argiudoll), with adequate drainage. Denitrification potential of similar plots in the area is limited (Brye et al., 2001). The experimental design of WICST has four replicates in the field combined with cropping sequences that allow for each phase of the rotation to be grown each year in each block of the trial. Thus, continuous corn has one sequence, corn-soybean has two, and corn-alfalfa-alfalfa-alfalfa has four. Full acidity budgets were prepared for each of the rotations selected and for 1997 through 2002.

**Plant tissue sampling and analysis:**

Corn, soybean, and alfalfa tissue samples were taken from the field and dried at 60EC; harvest indices were estimated for the corn and soybean crops in the rotations to supplement the grain and bean harvest data collected by the WICST team. After drying, plant materials were ground and sent to the Soil and Plant Analysis Laboratory (SPAL; Madison, WI) for total elemental analysis. Total macronutrients (Ca, Mg, K, Na, total-N, total-S, and P) were determined for grain, stover and cobs (corn), beans and straw (soybean), and whole tissue (alfalfa hay). Soluble $SO_4^{2-}$, $NH_4^+$, and $NO_3^-$ were measured in some tissue samples in order to estimate accumulation of N and S as inorganic anions that can affect the cation/anion balance calculations. Organic N and S were estimated as the difference between total tissue content and soluble forms. Grain and stover/straw yields were estimated based on the harvest index; nutrient concentrations of all tissues sampled were determined at the University of Wisconsin Soil and Plant Analysis Laboratory (SPAL).

**Acidity/alkalinity inputs:**

The inputs of acidity in agricultural systems are primarily due to chemically-reduced N (Helyar, 1976; Johnston et al., 1986; Bolan et al., 1991; Barak et al., 1997). The acidity budget therefore relies heavily on the knowledge of the reduced-N inputs as a source of potential acidity upon nitrification and permanent acidification upon nitrate leaching. The main sources of acidity associated with N inputs in the cropping systems of the WICST are: fertilizers in CS1 and CS2, dairy cattle manure in CS4, atmospheric $NO_x$ deposition, Fall $NO_3^!$-N measured by the WICST in CS2 and CS4 (assumed to be the result of BNF and subsequent nitrification), soybean credits to corn in CS2, alfalfa plowdown N credits to corn in CS4 (also from BNF), and crop residues (corn stover additions in CS1, CS2, and CS4, as well as soybean stover additions in CS2). In our computations, the N inputs from all sources are converted from lb N per acre or kg N $ha^{-1}$ to kmol $ha^{-1}$ (kilomoles of charge) and summed. This sum is the potential acidity of the reduced-N

inputs, assuming that one mole of reduced-N from any of these sources generates one mole of $H^+$ during nitrification.

In addition to acidity inputs from reduced N in these sources, alkalinity inputs from manure and H+/alkalinity excretion by the crops were considered. Crop excretion of H+/alkalinity was calculated following the procedure of van Beusichem et al. (1988), which assumes that in the corn crop, all N, S, and P were taken up as nitrate, sulfate, and $H_2PO_4^-$, respectively (see Avila-Segura [2004] for details). Manure alkalinity per unit N was calculated based on ASAE (2003).

**Crop potential Acidity:**

Organic alkalinity in plant tissue was based on plant tissue analysis of the various aboveground plant parts, following the procedure of van Beusichem et al. (1988). The potential acidity was calculated based on the total N and S composition of the plant material, after considering small corrections for nitrate and sulfate.

**Net H+/OH input of the cropping system:**

The net effect was calculated by summing the acidity/alkalinity inputs and crop potential acidity components, both for standard harvest and several additional scenarios. When comparing the effect of different crop rotations of different durations on the soil or nutrient fluxes, it is necessary to calculate the "average" annual effect of a particular rotation. Obviously this "average" does not have a statistical meaning for an individual block because the dry matter production or the nutrient fluxes due to harvest of two or more different crops belong to different statistical populations; however, the 'average' annual effect is necessary to compare a system with a one year rotation (continuous corn, CS1) to a two-year rotation (corn-soy, CS2) or a four yr rotation (corn-alfalfa-alfalfa-alfalfa, CS4). More details found in Avila-Segura, 2004. All quantities were tabulated for all replicates of each treatment, where indicated, and analyses of variance were performed using the Statistical Analysis System software with the General Linear Model and the Student-Newman-Kuels test for differences among treatment means.

## RESULTS AND DISCUSSION

The calculation of the acid/base balance of a crop or rotation of crops is not a trivial exercise since not only the fluxes of N must be known but also their origin, nature, and chemical formulation (whether nitrate or reduced). In order to calculate the acid/base balance of the rotation it is necessary to estimate and then sum the cation/anion uptake balance of the crops (acidity/alkalinity excretion), total acidity inputs from reduced-N sources, and the alkalinity inputs from manure and crop residues returned to the field at the end of the season. First, the cation uptake is calculated. Second, the total plant N and the uptake of P and S are calculated. The amount of N present in the tissues can have different origin depending upon the crop and the availability of $NO_3^-$ in the soil during the season. Thus, in the case of corn crops, all plant N is considered as $NO_3^-$ uptake. In the case of soybean and alfalfa, of the total N present in the plant only an amount equal to the N inputs to the crop (other than BNF) is considered as taken up in the form of $NO_3^-$; if the total plant N is greater than the N inputs then the difference is considered to be the result of biological $N_2$ fixation by soybean or alfalfa. Thus, if the soybean or alfalfa crops extract less N than the $NO_3^-$ available we assume that little or no BNF has taken

place throughout the season and that the crop fulfilled its N needs exclusively through $NO_3^!$ uptake.

Once the $NO_3^-$ uptake is calculated (total plant N in corn; total plant N minus soil available $NO_3^!$-N in soy and alfalfa) then the total anion uptake can be calculated as ($H_2PO_4^-$ + 2 $SO_4^{2-}$ + $NO_3^-$). Once the cation uptake and the anion uptake are calculated, $OH^-/H^+$ excretion is calculated as $\Sigma_{cations}$ - $\Sigma_{anions}$. If the total aboveground biomass is harvested, this is the contribution of the crop to the acid/base balance of the cropping system. However, if the corn stover or the soybean straw are returned to the field, the contribution of the stover/straw to the general acid/base balance (normally alkaline) has to be ascertained and explicitly included in the acid/base balance. Furthermore, the alkalinity from manures must be also added to the balance.

Finally, the acid/base balance of the cropping system is calculated by summing the acidity inputs (from reduced-N) plus the $OH^-/H^+$ excretion, manure alkalinity and the stover/straw alkalinity. This value can also be expressed as the calcium carbonate equivalent (in kg $ha^{-1}$ $yr^{-1}$) necessary for neutralizing the acidity added the cropping system, based on 50 kg $CaCO_3$ per kmol $H^+$.

**Acidity and alkalinity inputs in CS1, CS2, and CS4 of the WICST**

Results of these acidity/alkalinity calculations for WICST at Arlington are shown in Table 1. Examination shows that the total nitrogen fluxes—the sum of BNF and all other N inputs—in the continuous corn (CS1) and corn/soy rotation (CS2) are almost identical, 18.2 and 19.1 kmol N $ha^{-1}$ $yr^{-1}$, while the corn/alfalfa/alfalfa/alfalfa rotation (CS4) cycles 30.5 kmol N $ha^{-1}$ $yr^{-1}$, on average. Interestingly, BNF in the direct seeded alfalfa (DSA) phase of CS4 appears to be almost completely suppressed by the addition of manure-N and its mineralization.

Annual acidity inputs to CS1, CS2, and CS4 average 13.0, 10.7, and 17.5 kmol $H^+$ $ha^{-1}$, respectively (Table 1) and the means are statistically different in the order CS2 < CS1 < CS4. In CS4, acidity inputs come mainly from the manure applications to corn and DSA and from BNF during the two hay production years of the alfalfa rotation. For CS2, acidity inputs come from N fertilizers applied to the corn phase of the rotation and BNF by the soybean crop. In CS1, the acidity originates mainly from N fertilizers.

On the basis of total acidity inputs, it seems reasonable for CS4 to have greater net acidity input to the soil; however, the effects of manure alkalinity and crop anion excretion must be considered. Manure alkalinity inputs to CS4 average 6.0 kmol $OH^!$ $ha^{-1}$ $yr^{-1}$, and to a varying degree affect each phase of the rotation. Crop alkalinity excretion averages 3.9, 6.0, and 8.5 kmol $OH^-$ $ha^{-1}$ (negative values denote alkalinity; Table 1) in CS4, CS2, and CS1 and show that continuous corn at the WICST has much greater potential for neutralizing acidity inputs than either corn-soybean or corn-alfalfa (statistically significant in the order CS1 < CS2 < CS4, following sign convention). This is further confirmed by the distribution of the alkalinity excretion among the individual crops of CS2 and CS4 (Table 1). Alkalinity excretion by the corn crops of CS2 and CS4 average 8.6 and 10.0 kmol $OH^-$ $ha^{-1}$, respectively, and represent the bulk of the alkalinity excretion in both rotations. In CS2, soy alkalinity excretion accounts for only about a third of the anion excretion of the 2-yr rotation. In CS4, anion excretion is lower in the legume phases, particularly A1 and A2, where $NO_3^-$ uptake is replaced by BNF. The 1-yr corn phase in CS4 excretes more than 60% of the alkalinity excreted in the 4-yr rotation, and DSA excretes most of the rest, with the production phases contributing only minor amounts of alkalinity (A1) or acidity (A2) as the result of cation/anion uptake balance.

**Potential acidity in the crop:**

The harvested portions of these agroecosystems, whether corn, beans, or alfalfa hay, are major sources of potential acidity (Table 1), primarily by virtue of the reduced N as protein, stored in the harvest and the generally low quantities of organic alkalinity in the harvest. By contrast, corn stover and soy straw contain considerable organic alkalinity in the leaves, which offsets the potential acidity associated with the residual protein and gives a net alkaline value for these materials.

**Net H+/OH input of the cropping systems:**

The standard harvest of continuous corn (CS1) at WICST consists of a grain-only harvest (9.0 kmol $H^+$ $ha^{-1}$), returning -3.7 kmol $H^+$ $ha^{-1}$ as stover alkalinity to the soil, thereby offsetting a significant portion of the total acid input, 13.0 kmol $H^+$ $h^{-1}$. The net acidification rate for this crop and management practice is 0.8 kmol $H^+$ $ha^{-1}$ (±0.58), which is virtually zero and considerable lower than that cited by other authors (Bolan, 1991; Bouman et al., 1995; Barak et al., 1997) for other crops and management practices. The cause of this near-zero acidification rate in continuous corn at WICST is related to the both the residue and nitrogen management techniques. The return of corn stover to the soil returns both organic nitrogen, which is potentially acidic, and organic alkalinity. The mineralization of the residue and nitrification to nitrate generates acidity, but the acidity is counterbalanced by the greater amount of stover alkalinity that is added simultaneously. Furthermore, the WICST fertilization strategy is to employ pre-plant nitrate tests (PPNT) to assess residual nitrate in the soil profile and to subtract the amount of preplant nitrate from the total nitrogen added, thereby reducing the amount of acid-forming ammoniacal nitrogen added. This practice has led to application of 90 to 140 kg N $ha^{-1}$ (80 to 120 lb N per acre) at WICST instead of the full recommendation of 180 kg $ha^{-1}$ (160 lb N per acre) as fertilizer N, which is common in Midwestern corn agriculture. The use of PPNT at WICST is therefore likely to have reduced the net acidification of continuous corn by 5.2 kmol $H^+$ $ha^{-1}$.

The results for CS1 at WICST can be used to estimate the effect of total removal of corn grain and stover on soil acidification rates, assuming that the nitrogen in the corn stover would be replaced on a one-for-one basis with fertilizer to maintain identical nitrogen supply. Such a practice might be put in place if corn were harvested for silage or stover or biofuel. In such a case, harvest of total aboveground biomass would lead to an annual acidification rate of 4.5 kmol $H^+$ $ha^{-1}$, which is significantly higher than that of the current practice that removes grain only and is quite in line with rates reported by Barak et al. (1997) for continuous corn in Wisconsin.

The average annual acidification rate of corn/soybean rotation at WICST (CS2; Table 1) average 1.3 kmol $H^+$ $ha^{-1}$. The acidification process is here related entirely to BNF in the soybean phase, but averages out over the two phases to be not significantly different than those of continuous corn. If, on the other hand, crop residues were also removed, e.g., stover for silage or biofuel and soybean straw for animal bedding, then the annual acidification rate would be 4.7 kmol $H^+$ $ha^{-1}$, almost identical to that of continuous corn with complete removal of aboveground plant material.

The corn/alfalfa/alfalfa/alfalfa rotation (CS4) as practiced at WICST produced an average annual acidification rate of 6.5 kmol $H^+$ $ha^{-1}$, significantly greater than CS1 and CS2 (Table 1). The major acidifying phase of this rotation is A1 and A2, the period of great productivity and active BNF. The potential removal of corn stover would only modestly increase the annual acidification rate of CS4 to 7.6 kmol $H^+$ $ha^{-1}$. However, one of the interesting practices at

WICST associated with this cropping system is the use of dairy manure before and after the corn phase. Withholding the manure applications and its associated inputs of alkalinity in favor of enhanced BNF or added ammoniacal fertilizer (for non-legumes), both potentially acid-forming, would add an average of 6.0 kmol $H^+$ $ha^{-1}$ $yr^{-1}$, leading to projected total annual acidification rate of 12.5 kmol $H^+$ $ha^{-1}$. Such a value is slightly higher than the value reported by Bolan et al. (1991), 11.34 kmol $H^+$ $ha^{-1}$ $yr^{-1}$, for a highly productive (16.5 t dry matter $ha^{-1}$ $yr^{-1}$) rye grass/white clover pasture in a temperature climate with 1600 mm annual rainfall in Waikato, New Zealand; intensive dairy pastures in New Zealand require application of ~2.5 tons of lime per ha every 6 years and Bolan et al. predicted an annual requirement of 550 kg $CaCO_3$ $ha^{-1}$ $yr^{-1}$. At the WICST trials, the use of manure to return back to the alfalfa fields some of the alkalinity generated by the leafy tissue that was harvested from those fields serves as means to cycle alkalinity in a manner that had been previously considered only for nutrients; in the process, the manure serves as a liming agent and reduces the total lime requirement. Since 50 g $CaCO_3$ neutralizes 1 mole H+, the current CS4 rotation is predicted to generate a requirement for 380 kg $CaCO_3$ $ha^{-1}$ $yr^{-1}$or 1520 kg over a 4-yr rotation; in local units, the anticipated lime requirement would be 0.68 'English' tons aglime per acre, or 0.80 tons 80-89 aglime per acre, per 4-yr rotation. In the absence of manuring, the anticipated lime requirements per 4-yr rotation would be proportionately higher—2500 kg $CaCO_3$ $ha^{-1}$, or 1.31 tons 80-89 aglime per acre.

## CONCLUSIONS

Of the three cropping systems examined and compared, the total and net acidity inputs ranked CS1<CS2<CS4. When standard harvest practices are implemented, continuous corn (CS1) has net acidity inputs to the soil that average 0.8 kmol $H^+$ $ha^{-1}$. In comparison, corn-soybean (CS2) and corn-alfalfa (CS4) average 1.3 and 6.5 kmol $H^+$ $ha^{-1}$. Throughout, the legume phases of these systems were more strongly acidifying than the corn phase, even though continuous corn was fertilized by acid-forming ammoniacal fertilizers. This was largely due to lower anion excretion under BNF and nitrification of unutilized chemically-reduced N at the end of the season.

These acidification rates reported here are somewhat smaller than those reported in the literature for other sites and other agricultural systems (Barak et al., 1997, Bouman et al., 1995; Bolan et al., 1991). Examples of higher acidification rates documented (Barak et al., 1997) are associated with N fertilization rates normally greater (160 kg N $ha^{-1}$ or more) than those of the WICST in combination with total removal of aboveground biomass and no manuring practices. At the WICST fields, 'best management practices' included preplant nitrate tests that substantially reduced the rate of application of acid-forming ammoniacal fertilizers. The use of manure in the corn/alfalfa rotation also cut the potential acidification rate of that rotation in half.

A final observation worthy of mention is that the net acidity inputs in CS1 and CS2 are similar in size to those associated with acid rain in the Upper Midwest, which are ~0.5 kmol $H^+$ $ha^{-1}$ based on atmospheric N deposition data. However, the total acidity inputs in these three cropping systems—13.0, 10.7, and 17.5 kmol $H^+$ $ha^{-1}$ in CS1, CS2, and CS4, respectively—are 20 to 35 times greater than those from atmospheric inputs. Therefore, concerns about acidity inputs from acid rain to agricultural soils in the Midwestern United States are irrelevant in comparison to acidity inputs from sources related to agricultural activities.

**ACKNOWLEDGMENTS**

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**Table 1: Acid/base balance of CS1, CS2, and CS4 at the WICST**

| | CS1 | CS2 | | | CS4 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **corn** | **corn** | **soy** | **rotation** | **corn** | **DSA** | **A1** | **A2** | **rotation** | **LSD*** |
| | ---------- kmol $ha^{-1}$ ---------- | | | | | | | | | |
| **Nitrogen Inputs** | | | | | | | | | | |
| N input (other than BNF) | **18.2** | 16.9 | 4.5 | **10.8** | 26.4 | 20.6 | 13.3 | 11.0 | **16.1** | |
| Biological $N_2$ fixation (BNF) | **- -** | - - | 16.2 | **8.3** | - - | 1.1 | 21.4 | 27.5 | **14.4** | |
| **General Acidity and alkalinity inputs†** | | | | | | | | | | |
| Total $H^+$ input | **13.0b§** | 11.3 | 9.9 | **10.7c** | 17.9 | 17.9 | 15.2 | 18.1 | **17.5a** | 1.7 |
| Manure $OH^-$ | **0.0** | 0.0 | 0.0 | **0.0** | -6.4 | -8.6 | -5.4 | -3.5 | **-6.0** | |
| Crop $H^+/OH^-$ excretion | **–8.5c** | –8.6 | –3.6 | **–6.0b** | –10.0 | –5.8 | –0.6 | 0.8 | **–3.9a** | 0.5 |
| **Crop potential acidity‡** | | | | | | | | | | |
| grain, beans and hay | **9.0** | 9.2 | 11.8 | **10.4** | 10.3 | 5.8 | 15.0 | 14.2 | **11.5** | |
| stover stover/straw | **–0.6** | –0.6 | –1.3 | **–1.0** | –0.3 | 0 | 0 | 0 | **–0.1** | |
| Aboveground | **8.5** | 8.6 | 10.5 | **9.5** | 10.0 | 5.8 | 15.0 | 14.2 | **11.4** | |
| **Net $H^+/OH^!$ input of the cropping system** | | | | | | | | | | |
| Aboveground harvest | **4.5b** | 2.7 | 6.3 | **4.7b** | 1.5 | 3.5 | 9.2 | 15.4 | **7.6a** | 0.5 |
| stover/straw $H^+/OH^-$ return to soil | **–3.7b** | –3.8 | –3.0 | **–3.4b** | –4.3 | 0 | 0 | 0 | **–1.0a** | 0.2 |
| **Standard harvest** | **0.8b** | –1.1 | 3.3 | **1.3b** | –2.8 | 3.5 | 9.2 | 15.4 | **6.5a** | 0.58 |

* LSD = "Least Significant Difference" of a Duncan test for separation of experimental means, or the first "critical range" in the "Student-Newman-Keuls" multiple range test.

† Total H+ input although dependent on N inputs, is not identical in magnitude to N inputs due to internal recycling of N in the soil-plant system and decoupling between proton production and N uptake by the crop.

§ Means accompanied by different letters in the same row are statistically different at the 0.05 level.

¶ negative signs denote alkalinity and are used for convenience in this table but are not used in the discussion.

‡ The "net potential acidity" of corn aboveground material is identical to the "crop $OH^!/H^+$ excretion". In soy and alfalfa, however, BNF produces differences between these two quantities.

# WICST EDUCATIONAL OUTREACH 2003 and 2004

Janet Hedtcke[1]

WICST continues to serve as an 'outdoor laboratory' for learning about issues of sustainable agriculture such as crop rotation, environmental stewardship, economic sustainability, and bio-diversity. 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 2003 and 2004. WICST abstracts, theses and publications are listed in Appendix XI.

Several brochures were developed and passed out to UW Extension. They include the following titles: 'Leaching of Agricultural Chemicals to Tile Drains on WICST'; 'Using Pre-Plant Nitrate Test To Reduce N Inputs On Corn: 11-Year History On The WICST Plots'; 'Benefits of diversifying corn grain systems: Data from WICST'; and 'Restoring native prairie at the Arlington Research Station'. Our website (www.cias.wisc.edu/wicst) continues 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 2003 and Prairies Jubilee in both years, which is co-hosted by the Audubon Society (300 visitors). Two posters were presented at Prairies Jubilee in 2003 and 2004 describing WICST prairie restoration efforts and our work with rotational grazing in degraded oak savannas. A tour was led through the restored prairie plots to show the differences between high and low diversity treatments.

In addition to field days, WICST held its annual winter meeting on February 7, 2003 and February 13, 2004 discussing WICST data to a mixed audience of farmers, USDA staff, UW faculty, UW Extension, Ag consultants, UW students, and MFAI collaborators. Topics included comparison across systems of soil nutrient and physical properties; economic analysis of the WICST systems, including rotational grazing; a discussion on the Conservation Security Program by NRCS officials; and an update from several graduate students on the Linking Farms Project.

**Local/Regional** Research data from the WICST projects was presented in both oral and poster form at ASA, CSSA, SSSA annual meetings in Denver, CO (Nov. 2-6, 2003) and Seattle, WA (Oct 31-Nov 4, 2004). Posters were displayed at The Natural Areas Conference in Madison, WI (Sept. 26, 2003) and the 2004 North American Prairie Conference in mid-August.

John Hall and Ron Doetch (MFAI) along with local organizations and agency officials developed the SE Wisconsin Resource Conservation and Development District (RC&D) formed to cover 13 counties in SE Wisconsin. Hall represented WICST as chair of the Agriculture Issue Team for the new RC&D, and by serving on the NRCS State Technical Committee. Activities

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included hosting a farm tour that included the manure linking and organic grain trials at MFAI, and a presentation on "Diversified Farming Systems" at the annual Urban Rural Conference in October. We collaborated with Walworth County Extension and Town & Country RC&D to develop a Grazing Specialists position for the Southeast Wisconsin Grazing Network. The specialist is working with area NRCS conservationists to assist farmers in developing grazing plans that meet USDA program criteria for assistance.

Many face-to-face interviews with farmers, nutrient haulers, extension, ag consultants were conducted by grad students Amy Cook and Gregg Sanford to learn about current manure management strategies and to share with them our research ideas in the Linking Farms project. Interviews will be summarized in Amy and Gregg's theses.

**Table 1. Outreach activities involving the WICST project in 2003 and 2004.**

| | EVENT | LOCATION | DATE | ATTENDANCE |
|---|---|---|---|---|
| 2003 | | | | |
| | Westside Madison Rotary Club | Madison, WI | February 4 | 45 |
| | WICST Winter Meeting | Madison, WI | February 7 | 30 |
| | Waunakee 4th grade tour at plots | Arlington, WI | May 6 | 140 |
| | Agronomy Centennial | Madison, WI | May 22 | 200 |
| | 'Land Use in WI' mini course at plots | Arlington, WI | Early June | 20 |
| | VoAg Training Day at plots | Arlington, WI | June 26 | 11 |
| | Agronomy/Soils Field Day | Arlington, WI | July 9 | 140 |
| | Natural Areas Conference | Madison, WI | September 24 | 50 |
| | Prairies Jubilee at plots | Arlington, WI | September 28 | 100 |
| | Radio Tapes w/ Jeanie Gurnick | Madison, WI | October 2 | > 100 |
| | ASA, CSSA, SSSA | Denver, CO | November 2-6 | 1500 |
| | Soil Mgt Short Course at plots | Arlington, WI | December 9-10 | 30 |
| 2004 | | | | |
| | WICST Winter Meeting | Madison, WI | February 13 | 35 |
| | DeForest School tour | Arlington, WI | EarlyMay, 2days | 100 |
| | Holistic Mgt Grassland Monitoring Fld day | Arlington, WI | May 12 | 12 |
| | 'Land Use in WI' mini course at plots | Arlington, WI | Early June | 20 |
| | Tour for Australian scholarship recipient | Arlington, WI | July 29 | 2 |
| | North American Prairie Conference | Madison, WI | August 8-12 | 500 |
| | CESA #3 Fall Ag Day (grazing tour) | Arlington, WI | September 22 | 30 |
| | Prairies Jubilee | Arlington, WI | September 26 | 100 |
| | ASA, CSSA, SSSA | Seattle, WA | Oct. 31-Nov. 4 | 1500 |

# THE WISCONSIN INTEGRATED CROPPING SYSTEMS TRIALS: YIELDS, YIELD VARIABILITY, AND YIELD TRENDS 1990-2002.

Joshua Posner[1], Jon Baldock[2], and Janet Hedtcke[1]
Date: Sept 4, 2005

## ABSTRACT

In 1990, a large scale, and long-term study entitled the Wisconsin Integrated Cropping Systems Trial (WICST) was initiated at two locations in southern Wisconsin. The purpose of the project was to compare alternative grain and forage-based systems using three performance criteria: 1) productivity; 2) profitability; and, 3) environmental impact.

An obvious initial criterion in comparing alternative agricultural systems is crop productivity. Three fundamental research questions were asked: 1) do the low input, organically managed production systems have lower yields than the high input production systems; 2) do the low input, biologically diverse systems have greater annual yield variability than the high input systems; and 3) do the biologically diverse systems gradually increase in productivity over time.

Our conclusions are the following:

1-The lack of a site × system interaction in three of the four crops and the relatively small crossover in the other crop in spite of the large difference in drainage suggests that these results are widely applicable and could be averaged over sites. We propose that the trial results have a wide area of inference on prairie-derived soils of the upper mid-west.

2-The quasi-organic systems produced 10 to 20% smaller grain yields (corn and soybeans) than the high and medium external input systems during the first 8 to 13 years of the two trials. However, the low external input forage system, CS5, produced up to 10% more alfalfa in the same period. Thus, the size of the deficit production with the low external systems was less than expected by many.

3-Thus far, the data do not support the hypothesis that the low external input systems are more variable in an absolute or a relative sense than the higher external systems. In fact, the only significant difference between variabilities found that the low-external input system, CS5, had lower variability for first-year, established alfalfa than the high-external input system, CS4, at Arlington.

4-There were significant yield trends in the four crops examined (corn, soybeans, wheat, and alfalfa). These trends differed among the cropping systems. With a few exceptions, there were increasing trends with the high- and medium-external input systems, but steady to decreasing trends with the low-external input systems.

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5-Overall we conclude from these trials that differences in productivity, yield trends, and yield variability between the low external input systems and the higher external do exist. However, the differences are small enough and inconsistent enough that other factors; such as such as profitability, environmental impact, and life-style preferences; will often be the determinate in the selection of a cropping system.

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## INTRODUCTION AND OBJECTIVES

Southern Wisconsin and much of the upper Midwest was home to mixed grain and livestock production systems from the 1880's to the early 1960's (Felstehausen, 1986). Since that time however, with the introduction of herbicides and chemical fertilizers, farms have tended to become primarily focused on either livestock or annual grain production. At the same time that this trend in specialized rather than mixed farming has been taking place, there has been increased criticism of farms as sources of non-point pollution. In 1990, in response to growing public concern about the environmental impact of this changing agricultural model, a large scale, and long-term study entitled the Wisconsin Integrated Cropping Systems Trial (WICST) was initiated at two locations in southern Wisconsin. The purpose of the project was to compare alternative grain and forage-based systems using three performance criteria: 1) productivity; 2) profitability; and, 3) environmental impact.

The systems were designed to test the agroecological hypothesis that with increased biological complexity, agricultural systems would remain highly productive but with less reliance on external inputs (Altieri, 1987; Harwood, 1985). As a result, WICST is a nested factorial with two enterprise types (annual grain production or forage-based livestock production) and within each, three production strategies: a) low crop diversity with high inputs; b) medium crop diversity and medium inputs; and, c) high crop diversity and low inputs. These latter systems were designed to be managed organically. To adequately test this cropping diversity hypothesis, it was not possible to either; 1) fix cropping sequence and only vary input levels (an input management trial); nor, 2) fix input levels and only vary cropping sequence (a crop rotation trial). In this study, *production management strategies* are being compared, so the two factors, sequence and input level, are fixed simultaneously to represent realistic *cropping systems*.

An obvious initial criterion in comparing alternative agricultural systems is crop productivity. Three fundamental research questions were asked: 1) do the low input, organically managed production systems have lower yields than the high input production systems; 2) do the low input, biologically diverse systems have greater annual yield variability than the high input systems; and 3) do the biologically diverse systems gradually increase in productivity over time. The last objective is particularly important in view of the expectation that cropping systems, especially those that are organically managed, have a period of transition before reaching higher and more stable output levels (Liebhart et al., 1989; Dabbert and Madden, 1986) Also, it would be counterproductive to calculate and discuss simple means of crop yields averaged over time if time trends existed showing increasing or decreasing yields.

## LITERATURE REVIEW

Most of the work on the impact of crop diversity on crop yield has been conducted within high input crop rotation trials. A number of researchers have found shown that corn and soybeans yields, for example, increase often by 10 to 15% when not planted in a monoculture (Lund et al, 1991; Porter et al, 1997). It has also been shown that including a leguminous forage crop like alfalfa in a rotation can have a large impact on the following corn or soybean crop yield (Baldock and Musgrave, 1980; Baldock et al, 1981). However, relatively few studies have looked at the impact of crop diversity within a context of reduced chemical inputs. What work had been done has primarily compared conventional and organically managed

systems. At the time the WICST trial began, most of the literature suggested that organically managed cropping systems would be less productive than the higher input systems (Berardi, 1978; Crosson and Ostrov, 1990; Helmers et al., 1986; Klepper et al, 1977). A survey conducted in Ohio in 1990 indicated that the certified organic field crop producers (n=19) had yields equivalent to 72% for corn, 80% for soybeans, 70% for wheat and 68% for hay of their conventional farming counterparts in the Ohio Farm Household Longitudinal Survey (n=960) (Batte et al, 1993). By the mid-90's, this argument was being used by some (Avery and Avery, 1996) to justify that the agricultural research focus must be kept on high input agriculture, as shifting to organic agriculture would result in both a massive expansion of area cropped, and food shortfalls in the future. Some studies were available however, indicating that organic yields were nearly equivalent to conventional yields (Lockeretz et al, 1978; Lockeretz et al., 1981; Cacek and Langner, 1986).

There is less information available about the impact of crop diversity or rotations on yield stability. In one study however, it was reported that organic systems did not show increased variability in net returns (Helmers et al., 1986). Porter et al (1997a) in looking at approximately 10 years of data at four locations has shown that the rotation effect with corn and soybeans is greater in years with low average yields than in years with high average yields in the case of corn. Nevertheless, discussions with growers indicated that they were particularly concerned about the potential for increased weed pressure and reduced nutrient availability in the organically managed systems, resulting in economic losses in some years.

And, there was a general consensus that shifting to organic systems would require a period of transition before yields would rise. Initial analyses on the Rodale Conversion Trial (1981-1985) indicated that corn yields were only 75% of conventional yields during the first four years of the study (Liebhardt et al., 1989). Duffy and colleagues (1989) did an economic study of the alternative "starting points" of the organic rotation and concluded that these systems needed to start with low input crops (small grains) or nitrogen fixing crops (legumes) that would subsequently "set the stage" for high N demanding crops.

## MATERIALS AND METHODS

### Cropping System Trials and Terminology

Definitions of the terms: crop rotation, crop sequence, phase, cycle and test crop; are consistent with those originated by Cochran (1947) and Yates (1954). Cady (1991) provides a more recent statement of them. By "cropping system" we mean the combination of a crop rotation and a management philosophy. Our use of cropping system is more general than the definition in Cady that a cropping system is the combination of 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 rapidly changing technologies such as changes in varieties, weed control, and tillage. 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). Cropping system trials such as these may be viewed as fractions of the full factorial combinations of crop rotations by cultural practices discussed in Patterson and Lowe (1970) and Cady (1991). 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 that Cady warned of

are avoided. 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.

**Experimental Design and Establishment**

The WICST study consists of six cropping systems, replicated four times, at each of two sites in southern Wisconsin. Three cash grain systems and three forage systems were selected for study (**Table 1**). Although there were at least eight criteria in the selection and design process (Posner et al. 1995), the two key criteria were crop diversity and level of external inputs. Table 1 summarizes the key differences in cultural practices among the rotations. Since nearly the inception of the trial, CS3 and CS5, the organic grain and organic forage systems have meet the USDA requirements for a *certified* organic system (http://www.ams.usda.gov/nop/NOP/standards.html), except for the lack of twenty-five foot buffer zone around each plot, the use of certified organic seed prior to the 2003 season and, the cleaning and purging of equipment coming from conventionally managed fields. Thus, these are quasi-organic systems.

The trials were established in 1989 with all 60 acres at each site planted to corn to improve the uniformity of crop history and allow baseline measurements to be taken. Some of the baseline variables, especially yield, were used to block the trial into four blocks of 14 plots (0.75 acre per plot) for the 14 total phases in the six cropping systems.

Except during the staggered start, which was completed by 1993 (**Table 2**; Posner et al, 1995), every phase was present every year for all the crop rotations in the RCBD, thus meeting a core requirement of a crop rotation trial (Cady, 1991). The staggered start was used to replicate each phase of the crop rotations in time as well as space, thus providing a more powerful analysis of time trends by cycle than could be accomplished with an even start of all possible crop sequences for a crop rotation.

Plots were tilled, planted, and harvested with field equipment. Grain and dry matter yields were estimated by running the harvest wagons across a farm scale. Grab samples were taken for quality analysis. Grain crops samples were analyzed for moisture and protein levels; while forage samples (both hay and pasture) were tested with NIR to determine Relative Feed Value (RFV) (Rohweder et al, 1978; Rohweder, 1984). In the rotational grazing system, randomly selected samples (4 x 0.5 $m^2$) were hand-cut each week with a shears at ground level just prior to grazing by the heifers (Marten, 1989). Additional details on the design and conduct of the WISCT trial are provided in Posner et al (1995).

**Sites**

Both sites are in Major Land Resource Area 95B, which covers most of south central and southeastern Wisconsin. (U.S. Dept. of Agric., 1981). Soils in this land resource 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 site is the somewhat poorly drained Lakeland Agricultural Complex (LAC) on the Walworth County Farm near Elkhorn, WI (42 39'N; 88 29'W). The dominant soil types at this site are a Pella (fine-silty, mixed, mesic Typic Haplaquoll) and a mottled variant of Griswold (fine-silty, mixed, mesic Typic Argiudoll). The other is a well-drained site at the University of Wisconsin Arlington Research Station (ARS) (43 18'N; 89 21'W) and is located on a Plano soil type (fine-silty, mixed, mesic Typic Argiudoll).

For the most part, both sites had been in a dairy-forage cropping system of corn and alfalfa with manure for the 20 years prior to establishing the trial. As a result, both sites initially had high organic matter levels (4.7 and 5.2% at ARS and LAC respectively), medium soil pH levels (6.5 and 6.3), high soil test phosphorus (108 and 58 ppm Bray I), and high soil test potassium (255 and 188 ppm exchangeable K).

**Statistical Analyses**

**Yields.** To conduct the statistical analysis, we fit the crop yields and quality data to a linear, additive model using the Restricted Maximum Likelihood (REML) facility of SAS PROC MIXED (SAS Institute Inc., 1999). The model we fit for the preliminary analyses over locations and years was:

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

where

| | | |
|---|---|---|
| $Z_{ijkl}$ | = | observed yield or quality measurement for the ijkl-th case, |
| $\mu$ | = | overall mean yield, |
| $L_i$ | = | effect of location i, |
| $Y_j$ | = | effect of year j, |
| $LY_{ij}$ | = | interaction effect of location i with year j, |
| $B_k(L)$ | = | effect of block k nested within location, |
| $YBj_k(L)$ | = | interaction of effect of year j with block k within location, |
| $S_l$ | = | effect of cropping system l, |
| $LS_{il}$ | = | interaction effect of location i with cropping system l, |
| $YS_{jl}$ | = | interaction of year j with cropping system l, |
| $LYS_{ijl}$ | = | interaction of location i with year j and cropping system l, |
| $\varepsilon_{ijkl}$ | = | residual error, |

i = 1, 2;
j = 1, ..., x depending on crop and location;
k = 1, ..., 4;
l = 1, ...6 depending on crop and location

We also analyzed the data within sites using the above model without the terms involving locations because the LAC site data only ran from 1993 to 1998, while at ARS the data set continued to 2002. Both the full model and the reduce model disregard the different cycle lengths for the cropping systems and consider the year effect to be a whole plot factor as opposed to a subplot (or split-plot-in-time) factor. We believe this is the better choice because the weather aspects of years were larger than the time aspects of years (i.e., the number of years since the trial began). A separate analysis over cycles of the crop rotations (see below) not only provided a better way to investigate possible time trends, but also a more appropriate way to address the potential correlations of measurements on the same plot inherent in crop rotation studies (Cady, 1991). We regarded years, blocks, and interactions as random factors so the inference space extends beyond the particular levels in these trials. To help answer some questions, we calculated the 90% confidence interval or LSD at the 10% significance level from the standard error and degrees-of-freedom reported by the appropriate ESTIMATE statement in SAS PROC MIXED.

**Yield variability.** We compared the variances of the annual mean yields (averaged over replications within a year) as a measure of the absolute yield variability of the systems with an F-test for two systems or with Barlett's test for more than two systems (Snedecor and Cochran, 1967). Both of these tests assume a normal distribution and Barlett's test is especially sensitive to minor departures from the normal distribution (Bonett and Seier, 2003). Consequently, we also examined the variability among systems with the mean absolute deviation from the median, which is a distribution-free method that is less affected by extreme values (Bonett and Seier, 2003). However, even if there are no differences in the absolute variability, there may be differences in the relative variability as measured by the coefficient of variation (CV). The computations to compare CVs statistically are formidable; however, Verrill (2003) developed a procedure and published a web-based program to do them.

**Yield trends over time.** Cady (1991) described four methods for determining the existence of yield trends overtime: 1) univariate split-plot analyses where the subplot is time, 2) multivariate repeated measures analyses, 3) analyzing estimated polynomials coefficients for each plot, and 4) modeling approaches; e.g., using the Mitscherlich equation. He also discussed the need to quantify the correlation between errors in measurements necessarily made on the same plots over time in crop rotation studies. Recent advances in REML models add a fifth method to estimate trends over time that is related to the repeated measures analysis and has the capability to simultaneously estimate the correlation of observations (Singh and Jones, 2002). We used the REML models as implemented in the SAS PROC MIXED to first determine how best to describe the possible correlation and heterogeneity of errors as described in Wolfinger (1996) and then test for time trends using the sequence of models outlined in the analysis of covariance chapter in Little et al. (1996). In these analyses, we used cycle number of the crop rotation as the unit of time instead of years that provided a direct measure of the number of times the plot had been through the corresponding rotation. Furthermore, cycles afford replication over time, as well as space, when the staggered-start is used and every phase of every rotation is grown in each year **(Table 2)**. Initial runs estimated the block, block by cycle interaction, and individual plot effects to be negligible when plots were used as the subjects. Thus, these effects were not included in the analyses for time trends. We investigated yield trends at ARS and not LAC because changes in rotations and management in 1999 at LAC reduced the number of cycles to the point few of the REML analyses would converge to a solution.

## RESULTS AND DISCUSSION

### Crop Yields Over Locations

**Table 3 (a & b)** and **Fig. 1 (a & b)** summarize the preliminary analyses of crop yields over sites for the four crops that appeared in more than one cropping system. The effect of cropping systems was statistically significant for corn, soybeans, and first-year alfalfa yields; but not for seeding-year forage yields. Corn yields in the forage systems averaged 13 bushels/acre more than in the cash grain systems ($P<0.01$). In the cash grain systems, the quasi-organic system yielded 91% as much corn than as the average of the two higher external input systems ($P=0.04$). In the forage systems, the quasi-organic system, CS5, produced 88% as much corn as the high

external input system CS4 (P=0.01). For soybean, the quasi-organic system, CS3, generated 96% as much yield as the high external input system, C2 (P=0.09), but there was a site × system interaction (see below). The quasi-organic system, CS5, produced 105% as much dry matter as the high external input system, CS4, in the first hay year of alfalfa (P=0.03); however, the difference between the two systems in the seeding year yields was not statistically significant due to greater variability and fewer years of data.

The effect of site was statistically significant for corn and the two forage crop phases with the well-drained ARS soils providing higher yields than the poorly drained LAC soils for all crops and systems except CS2 soybeans. In the three crops where sites were significantly different, the site × system interaction was not significant. The nearly parallel results over sites shown in **Fig. 1a and 1b**, corroborated the lack of a site × system interaction for the three crops. In soybean, however, the effect of site was not significant, but the site × system interaction was significant, which was confirmed by the crossover pattern for soybean in **Fig 1a**. The lack of a site × system interaction in three of the four crops and the relatively small crossover in the other crop, in spite of the large difference in drainage, suggests that these results are widely applicable in the upper Midwest on prairie derived soils. However, we decided to re-run the analysis by site for three reasons;

- As can be seen in **Table 3c**, there is a large variance component for year × site (the only variance component larger than the residual in all four crops;
- There was greater variability of the data from LAC than ARS; and,
- There were a greater number of years of data at ARS than LAC.

## Crop Yields Within Locations

**Corn.** When we analyzed all the corn data after the staggered start for all five systems at ARS (1993-2002), the effect of system was significant (P<0.01) and the ranking of the cropping system mean yields did not change from the ranking obtained from the analysis over sites: CS4>CS2>CS5>CS1>CS3 (**Table 4a**). When we analyzed the data for wetter LAC (1993-1998), the effect of systems was again significant (P=0.05). However, the order of CS1 and CS5 reversed (**Table 4b**) putting the two quasi-organic systems at the low end of the list. These analyses confirmed the residual variance of corn yields at LAC was larger than at ARS. In fact, the variance at LAC was over twice as large as it was at ARS, which was statistically significant (P<0.01).

Weed competition in the quasi-organic systems was one of the major causes of yield differences between years. Poor weed control in the quasi-organic systems as a result of wet spring weather occurred in 1993 and 1998 at LAC. Corn yields for these two years averaged 120 bushels/acre compared to 160 bushels for the three years (1994, 1995, and 1997) with drier springs and better mechanical weed control. We omitted 1996 from this set of analyses because the spring was so wet that it was not possible to plant the corn until late June. Consequently, very low corn yields and good weed control were obtained with all five systems in that year. When we investigated the weather records it was clear that May plus June rainfall in excess of 10 inches (140% of the norm) fit our set of problem years perfectly (**Fig 2**).

Similarly, we noted incomplete weed control in the quasi-organic systems impacted the comparison with the higher-external input systems in 1993, 1996, 2000, and 2001 at ARS. As

was the case at LAC, these years had May plus June rainfall in excess of 140% of the norm **(Fig. 3)**. In these four years, the corn grain yields in the quasi-organic grain system, CS3, averaged only 76% of the mean for the higher-external input systems, CS1 and CS2. In contrast to LAC, two other years (1994 and 1998) also had excessive rain in the spring, but these two years also had slightly above normal Growing Degree Days (GDD) for that period **(Fig. 3**). Thus, on the better-drained soils at ARS, it appears that both wet and cold weather are necessary to inhibit the effectiveness of mechanical weed control in corn. However, in the six years with more favorable spring weather, quasi-organic grain system (167 bu/a) averaged 96% of the two conventional systems. Likewise in the forage systems at ARS, the quasi-organic system, CS5, yielded 83% as well as CS4 in the four unfavorable years; but it yielded 94% as well in the six favorable years. Porter et al (2003) working in Minnesota also found that wet springs reduced the efficacy of mechanical weed control and adversely affected organic corn and soybean yields.

These differences in cropping system corn yields between years with springs favorable versus unfavorable for mechanical weed control account for most of the large year × system variance component in **Table 3c**. It is also likely however, that the colder, wet weather would have also limited nitrogen mineralization in the quasi-organic systems (CS 3 & CS 5) (Andraski and Bundy, 2002) reducing the competitiveness of the corn with weeds, further resulting in the lower yields). Regardless of whether one or both factors caused the lower yield, it is clear the performance of the quasi-organic systems relative to the higher-external input systems during years with wet springs at LAC (61 to 77%) or cold wet springs at ARS (76 to 83%) was comparable to that Batte et al, (1993) reported (72%). However, their relative corn yields in years with drier springs at both sites (94 to 97%) was much better than expected from that report.

In addition to the low versus high external input comparison, the corn yields in the forage systems were significantly greater than those in the cash grain systems for the 10-year analysis at ARS ($P<0.01$) and for the years with a dry spring at LAC. ($P=0.02$). A key component of this linear contrast is the comparison of continuous corn to corn grown after any other crop when adequate N has been supplied. Baldock et al. (1981) found this rotation effect to be 17.0 to 18.0 bu/a following two years of alfalfa and Porter et al. (1997b) reported it was 23.3 to 27.1 bu/a following one year of alfalfa. In the WICST, the rotation effect was 23.1 ± 10.1 bu/a at ARS and 21.4 ± 16.2 bu/a for the three, dry-spring years at LAC, which is consistent with the prior research. However, the smaller, nonsignificant, estimate of 14.3 bushels/acre for the three wet-spring years at LAC is contrary to Porter et al. (2003) where the rotation effect was larger in low yielding years. Also, the estimated rotation effect for corn following soybean; i.e. the comparison of CS1 to CS2 corn, at both WICST locations was smaller (six to nine bushels/a) and nonsignificant (**Tables 4a and 4b**).

**Soybeans.** Similar to corn, soybean yields in the quasi-organic system, CS3, averaged 10% less than those in the high-external input system, CS2, at ARS for 1990 through 2002. (**Table 4c**). As was the case with corn, we had difficulty controlling weeds mechanically in CS3 in some years; specifically in 1992, 1994, 1999, 2000, and 2001 at ARS. In those five years the CS3 soybean yields averaged 38 bushels/acre, which was 79% of the CS2 soybean yields for the same years. But in the other eight years CS3 soybean yields averaged 48 bushels/acre, which was 96% of those in CS2 over the same years. We obtained a similar result at LAC. Over all nine years of data, soybean CS3 produced only 85% as well as in CS2 and the difference was

statistically significant (P=0.04). However, our notes indicate problems controlling weeds in 1993, 1994 and 1998. In those years CS3 soybean production averaged 69% of that in CS2; but in the five years with good mechanical weed control, CS3 soybean production averaged 96% of that in CS2. The years of poor weed control fit well with the value of 80% Batte et al. (1993) reported. However, in the majority of years in which we obtained good weed control mechanically the performance of soybean in CS3 relative to that in CS2 was much better (96%) at both sites.

**Wheat.** The 90% confidence interval for the CS3 wheat yields at ARS was 54.0 ± 6.2 bushels/acre over the period 1991 through 2002 (**see Table 4d**). This was approximately 6% less than the county average yield for the same period, 57.3 bushels/acre (http://www.nass.usda.gov/wi/annbull/). For Lakeland, the 90% confidence interval for CS3 wheat yields was 43.6 ± 12.9 bushels/acre for the years 1991 through 1998 (omitting 1996 when the wheat winterkilled, not only at this site, but over most of southern Wisconsin). This was 20% less than the county average for the same years, 54.4 bushels/acre. These yield losses associated with organic production were nevertheless, smaller than the 30% reduction reported in the Batte et al. (1993) survey.

**Forages.** **Tables 4e and 4f** show that the quasi-organic system, CS5, produced 7 to 42% more forage dry matter than the high external system, CS4. In the seeding year at ARS (**Table 4e**), the difference between the companion seeding with oats and field peas and sole seeding was barely statistically significant (P=0.10); and at LAC **(Table 4f)** the difference was not quite statistically significant (P=0.13). In both systems the first year forage production was significantly greater than during the establishment year. During the first year after seeding, the advantage of CS5 over CS4 was significant at ARS (P=0.04), but not at LAC (P=0.33). At ARS there was a significant decline in the forage produced in second hay year of alfalfa compared to the first hay year in CS4 (P=0.01). Although there was a similar decline between the alfalfa phases at Lakeland, the difference was not statistically significant.

After the pastures were established we rotationally grazed them with approximately 500 lb heifer calves. We tried several methods of rotational grazing and settled on using a cohort technique in which we moved all the animals together from plot to plot. We have hand sampled forage yield and quality data from this pasture system for 1997 through 2002 at ARS, where the overall mean forage yield was 4.98 ± 0.96 tons dm/acre. Because this 90% confidence interval encloses the established alfalfa yields in CS4 and CS5, the CS6 forage yields were not significantly different from them (**Table 4e**).

Because animal production in the form of meat or milk is the ultimate goal of forage production, forage quality is as important as dry matter yield. We determined relative feed value (RFV) as a measure of forage quality and estimated milk production with MILK91 (Undersander et al. 1993). **Tables 4g and 4h** show the results of these observations. Not surprisingly, there was a 23 (ARS) to 35 (LAC) point RFV advantage between forage that was primarily composed of alfalfa versus the companion-seeded option (oats/peas) in the establishment year. 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 between the two systems. Similar offsets occurred, but to a lesser extent, in the other comparisons so there were no significant differences in milk production in any of the comparisons at ARS or LAC.

**Crop Yield Variability Over Years Within Locations**

Although the primary concern of the farmers and researchers on the WICST advisory panels was on long-term mean productivity, they were also very concerned about variation in yields from year-to-year, especially in the quasi-organic systems. The above results appear to validate that concern. Both corn and soybean yields in the quasi-organic systems showed substantial variability over years depending primarily on the favorability for mechanical weed control.

**Corn.** **Table 4a and 4b** give the standard deviations and the CVs of the annual mean corn yields for each system at ARS and LAC. There is a hint of greater variation with the quasi-organic systems, CS3 at ARS and CS5 at LAC; however, the differences are too small to be statistically significant at either site with Bartlett's test (P=0.8 at ARS and P=0.9 at LAC). In addition, there were no differences among the systems using the mean absolute deviation from the median (data not shown). On the other hand, the systems with the greatest variability are also those with some of the lower yields. Thus, even though there were no significant differences in the absolute variabilities, there may be significant differences in the relative variabilities (i.e., the ratio of the standard deviations to the mean, which is the Coefficient of Variation (CV). At ARS, the 90% confidence intervals for the CV of all the systems except the quasi-organic system, CS3, could be approximated by the interval [0.1, 0.3]. Although the 90% confidence interval for the CV in CS3 was shifted up approximately by 0.1 to [0.2, 0.4], there was still substantial overlap between it and the interval for the other systems. Similarly at LAC, the 90% confidence interval for the CV in CS1 through CS4 were within the interval [0.1, 0.8], but the 90% confidence interval for the CV in the quasi-organic system, CS5, was about 0.2 units higher. Again there was substantial overlap between the 90% confidence intervals for all the systems, including CS5, so there were no significant differences. Therefore, in spite of the hint of greater variability of annual mean corn yields section for the quasi-organic systems, CS3 and CS5, in the previous section; there were no significant differences between these systems and the conventional systems in absolute or relative variability at either location.

**Soybeans.** **Table 4c** states the variability statistics for the annual mean soybean yields at both sites. The F-test of the variance ratio for CS3 to CS2 was not statistically significant at ARS (P=0.35) or at LAC (P=0.31). Furthermore, the mean absolute deviations from the median were not different stastistically (data not shown). The relative variabilities, i.e., the CVs, were not significantly different at either site. Although the previous section found substantial year-to-year variability for soybean yields in the quasi-organic system, this variability was not significantly greater than that in the conventional system.

**Wheat.** **Table 4d** presents the variability information for annual mean wheat yields in the quasi-organic system, CS3. The standard deviation for CS3 was actually smaller than those calculated for the same time period from the Wisconsin Department of Agriculture statistics (http://www.nass.usda.gov/wi/annbull/) for Columbia County (the location of the ARS), so the

difference was not statistically significant. In CS3 at LAC, the standard deviation of the annual mean wheat yields for 1991 through 1998, including 1996 when the wheat crop failed, was 22.45 bushels/acre. If 1996 was omitted, then the standard deviation was 17.62 bushels/acre. In either case, the WICST results had a larger standard deviation than those for Walworth County, but the differences were not statistically significant.

**Alfalfa.** The variability statistics for forages are given in **Tables 4e and 4f**. In the seeding year there were no significant differences in absolute or relative variation in annual mean yields between the high external input system (CS4) and the low external input system (CS5) at either site. However, in the first established year of alfalfa at ARS, the variance of the annual mean forage yields from CS4 was significantly larger than that for CS5 using the F test (P=0.06). In addition, the mean absolute deviations from the median for the two systems were significant at the 10% level (data not shown). At Lakeland, the variance for CS4 was also significantly greater than that for CS5 (P= 0.06). However, the mean absolute deviations from the median values, were not significantly different at the 10% level (data not shown). The CVs for CS4 were approximately 1.8 times those for CS5, but the CVs were not significantly different at either site.

Thus, the only evidence of greater variability we found was that the high external input system, CS4, had more variable alfalfa yields in the year after establishment than the quasi-organic system, CS5, at both locations. There are two causes of this result, which is counter to the expectations of many. First, the quasi-organic systems are less variable than anticipated. And second, with all the focus on the organic systems, many have forgotten how variable the high input systems are. For example, in the established alfalfa the high input system, CS4, had much greater winterkill than CS5 and it had to be reseeded with red clover and ryegrass in 1992, which led to 2 tons dm/acre yield differential. We attributed this difference to the more aggressive cutting schedule weakening the stand. Also, during 1999, dry weather reduced CS4 established yields more than in CS5, probably for the same reason. CS1 has succumbed to whatever constitutes the "rotation effect" (see above) compared to the other systems in some years more than others. In CS2, rodent problems have plagued the notill corn phase and herbicide injury was so severe in the very cold, dry spring of 1992 **(Fig. 3)** that the soybean crop had to be replanted. Thus, each system has its unique challenges as well as those that are similar across systems; consequently, except for first-year alfalfa where the high input system was more variable, the yield variabilities were not statistically different.

## Crop Yield Trends at Arlington

While the mean yields of a long-term study are very important parameters, it is also essential to determine if the yields are stable over time, or if trends have developed that could eventually change the differences among the cropping systems.

**Corn**. **Fig. 4** shows the corn yields trends for continuous corn, CS1, and corn in the soybean-corn system, CS2, over 6 cycles. Initially CS2 yields were greater than those in CS1, however in the last two cycles, CS1 performed better than CS2. This difference plus the decrease in yields during Cycles 2 and 3 (due largely to the cold, wet weather in May and June 1992 and 1993, **Fig**

**3**) led to a separate quadratic equation for the two systems being the best fitting model. From the low at Cycle 3 to the high at Cycle 6, the yields in CS1 increased 50.7 bushels/acre, thus the average annual increase was 8.5 bushels/acre. In CS2 the yield increase over this period was 20.4 bushels/acre making the average annual increase only 3.4 bushels/acre.

**Fig. 5** illustrates the trend in corn yields for the high external input, continuous system, CS1, compared the trends for corn yields in the quasi-organic systems, CS3 and CS5 over cycles. Although the data look as if the quadratic model would provide a good fit as it did for CS1 and CS2, none of the terms in the quadratic model were statistically different from zero. Also, the linear slope term for CS3 was not statistically significant. That leaves the overall mean corn yield in CS3, 142 bu/a, as the best estimate of the corn yields in this system. (Jon, how important is this next sentence. Can we drop it ?) In this analysis, regrouping the CS1 data as if it had 3 phases had little effect on the rate of yield increase compared to the 2-year cycle grouping in **Fig. 4** over the last several cycles. In other words, there was an increase of 23.7 bushel/acres per cycle in **Fig. 4**, which translates into an improvement of 7.9 bushel/acre per year, which is very close to that calculated for CS1 above. As a result of the increasing corn yields for CS1 and the flat yields for CS3 these data project an increasing advantage for CS1 over CS3. The forage based, quasi-organic system, CS5, had a significantly positive slope showing corn yields rising at a rate of 11.1 bu/a per cycle (3.7 bu/a/year). Thus, it too had an increasing advantage over CS3, but its rate of increase was less than half of that in CS1.

We also found significant linear trends in slopes in the comparison of CS1 and CS4 corn yields (**Fig. 6**). The regression equations estimate a 37 bushel/acre advantage for CS4 during Cycle 1. However, they also estimate the advantage will switch to CS1 by Cycle 5 (i.e., 2010 in this trial) due to the significantly larger slope for CS1. The slope of CS1 suggests an increase of 29.7 bushels/acre per cycle, or 7.4 bushels/acre per year*, which is very close to the rate estimated with the 2- and 3-year cycles discussed above.* In the CS4, the comparable estimates are 18.6 bushels/acre per cycle, which equates to 4.7 bushels/acre per year.

Thus, corn yields in four of the five cropping systems at ARS had significantly positive yield trends over the first twelve years of the WICST. If these slope trends continue at the rates observed, CS1>CS4>CS5>CS2 and CS3=0 (assuming the linearization of the trend for CS2 estimated above), then the corn yield rankings will eventually follow that order, which is substantially different from the one observed over the first thirteen years (see above). The most astounding of these forecasts is for the continuous corn system, CS1, to go from next-to-last to first. While it is not unprecedented for continuous corn to yield as well as corn in a rotation (i.e. have a rotation effect of zero, Shrader et al., 1966; Baldock and Musgrave, 1980), we are unaware of any reports in refereed journals that continuous corn produced greater grain yields than corn in a rotation. On the other hand, there are such reports in the trade press. For example, Reichenberger (2004) reported that the record yields in the National Corn Growers Association yield contest have been obtained in fields that have been in corn for over 20 years and that continuous corn has performed better than a corn-soybean rotation after the initial three to four years. Consequently, the next 10-year of the WICST should help answer some key questions in regard to corn yields. Will the continuous corn system continue to have the most rapid increase to become the top corn producing system? Will the rates level off so its yields equal those of the

longer rotations? Or, are the current rates an aberration that will be corrected so that continuous corn resumes a position near the bottom of the order?

**Soybeans.** The cycle lengths of CS2 and CS3 are not the same, which causes missing cell problems for conducting an analysis of covariance for soybean yields like we did with corn. However, even without applying statistical tests, the trends for the two systems are clearly different **(Fig. 7**). The saw-tooth oscillations in soybean yields in CS2 resulted in a slightly negative yield trend of 0.6 bushels/acre per year. In CS3, soybean yields followed a concave quadratic trend. The estimated slope at Cycle 4 was a negative 8.0 bushels/acre per year. If these trends continue, then the gap between CS2 and CS3 soybean yields will be much wider than the 5 bushels/acre we reported above. But in the yield section above, we also identified cold, wet spring weather as having caused a problem with weed control in several years in the last two cycles of CS3. If this was the major reason for the steep decline observed, then it is likely that the weather would return to a more normal pattern and the CS3 yield would again approach the smaller 5 bushel/acre difference compared to CS2, especially if more aggressive weed control measures are implemented in this quasi-organic system. This will be another interesting question to follow to see which interpretation is born out.

**Wheat.** **Fig. 8** illustrates the trend in wheat yields. After an increase from the first to the second cycle, the trend has been down. The resulting quadratic trend predicts yields are now falling at 1.9 bushels/acre per year. It may be that decreasing soil fertility levels and increasing weed pressure in this quasi-organic system that, although not pronounced, are causing lower yields. On the other hand, the yields could also be responding to variations in weather patterns, in which case the trend might reverse once the weather improves. However, a statistically significant, linear increase in county average yields of 3.4 bushels/acre per year over the same period argues against the latter alternative. So once again, additional years of data are necessary to distinguish between these alternatives.

**Alfalfa.** Amongst the forage crops, the possible trends in the first year of established alfalfa yields are most interesting because two systems, CS4 and CS5, can be compared. The yields in both systems have followed a quadratic trend with the better yields in the early and later cycles (**Fig. 9**). During Cycle 3, CS4 yields have been increasing by 0.325 tons dm/acre per year, while during its last cycle CS5 yields have been increasing at 0.226 tons/acre per year. The nearly 50% faster increase in CS4 yields suggests that the first 13-year results (see above) showing that CS5 yields exceeded CS4 yields by nearly 0.5 ton dm/acre may be reversed in several more cycles.

Thus, statistically significant yield trends occurred over the first 13 years in the four major crops of the WICST at ARS. As a result, the mean yields presented in the yield section cannot be regarded as the final outcome of these trials. Some might put the emphasis on the overall means, while other might emphasize the yield trends. However, we agree with Singh and Jones (2002) that a system must have both a high overall yield level as well as a positive yield trend to have sustainable production. For example, continuous corn, CS1, has the most rapidly increasing yields, but it cannot be deemed to have the most sustainable productivity of the systems in the WICST because it was next-to-last in overall yield. Also, CS2 is not the second most sustainable system although its overall all mean corn yield was second only to CS4 because it had the next-

to-the-lowest rate of corn yield increase and the trend in soybean yields was negative. Consequently, some way needs to be found to combine these two facets of yield sustainability

If the yield trends eventually reached an equilibrium level, then there would not be a conflict between the overall means and the yield trends. Cady, (1991) argued that yield trends in long-term studies are the result of the cumulative effects of crop rotations or other treatments on soils that would change rapidly at first, then slow and eventually level off at an equilibrium. That may be true of long-term trials with fixed treatments, but the problem with such trials are that by the time the trend and the equilibrium point are identified the treatments may be obsolete. The advantage of a cropping system trial with philosophical goals such as reported here is that the treatments are adjusted to keep up with technology. For example, superior cultivars, such as herbicide resistant soybean varieties, are selected as they are identified; more effective herbicides are applied when they have been proven; and more effective equipment, such as better drills and rotary hoes, are used when they are developed. As a consequence, it is doubtful that an equilibrium level will ever be reached. The best we can hope is that the rate of change approaches that of the overall technology rate.

One cropping system had the lowest overall yields and yield trends below the rate of technological advances for all crops in the system; namely, CS3, which is the quasi-organic, cash-grain system. Thus, this system may not be sustainable as we designed it. We knew from the beginning that this was a marginally sustainable system because it is a very "tight rotation with 4 crops in three years, no forage phase, and because it does not include a complete source of plant nutrients such as animal manure or compost. But it serves as a reference point for cash grain producers. The fact that the crop yields in CS3 has done so well for so long (88 to 94% of conventional system yields for 13 years at ARS and 80 to 90% for 9 years at LAC) bodes well for the quasi-organic in the long run. In fact, we believe the primary conclusion of the WICST to this point is that the differences in the overall yields, variability in yields, and yield trends among systems (including quasi-organic and conventional) are small enough that other factors; such as profitability, environmental impact, and life-style preferences; will often be the determinate in the selection of a cropping system.

## CONCLUSIONS

1-The lack of a site × system interaction in three of the four crops and the relatively small crossover in the other crop in spite of the large difference in drainage suggests that these results are widely applicable and could be averaged over sites. This suggests that the trial results have a wide area of inference on prairie-derived soils of the upper mid-west.

2-The quasi-organic systems produced 10 to 20% smaller grain yields than the high and medium external input systems during the first 8 to 13 years of the two trials. However, the low external input forage system, CS5, produced up to 10% more alfalfa in the same period. Thus, the size of the deficit production with the low external systems was less than expected by many.

3-Thus far, the data do not support the hypothesis that the low external input systems are more variable in an absolute or a relative sense than the higher external systems. In fact, the

only significant difference between variabilities found that the low-external input system, CS5, had lower variability for first-year, established alfalfa than the high-external input system, CS4, at Arlington.

4-There were significant yield trends in the four crops examined (corn, soybeans, wheat, and alfalfa). These trends differed among the cropping systems. With a few exceptions, there were increasing trends with the high- and medium-external input systems, but steady to decreasing trends with the low-external input systems.

5-Overall we conclude from these trials that differences in productivity, yield trends, and yield variability between the low external input systems and the higher external do exist. However, the differences are small enough and inconsistent enough that other factors; such as such as profitability, environmental impact, and life-style preferences; will often be the determinate in the selection of a cropping system.

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Table 1. **Description of the six cropping systems.**

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

(1) Manure application calculated in the forage systems CS4 & CS5 at the rate of 10 t/a/yr. Manure applied in the fall of the year prior to planting

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

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

§ Prior to 1994 at Lakeland and 1995 at Arlington, conventional tillage and drilling were used. After that the system was entirely no-till

¶ Soybeans planted in 30-inch rows.

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

| System | Plot | Year | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 |
| CS2 | 101 | F | $Sb_1$ | $C_1$ | $Sb_2$ | $C_2$ | $Sb_3$ |
| | 108 | F | F | $Sb_1$ | $C_1$ | $Sb_2$ | $C_2$ |

† F, background or filler corn; Sb soybeans; C, corn; and the subscripts denote the cycle.

**Table 3a. Means squares for analyses of grain crops over sites.**

| Source | Corn 1993-1998 | | | Soybeans 1990-1998 | | |
|---|---|---|---|---|---|---|
| | Num. df | Denom df | MS | Num. df | Denom df | MS |
| Site | 1 | 5 | 816† | 1 | 6 | 2 NS |
| System | 4 | 20 | 923 ** | 1 | 8 | 88† |
| Site x system | 4 | 20 | 137 NS | 1 | 8 | 145* |

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Significant at the 0.10 probability level.

**Table 3b. Means squares for analyses of forage crop dry matter yields over sites.**

| Source | Establishment year forage, 1994-1998‡ | | | First-year alfalfa, 1991-1998 | | |
|---|---|---|---|---|---|---|
| | Num. df | Denom df | MS | Num. df | Denom df | MS |
| Site | 1 | 4 | 2.96* | 1 | 14 | 2.27* |
| System | 1 | 8 | 0.71 NS | 1 | 14 | 2.64* |
| Site x system | 1 | 8 | 0.00 NS | 1 | 14 | 0.39 NS |

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.
† Significant at the 0.10 probability level.
‡ 1996 omitted because oat companion crops were harvested as grain.

Table 3c. **Mean square for the variance components for analyses of grain and forage crops over sites.**

| Source | Corn 1993-1998 | Soybeans 1990-1998 | Seeding year 90-98 | Alfalfa 1991-1998 |
|---|---|---|---|---|
| Year, Y | 1191 | 0 | 0.07 | 0 |
| Block (Site), B(S) | 12 | 1 | 0 | 0 |
| Y x B(S) | 4 | 4 | 0.03 | 0 |
| Y x Site | 511 | 54 | 0.29 | 0.40 |
| Y x System | 52 | 14 | 0 | 0 |
| Y x Site x System | 145 | 15 | 0.61 | 0.12 |
| Residual | 150 | 25 | 0.13 | 0.31 |
| | | | | |

**Table 4a. Mean corn yields and variability of the annual mean yield at Arlington 1993-2002.**

| System | Overall mean (Bu/a) | S† | CV†; 90% confidence interval |
|---|---|---|---|
| | ----------bushels/acre---------- | | |
| CS1 | 162 | 28.5 | 0.18; 0.13, 0.30 |
| CS2 | 168 | 27.4 | 0.16; 0.12, 0.27 |
| CS3 | 146 | 37.2 | 0.25; 0.18, 0.44 |
| CS4 | 185 | 26.4 | 0.14; 0.10, 0.24 |
| CS5 | 166 | 27.2 | 0.16; 0.12, 0.27 |
| Mean | 165 | | |
| LSD(10%) | 23.5 | | |

† S, standard deviation; CV, coefficient of variation.

**Table 4b. Mean corn yields and variability of the annual mean yield at Lakeland 1993-1998.**

| System | Overall mean (Bu/a) | S† | CV†; 90% confidence interval |
|---|---|---|---|
| | ----------bushels/acre---------- | | |
| CS1 | 125 | 33.6 | 0.24; 0.15, 0.61 |
| CS2 | 134 | 31.8 | 0.21; 0.13, 0.53 |
| CS3 | 117 | 38.7 | 0.29; 0.18, 0.78 |
| CS4 | 146 | 35.3 | 0.22; 0.14, 0.55 |
| CS5 | 121 | 47.6 | 0.36; 0.22, 1.01 |
| Mean | 128 | | |
| LSD(10%) | 53.0 | | |

† Omitting 1996, n=5; S, standard deviation; CV, coefficient of variation.

**Table 4c. Mean soybean yields and variability of the annual mean yield†.**

| Site, System | Overall mean (Bu/a) | S‡ | CV‡; 90% confidence interval |
|---|---|---|---|
| | ----------bushels/acre---------- | | |
| ARS, CS2 | 53.0 | 8.5 | 0.16; 0.12, 0.25 |
| ARS, CS3 | 47.9 | 9.5 | 0.20; 0.15, 0.31 |
| Mean | 50.5 | | |
| LSD(10%) | 6.3 | | |
| | | | |
| LAC, CS2 | 54.5 | 8.6 | 0.16; 0.11, 0.27 |
| LAC, CS3 | 46.4 | 10.3 | 0.22; 0.16, 0.39 |
| Mean | 50.4 | | |
| LSD(10%) | 8.0 | | |

† ARS = Arlington Research Station, 1990-2002; LAC = Lakeland Agricultural Complex, 1990-1998.
‡ S, standard deviation; CV, coefficient of variation.

**Table 4d. Mean winter wheat yields and variability of the annual mean yield[†].**

| Site, System | Overall mean (bu/a) | S[‡] | CV[‡]; 90% confidence interval |
|---|---|---|---|
| | ----------bushels/acre---------- | | |
| ARS, CS3 | 54.0 | 12.0 | 0.22; 0.16, 0.35 |
| LAC, CS3 | 43.6 | 17.6 | 0.40; 0.27, 0.89 |

[†] ARS = Arlington Research Station, 1991-2002; LAC = Lakeland Agricultural Complex, 1991-1998 (1996 omitted at LAC due to winter kill).
[‡] S, standard deviation; CV, coefficient of variation.

**Table 4e. Mean forage yields and variability of the annual mean yield at Arlington.**

| System | Overall mean (Tdm/a) | S[†] | CV[†]; 90% confidence interval |
|---|---|---|---|
| | ----------tons dm/acre---------- | | |
| CS4, sole seeded alfalfa[‡] | 3.17 | 0.853 | 0.27; 0.20, 0.42 |
| CS4, first-year alfalfa[§] | 4.70 | 0.784 | 0.17; 0.12, 0.26 |
| CS4, second year alfalfa[¶] | 4.09 | 0.910 | 0.22; 0.16, 0.37 |
| CS5, companion seeded[‡] | 3.82 | 0.943 | 0.25; 0.18, 0.41 |
| CS5, first-year alfalfa§ | 5.12 | 0.479 | 0.09; 0.07, 0.15 |
| CS6, hay 1990-1992 | 3.85 | Xxyy | ssyy |
| CS6, rotational pasture[††] | 4.92 | | |

[†] S, standard deviation, CV, coefficient of variation.
[‡] 1990-2002, except no data for CS5 in 1991 and 1993 because oats were harvested as grain.
[§] 1991-2002.
[¶] 1992-2002.
[††] Based on nine years of data.

**Table 4f. Mean forage yields and variability of the annual mean yield at Lakeland.**

| System | Overall mean (Tdm/a) | S[†] | CV[†]; 90% confidence interval |
|---|---|---|---|
| | ----------tons dm/acre---------- | | |
| CS4, sole seeded alfalfa[‡] | 1.30 (1.55)[††] | 0.905 | 0.58; 0.39, 1.36 |
| CS4, first-year alfalfa[§] | 3.64 | 1.08 | 0.30; 0.20, 0.57 |
| CS4, second year alfalfa[¶] | 3.54 | 0.547 | 0.15; 0.11, 0.30 |
| CS5, companion seeded alfalfa[‡] | 1.74 (2.04) [††] | 0.995 | 0.49; 0.31, 1.31 |
| CS5, first-year alfalfa§ | 3.88 | 0.657 | 0.17; 0.12, 0.31 |
| CS6, hay 1991 | 3.39 | - | Insufficient data |
| CS6, rotational pasture[‡‡] | 3.98 | | |

[†] S, standard deviation; CV, coefficient of variation.
[‡] 1990-1998, except no data for CS5 in 1991, 1992 and 1996 because oats were harvested as grain
[§] 1991-1998.
[¶] 1992-1998.
[††] The overall mean annual mean yield in parentheses differs from the REML value because of missing plots. (Do we need this nuance Jon?)
[‡‡] Based on four years of data.

**Table 4g. Forage quality and estimated milk yield at Arlington**.

| System, comparison | Relative feed value | Milk production(1), Cwt/acre |
|---|---|---|
| CS4-sole seeded alfalfa, vs.<br>CS5-companion seeded alfalfa‡ | 143<br>120** | 61.5<br>62.0 NS† |
| CS4-first-year alfalfa, vs.<br>CS5-first-year alfalfa§ | 142<br>138 NS | 97.4<br>104.6 NS |
| CS4-first-year alfalfa, vs.<br>CS4, second year alfalfa¶ | 143<br>149 NS | 95.9<br>88.6 NS |

Estimated using MILK91 (Undersander et al. 1993)

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.
† NS, not significant at the 0.1 probability level.
‡ 1990-2002, except no data for 1991 and 1993 because oats were harvested as grain.
§ 1991-2002.
¶ 1992-2002.

**Table 4h. Forage quality and estimated milk yield at Lakeland.**

| System, comparison | Relative feed value | Milk production (1), Cwt/acre |
|---|---|---|
| CS4-sole seeded alfalfa, vs.<br>CS5-companion seeded alfalfa‡ | 149<br>114** | 47.4<br>43.5 NS† |
| CS4-first-year alfalfa, vs.<br>CS5-first-year alfalfa§ | 146<br>143 NS | 83.8<br>88.1 NS |
| CS4-first-year alfalfa, vs.<br>CS4, second year alfalfa¶ | 148<br>152 NS | 83.9<br>84.7 NS |

Estimated using MILK91 (Undersander et al, 1993)

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.
† NS, not significant at the 0.1 probability level.
‡ 1993-1998, except no data for 1996.
§ 1991-1998.
¶ 1992-1998.

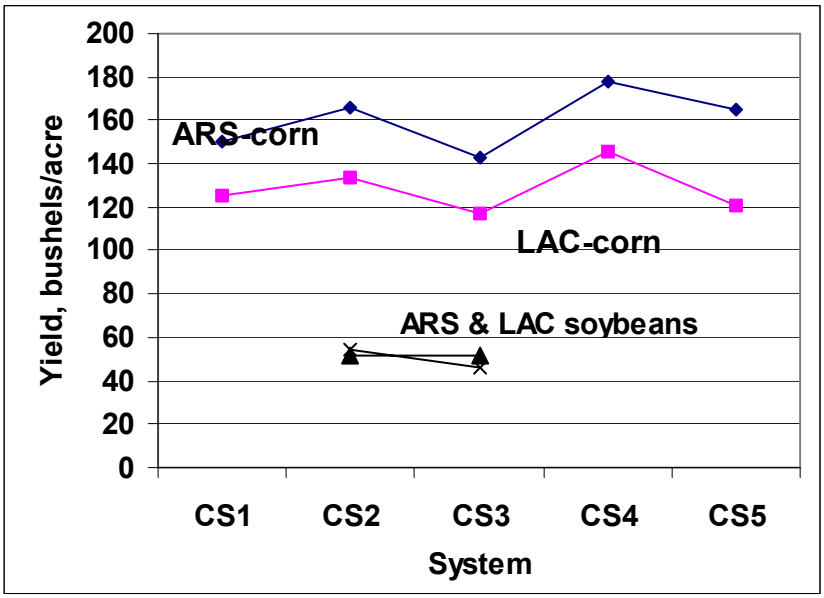


**Fig. 1a. Mean yields of corn and soybeans by site and system**.
ARS =Arlington Research Station; LAC = Lakeland Agricultural Complex

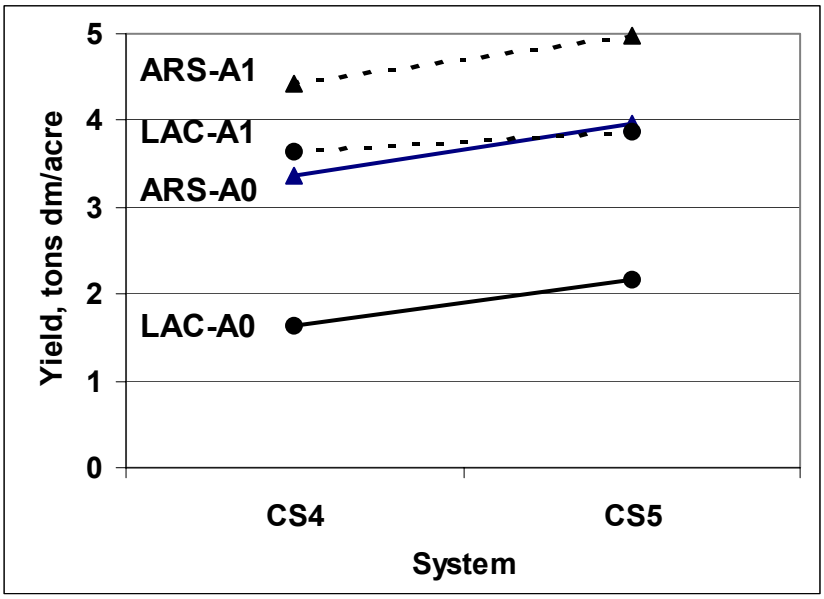


**Fig. 1b. Mean forage yields by site and system.**
ARS=Arlington Research Station; LAC= Lakeland Agricultural Complex
A1=alfalfa hay year I; A0=alfalfa seeding year

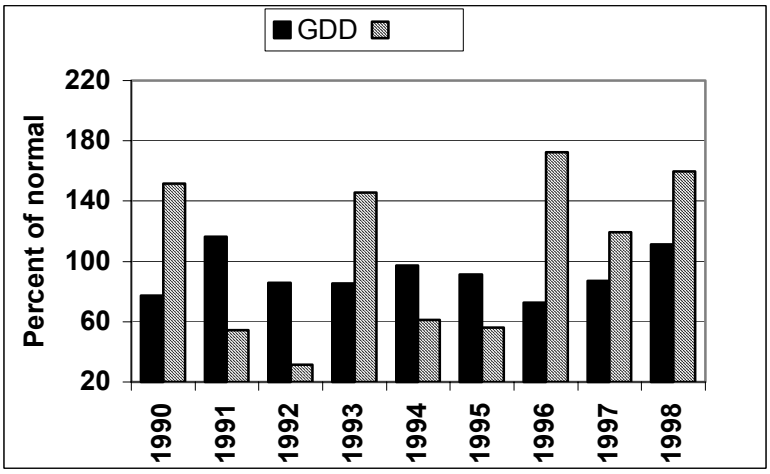


**Fig. 2. Lakeland Ag Complex, WI, May plus June Growing Degree Days (GDD, base 50ºF) and May plus June rainfall, as a percentage of the 1971-2002 norms**.

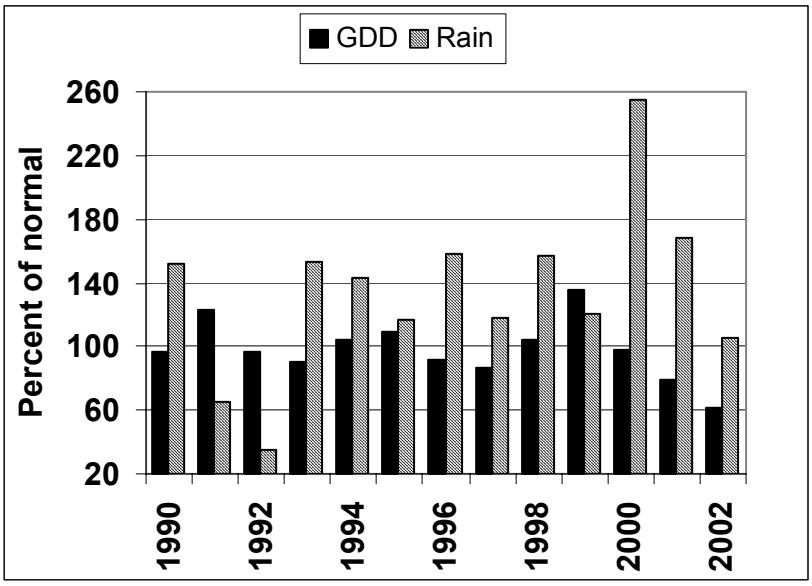


**Fig. 3. Arlington, WI, May plus June Growing Degree Days (GDD, base 50ºF) and May plus June rainfall, as a percentage of the 1971-2002 norms.**

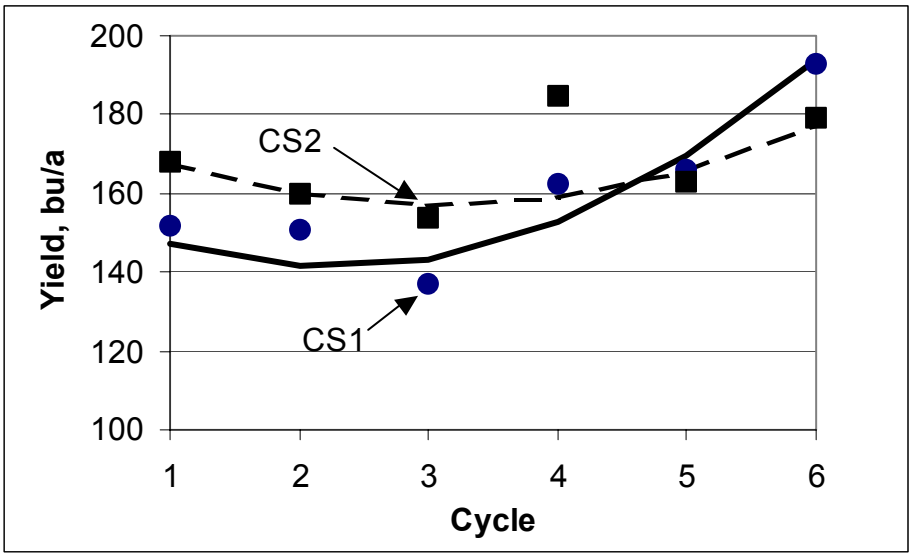


**Fig. 4. Trend of corn yields for CS1 and CS2 over cycles at Arlington (n=8)**. The regression:equation are CS1: Yield = 160.7 – 17.2*Cycle + 3.8*Cycle$^2$; and CS2: Yield = 180.0 – 14.9*Cycle + 2.4* Cycle$^2$. Each term in these models is significant at the 10% level or better.

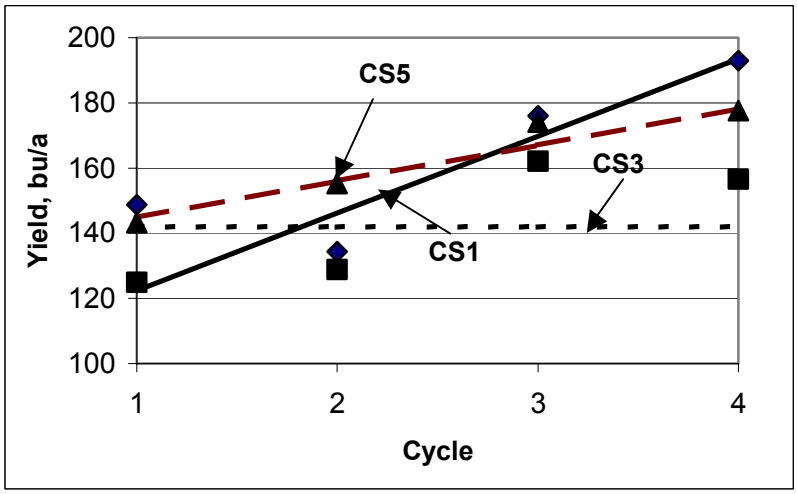


**Fig. 5. Corn yield trends for CS1, CS3, and CS5 over cycles (n=12 for Cycles 1-3 and n=8 for Cycle 4)**. The regression equations are CS1: Yield = 98.7 + 23.7*Cycle; CS3: Yield = 141.9; and CS5: Yield = 133.7 + 11.1*Cycle. Each term in these models is significant at the 1% level.

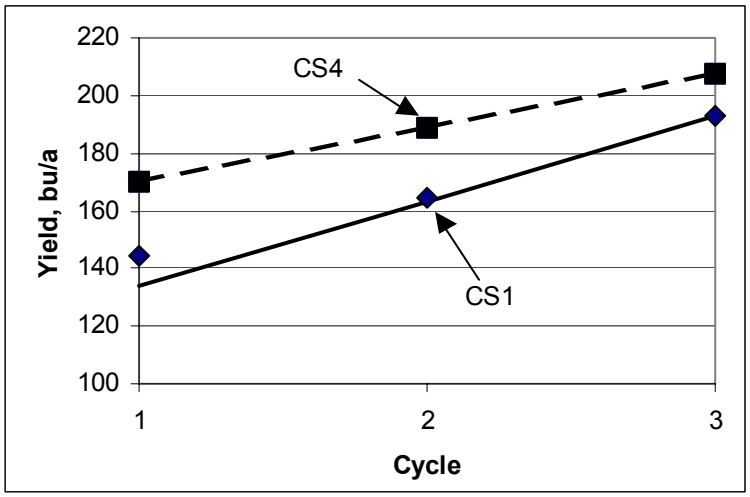


**Fig. 6. Corn yields for CS1 and CS4 over cycles (n=16 for Cycles 1-2, n=8 for Cycle 3).** The regression equations are CS1: Yield = 103.9 + 29.7*Cycle and CS4: Yield = 151.5 + 18.6*Cycle, each term in the models is statistically significant at the 2% level.

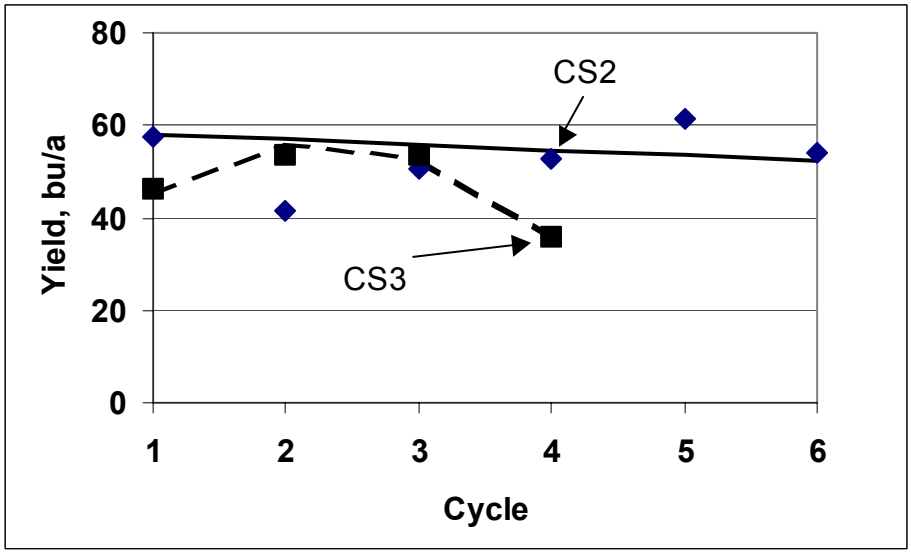


**Fig. 7. Trend of soybean yields for CS2 (n=8) and CS3 (n=12) over cycles**. The regression equations are CS2: Yield = 59.180 – 1.150*Cycle and CS3: Yield = 20.52 + 31.58*Cycle – 6.94*Cycle$^2$. The coefficients in both equations are statistically significant at the 1% level.

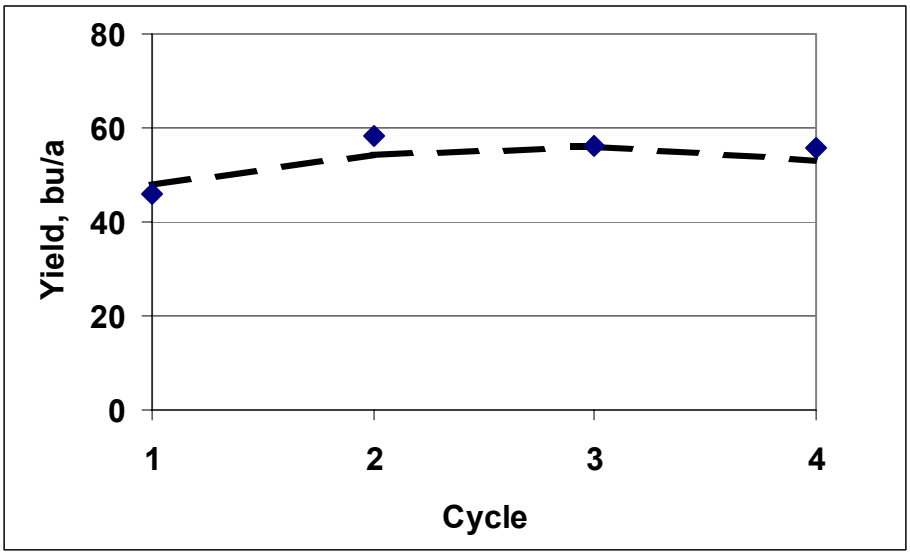


Fig. 8. **Trend of mean wheat yields for CS3 over cycle (n=12).** The regression equation is Yield = 36.46 + 13.87*Cycle – 2.43*Cycle$^2$. The coefficients are statistically significant at the 5% level.

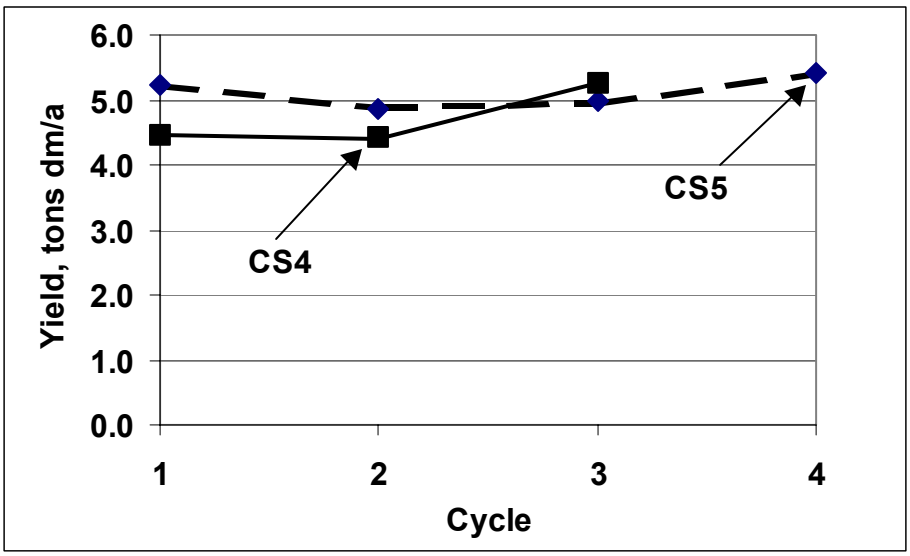


Fig. 9. **Trend of mean 1st year alfalfa yields for CS4 (n=16, except Cycle 2 n=15) and for CS5 (n=12) over cycles**. The regression equation is CS4: Yield = 5.41 –1.40*Cycle + 0.45*Cycle$^2$. and CS5: Yield = 5.99 – 0.96*Cycle + 0.2049* Cycle$^2$. The coefficients for both equations are statistically significant at the 10% level.

# WEED SEEDBANK COMMUNITY CHANGES ON THE WISCONSIN INTEGRATED CROPPING SYSTEMS TRIAL (WICST): 1992-2004.

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## INTRODUCTION

Weed seedbanks are the viable seeds present in the soil, and its surface. Seedbanks consist of both recent and older seeds shed; so, the soil weed seedbank can be regarded as the 'memory' of a weed community. The seedbank influences both the weed populations that occur in a field and the success of weed management strategies (Iowa State university 1996). Changes in weed community and weed seedbank size occur as time passes. Dekker (1999) explains that species once present may be replaced, or reduced due to the arrival of more competitive intra-specific variants, variable weather and crop management practices. He emphasizes however, that changes in the environment (especially wet or dry seasons that reduce weed control efficacy), and agricultural activities are the two most important factors influencing multiple year changes in the soil seedbank. A number of authors have shown for example, that crop rotation alone (Buhler et al. 2001; Forcella et al. 1988; Hill 1989; Schreiber 1992), tillage systems alone (Cardina et al. 1991; Mulugeta and Stoltenberg 1997), cultivations (Roberts and Dawkins 1967), crop rotation *and* tillage (Cardina et al. 2002), cropping systems (Davis et al. 2005), and weed management (Roberts and Chancellor 1986) are all important practices impacting seedbanks on arable land.

With agronomic systems, the seedbank itself is the primary source of annual weeds (Dekker 1999). Therefore, tracking the changes in weed seedbank composition can help one understand and evaluate the long-term effects of alternative cropping systems. Iowa State University's study of agricultural fields found that the weed seedbank density in the north central Corn Belt ranges from 2,100 to 580,000 seeds/m² (Iowa State University 1996). Forcella et al. (1992) in a study centered on Minnesota and Wisconsin found that the range in seed bank density in crop fields was between 1,500 seed/m² to 22,000 seed/m². These weed seedbanks are composed of many species, but 70 to 90% of the total seeds are from few dominant species. A second group comprising 10 to 20% of the total seedbank is generally made of species adapted to the geographic area, but not to current production practices. A final small percentage of the total seeds include recalcitrant seeds from previous seedbanks, newly introduced species, and seeds of previous crops (Buhler 1997).

Long-term studies of weed seedbanks are necessary however, to understand cropping management effects on seedbanks. This is because, for example, tillage systems require from 4 to 10 years to reach equilibrium in yield, weed populations, and soil characteristics (cited in Cardina et al. 1991). In addition, Roberts and Dawkins (1967) found that improvements in estimating seed bank could be achieved by sampling the same time of the year in successive years (cited in Dekker 1996).

Seedbanks have been estimated using: 1) seedling emergence, also called tray method (Forcella et al. 1992, 1997; Hill et al. 1989; Roberts and Dawkins 1997; Mulugeta and Stoltenberg 1997a, 1997b); 2) direct extraction from the soil called as extraction method (Buhler et al. 2001; Schreiber 1992); and 3) seedling emergence from undisturbed cores called core

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method (Forcella and Sparrow 1996). All three approaches have its pros and cons. While, seedling emergence may under estimate the weed seed density due to unknown quantities of dormant seeds remaining in the soil, extraction of seeds directly from the soil may over estimate the weed seed density due to the difficulty in judging seeds viability and fitness (Dekker 1999). There have been also some studies conducted to evaluate and/or compare methods to predict weed seedling populations from the soil seedbank. Forcella and Sparrow (1996) found that the three methods (extraction, trays germination and core methods) were essentially equivalent in variability and in predictability of seedling populations. They report that the main difference between methods was the time and effort required to complete the procedure. While the seed extraction method required the most effort, and the core method over the standard tray method required minimum sample manipulation. However, in general Forcella and Sparrow found that the emergence percentage was lower from the core method that from the tray method (Forcella and Sparrow 1996). A second issue in estimating weed seed density is how to soil sample. Kropac (1966) and Roberts (1970) each reported that it is better to take large numbers of smaller soil samples rather than relatively smaller numbers of lager samples (cited in Dekker 1996).

The goal of this study was to compare the effect of six different cropping systems over a 14-year period on:

- Weed seed density;
- The weed seed community; and,
- To statistically test the hypothesis developed at the onset of the Wisconsin Cropping Systems Trial (WICST) at ARL UW- Research Station trial in 1990.

## MATERIAL AND METHODS

The Wisconsin Cropping Systems Trial (WICST) started in 1989 and consists of three grain, and three forage cropping systems. (See **Table 1**) The fields were in a dairy rotation (a-a-c) with manure for the previous 20 years. The weed seedbank at the trial has been monitored annually since 1989 by counting weed seedlings that germinate in soil collected from selected plots early in the spring. Seeds include seeds (fertilized ripened ovule of a flowering plant) and fruits, but not vegetative propagules or spores.

Dr Jerry Doll initially conducted the sampling protocol and data collection and the results are available in an earlier WICST report (WICST Technical Report #8 1997-1998). Initially (1989-1992) three subsamples of soil per plot, each consisting of ten 0.75in. diameter cores and 6 in. deep were taken. In 1994 six subsamples of ten 0.75in. diameter cores and 6 in. deep were taken. Since 1995 four subsamples of soil per plot, each consisting of eight 0.75in. diameter cores and 6 in. deep are taken. This results in approximately 1.0 to 1.3 lb of soil per subsample. The soil is then mixed with an equal weight of silica sand, placed in 8 X 12-in. plastic trays with small holes in the bottom (giving a 0.75- to 1-inch soil depth). Trays are then placed on capillary mat on a greenhouse bench and subirrigated every other day, or daily when necessary. As seeds germinate, the seedlings are identified, counted and removed. After the first flush of seedlings is counted, the soil is let to dry completely, remixed and returned to the trays for another germination cycle. Three cycles of weed seed germination are conducted from May to September, and when all germination observations are completed, the number of seedlings per square meter is calculated for each system as follow:

$\leq$ 1995 when tray sample was made of 10 cores: # plants / tray * 350.849 = weed seed /m²

$\geq$1997 when tray sample was made of 8 cores: # plants / tray * 438.56 = weed seed /m².

Currently, the sampling strategy is to sample all plots in the spring following the corn phase because this helps to standardize the results since corn is a common crop in 5 of the 6 systems. The permanent pasture and continuous corn system are sampled every year. For this report the weed seedbank density results from 2004 for the 6 cropping systems were compared to the baseline data from 1991 for CS1 and CS6, and 1992 for the other four systems. The plots were sampled on March , 2004. The design of the trial is a randomized complete block with four replications for each of the six systems. In total, there are 14 plots per repetition to cover each phase of the 6 cropping systems and the individual plots are 0.73 acres in size. Each sampled plot had 3 subsamples (germination trays) for the baseline years and 4 subsamples (germination trays) for 2004. The data was analyzed with PROC MIXED (SAS 8.2). Analysis of variance and test for normality were performed on the total weed density data. Years and repetitions were considered random, and cropping systems as fixed effects. In addition to PROC MIXED, which gives a preliminary test of the average effect of the sources of variation (i.e. system, block, block (sample)), linear comparisons were used to provide a more detailed assessment of the factors influencing weed seed density.

## RESULTS AND DISCUSSION

### I) EVOLUTION OF WEED SEED NUMBERS

Viable seeds of 9 broadleaf weed species were found, and they were: red root pigweed (Rrpw), common lambsquarter (Colq), velvetleaf (Vele), shepard's purse (Shpu), smartweed (Smwe), eastern black nightshade ( Blns), broadleaf plantain (BdPlntn), dandelion (Dali), white cockle (Whco), and others (O_Bdlf). The viable seeds of grass weeds found were giant foxtail (Gift), green foxtail (Grft), yellow foxtail (Yeft), fall panicum (Fapa), barnyard grass (Bygr), large crabgrass (Lacg), and others (O_Grs). In all six systems, the total weed seedbank density decreased since 1992. (See **Table 2a**) Except for the rotational grazing plots, the reserves of viable seed in the soil are typically dominated by one or two species in each system. Total viable seedbank densities found ranged from 2,000 to 13,000 seed /m² in the earlier years of 1991-92 and 600 to 10,000 seed /m² in 2004. These numbers are toward the lower range found in the Iowa State studies (1996) and are similar to Forcella et al. (1992) findings in Wisconsin and Minnesota. Weed seedbanks densities are categorized into population categories: **low** (< 4,300 seeds/m²), **moderate** (4,301- 8,600 seeds/m²), **high** (8,601 – 12,900 seeds /m²), and **severe** (> 12,901 seeds/m²) (WICST Report #8).

In the continuous corn cropping system (**CS1**), which receives conventional rates of herbicides and tillage, the weed seedbank decreased 66% since 1991 (currently 600 seeds/m²). The plots sampled and analyzed in 2004 were established in a low to moderate weed seed density area to begin with (WICST Uniformity Year Report 1989). The 2004 data shows that the weed seed density in this high input, low diversity system is considerably less than when the system was last sampled in 1998. Completion of the data analysis from the 2005 sampling on these plots will allow us confirm this reduction in weed seed load. Cardina et al. (1991) compared weed seed density in three locations following 25-26 years of continuous corn and found that the weed seed density under minimum tillage (chisel plow) ranged from 4,800 to 400 seeds/m², similar to our findings.

The weed seedbank in the no-till (**CS2**) cropping system had decreased by 60% since 1992 (2,400 seeds/m²). The weed seed density is low, and even though the total weed seed

density is quite variable from year to year, it has been decreasing over time. Weed seed density declined sharply from 5,838 seed/m² in 1998 to 2412 seed/m² in 2004. The decline may be due to changes in weed management. In 1998 we switched from Asgrow 1900 using glyphosate only as a pre emergence herbicide to Asgrow 2301 using glyphosate pre and post emergence.

The organically managed grain system **CS3** has the lowest decrease in weed seedbank density over time among all the systems in WICST. The weed seed density was high in 1992 and after 13 years it decreased 18% maintaining high weed seed density (9,300 seeds/m²). Total weed seed density decreased by 55% from 1992 to 1995. However, the total weed seed density is increasing steadily since 1995.

In the conventional forage system **CS4** the weed seedbank density is low and it has been steadily decreasing over time (1,650 seeds/m²). The use of herbicide in the corn and alfalfa establishment phase's plus intensive management of the forage phases has proved effective again weed encroachment. The major weak link in this system is the openings in the sod, created by winterkill. The total weed seed density in this forage system decreased 74% since 1992.

The weed seedbank density in the organic forage **CS5** decreased 77% since 1992 (3,000 seeds/m²) changing from moderate to low. However, visual observations show that quack grass, which is not counted in the germination trays, is building up in CS5.

The weed seedbank density at the rotational grazing plots (**CS6**) is low, and decreased 60% since 1991 to 1,700 seeds.m². Reducing the stocking rate on the paddocks plus a timely schedule of clipping and hay making in early spring and late fall has increased the competitiveness of the pastures to weed development since 1996.

The weed management regime in the high input, low diversity systems (CS1) and (CS4), seems to successfully hold steady or even decrease the total weed seed density over time. Meanwhile, it appears that weed control is more challenging in the low input, high diversity systems, especially CS3. Still, our findings are optimistic. For instance, when studying weed seedbank dynamics in three organic farming cropping systems, Teasdale et al. (2004) found that seedbank populations in different organic cropping systems tended to "fluctuate within a range that was considerably higher than the initial levels." Their study compared the weed seedbank of a 2 yr corn-soybean, 3 yr corn-soybean-wheat/fallow and a 4yr corn-soybean-wheat-red clover/orchard grass hay rotations using the tray method sampling the systems following the corn phase also.

Davis et al. (2005) analyzed the effects of cropping systems in the weed seedbank in four systems: conventional (CONV), no-till (NT), reduced input (RI) and organic (ORG). The long-term project started in 1990 at Michigan State University's Biological Station and from 1990 to 1993 the CONV and NT systems were in corn-soybean crop sequence and RI and ORG systems were in corn-soybean- wheat/underseed with red clover crop sequence. After 1993 CONV and NT were switched to the same rotation as RI and ORG. The moldboard plow was used as primary tillage for CONV, RI and ORG systems. The seed densities found in ARL are well bellow the ones found in their study. He reports that the weed seed density after 12 years were 22,600, 21,780, 29,350, and 18,540 seed/m² in CONV, NT, RI, ORG respectively. Similarly to our findings, they found that high input systems (CONV, NT) and low input systems (RI, ORG) changed in similar manner over time. Although, they found that the weed seed density in the ORG system was slightly lower than the other systems (Davis et al. 2005).

In the early years of 91 and 92, system as a fixed effect did not significantly effect weed seed density. This was expected because all the plots were managed similarly for the 10 years

before 1989. However, the test shows that cropping system significantly affects the total weed seedbank density after 13 years (see **Table 2b**).

## II) Changes in weed community

### Ratio of broadleaves to grasses

As can be seen in **Table 3**, the proportion of broadleaf to grasses was fairly constant in continuous corn (CS1), green gold alfalfa (CS4), and the rotational grazing (CS6). Whereas the proportion of broadleaves grew in importance in the no-till corn/soybean rotation (CS2), the proportion of grasses increased in the two organic rotations (CS3 & CS5).

Tillage effects weed seedbank due to several factors as depth distribution, abundance, and species composition of seeds in soil (Cardina et al. 2002). However, seed depth in the soil seems to be the most important factor (Buhler 1995). No-till systems favors emergences of small-seeded annual broadleaf and annual grasses that are adapted to germinate well near the surface (Buhler 1995). In no-tillage systems over 60% of all the weed seeds are located in the upper 1–4 cm of soil where most germination occurs and establishment is favored (Buhler 1995; Buhler 1997; Mulugeta and Stoltenberg 1997). In the wet spring years of 1996, 1998, 2000 and 2001 the moisture level on the soil surface may had favored broadleaf seed germination and the number of broadleaf weeds established, consequently the number of escape seeds increased.

It appears that grass control is more challenging in the organic systems, especially CS3. Our hypothesis is that in CS3 the grass seedbank started to increase heavily in wet spring years especially in the corn phase (WICST 7th report). WICST data has shown that when May and June rainfall exceeds 10 inches, organic corn yields are severely impacted due poor mechanical weed control resulting in heavy weed pressure (Baldock et al in press). Indeed, the climate data shows that there were wet springs in 1996, 1998, 2000 and 2001 reducing mechanical weed control performance and providing ideal conditions for late emergence and consequent weed seed production (WICST Report #7). Likewise, Teasdale et al. (2004) found that seedbanks in organic systems tend to rise the following years when a high abundance of weeds generated high seed inputs.

### Weed Community Analysis

In continuous corn (**CS1**), redroot pigweed and common lambsquarters dominated the broadleaf seed bank (74%) and fall panicum (60% of the grasses species), and foxtails were the predominant grasses. The 2004 data reveals that common lambsquarters still composes 34% of the broadleaf weed seed community, but pigweed seeds decreased its percentage among broadleaves from 34% to 12%. Curiously, the winter annual shepherd's purse which was present in 1991 at 12% of the broadleaf weed seeds wasn't detected in 2004, and the summer annual eastern black nightshade increased from 2% in 91 to 24% of the broadleaves weed seed community in 2004. The data in 2004 showed species not found in 91 like large crabgrass, and barnyard. Fall panicum wasn't found in 2004 samples; however, 40% of the grass seedlings were not identified due to a hot weekend when they wilted and died before identification. Maybe, fall panicum seedlings, which aren't as drought tolerant as large crabgrass and barnyard, were the first to die. (See **Appendix II**)

Even though the plots sampled in 2004 for **CS2** were initially located in moderate to high grass weeds areas, the grass weed seedbank density decreased from composing 22% of the seedbank in 1992 to 7% in 2004. The grass weed community changed from a diverse and

proportional mixture of foxtails, fall panicum, barnyard and large crabgrass to a seedbank composed primarily of large crabgrass (49%). Among the broadleaf seeds community, common lambsquarters was the dominant specie, and still is. (More than 50% of the broadleaf seeds detected in the soil weed seedbank. Broadleaves composed 78% of the seedbank in 1992 and in 2004, represented 93% of the seed bank. (See **Appendix II**)

The organic grain system (**CS3**) broadleaf seed community doesn't show any major changes in its composition. Common lambsquarters represents 70% of the broadleaf weed seed community just as it did in 1992. Other summer annuals such as redroot pigweed and eastern black nightshade still comprise relatively the same percentage of the broadleaf seedbank compared to the 1992 baseline data. However, there is a clear shift from broadleaf weeds to grass weeds in the seedbank after 1995. (See **Figure 1**) The grass community was composed of 50% of fall panicum and 41% of a mix of yellow, green and giant foxtails. Today, 72% of the grass community is composed by giant foxtail. (See **Appendix II**) Indeed, Buhler and Daniel (1988); Buhler and Oplinger (1990) and Johnson et al. (1989) reported that the most troublesome change in annual weed populations is the increase in summer annual grasses such as giant foxtail (cited in Buhler, 1995).

There may be several reasons for such a shift in the weed seed community in cropping system 3. First, as mentioned above the climate data shows that there were wet springs in 1996, 1998, 2000 and 2001 reducing mechanical weed control performance and providing ideal conditions for late emergence and consequent weed seed production (WICST Report #7). Second, in addition to the weather, the tillage system used in CS3 and CS5 (chisel plow) may be giving the weeds a higher chance to succeed. It had been reported by Buhler (1995) and Mulugeta and Stoltenberg (1997) that giant foxtail density is greater under reduced chisel plow than under moldboard plow. Thirdly, we have found that wheat and red clover "sod" phase hasn't been very effective for weed control, allowing many foxtail plants to go to seed. Lastly, it has been observed in the past seasons that the giant foxtail escapes from poor past weed control is vigorously growing in the soybean phase and the within-row weeds do not get buried by the cultivator and go to seed.

Many researchers observed that indeed, the seedbank can increase rapidly following a year of poor weed control because many weed species are prolific seed producers (Iowa State University 1996). In addition, a species that produces seed population with individuals that each has different germination requirements is even more likely to succeed (Dekker 1996). Giant foxtail according to Dekker, possess a very wide range of germination requirements when shed from the parent plant, and this heterogeneity arises from many sources in an individual plant, including the type of tiller the panicle appears on, the position of the seed in the panicle, and the position of the seed on the fascicle in the panicle (Dekker 1996). While it is true that weed seed densities can rapidly increase if plants are allowed to produce seeds, weed seed densities can also greatly be reduced if seed production is eliminated by a few years.

The conventional forage system (**CS4**) maintained the proportion of 90% broadleaves to 10% grasses comparing 1992 to 2004 data. The only change in the weed seed community since 1992 is the presence of initially not detected white cockle seeds. (Currently it composes 20% of the broadleaf community). White cockle is commonly found in alfalfa and probably it got in the field with the manure applied. (See **Appendix II**)

The weed seedbank in **CS5**, the other organically managed system, is 77% lower than it was in 1992. However, grass weed seeds represent a higher percentage of the total weed seeds than it did in 1992. Initially, the system weed seeds were composed of 86% of broadleaves and

14% of grasses. Currently, grasses represent 40% of the total weed seeds in the soil seedbank. The broadleaf weed seed community became much more diverse. There were four detected broadleaves species in 1992 against nine species detected in 2004. The broadleaves community is dominated by common lambsquarters and redroot pigweed by 73%, but also contains yellow wood sorrel, dandelion, velvetleaf, shepherd's purse, black nightshade and smartweed. This is probably due to the use of manure in this system. (See **Appendix II)**

Comparing the two organically managed cropping systems we find that CS3 is presenting a much more problematic weed control. Because they are managed similarly (chemical free, chisel plow as primary tillage, cultivation as the main weed control, and delayed planting of the row crops into a "stale seedbed"), it seems likely that the longer alfalfa rotation in CS5 is providing a better "sod" phase to smother weeds than is the wheat/red clover phase in CS3. Foxtail is emerging throughout summer and setting seed with the onset of the fall.

The weed seedbank density at the rotational grazing plots (**CS6**) is low and the proportion of broadleaf weed seeds to grass weed seeds in 2004 is still basically the same. The broadleaf weed community, which was dominated by common lambsquarter and redroot pigweed, is now more diverse and balanced. This isn't surprising since constantly disturbed agricultural sites are normally dominated by a few species in contrast to not disturbed sites like grasslands. To our advantage, one of the broadleaf weed specie to increase its presence from 1% to 10% at the CS6 sites was dandelion, which is considered palatable forage. Another change in the weed seed community is the increase in white cockle seeds, which is a common weed of pastures. All the weed community changes in CS6 have been positive so far. For example, eastern black nightshade seed density has decreased since 1991. Eastern black nightshade contains glycoalkaloid solanine and can cause gastrointestinal irritation and its vegetative parts and fruit can poison all classes of livestock (Stubbendieck et al. 2003). (see **Appendix II**)

## III) Hypothesis testing with linear contrasts

We have been collecting the density and diversity of weed species to be able to compare the effects of cropping systems in weed seedbank and species shifts hoping to test the following hypotheses:

### *Cash Grain Systems*

**Ho:** Weed seed numbers: with herbicides as part of the program, there will be fewer escapes and weed seed numbers will decrease more rapidly in the high input grain systems than in mechanical weed control systems (CS1&CS2 < CS3).

**Results:** As can be seen in **Table 4,** although total weed seed number was not different among the three systems at the beginning of the trial, by spring 2004 CS3 had significantly more weed seeds than CS1 and CS2. Thus our hypothesis was confirmed and there is better weed control in the chemical systems than in the organic grain system.

**Ho:** Weed shifts: annual grasses will increase in proportion under continuous corn (CS1) in comparison to more diverse CS2 and CS3.

**Results:** Annual grasses increased in proportion under continuous corn (CS1), organic grain (CS3), organic forage (CS5), and rotational grazing (CS6). However, CS3 and CS5 had a greater increase in the proportion of annual grasses than CS1. (See Table 3)

*Forage Systems*

**Ho:** Weed seed numbers**:** due to the longer sod phase, more intensive forage harvesting schedule, and use of herbicides on the corn, weed seed numbers will be lower in CS4 than CS5.

**Results:** As can be seen in **Table 4**, similar to the cash grain contrasts, the high input CS4 had fewer weed seeds than the organic CS5 system. However, the difference was not as marked (only at 10% probability) as with the cash grain comparison (.01 % probability) CS4 and CS5 didn't present any difference in total weed seedbank density in 1992. In contrast, CS4 < CS5 regarding grasses seedbank density in 2004. (See **Table4**)

*Cash Grain and Hay Systems vs. Rotational Grazing*

**Ho:** Weed seed numbers: due to the grazing clipping regime and no-tillage, it is expected that the rotational grazing (CS6) system will have the lower weed seed numbers that the systems including annual crops (CS1 thru CS5 > CS6).

**Results:** As can be seen in **Table 4,** CS6 has indeed a lower total weed seed density when compared to the average of the other five systems. It is surprising to note that agronomically CS1 is almost the complete opposite of CS6, and yet CS1 has the lowest actual weed seed density (603 vs. 1,727 seeds/m²) among all the systems in 2004. (See **Table 4**).

## CONCLUSION

The long-term cropping systems trial (WICST), conducted in the UW-research station at in Arlington, Wisconsin shows that cropping systems significantly affect weed seed density over time. The results show that in all six systems, for the plots sampled in 2004, the total weed seed density decreased over time. Initially weed seed densities ranged from 2,000 seed /m² to 13,000 seed /m² in, while recent data reveals weed seed densities ranging from 600 seed /m² to 10,000 seed /m². Except for CS3, all the other cropping systems show low weed seed density (< 4,300 seeds/ m²). Shifts in the ratio of broadleaves to grasses were only important in the two organic systems (increased proportion of grasses in CS3 and CS5) and in the no-till corn-soybean rotation (increased proportion of broadleaves).

It is observed that CS3 weed community clearly shifted from a system dominated by broadleaf weeds to a system dominated by grass weeds. The community shift may have occurred due to environmental, tillage and crop rotation effects. Wet springs in 1996, 1998, 2000 and 2001 made cultivation challenging and weeds had a chance to shed seeds, especially in the corn phase of the rotation. Also, the chisel plow may not be aggressive enough to bury the weed seeds under the favorable germination increasing weed emergence. Consequently, more weeds have a change to succeed and boost the weed seedbank. Furthermore, the forage rotation in CS3 may not be long enough to smother the weeds and avoid new seeds to enter the seedbank. Thus, organic grain farmers may choose to use the moldboard plow instead of chisel plow if erosion is not a problem in their land and/or have a longer hay crop into the organic corn and soybean rotations in order to minimize opportunities for rapid buildup of the seedbank.

On the whole, the hypothesis that over the years the weed seed density in CS1 and CS2 would be lower than CS3 due to herbicide usage is supported by the linear contrast among the systems. Also the hypothesis that over time CS4 would have a lower weed seed density than CS5 due to the fact that CS4 has not only a longer forage rotation phase, but also uses herbicides is supported by our data. The other hypothesis that ultimately CS6 would have the lowest weed seed density of all systems is not supported by the data yet. However, CS6 presents a more balanced broadleaf community than it did back in 1991. The weed seed community in CS6 isn't categorized by a few dominant species, but by various proportionally represented species. With fewer disturbances than the other systems, CS6 doesn't present as much space for opportunistic annual weeds to get established. In addition, annual weeds do not have the chance to go to seed because of the frequent grazing by the heifers.

The trends over time of the weed seedbank due to differences in cropping systems will be strengthened when 2005 data is analyzed and the plots in a different phase of the rotation will be compared to their baseline data.

**Table 1- Cropping weed and nutrient management summary by system.**

| Cropping System | Weed management | Nutrient management |
|---|---|---|
| **(CS1)**<br>Conventional corn<br>"Continuous corn"<br><br>*corn* | *conventional rates of herbicides<br>*cultivation when needed<br>*conventional tillage[1] | *Recommended rates of fertilizers |
| **(CS2)**<br>No-till<br>"No-till corn"<br><br>*corn – soybeans* | *reduced rates of herbicides in corn followed by cultivation<br>*conventional rates of herbicides in soybean phase until 1998 when glyphosate- resistant soybeans were adopted | *Recommended rates of fertilizers in the corn phase. |
| **(CS3)**<br>Organically managed<br>"Organic grain"<br><br>*corn – soybeans – winter wheat/red clover* | *primary[1] and secondary tillage [2]<br>*delayed planting<br>*rotary hoeing and cultivation<br>* no herbicides | *green manure plowed down before corn planting |
| **(CS4)**<br>Conventional forage<br>"Green gold alfalfa"<br><br>*corn – alf – alf – alf* | *full rates of herbicides and cultivation in the corn phase<br>Recommended rates of herbicide with alfalfa seeding<br>*last alfalfa crop is killed with fall-applied glyphosate<br>*conventional tillage[1] | *cattle manure application 20t/a in fall prior to corn planting and again before the alfalfa seeding phase |
| **(CS5)**<br>Organically managed<br>"Organic forage"<br><br>*corn – oats/peas/alf – alf* | *delayed planting<br>*rotary hoeing and cultivation<br>*last alfalfa crop is chisel plowed<br>*no herbicides | *green manure<br>*cattle manure 15t/a prior to the corn and oat/pea/alf phases |
| **(CS6)**<br>Rotational grazing<br>"Rotational grazing" | *intensive rotational grazing by dairy heifers<br>*spot herbicide application for thistles | *cattle manure deposited directly on the paddocks |

[1] shank, disc chisel

[2] mulch master, field digger, soil finisher, cultivator and/or disc.

**Table 2a - Mean of total weed seed/m2 in the spring following corn (n=4).**

| | **91** | **92** | **93** | **94** | **95** | **96** | **97** | **98** | **04** |
|---|---|---|---|---|---|---|---|---|---|
| **CS1** | 1,784 | 2,222 | 2,866 | 1,842 | | 3,860 | 2,686 | 3,947 | 603 |
| **CS2** | 5,162 | 6,140 | | 11,373 | | 2,916 | | 5,838 | 2,412 |
| **CS3** | | 11,257 | | | 5,087 | | | 6,387 | 9,319 |
| **CS4** | | 6,286 | | | | 2,149 | | | 1,645 |
| **CS5** | | 12,894 | | | 3,004 | | | 2,357 | 2,988 |
| **CS6** | 4,356 | | | | 4,144 | 6,513 | | | 1,727 |

**Table 2b – Total weed seed ANOVA of 6 systems initially and in 2004.**

| Effect | Num DF | F Value | Pr > F |
|---|---|---|---|
| System initially (91-92) | 5 | 11.01 | 0.2247 |
| System in 2004 | 5 | 31.17 | <. 0001 |

**Table 3 – Percentage of broadleaf to grass of total weed seed per system.**

| | **1991-1992** | **2004** | **From 1991-2 to 2004** |
|---|---|---|---|
| **Cropping System** | **% Broadleaf / %Grass** | **%Broadleaf / %Grass** | **% Grass** |
| **CS1** | 84 / 16 | 77 / 23 | From 16% to 23% = 7% |
| **CS2** | 78 / 22 | 93 / 7 | |
| **CS3** | 88 / 12 | 18 / 82 | From 12% to 82% = 70% |
| **CS4** | 90 / 10 | 90 / 10 | |
| **CS5** | 86 / 14 | 60 / 40 | From 14% to 40% = 26% |
| **CS6** | 75 / 25 | 68 / 32 | From 25% to 32% = 7% |

**Table 4- Linear Contrasts**

**Ho: CS1&CS2<CS3**

| | Baseline 91/92 | | | 2004 | | |
|---|---|---|---|---|---|---|
| **Total seeds** | **df** | **p>F** | **Means** | **df** | **p>F** | **Means** |
| 2) CS1, 2 (conv. grains) vs. | | | 4,181 | | | 1,508 |
| CS3 (org grain) | 1 | 0.1338 | 11,256 | 1 | <.0001 | 9,319 |

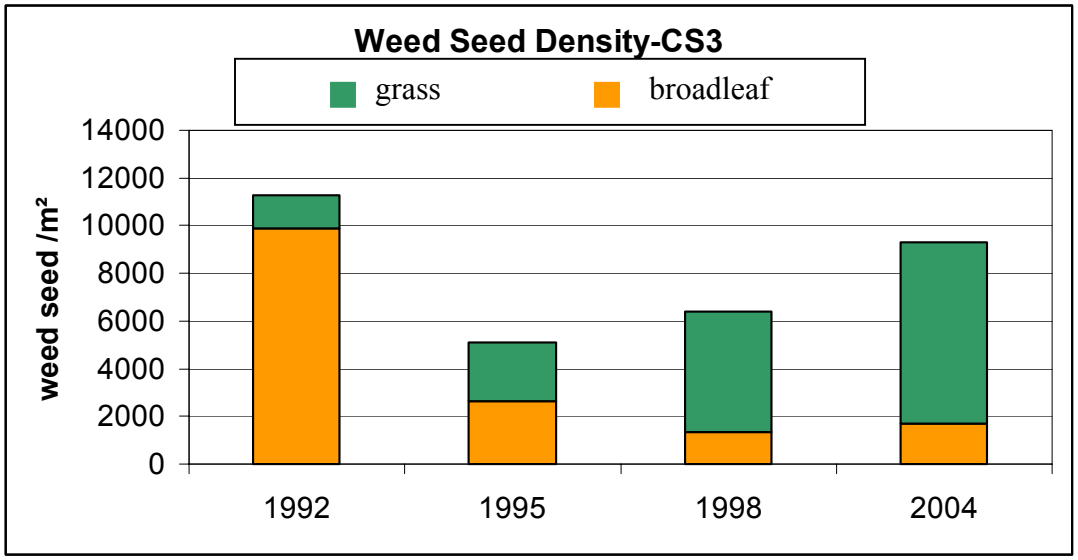
**Ho: Total weed seed in CS4 < CS5**

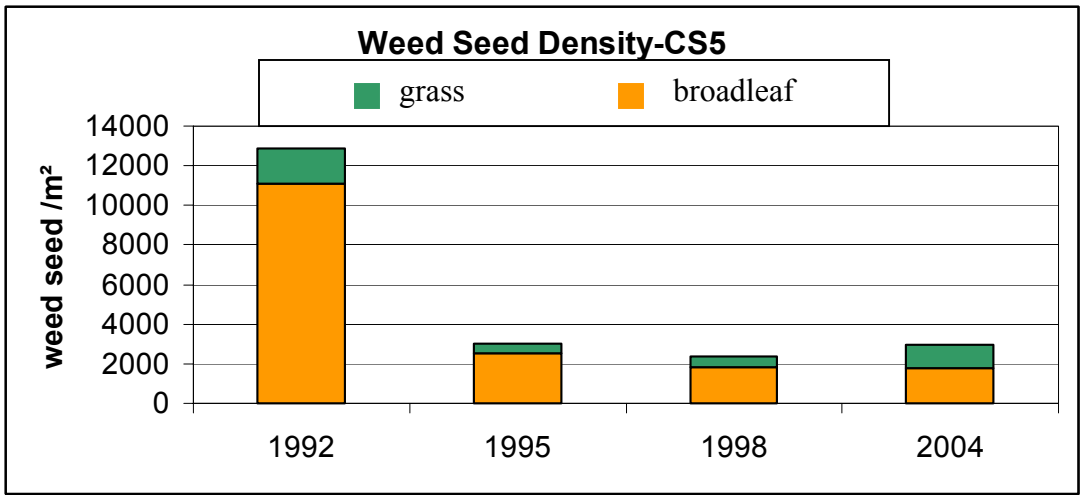
| **Total seeds** | **df** | **p>F** | **Means** | **df** | **p>F** | **Means** |
|---|---|---|---|---|---|---|
| 4) CS4 (forage) vs. CS5 | | | 6,286 | | | 1,645 |
| (org forage) | 1 | 0.1642 | 12,894 | 1 | 0.0952 | 2,988 |

**Ho: Total weed seed in CS1 thru CS5 > CS6**

| **Total seeds** | **df** | **p>F** | **Means** | **df** | **p>F** | **Means** |
|---|---|---|---|---|---|---|
| 2) CS1,5 (sys w/ Corn) vs. | | | 7,760 | | | 3,393 |
| CS6 (sys w/out Corn) | 1 | 0.2405 | 4,356 | 1 | 0.0082 | 1,727 |

**Figure 1 – CS3 and CS5 total weed seed density divided into grass and broadleaf species.**



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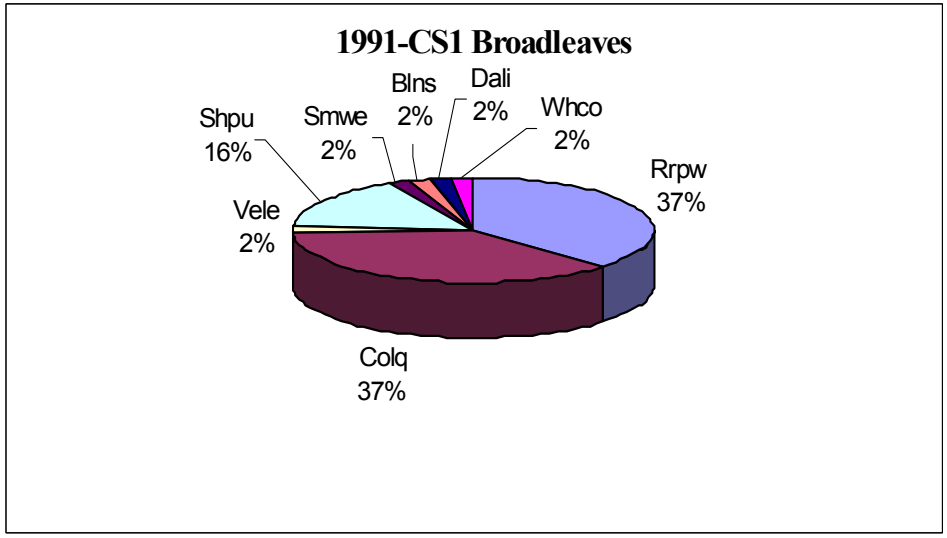
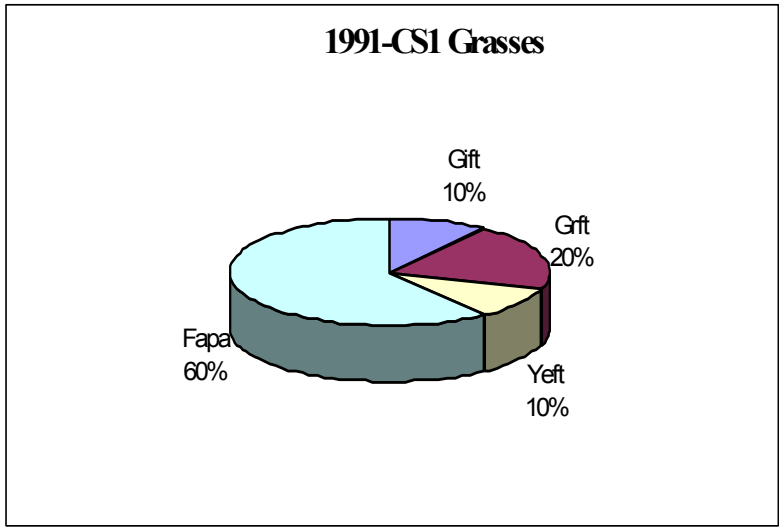
**Appendix I- Summary of linear contrasts to determine the influence of agricultural management practices on weed seedbank (1991/92 - 2004)**

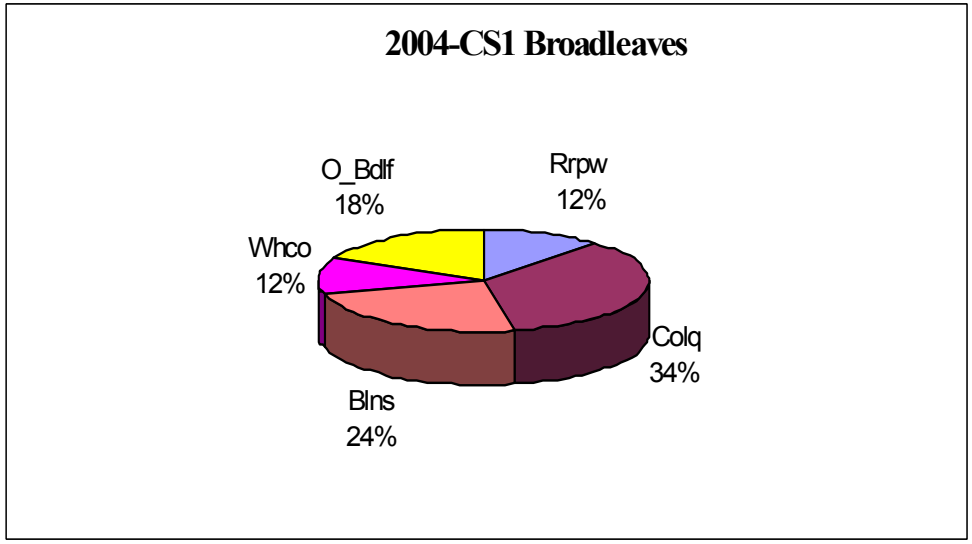
| | Baseline 91/92 | | | 2004 | | |
|---|---|---|---|---|---|---|
| **Total seeds** | **df** | **p>F** | **Means** | **df** | **p>F** | **Means** |
| 1) CS3 (org grain) vs. CS5 (org forage) | 1 | 0.5200 | 11,256<br>12,894 | 1 | <.0001 | 9,319<br>2,988 |
| 2) CS1,5 (sys w/ Corn) vs. CS6 (sys w/out Corn) | 1 | 0.2405 | 7,760<br>4,356 | 1 | 0.0082 | 3,393<br>1,727 |
| 3) CS4, 5 (hay forages) vs. CS6 (pasture) | 1 | 0.1788 | 9,590<br>4,356 | 1 | 0.3952 | 2,316<br>1,727 |
| 4) CS4 (forage) vs. CS5 (org forage) | 1 | 0.1642 | 6,286<br>12,894 | 1 | 0.0952 | 1,645<br>2,988 |
| 5) CS1 (C corn) vs. CS2 (no-till Corn) | 1 | 0.2665 | 2,222<br>6,140 | 1 | 0.0255 | 603<br>2,412 |
| 6) CS2 (no-till grain) vs. CS6 (no-till forage) | 1 | 0.4928 | 6,140<br>4,356 | 1 | 0.3919 | 2,412<br>1,727 |
| 7) CS1, 3 (grains) vs. CS4, 5 (forages) | 1 | 0.2250 | 6,539<br>9,590 | 1 | 0.0007 | 4,111<br>2,316 |
| 8) CS1, 2 (grains) vs. CS3 (org grain) | 1 | 0.1338 | 4,181<br>11,256 | 1 | <.0001 | 1,508<br>9,319 |

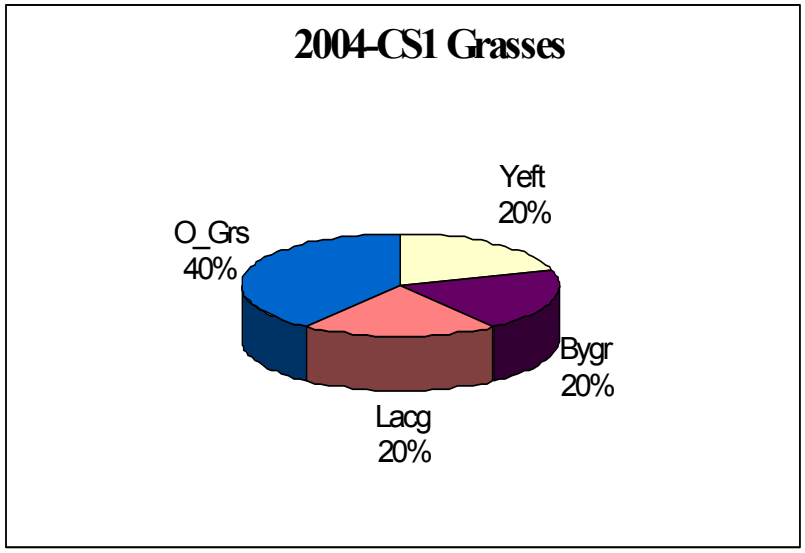
| | Baseline 91/92 | | | 2004 | | |
|---|---|---|---|---|---|---|
| **Broadleaf seeds** | **df** | **p>F** | **Means** | **df** | **p>F** | **Means** |
| 1) CS3 (org grain) vs. CS5 (org forage) | 1 | 0.6078 | 9,911.50<br>11,052 | 1 | 0.8223 | 1,672.06<br>1,781.63 |
| 2) CS1,5 (sys w/ Corn) vs. CS6 (sys w/out Corn) | 1 | 0.2244 | 6,666.15<br>3,274.50 | 1 | 0.3548 | 1,529.53<br>1,178.81 |
| 3) CS4, 5 (hay forages) vs. CS6 (pasture) | 1 | 0.1708 | 8,347.33<br>3,274.50 | 1 | 0.2864 | 1,630.97<br>1,178.81 |
| 4) CS4 (forage) vs. CS5 (org forage) | 1 | 0.1842 | 5,642.92<br>11,052 | 1 | 0.5374 | 1,480.31<br>1,781.63 |
| 5) CS1 (C corn) vs. CS2 (no-till Corn) | 1 | 0.3260 | 1,929<br>4,795 | 1 | 0.0005 | 466.06<br>2,247.56 |
| 6) CS2 (no-till grain) vs. CS6 (no-till forage) | 1 | 0.5183 | 4,795<br>3,274.5 | 1 | 0.0310 | 2,247.56<br>1,178.81 |
| 7) CS1, 3 (grains) vs. CS4, 5 (forages) | 1 | 0.2262 | 5,545.13<br>8,347.33 | 1 | 0.5917 | 1,461.89<br>1,630.97 |
| 8) CS1, 2 (grains) vs. CS3 (org grain) | 1 | 0.1336 | 3,362.29<br>9,911.5 | 1 | 0.4564 | 1,356.81<br>1,672.06 |
| **Grass seeds** | **df** | **p>F** | **Means** | **df** | **p>F** | **Means** |
| 1) CS3 (org grain) vs. CS5 (org forage) | 1 | 0.3329 | 1,345<br>1,842.17 | 1 | <.0001 | 7,647.38<br>1,206.00 |
| 2) CS1,5 (sys w/ Corn) vs. CS6 (sys w/out Corn) | 1 | 0.9764 | 1,093.55<br>1,081.83 | 1 | 0.0059 | 1,863.93<br>548.31 |
| 3) CS4, 5 (hay forages) vs. CS6 (pasture) | 1 | 0.7165 | 1,242.71<br>1,081.83 | 1 | 0.7935 | 685.28<br>548.31 |
| 4) CS4 (forage) vs. CS5 (org forage) | 1 | 0.0221 | 643.25<br>1,842.17 | 1 | 0.0873 | 164.56<br>1,206.00 |
| 5) CS1 (C corn) vs. CS2 (no-till Corn) | 1 | 0.0433 | 292.42<br>1,344.92 | 1 | 0.9638 | 137.13<br>164.56 |
| 6) CS2 (no-till grain) vs. CS6 (no-till forage) | 1 | 0.6073 | 1,344.92<br>1,081.83 | 1 | 0.5258 | 164.56<br>548.31 |
| 7) CS1, 3 (grains) vs. CS4, 5 (forages) | 1 | 0.4524 | 994.12<br>1,242.71 | 1 | <.0001 | 2,649.69<br>685.28 |
| 8) CS1, 2 (grains) vs. CS3 (org grain) | 1 | 0.2375 | 818.67<br>1,345.00 | 1 | <.0001 | 150.84<br>7,647.38 |

**Appendix II - Weed community analysis for CS1 from 1991 to 2004.**

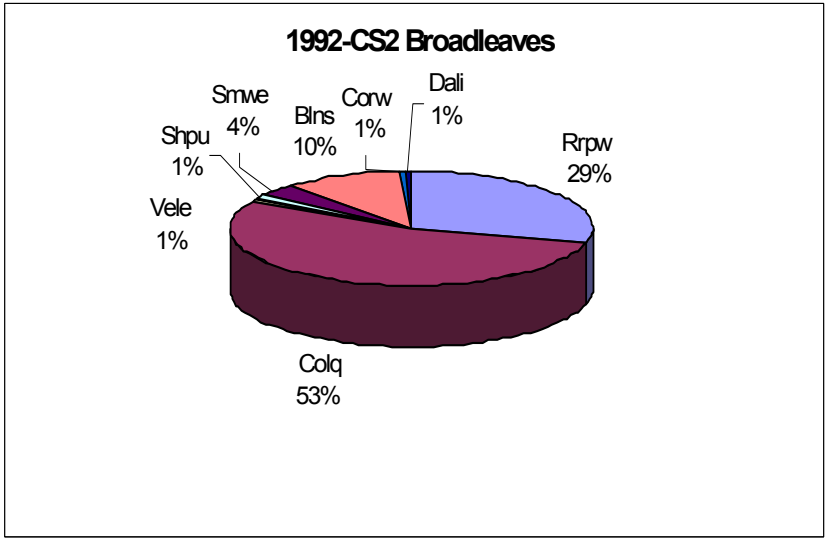


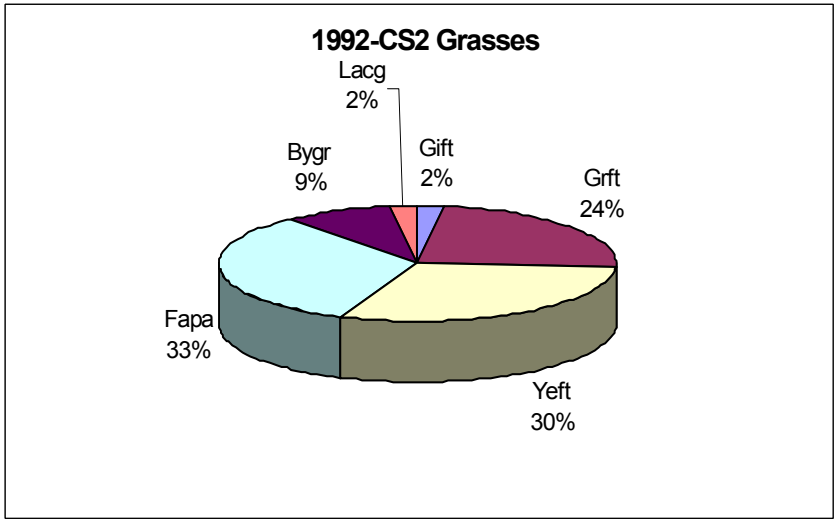



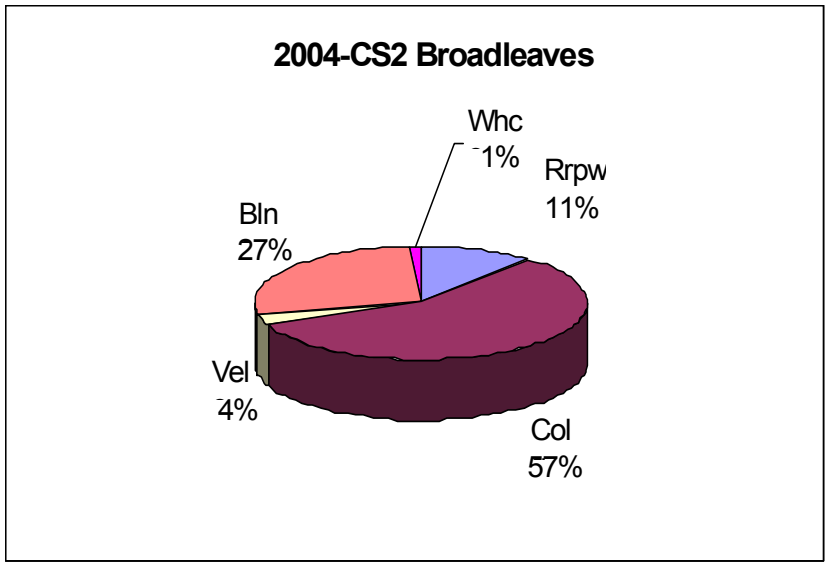



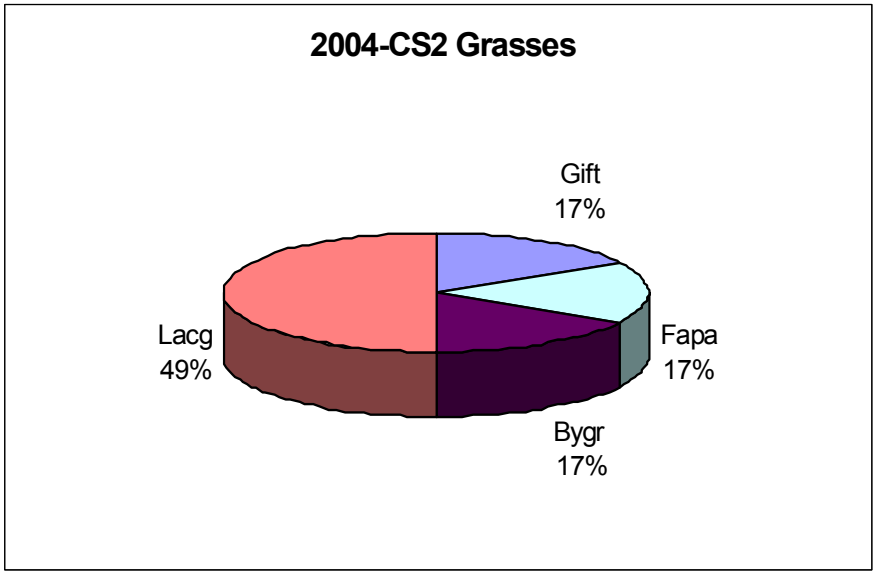



**Weed community analysis for CS2 from 1992 to 2004.**

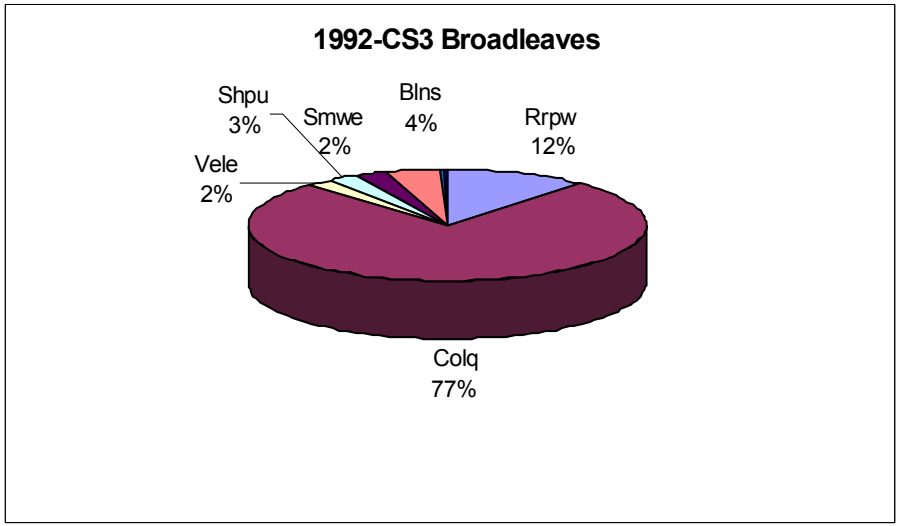


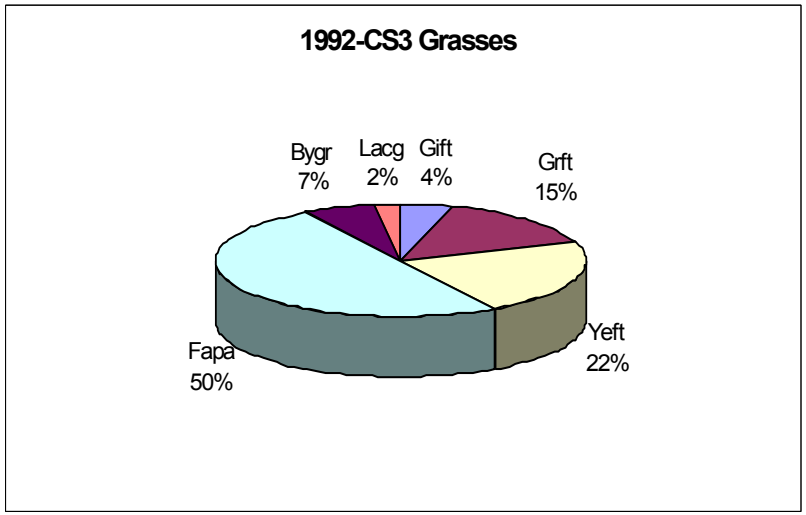



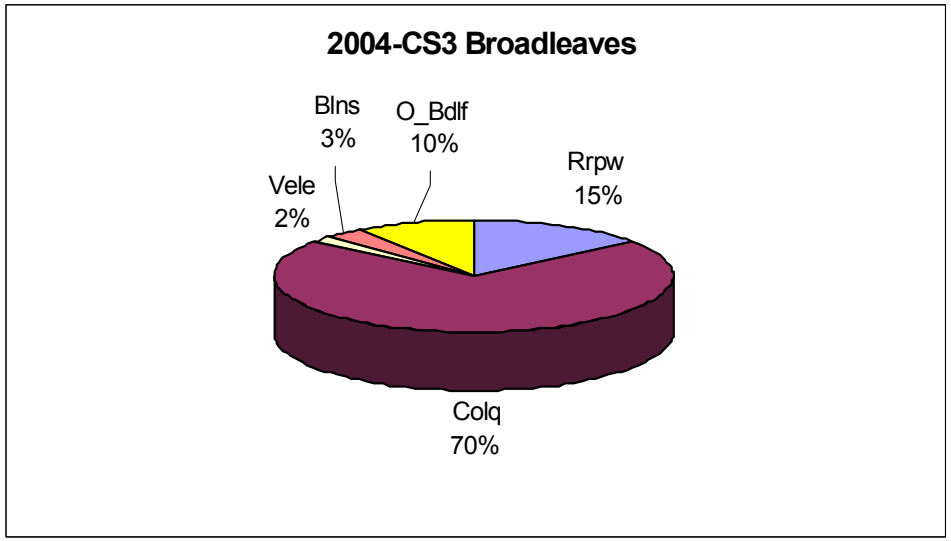



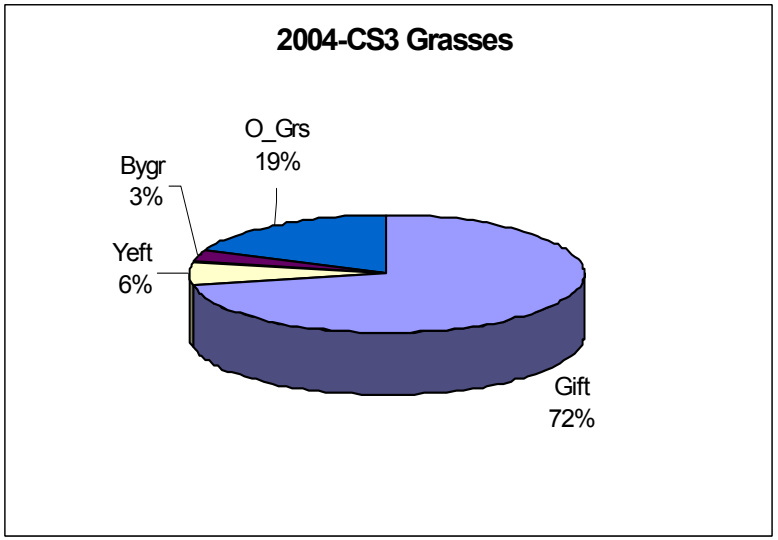



**Weed community analysis for CS3 from 1992 to 2004.**



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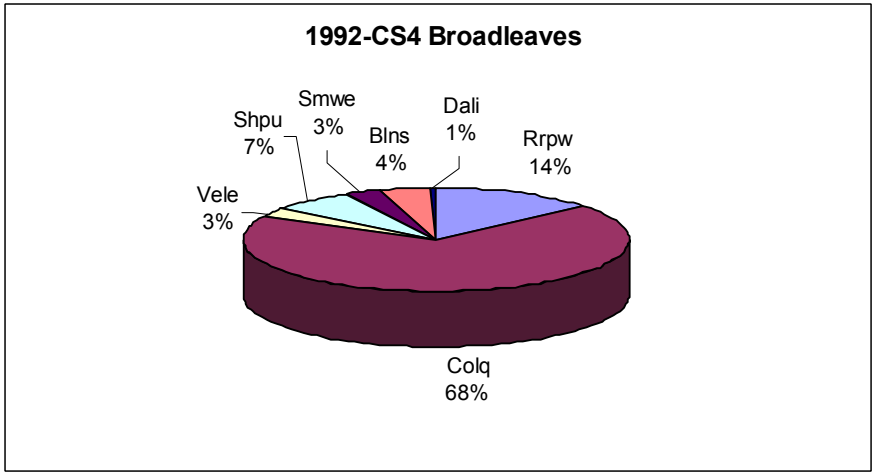


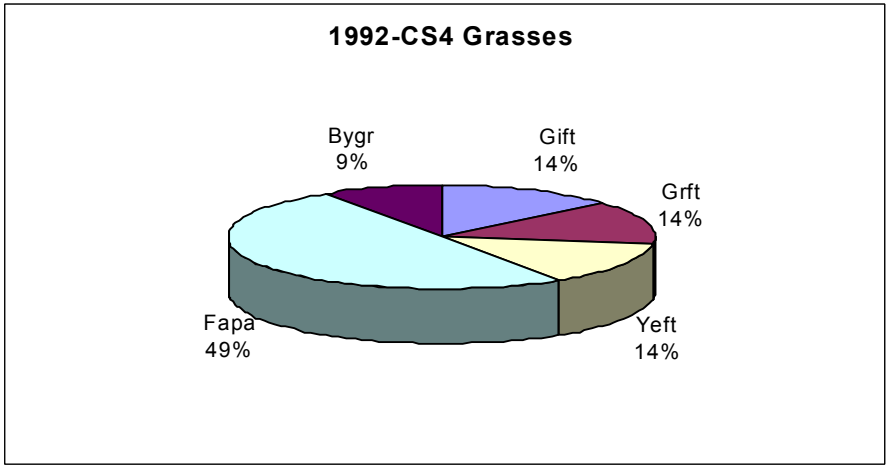


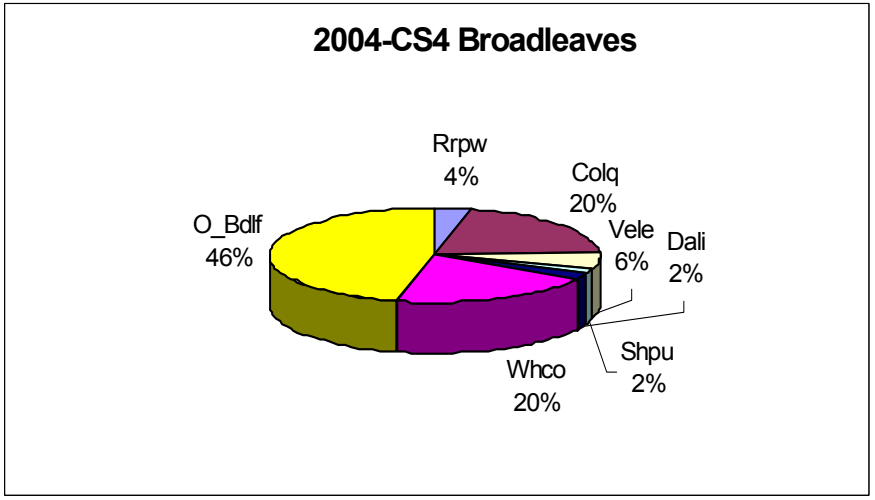


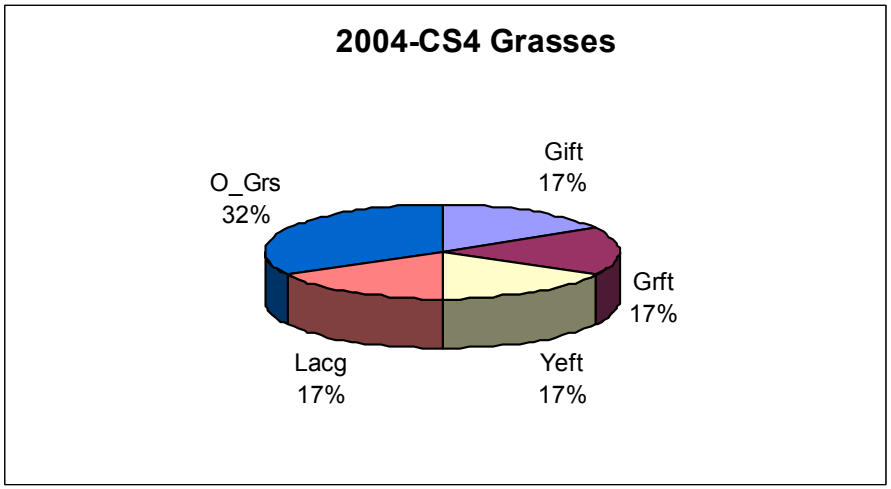

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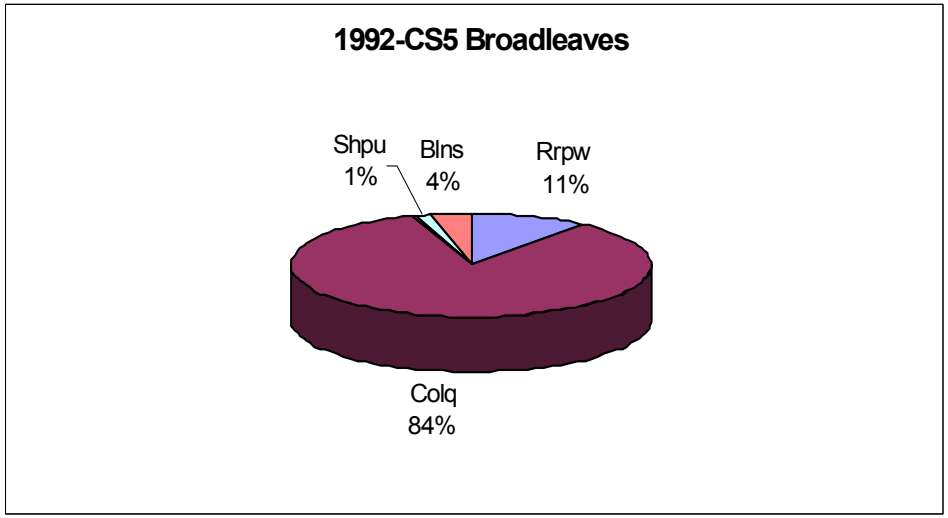
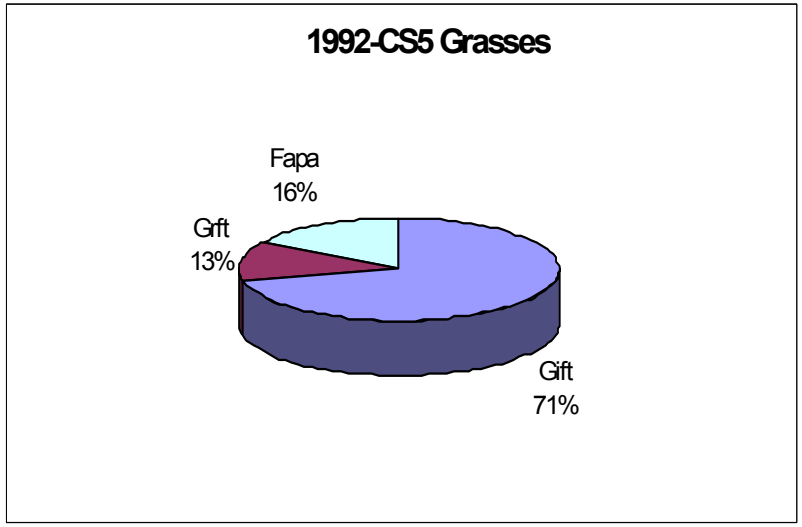
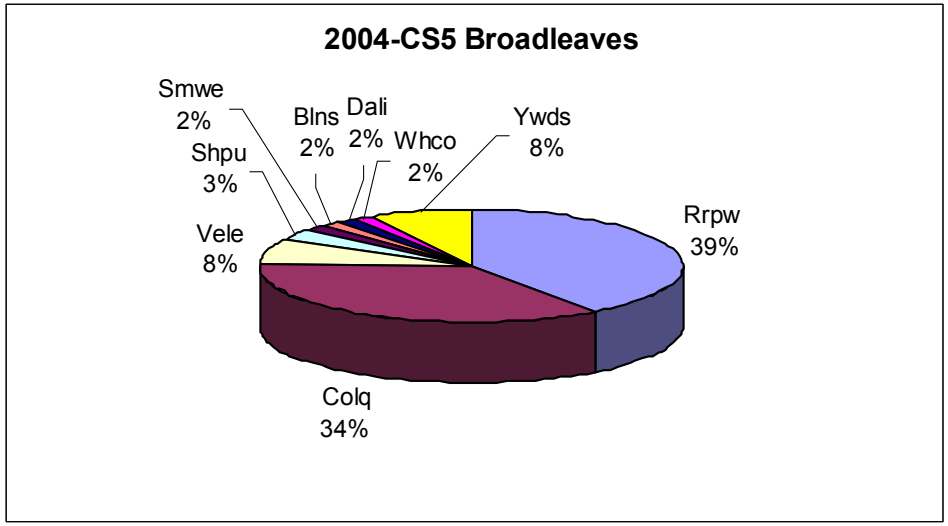
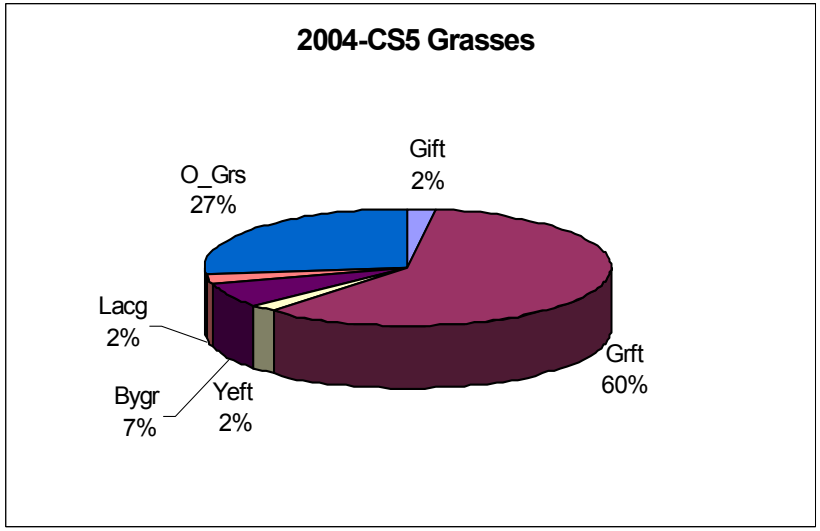
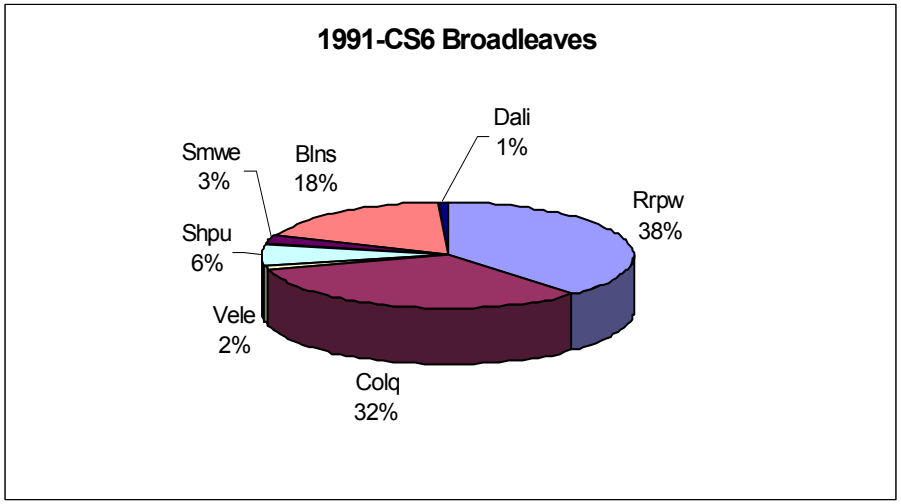


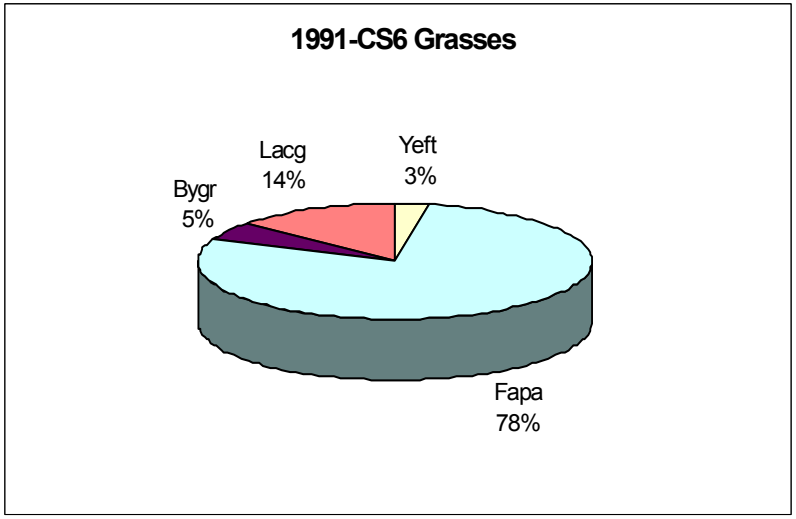



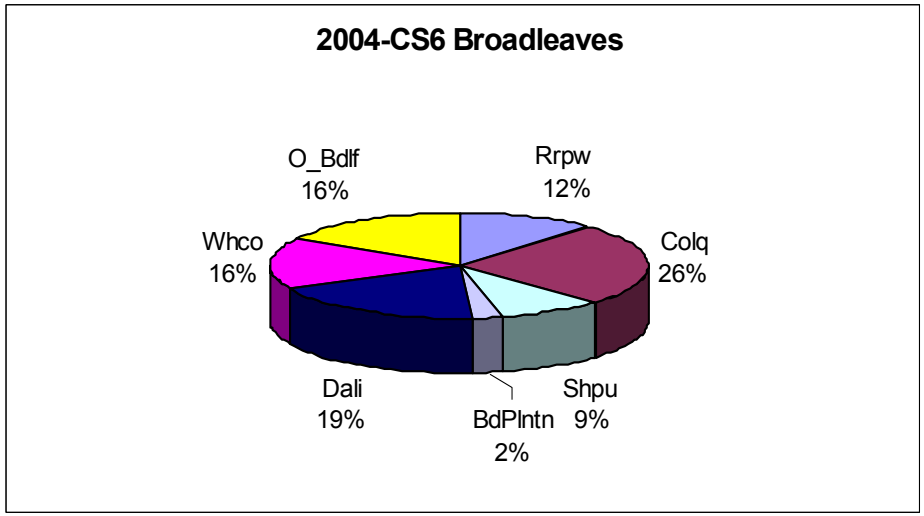



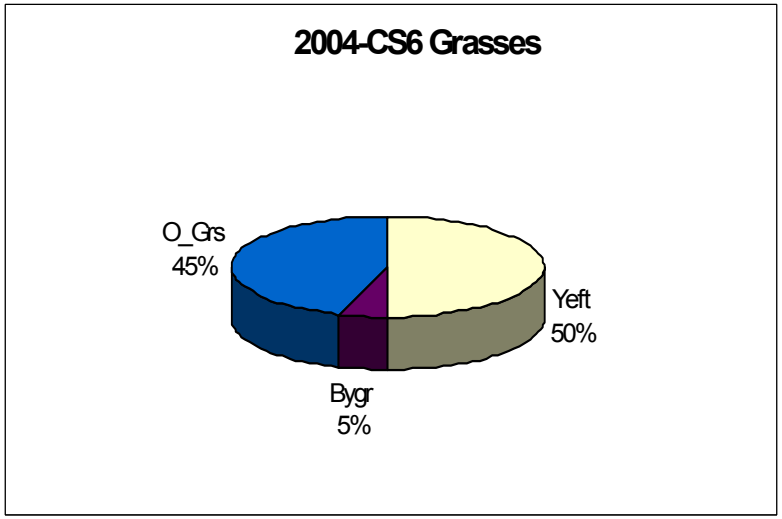



**Weed community analysis for CS6 from 1991 to 2004.**



## Appendix III- Weed seedbank changes in WICST at ARL from 1990 to 2004.

| trt | | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | ..... | 04 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Seeds/m$^2$ | C 4,823 | C 1,787 | C 2,218 | C 2,864 | C 1,841 | C | C 3,827 | C 2,821 | C 3,951 | | C 603 |
| | % brdlf | 86 | 84 | 87 | 86 | 81 | -- | 92 | 97 | 79 | ..... | 77 |
| | % grass | 14 | 16 | 13 | 14 | 49 | -- | 8 | 3 | 21 | | 23 |
| 2 | Seeds/m$^2$ | FC | S 1,548 | C | S 2,312 | C | S 3,043 | C | S 2,247 | C | | C |
| | % brdlf | -- | 70 | -- | 86 | -- | 93 | -- | 95 | -- | ..... | -- |
| | % grass | -- | 30 | -- | 14 | -- | 7 | -- | 5 | -- | | -- |
| 3 | Seeds/m$^2$ | S 4,613 | C 5,162 | S 6,140 | C | S 11,366 | C | S 2,871 | C | S 5,828 | | S 2,409 |
| | % brdlf | 75 | 73 | 78 | -- | 88 | -- | 96 | -- | 88 | ..... | 93 |
| | % grass | 25 | 27 | 22 | -- | 12 | -- | 4 | -- | 12 | | 7 |
| 4 | Seeds/m$^2$ | FC | FC | S 11,247 | W/Rc | C 7,677 | S5,130 | W/Rc | C | S 6,376 | | Sb 9,312 |
| | % brdlf | -- | -- | 88 | -- | 64 | 51 | -- | -- | 21 | ..... | 18 |
| | % grass | -- | -- | 12 | -- | 36 | 49 | -- | -- | 79 | | 82 |
| 5 | Seeds/m$^2$ | S 2,215 | W 2,935 | C 9,613 | S 9,140 | W | C | S 3,645 | W | C | | C |
| | % brdlf | 68 | 80 | 85 | 83 | -- | -- | 95 | -- | -- | ..... | -- |
| | % grass | 32 | 20 | 15 | 17 | -- | -- | 5 | -- | -- | | -- |
| 6 | Seeds/m$^2$ | FC | S 7,559 | W | C 11,602 | S 10,807 | W | C | S 13,990 | W | | W |
| | % brdlf | -- | 88 | - | 67 | 43 | -- | -- | 13 | -- | ..... | -- |
| | % grass | -- | 12 | -- | 33 | 57 | -- | -- | 87 | -- | | -- |
| 7 | Seeds/m$^2$ | A 5,075 | A 2,839 | A | C | A 2,570 | A | A | C | A 3,258 | | A |
| | % brdlf | 82 | 81 | -- | -- | 93 | -- | -- | -- | 57 | ..... | |
| | % grass | 18 | 19 | -- | -- | 7 | -- | -- | -- | 43 | | |
| 8 | Seeds/m$^2$ | FC | A 3,097 | A | A | C 12,301 | A 3,720 | A | A | C | | A |
| | % brdlf | -- | 59 | -- | -- | 99 | 96 | -- | -- | -- | ..... | -- |
| | % grass | -- | 41 | -- | -- | 1 | 4 | -- | -- | -- | | -- |
| 9 | Seeds/m$^2$ | FC | FC | A 6,280 | A | A | C 2,925 | A 2,258 | A | A | | A 1,645 |
| | % brdlf | -- | -- | 90 | -- | -- | 94 | 83 | -- | -- | ..... | 90 |
| | % grass | -- | -- | 10 | -- | -- | 6 | 17 | -- | -- | | 10 |
| 10 | Seeds/m$^2$ | FC | FC | FC 7,742 | A 2,892 | A | A | C 4,011 | A 1,893 | A | | C |
| | % brdlf | -- | -- | 93 | 88 | -- | -- | 60 | 86 | -- | ..... | -- |
| | % grass | -- | -- | 7 | 12 | -- | -- | 40 | 14 | -- | | -- |
| 11 | Seeds/m$^2$ | Oa 4,774 | A 8,118 | C 7,441 | Oa 3,645 | A | C 4,205 77 | Oa 2,301 | A | C | | C |
| | % brdlf | 82 | 64 | 91 | 95 | -- | 23 | 63 | -- | -- | ..... | -- |
| | % grass | 18 | 36 | 9 | 5 | -- | | 37 | -- | -- | | -- |
| 12 | Seeds/ft$^2$ | FC | Oa 5,871 | A | C 5,441 | Oa 4,968 | A | C 6,355 | Oa 4,269 | A | | A |
| | % brdlf | -- | 82 | -- | 88 | 86 | -- | 57 | 58 | -- | ..... | -- |
| | % grass | -- | 18 | -- | 12 | 14 | -- | 43 | 42 | -- | | -- |
| 13 | Seeds/ft$^2$ | FC | FC | Oa12,882 | A | C 3,452 | Oa 3,000 | A | C | Oa 2,355 | | Oa 2,990 |
| | % brdlf | -- | -- | 86 | -- | 90 | 83 | -- | -- | 77 | ..... | 60 |
| | % grass | -- | -- | 14 | -- | 10 | 17 | -- | -- | 23 | | 40 |
| 14 | Seeds/ft$^2$ | P 4,151 | P 4,312 | P | P | P | P 4,118 | P 6,462 | P | P | | P 1,720 |
| | % brdlf | 82 | 75 | -- | -- | -- | 89 | 73 | -- | -- | ..... | 68 |
| | % grass | 18 | 25 | -- | -- | -- | 11 | 27 | -- | -- | | 32 |

# A NOTE ON SOIL ORGANIC CARBON, SOIL ORGANIC NITROGEN, AND PARTICULATE ORGANIC MATTER ON THE WICST PLOTS

Joshua Posner[1], Leslie Cooperband[2], Ana Wells[3], and Janet Hedtcke[1]

## INTRODUCTION

Soil organic matter is one of the most important attributes of a soil because it affects nutrient cycling, soil structure, and water availability. Maintaining, or better yet, increasing soil organic carbon (SOC) content is an important measure of the sustainability of a cropping system. In fact, the USDA has developed a Soil Conditioning Index (SCI) that is a tool that can predict the consequence of cropping systems and tillage practices on the trend of soil organic matter accumulation (USDA, 2002). A positive index is the first criteria used in the Conservation Security Program (CSP) for advancement from Tier I to Tier II stewardship payments (USDA, 2004). Overall, management practices that contribute to increasing SOC levels include those that add more organic carbon to the soil than the amount removed from the system (e.g. crop residues), increase the diversity of organic materials added (e.g. cover crops, manure), or decrease the rate of organic matter loss (e.g. reduced tillage, reduced erosion) (Magdoff, and Weil, 2004).

Soil organic carbon can be usefully envisioned as consisting of three pools: an active rapid-turnover pool (0-5 years); a moderate to slow turnover pool (6-25 years); and a recalcitrant pool that may have a half-life of several hundred years (Paustian et al., 1992). According to Wander (2004), the active fraction of organic matter (usually considered as organic material of recent origin) is most closely associated with soil biological activity, materials of intermediate age contribute to soil physical structure and the carbon with the longest residence time in the soil has its greatest influence on the physicochemical reactivity of the soil. The labile, or active fraction of soil organic matter can be assessed by characterizing the Particulate Organic Matter (POM), which is composed primarily of plant-derived remains and includes fungal spores, hyphae and in some cases, charcoal. (Wander, 2004). POM's primary value is as an indicator of early trends of changes in soil organic matter characteristics.

Soil organic matter and POM were measured on the Wisconsin Integrated Cropping Systems Trial (WICST) plots at the Arlington Research Station (ARS) and the Lakeland Agricultural Complex (LAC). These plots were established in 1990 to compare alternative cropping systems and their impact on productivity, profitability and the environment. Three of the rotations are cash grain based [CS1-continous corn (CC); CS2-no-till corn-soybeans (NT CSb); CS3- Organic Grain (OG) corn-soybeans-wheat/red clover] and three forage based systems [CS4- Conventional Forage (CF) alfalfa-alfalfa-alfalfa-corn with manure; CS5- Organic Forage (OF) oats/peas/alfalfa -alfalfa-corn with manure; and, CS6-rotational grazing (RG)]. (**see Figure 1**)

These systems are common to Upper Midwestern farms and vary in the intensity of tillage, amount and type of biomass amendments, and crop diversity.

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Our initial hypotheses were:
**H1:** The dairy rotations, due to the inclusion of manure and leguminous forage crops would have higher levels of soil organic carbon (SOC), particulate organic matter (POM), and POM would represent a higher percentage of total SOC than in the grain based systems (CS4 + CS5 + CS6 > CS1 + CS2 + CS3);

**H2:** Since tillage and cultivation promote organic matter oxidation, it was hypothesized that the systems with these interventions would result in lower levels of SOC, lower levels of readily oxidizable organic matter and POM would represent a lower percentage of SOC than in the no-till systems (CS1 + CS3 + CS4 + CS5 < CS2 + CS6).

**H3:** The systems with higher biological diversity would have higher levels of soil organic carbon (SOC), particulate organic matter (POM), and POM would represent a higher percentage of total SOC than the lower crop diversity systems (CS3 + CS6 > CS1 + CS4);

In addition, we anticipated that within the grain-based systems and the forage-based systems, the more diverse rotations would have higher levels of soil organic carbon (SOC), particulate organic matter (POM), and POM would represent a higher percentage of total SOC than the less diverse rotations (CS3>CS1; CS6>CS4).

## METHODS

Soils were sampled from the Arlington site (ARS) on April 11, 2003 and from the Lakeland site (LAC) on April 12, 2003. This was 13 years after the plots had been established. Only the initial 6 plots/replicate that were established in 1990 (T1, T3, T5, T7, T11 and T14) were sampled at Arlington. In addition, the newly established (1999) prairie plots (high diversity) and the companion continuous corn plots were sampled. At Lakeland, the initial plots established in 1990 were also sampled, however, due to the change in cropping pattern in Cropping System 5, there were only 5 plots/replicate (T1, T3, T5, T7, T14). At each site there were four replicates (**see Figure 2a and b**). Three sub samples, from the north, center and south ends of each plot, each constituted by bulking six cores that were in near proximity to each other (3/4" dia. probe), were collected. Soil was sampled to 3 depths: 0 to 5 cm, 5 to 10 cm, and 10 to 20 cm.

Soil samples were air dried on the lab bench and then sieved through a 2-mm screen to remove rocks and plant debris. 50g of soil were ground to pass a 10-µm sieve for Total C and Total N. To determine the particulate organic matter or POM fraction of whole soil, a 20-g sub sample was place in a 250 ml Nalgene bottle with 100 ml of dionized water and 10 6-mm glass beads, and shaken for 16 hours at 180 cycles per min (Cambardella and Elliot, 1992; Chantigny et al., 1999). Then the soil was passed through a 53-µm sieve. The material retained in the sieve was oven dried at 50° C and ground to pass a 10 -µm sieve. Total soil C and N were determined by dry combustion (LECO CNS-2000, Leco Corp., St. Joseph, MI).

We are reporting the coarse POM fraction including loose and occluded fractions. The occluded fraction refers to aggregated and protected soil organic matter and the loose fraction refers to non-aggregated soil organic matter (Wander, 2004).

Bulk density samples (2 per plot) were taken concurrently from 0-10-cm depth.

## RESULTS & DISCUSSION

### Combined Analysis

### Soil Organic Carbon and Total Nitrogen

Initially the data was analyzed across both sites for the five common production systems. The probability of significant differences is summarized in **Table 1**. Total SOC was highly significantly different between sites at all three depths (e.g.; 0-5 cm, LAC=36.47 g C/kg of soil; ARS=30.12 g C/kg of soil). And by the same token, Total N was also highly significantly different at all three depths (e.g. 0-5, LAC= 3.23 g N/kg of soil; ARS= 2.58 g N/kg of soil). This is primarily due to the more poorly drained status of the soils at the Lakeland Agricultural Complex (Griswold and Pella series). Cropping systems SOC and total N were also significantly different at 0-5 and 5-10 cm, but not at 10-20 cm depth. At both sites, the pasture plots were the highest in SOC and total N (see **Table 2**). For SOC and total N, there was no interaction between site and cropping systems (**Table 1).**

### POM-Carbon, POM-Nitrogen and % POM-C and % POM-N

POM-C and POM-N were significantly different between sites at all three depths (LAC > ARS) but not the % POM-C or % POM-N. This suggests that like total organic matter, the g POM/kg of soil was also higher at the more poorly drained Lakeland site, but the "quality" or % POM was not different- on average between sites. Not surprisingly, cropping systems POM-C and POM-N were significantly different, as were their proportion in the organic matter (% POM-C, % POM-N) at all three depths. The range in % POM-C by systems across sites (0-5 cm) was 22.4 % for the rotational grazing to 15.2% in the no-till system and 18 % to 11.8 % for total N. This indicates that quality of the organic matter, assuming that more POM indicates a more biologically active organic matter component did change with cropping system.

An interesting anomaly in the data is the interaction at 0-5 and 5-10 cm depth between cropping systems and site for POM-C, POM-N and their percent of the total SOC content. Most of the interaction at 0-5 cm is due to the organic grain system (CS3) that actually was lower in POM-C at Lakeland than it was at Arlington (**Figure 3a)**. The other four systems produced higher POM-C at Lakeland, although the increase was very modest in CS1 (continuous corn) and CS2 (no-till corn/soybean). At 5-10 cm depth (**Figure 3b**), POM-C in CS3 was again lower at Lakeland and CS1 was nearly constant. It is surprising that although there was no interaction at 10-20 cm depth—all five systems had higher POM-C at Lakeland and the arithmetically highest was CS3 (data not shown). The same pattern was found for POM-N (**Figure 4a & b**).

### Site Analysis

Total SOC, POM-C, and %POM-C were generally highest in the rotationally grazed plots (CS6) at both locations (see **Table 3 & 4**). The same was the case for total N, POM-N and % POM-N. Surprisingly, the system with the lowest levels of SOC, POM-C and %POM-C at Arlington was the no-till corn and soybean system (CS2). The trend was the same for total N, POM-N and % POM-N. At Lakeland, it was more difficult to distinguish a trend other than that the three grain systems (CS1, CS2, CS3) were generally lower in both the carbon and nitrogen variables than the forage systems (CS4 and CS6).

**Prairie vs. Continuous corn**
The prairie and continuous corn plots were initiated at Arlington in 1999, so this analysis was conducted after only four years. SOC and total N were not yet different between the two systems but the amount of POM-C in the surface horizon (0-5 cm) was significantly higher in the prairie plots (**see Table 3**).

**Hypothesis testing**

Linear contrasts were used to test the hypotheses set out in the introduction

**H1: The dairy systems with manure and forage legumes would have increased levels of soil organic matter (SOC), levels of POM, and that POM would represent a larger percentage of total carbon. Table 5a** summarizes the results from the contrasts between the dairy (CS6, CS5, CS4) systems and the grain (CS3, CS2, CS1) systems. Not surprisingly, the combined analyses, as well as the individual site contrasts showed that the dairy systems tended to have higher SOC levels and higher POM-C levels as well as a greater percentage of their total carbon in the active POM fraction.

**H2: The systems with tillage would have lower levels of soil organic carbon (SOC), lower levels of POM, and that POM would represent a lower percentage of total SOC than the systems without tillage.** The results of the contrasts between the systems with tillage (CS1, CS3, CS4, CS5) and the systems without tillage (CS2, CS6) are presented in **Table 5b**. In the combined and individual site analyses, the systems with tillage had lower SOC levels, lower POM-C levels, as well as a lower percentage of their total carbon in the active POM fraction. This contrast is not consistent at Arlington, where the no-till pasture was much higher, in SOC than the other systems, while the no-till corn and soybean system was actually the lowest of the six. Nonetheless, on average, SOC and POM were significantly higher in non-tilled systems than the other four systems with tillage. In contrast, at Lakeland, both no-till systems were among the highest in SOC.

**H3: The systems with higher biological diversity would have higher levels of soil organic carbon (SOC), particulate organic matter (POM), and POM would represent a higher percentage of total SOC than the lower crop diversity systems.** These contrasts are summarized on **Table 5c**. This is the hypothesis that is least supported by the data. Generally the contrasts were non-significant at the 5-10 cm depth for most of the analyses, nor were they significant at Lakeland. At Arlington, there was a clear tendency to find higher SOC, higher POM-C and a higher percentage of SOC that was POM when comparing the more diverse organic grain (CS3) and pasture systems (CS6) versus the less diverse conventional forage (CS4) and continuous corn (CS1) plots.

When we looked within the dairy systems (**Table 5d**), for SOC, POM-C, and % POM-C, the more diverse grazing system (CS6) generally had higher values than the less diverse conventional forage system (CS4) at both sites. Within the grain systems (Table 5d), the picture was less clear due to anomalous behavior of CS3. We noted earlier that although for the carbon and nitrogen variables, all the systems showed higher values at LAC than ARS, the organic grain system (CS3) was an exception. As a result, at Arlington the more diverse CS3 had significantly

higher SOC, POM-C and % POM-C than continuous corn (CS1), but this was not the case at Lakeland.

## CONCLUSION

Cropping systems, after a relatively modest time after establishment (13 years), do alter soil carbon and nitrogen characteristics. This is particularly the case in the surface soil depths: 0 to 5 and 5 to 10 cm. Below 10 cm depth, few significant differences were observed. In this case the research was conducted on prairie derived silt loam soils at two locations, a somewhat poorly drained site (Lakeland Agricultural Complex) and at a well drained site (Arlington Research Station).

As might be expected, soil organic carbon, particulate organic matter, and the percentage of organic matter as POM were higher in the dairy-based systems than the grain-based systems. Intensity of tillage also modified organic matter characteristics, and systems without tillage had higher levels of SOC than those with tillage. It is more difficult to argue that the more diverse systems promoted higher levels of SOC, POM or % POM-C.

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**Fig. 1. Schematic drawing of cropping systems in the Wisconsin Integrated Cropping Systems Trial. Numbers within circles represent year of rotation.**

**Cash Grain Cropping Systems:**

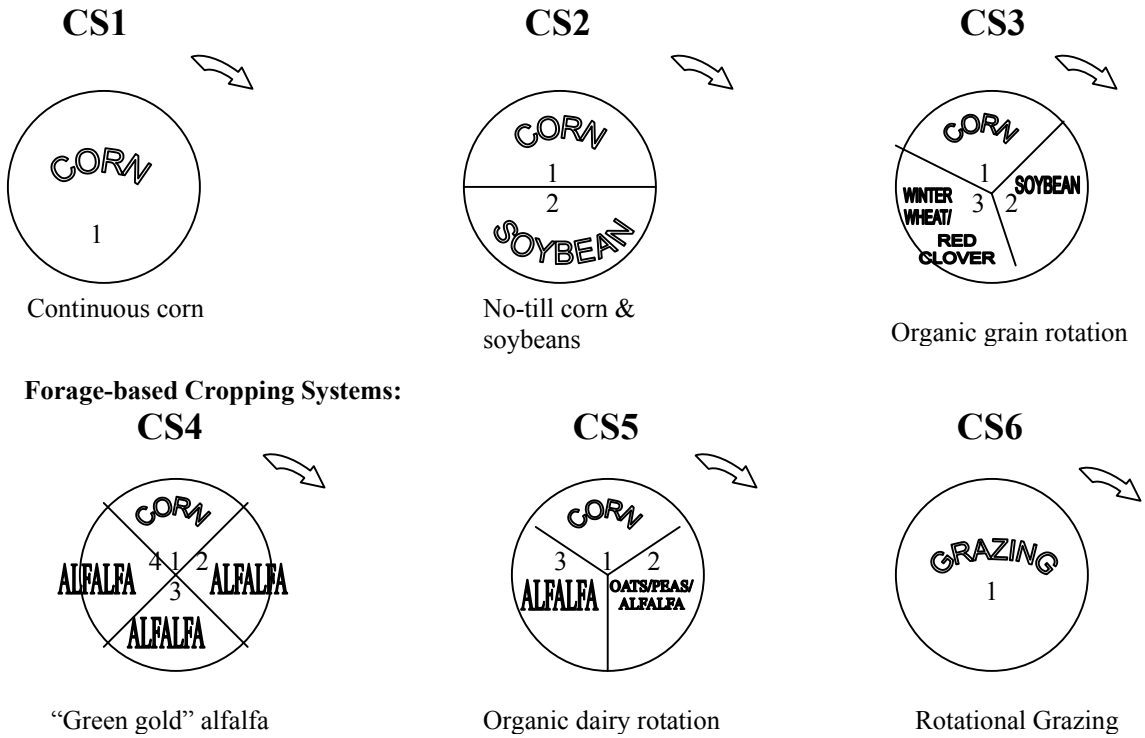

**Figure 2a. Arlington Research Station (ARS) Site Map. Location of initial plots (1990)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 414 | CS4 | **T8** | DS Alfalfa | | 408 | CS2 | T2 | NR Soybeans |
| 413 | CS5 | **T11** | Est. Alfalfa I | | 407 | CS3 | T6 | WR Soybeans |
| 412 | CS1 | **T1** | Continuous Corn | | 406 | CS4 | T9 | Corn |
| 411 | CS3 | **T5** | Wheat/red clover | | 405 | CS6 | T14 | Pasture |
| 410 | CS5 | **T12** | Oat/pea/alfalfa | | 404 | CS4 | T10 | Est. Alfalfa II |
| 409 | CS4 | **T7** | Est. Alfalfa I | | 403 | CS5 | T13 | Corn |
| Restored prairie | | | | | 402 | CS3 | T4 | Corn |
| | | | | | **401** | CS2 | T3 | No-till Corn |
| | | | | | 309 | CS4 | T10 | Est. Alfalfa II |
| | | | | | 308 | CS4 | T9 | Corn |
| 314 | CS5 | T12 | Oat/pea/alfalfa | | 307 | CS3 | T5 | Wheat/red clover |
| 313 | CS3 | T6 | WR Soybeans | | 306 | CS1 | T1 | Continuous Corn |
| Restored prairie | | | | | 305 | CS4 | T7 | Est. Alfalfa I |
| | | | | | 304 | CS5 | **T11** | Est. Alfalfa I |
| 312 | CS5 | T13 | Corn | | 303 | CS2 | T3 | No-till Corn |
| 311 | CS4 | T8 | DS Alfalfa | | 302 | CS6 | T14 | Pasture |
| 310 | CS2 | T2 | NR Soybean | | 301 | CS3 | T4 | Corn |
| 114 | CS5 | T13 | Corn | | 214 | CS2 | T3 | No-till Corn |
| 113 | CS4 | T8 | DS Alfalfa | | 213 | CS5 | T12 | Oat/pea/alfalfa |
| 112 | CS6 | T14 | Pasture | | 212 | CS3 | T6 | WR Soybeans |
| 111 | CS4 | T7 | Est. Alfalfa I | | 211 | CS5 | T13 | Corn |
| 110 | CS5 | T11 | Est. Alfalfa I | | 210 | CS4 | T8 | DS Alfalfa |
| 109 | CS1 | T1 | Continuous Corn | | 209 | CS4 | T7 | Est. Alfalfa I |
| 108 | CS2 | T2 | NR Soybean | | 208 | CS5 | T11 | Est. Alfalfa I |
| 107 | CS4 | T10 | Est. Alfalfa II | | 207 | CS6 | T14 | Pasture |
| 106 | CS3 | T5 | Wheat/red clover | | 206 | CS2 | T2 | NR Soybeans |
| 105 | CS4 | T9 | Corn | | 205 | CS4 | T10 | Est. Alfalfa II |
| 104 | CS3 | T4 | Corn | | 204 | CS1 | T1 | Continuous Corn |
| 103 | CS5 | T12 | Oat/pea/alfalfa | | 203 | CS4 | T9 | Corn |
| 102 | CS3 | T6 | WR Soybeans | | 202 | CS3 | T5 | Wheat/red clover |
| 101 | CS2 | T3 | No-till Corn | | 201 | CS3 | T4 | Corn |
| A | CS3 | 50#N | Wheat/Red Clover | | D | CS3 | 50#N | Corn w/starter |
| B | CS3 | | WR Soybeans | | E | CS3 | 50#N | Wheat/Red Clover |
| C | CS3 | 50#N | Corn w/starter | | F | CS3 | | WR Soybeans |

**Figure 2b. Lakeland Agricultural Complex (LAC) Site Map. Location of initial plots (1990)**

| | | | |
|---|---|---|---|
| 101 CS1 T1 | 201 CS5 T23 | 301 CS4 T20 | 401 CS1 T1 |
| 102 CS15 18 | 202 CS4 T7 | 302 CS14 T19 | 402 CS15 T18 |
| 103 CS4 T7 | 203 CS2 T2 | 303 CS1 T1 | 403 CS4 T20 |
| 104 CS6 T14 | 204 CS3 T4 | 304 CS2 T2 | 404 CS3 T4 |
| 105 CS15 T22 | 205 CS3 T5 | 305 CS15 T18 | 405 CS5 T23 |
| 106 CS15 T21 | 206 CS2 T3 | 306 CS3 T6 | 406 CS3 T5 |
| 107 CS3 T5 | 207 CS15 T22 | 307 CS3 T5 | 407 CS3 T6 |
| 108 CS2 T2 | 208 CS3 T6 | 308 CS3 T4 | 408 CS6 T14 |
| 109 CS3 T4 | 209 CS15 T18 | 309 CS15 T22 | 409 CS2 T2 |
| 110 CS14 T19 | 210 CS1 T1 | 310 CS4 T7 | 410 CS2 T3 |
| 111 CS3 T6 | 211 CS15 T21 | 311 CS2 T3 | 411 CS4 T7 |
| 112 CS4 T20 | 212 CS14 T19 | 312 CS15 T21 | 412 CS15 T22 |
| 113 CS2 T3 | 213 CS6 T14 | 313 CS5 T23 | 413 CS15 T21 |
| 114 CS5 T23 | 214 CS4 T20 | 314 CS6 T14 | 414 CS14 T19 |

**Table 1. Combined Soil Organic Matter Analysis of WICST Cropping Systems (4/2003). Probability that the F-test is significant**

**A. Main effect of Site (Arlington & Lakeland)**

| depth | Total SOC | Total N | POM C | POM N | % POM C | % POM N |
|---|---|---|---|---|---|---|
| **0-5 cm** | 0.0210 | 0.0077 | 0.0017 | 0.0012 | 0.8966 | 0.6674 |
| **5-10 cm** | 0.0165 | 0.0044 | 0.0025 | 0.0001 | 0.4155 | 0.1458 |
| **10-20 cm** | 0.0021 | 0.0037 | 0.0216 | 0.0007 | 0.8548 | 0.4227 |

**B. Main effect of Cropping System (Systems 1-4 & 6)**

| depth | Total SOC | Total N | POM C | POM N | % POM C | % POM N |
|---|---|---|---|---|---|---|
| **0-5 cm** | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| **5-10 cm** | 0.0633 | 0.0194 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| **10-20 cm** | 0.5294 | 0.4229 | 0.0135 | 0.0038 | 0.0051 | 0.0007 |

**C. Interaction of Site x System**

| depth | Total SOC | Total N | POM C | POM N | % POM C | % POM N |
|---|---|---|---|---|---|---|
| **0-5 cm** | 0.2197 | 0.0743 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| **5-10 cm** | 0.4610 | 0.1201 | 0.0043 | 0.0160 | 0.0070 | 0.0001 |
| **10-20 cm** | 0.8884 | 0.5256 | 0.9291 | 0.8145 | 0.9656 | 0.0766 |

**Figure 3a. POM-C Site x System interaction (0-5 cm)**

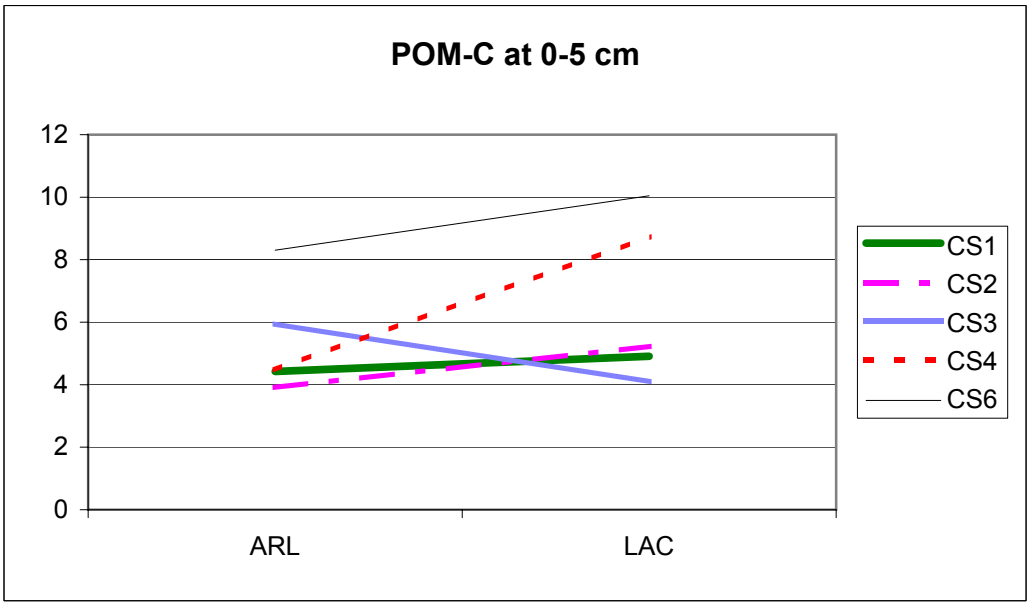


**Figure 3b. POM-C Site x System interaction (5-10 cm)**

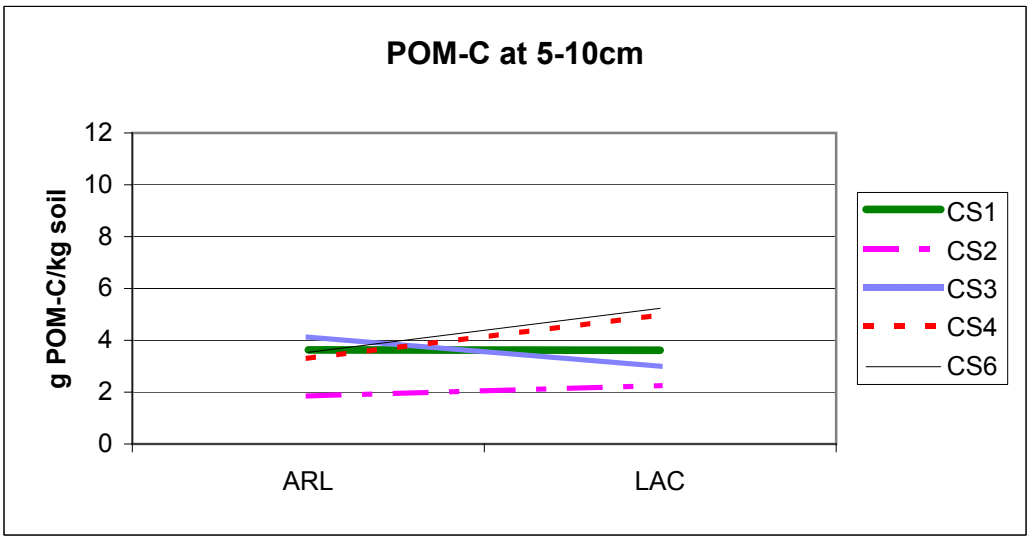

**Table 2. Combined site analysis of systems 1-4 and 6**
**Means across sites ***

| System | Total g SOC/kg soil | | | | | g POM-C /kg soil | | | | | % POM C | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-5cm | | 5-10cm | | 10-20cm ns | 0-5cm | | 5-10cm | | 10-20cm | 0-5cm | | 5-10cm | | 10-20cm | |
| 1.Cont. corn | 29.54 | c | 27.98 | b | 24.93 | 4.67 | c | 3.63 | ab | 2.02 | a | 0.159 | c | 0.131 | a | 0.079 | a |
| 2. No-till Csb | 30.05 | bc | 26.24 | b | 24.33 | 4.57 | c | 2.05 | c | 1.38 | b | 0.152 | c | 0.079 | b | 0.058 | b |
| 3. C-sb/w-w/rcl | 30.48 | bc | 28.88 | ab | 26.39 | 5.02 | c | 3.56 | b | 2.33 | a | 0.165 | c | 0.125 | a | 0.088 | a |
| 4. A-A-A-C | 34.70 | b | 31.17 | ab | 26.33 | 6.61 | b | 4.14 | ab | 1.95 | a | 0.187 | b | 0.134 | a | 0.075 | a |
| 6. Rot. graze | 41.69 | a | 33.33 | a | 28.47 | 9.17 | a | 4.39 | a | 2.33 | a | 0.224 | a | 0.134 | a | 0.086 | a |

| System | Total g N/kg/soil | | | | | g POM-N/kg of soil | | | | | % POM N | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-5cm | | 5-10cm | | 10-20cm ns | 0-5cm | | 5-10cm | | 10-20cm | 0-5cm | | 5-10cm | | 10-20cm | |
| 1. Cont. corn | 2.59 | c | 2.49 | bc | 2.25 | 0.301 | c | 0.234 | b | 0.136 | a | 0.118 | c | 0.095 | b | 0.061 | b |
| 2. No-till Csb | 2.57 | c | 2.31 | c | 2.13 | 0.304 | c | 0.148 | c | 0.098 | b | 0.118 | c | 0.064 | c | 0.047 | c |
| 3. C-sb/w-w/rcl | 2.64 | c | 2.55 | bc | 2.33 | 0.304 | c | 0.242 | b | 0.165 | a | 0.119 | c | 0.099 | ab | 0.072 | a |
| 4. A-A-A-C | 3.06 | b | 2.79 | ab | 2.36 | 0.486 | b | 0.311 | a | 0.150 | a | 0.156 | b | 0.111 | a | 0.063 | ab |
| 6. Rot graze | 3.68 | a | 2.97 | a | 2.50 | 0.640 | a | 0.317 | a | 0.168 | a | 0.180 | a | 0.109 | a | 0.071 | ab |

*** multiple range test (p=0.05)**

**Figure 4a POM-N Site by System Interaction (0-5 cm)**

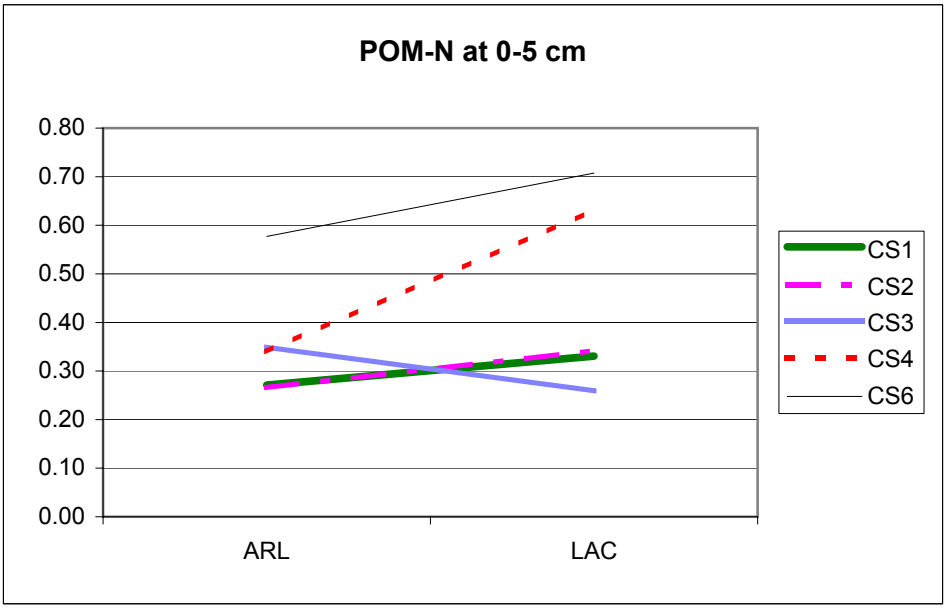


**Figure 4b POM-N site by system Interaction (5-10 cm)**

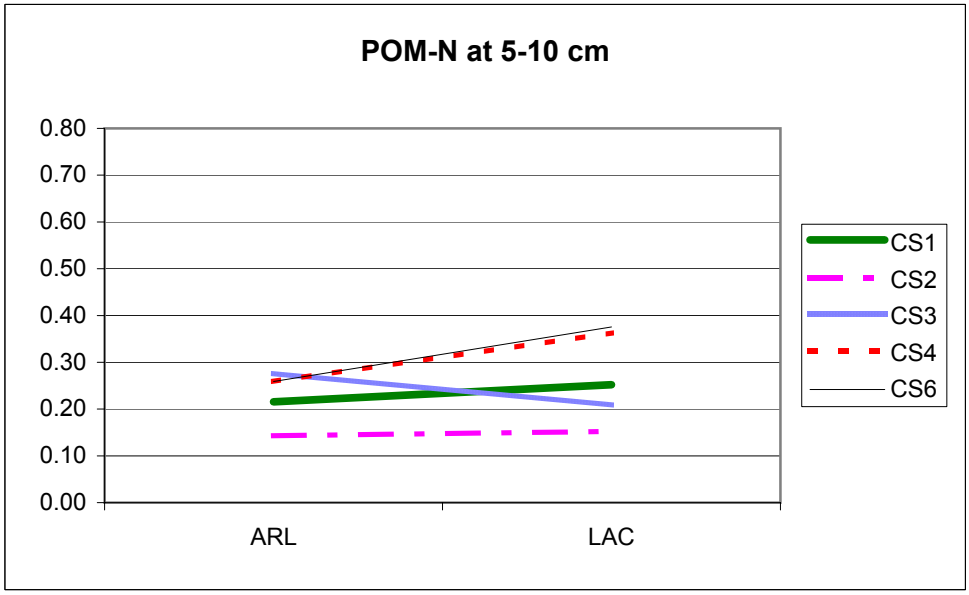

**Table 3. SOC, POM and Total N analysis at Arlington (ARS)***

| System | Total g SOC/kg soil | | | | | g POM-C/kg soil | | | | | % POM-C | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 to 5 cm | | 5 to 10 cm | | 10 to 20 cm | 0 to 5 cm | | 5 to 10 cm | | 10 to 20 cm | 0 to 5 cm | | 5 to 10 cm | | 10 to 20 cm |
| **1. Cont. corn** | 28.37 | bc | 26.95 | ab | 23.03 | 4.42 | d | 3.63 | ab | 1.88 | 0.158 | c | 0.139 | a | 0.079 |
| **2. No-till Csb.** | 25.76 | c | 22.25 | b | 20.29 | 3.91 | d | 1.85 | c | 1.19 | 0.152 | c | 0.080 | b | 0.059 |
| **3. C-sb/w-w/rcl** | 29.85 | bc | 27.77 | b | 23.9 | 5.94 | b | 4.13 | a | 2.01 | 0.198 | b | 0.150 | a | 0.085 |
| **4. A-A-A-C** | 28.92 | bc | 26.91 | ab | 22.75 | 4.47 | d | 3.30 | b | 1.63 | 0.156 | c | 0.125 | a | 0.073 |
| **5. C-o/p/a-A** | 31.71 | b | 30.13 | a | 25.31 | 5.21 | c | 3.89 | ab | 1.94 | 0.168 | c | 0.134 | a | 0.079 |
| **6. Rot. Graze** | 37.67 | a | 29.25 | a | 26.35 | 8.30 | a | 3.53 | ab | 2.18 | 0.226 | a | 0.126 | a | 0.087 |
| ***p-value*** | *0.0010* | | *0.0511* | | *0.2375* | *0.0001* | | *0.0001* | | *0.1915* | *0.0001* | | *0.0079* | | *0.2797* |
| **grand mean** | 30.38 | | 27.21 | | 23.61 | 5.38 | | 3.39 | | 1.81 | 0.176 | | 0.126 | | 0.077 |
| **HD prairie** | 30.02 | | 24.30 | | 20.95 | 5.92 | a | 3.13 | | 1.58 | a | 0.197 | | 0.135 | | 0.080 |
| **prairie corn** | 25.01 | | 23.31 | | 18.65 | 4.60 | b | 2.94 | | 1.46 | b | 0.184 | | 0.121 | | 0.076 |
| ***p-value*** | *0.1138* | | *0.5856* | | *0.2874* | *0.0499* | | *0.4890* | | *0.0218* | | *0.1603* | | *0.2381* | | *0.6142* |

| System | Total g N/kg soil | | | | | g POM-N/kg soil | | | | | | % POM-N | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 to 5 cm | | 5 to 10 cm | | 10 to 20 cm | 0 to 5 cm | | 5 to 10 cm | | 10 to 20 cm | | 0 to 5 cm | | 5 to 10 cm | | 10 to 20 cm | |
| **1. Cont. corn** | 2.23 | b | 2.17 | b | 1.87 | 0.271 | c | 0.215 | b | 0.119 | ab | 0.124 | c | 0.102 | b | 0.064 | ab |
| **2. No-till Csb** | 2.39 | b | 2.12 | b | 1.91 | 0.266 | c | 0.143 | c | 0.091 | b | 0.111 | c | 0.068 | c | 0.048 | b |
| **3. C-sb/w-w/rcl** | 2.37 | b | 2.22 | b | 1.93 | 0.349 | b | 0.276 | a | 0.149 | a | 0.147 | b | 0.126 | a | 0.078 | a |
| **4. A-A-A-C** | 2.91 | a | 2.69 | a | 2.24 | 0.349 | b | 0.259 | a | 0.123 | ab | 0.117 | c | 0.097 | b | 0.055 | b |
| **5. O/p/a-A-C** | 2.82 | a | 2.66 | a | 2.21 | 0.351 | b | 0.263 | a | 0.134 | a | 0.126 | c | 0.100 | b | 0.061 | b |
| **6. Rot. Graze** | 3.02 | a | 2.35 | ab | 2.11 | 0.577 | a | 0.259 | a | 0.159 | a | 0.196 | a | 0.114 | ab | 0.078 | a |
| ***p-value*** | *0.0006* | | *0.0086* | | *0.1621* | *0.0001* | | *0.0001* | | *0.0354* | | *0.0001* | | *0.0002* | | *0.0063* | |
| **grand mean** | 2.62 | | 2.37 | | 2.05 | 0.359 | | 0.236 | | 0.129 | | 0.137 | | 0.101 | | 0.064 | |
| **HD prairie** | 2.63 | | 2.14 | | 1.85 | 0.381 | | 0.205 | | 0.106 | | 0.145 | | 0.100 | | 0.059 | |
| **prairie corn** | 2.18 | | 2.06 | | 1.66 | 0.285 | | 0.195 | | 0.097 | | 0.130 | | 0.090 | | 0.058 | |
| ***p-value*** | *0.0713* | | *0.5290* | | *0.2636* | *0.0891* | | *0.6595* | | *0.2570* | | *0.1754* | | *0.3196* | | 0.8029 | |

*** mulitple range test at (p=0.05)**

**Table 4. SOC, POM and Total N analysis at Lakeland (LAC)***

| | Total g SOC/kg soil | | | | | g POM-C/kg soil | | | | | % POM-C | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **System** | **0 to 5 cm** | | **5 to 10 cm** | | **10 to 20 cm** | **0 to 5 cm** | | **5 to 10 cm** | | **10 to 20 cm** | **0 to 5 cm** | | **5 to 10 cm** | | **10 to 20 cm** | |
| **1. Cont. corn** | 30.70 | c | 29.00 | | 26.83 | 4.91 | b | 3.62 | bc | 2.15 | 0.161 | b | 0.123 | a | 0.078 | a |
| **2. No-till Csb** | 34.33 | bc | 30.23 | | 28.38 | 5.23 | b | 2.26 | c | 1.58 | 0.153 | bc | 0.075 | c | 0.058 | b |
| **3. C-sb/w-w/rcl** | 31.10 | bc | 30.00 | | 28.90 | 4.09 | b | 2.99 | c | 2.64 | 0.132 | c | 0.100 | b | 0.092 | a |
| **4. A-A-A-C** | 40.48 | ab | 35.43 | | 29.90 | 8.74 | a | 4.98 | ab | 2.27 | 0.218 | a | 0.143 | a | 0.078 | a |
| **6. Rot. Graze** | 45.71 | a | 37.40 | | 30.59 | 10.04 | a | 5.24 | a | 2.47 | 0.223 | a | 0.141 | a | 0.085 | a |
| ***p-value*** | *0.0240* | | *0.2768* | | *0.9243* | *0.0001* | | *0.0031* | | *0.1153* | *0.0001* | | *0.0001* | | *0.0113* | |
| **grand mean** | 36.47 | | 32.41 | | 28.91 | 6.60 | | 3.81 | | 2.22 | 0.177 | | 0.116 | | 0.078 | |

| | Total g N/kg soil | | | | | g POM-N/kg soil | | | | | % POM-N | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **System** | **0 to 5 cm** | | **5 to 10 cm** | | **10 to 20 cm** | **0 to 5 cm** | | **5 to 10 cm** | | **10 to 20 cm** | **0 to 5 cm** | | **5 to 10 cm** | | **10 to 20 cm** | |
| **1. Cont. corn** | 2.94 | b | 2.81 | b | 2.63 | 0.331 | b | 0.252 | bc | 0.152 | 0.113 | cd | 0.088 | bc | 0.057 | ab |
| **2. No-till Csb** | 2.76 | b | 2.50 | b | 2.34 | 0.342 | b | 0.152 | c | 0.106 | 0.124 | c | 0.061 | d | 0.046 | b |
| **3. C-sb/w-w/rcl** | 2.90 | b | 2.88 | ab | 2.72 | 0.259 | b | 0.209 | c | 0.181 | 0.090 | d | 0.073 | cd | 0.067 | a |
| **4. A-A-A-C** | 3.22 | b | 2.90 | ab | 2.49 | 0.632 | a | 0.363 | ab | 0.176 | 0.195 | a | 0.126 | a | 0.071 | a |
| **6. Rot. Graze** | 4.34 | a | 3.60 | a | 2.89 | 0.708 | a | 0.375 | a | 0.176 | 0.164 | b | 0.104 | b | 0.063 | a |
| ***p-value*** | *0.0027* | | *0.0933* | | *0.5929* | *0.0001* | | *0.0040* | | *0.1173* | *0.0001* | | *0.0002* | | *0.0313* | |
| **grand mean** | 3.23 | | 2.94 | | 2.61 | 0.454 | | 0.270 | | 0.158 | 0.137 | | 0.090 | | 0.061 | |

*** multiple range test (p=0.05)**

**Table 5a. Linear contrasts comparing dairy-based vs grain based system effects on soil organic matter characteristics**

| | Total g SOC/kg of soil | | | | | |
|---|---|---|---|---|---|---|
| | Combined analysis | | ARS analysis* | | LAC analysis | |
| | mean | probability | mean | probability | mean | probability |
| **0-5 cm depth** | | | | | | |
| **CS 4, CS 5* CS6** | 38.2 | 0.0001 | 32.8 | 0.0001 | 43.1 | 0.0001 |
| **CS1, CS2, CS3** | 30 | | 28 | | 32 | |
| **5-10 cm depth** | | | | | | |
| **CS4, CS5*, CS6** | 32.3 | 0.0010 | 29.8 | 0.0025 | 36.4 | 0.0001 |
| **CS1, CS2, CS3** | 27.7 | | 25.7 | | 29.7 | |

| | g POM-C/kg of soil | | | | | |
|---|---|---|---|---|---|---|
| | Combined analysis | | ARS analysis* | | LAC analysis | |
| | mean | probability | mean | probability | mean | probability |
| **0-5 cm depth** | | | | | | |
| **CS 4, CS 5* CS6** | 7.9 | 0.0001 | 6.0 | 0.0001 | 9.4 | 0.0001 |
| **CS1, CS2, CS3** | 4.8 | | 4.8 | | 4.7 | |
| **5-10 cm depth** | | | | | | |
| **CS4, CS5*, CS6** | 4.2 | 0.0001 | 3.6 | 0.0090 | 5.1 | 0.0001 |
| **CS1, CS2, CS3** | 3.1 | | 3.2 | | 3.2 | |

| | % POM-C | | | | | |
|---|---|---|---|---|---|---|
| | Combined analysis | | ARS analysis* | | LAC analysis | |
| | mean | probability | mean | probability | mean | probability |
| **0-5 cm depth** | | | | | | |
| **CS 4, CS 5* CS6** | 20.6 | 0.0001 | 18.3 | 0.0160 | 22.1 | 0.0001 |
| **CS1, CS2, CS3** | 15.9 | | 16.9 | | 14.9 | |
| **5-10 cm depth** | | | | | | |
| **CS4, CS5*, CS6** | 13.4 | 0.0001 | 12.8 | 0.4800 | 14.2 | 0.0001 |
| **CS1, CS2, CS3** | 11.2 | | 12.3 | | 9.9 | |

*** CS5 was present at ARS, but not LAC so is only included in contrasts at ARS**

**Table 5b. Linear contrasts comparing the effect of tillage vs no-tillage on soil organic matter characteristics**

| | Total g SOC/kg of soil | | | | | |
|---|---|---|---|---|---|---|
| | Combined analysis | | ARS analysis* | | LAC analysis | |
| | mean | probability | mean | probability | mean | probability |
| **0-5 cm depth** | | | | | | |
| **CS1, 3, 4, 5*** | 31.6 | 0.0001 | 29 | 0.0500 | 34.1 | 0.0001 |
| **CS2, CS6** | 35.9 | | 31.7 | | 40 | |
| **5-10 cm** | | | | | | |
| **CS1, 3, 4, 5*** | 29.3 | 0.6000 | 27.2 | 0.0390 | 31.5 | 0.1000 |
| **CS2, CS6** | 29.8 | | 25.8 | | 33.8 | |

| | g POM-C/kg of soil | | | | | |
|---|---|---|---|---|---|---|
| | Combined analysis | | ARS analysis* | | LAC analysis | |
| | mean | probability | mean | probability | mean | probability |
| **0-5 cm depth** | | | | | | |
| **CS1, 3, 4, 5*** | 5.4 | 0.0001 | 5 | 0.0001 | 5.9 | 0.0010 |
| **CS2, CS6** | 6.9 | | 6.1 | | 7.6 | |
| **5-10 cm** | | | | | | |
| **CS1, 3, 4, 5*** | 3.8 | 0.0001 | 3.7 | 0.0001 | 3.9 | 0.5600 |
| **CS2, CS6** | 3.2 | | 2.7 | | 3.8 | |

| | % POM-C | | | | | |
|---|---|---|---|---|---|---|
| | Combined analysis | | ARS analysis* | | LAC analysis | |
| | mean | probability | mean | probability | mean | probability |
| **0-5 cm depth** | | | | | | |
| **CS1, 3, 4, 5*** | 17 | 0.0002 | 17 | 0.0023 | 17 | 0.0100 |
| **CS2, CS6** | 18.8 | | 18.9 | | 18.8 | |
| **5-10 cm** | | | | | | |
| **CS1, 3, 4, 5*** | 13 | 0.0001 | 13.7 | 0.0001 | 12.2 | 0.0010 |
| **CS2, CS6** | 10.6 | | 10.3 | | 10.8 | |

*** CS5 was present at ARS, but not LAC so is only included in contrasts at ARS**

## Table 5c. Linear contrasts comparing the effect of high crop diversity vs. low crop diversity on soil organic matter characteristics

| | Total g C/kg of soil | | | | | |
|---|---|---|---|---|---|---|
| | Combined analysis | | ARS analysis | | LAC analysis | |
| | mean | probability | mean | probability | mean | probability |
| **0-5 cm depth** | | | | | | |
| **CS3, CS6** | 36.1 | 0.0001 | 33.8 | 0.0001 | 38.4 | 0.6500 |
| **CS1, CS4** | 32.1 | | 28.6 | | 35.6 | |
| **5-10 cm depth** | | | | | | |
| **CS3, CS6** | 31.1 | 0.1060 | 28.5 | 0.1900 | 33.7 | 0.3400 |
| **CS1, CS4** | 29.6 | | 26.9 | | 32.2 | |

| | g POM-C/kg of soil | | | | | |
|---|---|---|---|---|---|---|
| | Combined analysis | | ARS analysis | | LAC analysis | |
| | mean | probability | mean | probability | mean | probability |
| **0-5 cm depth** | | | | | | |
| **CS3, CS6** | 7.1 | 0.0001 | 7.1 | 0.0001 | 7.1 | 0.4900 |
| **CS1, CS4** | 5.6 | | 4.4 | | 6.8 | |
| **5-10 cm depth** | | | | | | |
| **CS3, CS6** | 4 | 0.5400 | 3.8 | 0.0300 | 4.1 | 0.4100 |
| **CS1, CS4** | 3.9 | | 3.5 | | 4.3 | |

| | % POM-C | | | | | |
|---|---|---|---|---|---|---|
| | Combined analysis | | ARS analysis | | LAC analysis | |
| | mean | probability | mean | probability | mean | probability |
| **0-5 cm depth** | | | | | | |
| **CS3, CS6** | 19.5 | 0.0001 | 21.2 | 0.0001 | 17.8 | 0.1000 |
| **CS1, CS4** | 17.3 | | 15.7 | | 19 | |
| **5-10 cm depth** | | | | | | |
| **CS3, CS6** | 13 | 0.4900 | 13.8 | 0.4400 | 12.1 | 0.0080 |
| **CS1, CS4** | 13.3 | | 13.2 | | 13.3 | |

## Table 5d. Linear Contrasts comparing the effect of high crop diversity vs low crop diversity on soil organic matter within dairy and grain systems

**Total g SOC/kg soil in dairy systems**

| | Combined analysis | | ARS analysis | | LAC analysis | |
|---|---|---|---|---|---|---|
| | mean | probability | mean | probability | mean | probability |
| **0-5 cm depth** | | | | | | |
| **CS6** | 41.7 | 0.0001 | 37.7 | 0.0001 | 45.7 | 0.0170 |
| **CS4** | 34.7 | | 28.9 | | 40.5 | |

**g POM-C/kg of soil in dairy systems**

| | Combined analysis | | ARS analysis | | LAC analysis | |
|---|---|---|---|---|---|---|
| | mean | probability | mean | probability | mean | probability |
| **0-5 cm depth** | | | | | | |
| **CS6** | 9.2 | 0.0001 | 8.3 | 0.0010 | 10.04 | 0.0120 |
| **CS4** | 6.6 | | 4.5 | | 8.74 | |

**% POM-C in dairy systems**

| | Combined analysis | | ARS analysis | | LAC analysis | |
|---|---|---|---|---|---|---|
| | mean | probability | mean | probability | mean | probability |
| **0-5 cm depth** | | | | | | |
| **CS6** | 22.4 | 0.0001 | 22.6 | 0.0001 | 22.3 | 0.6300 |
| **CS4** | 18.7 | | 15.6 | | 21.8 | |

**Total g SOC/kg of soil in grain systems**

| | Combined analysis | | ARS analysis | | LAC analysis | |
|---|---|---|---|---|---|---|
| | mean | probability | mean | probability | mean | probability |
| **0-5 cm depth** | | | | | | |
| **CS3** | 30.5 | 0.4700 | 29.9 | 0.3700 | 31.1 | 0.8500 |
| **CS1** | 29.5 | | 28.4 | | 30.7 | |

**g POM-C/kg of soil in grain systems**

| | Combined analysis | | ARS analysis | | LAC analysis | |
|---|---|---|---|---|---|---|
| **0-5 cm depth** | mean | probability | mean | probability | mean | probability |
| **CS3** | 5 | 0.2400 | 5.94 | 0.0001 | 4.09 | 0.1100 |
| **CS1** | 4.7 | | 4.42 | | 4.91 | |

**% POM-C in grain systems**

| | Combined analysis | | ARS analysis | | LAC analysis | |
|---|---|---|---|---|---|---|
| | mean | probability | mean | probability | mean | probability |
| **0-5 cm depth** | | | | | | |
| **CS3** | 16.5 | 0.4100 | 19.8 | 0.0001 | 13.2 | 0.0070 |
| **CS1** | 15.9 | | 15.8 | | 16.1 | |

# FORAGE VALUE OF MIDSTORY SHRUBS FOUND IN DEGRADED OAK SAVANNAS

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Key Index Words: grazing, shrub quality, oak woodland, Scottish Highland cattle

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# FORAGE VALUE OF MIDSTORY SHRUBS FOUND IN DEGRADED OAK SAVANNAS


## ABSTRACT

Oak (*Quercus* spp.) savanna, once a dominant grassy ecosystem of the southern Wisconsin has become very rare due the clearing of vast areas for agriculture. The absence of grazing and burning along with the arrival of new invasive species has resulted in severe degradation of most of the remaining patches of this ecosystem. Research was undertaken to see if grazing cattle would contribute to restoration of oak savanna structure. In this paper we report on the forage quality of the shrub layer. This study took place at three sites in southwestern Wisconsin. Shrub species included prickly ash (*Xanthoxylem americana* P. Mill), gooseberry (*Ribes* spp.), gray dogwood (*Cornus racemesa* L.), multiflora rose (*Rosa multiflora* Thunb. ex Murr.), berries (*Rubus* spp.) and wild parsnip (*Pastinaca sativa* L.). Leaf biomass was collected pre-grazing in June 2001 and 2002 and analyzed for crude protein (CP), fiber, in vitro total digestibility (IVTD) and minerals (P, K, Ca, Mg). Animals were observed frequently to determine eating and behavior patterns. Cattle chose a diverse diet, equally mixed with shrub leaves, grass, and herbaceous forbs. Prickly ash and *Rubus* spp. were the most frequently browsed shrubs accounting for more than 60% of shrub and tree species eaten. Across years, prickly ash and *Rubus* spp. also had the highest CP (19.0%) while multiflora rose and dogwood had the lowest levels (12.0%). All shrubs had high IVTD when compared to alfalfa (*Medicago sativa* L), with prickly ash and wild parsnip ranking the highest, approaching 85%. Microorganisms collected from the rumen of Scottish Highland (*Bos taurus* spp.) or Angus (*Bos taurus* spp.) cattle had similar capacity to digest the six shrub species evaluated. We found that the invasive shrub layer provides nutritional support for beef cattle under rotational grazing. Continued application of managed grazing and some mechanical thinning would further reduce the shrub layer, possibly releasing the production of native prairie grasses and forbs once present in healthy oak savannas.

## INTRODUCTION

Oak savanna, characterized by widely scattered oaks with an understory of herbaceous prairie grass and forb species is now one of Wisconsin's rarest ecosystems with less than 620 acres of intact savanna remaining (Henderson 1995). Grassland ecologists agree that the loss of oak savanna can be attributed to clearing and plowing and cessation of fire and grazing (Henderson 1995; Anderson 1998; Bowles and McBride 1998). Most existing oak savannas are highly degraded with a thick, impenetrable layer of shrubs in the under and mid-story allowing little sunlight penetration. Removing these shrubs and thus increasing light penetration could partially restore these oak savannas, as well as expand the pasture base for some landowners. Further, while the feed production might be modest, an oak savanna or oak woodland can offer livestock protection from harsh weather i.e. shade on the hottest days of summer and windbreak in the winter.

Fire and grazing are two mechanisms that may be used for savanna recovery. Fire is not always successful at reducing dense shrubs (Haney and Apfelbaum 1993) and may subject farmers to serious liability issues. Continuous grazing is problematic in that it causes soil compaction (Van Haveren 1983, Dudley et al. 2002), and promotes erosion (Fleischner 1994, Gifferd et al. 1977). Managed (rotational) grazing, however, has not been thoroughly tested in restoring oak savanna structure and it may be a potential conservation management tool if the initial shrub quantity and quality can maintain animal performance. The overall objective of this study was to determine the effectiveness of rotational grazing and fire on reducing the shrub layer in degraded oak savannas thereby restoring their openness. Anecdotal information suggest that Scottish Highland cattle are good browsers that make them an ideal choice for grazing rough habitat such as the overgrown shrub layer of degraded oak savanna. In this paper, we will describe the shrub quality and diet selection by cattle grazing various shrubs common to degraded oak savannas.

## MATERIALS AND METHODS

This study took place at three sites in southern Wisconsin: Yellowstone Lake Wildlife Area (YLWA) in Lafayette County, owned and managed by the Wisconsin Department of Natural Resources (WDNR); Prairie Oaks Farm, also in Lafayette County; and Creag-Is-Daru Farm, in Iowa County. Current conditions at the three sites reflect soil differences and past land use history. Prairie Oaks Farm is a shrub-infested oak woodland, dominated by bur (*Quercus macrocarpa*) and/or white oak (*Quercus alba*). YWLA was once savanna that has been highly degraded by encroaching shrubs and invasive species. Soils (Dubuque silt loam >12% slope) at these two sites are well-drained and shallow. Creag-Is-Daru Farm is the least degraded of all sites with significant oak savanna components present. The soil there (Northfield sandy loam, > 12% slope) is well drained, shallow, and sandy. Each site had remnant prairie patches with species common to historic tall grass prairie-oak savanna regions of southern Wisconsin. The soil test values for each site are reported in Table 1. YLWA and Prairie Oaks Farm are on higher fertility and higher organic matter soils, and were not brought under the plow primarily due to the steep slopes. At Craeg-Is-Daru, the soils are acidic and have lower soil fertility and not conducive to row-crop agriculture.

The field experimental design was a randomized complete block with five replicates at each site. Plots were one acre in size. Grazing with Scottish Highland cattle (*Bos taurus* spp.) for about two days per month with six animal units/a (1 au =1000 lbs) occurred from June to September in

2001 and 2002. Shrub species that were most prevalent at each site were chosen for analysis. The shrub species at YLWA were prickly ash, gooseberry, and gray dogwood. An additional treatment of fire (annually burned in April or not burned) was included at YLWA since prescribed burns are commonly practiced on publicly managed lands. Due to species and treatment differences between YLWA and on-farm, they were analyzed separately. On-farm shrub species were prickly ash, multiflora rose (Prairie Oaks Farm), and berries and wild parsnip (Creag-Is-Daru Farm). Although wild parsnip is not a shrub, it was included because of its notoriety among herbaceous plants, and cattle readily grazed it.

Before grazing occurred, shrub leaves were hand-stripped from the branches in late June each year to determine nutritional content. Samples were taken randomly from the test plots from each replication with an effort to sample that which the cattle were likely to browse (based on observation), avoiding woody stems or canes. Samples were analyzed for CP using macro-Kjeldahl method to determine N, then multiplying N by 6.25 (AOAC 1990). Neutral detergent fiber (NDF) was analyzed according to Goering and Van Soest 1970; Van Soest et al. 1991; Mertens 2002. In-vitro true digestibility (IVTD) was used to measure forage digestibility with adaptations from various methods: Goering and Van Soest 1970; Marten and Barnes 1979; Craig et al. 1984; and Tilley and Terry 1963. Forage samples, including alfalfa lab standards, were simultaneously tested for digestibility using both Scottish Highland and Angus rumen fluid. Forage IVTD was measured only in 2001 due to the complexity and cost associated with the assay and finding no differences between cattle type. Phosphorus (P) was analyzed as dry ash by spectrophotometer; potassium (K), calcium (Ca) and magnesium (Mg) were determined as dry ash by atomic absorption.

Cattle behavior, feeding choice, and location data were recorded throughout the summer within each block at each site in both years. All animals were observed either directly or with binoculars for 5-minute periods with feeding or behavioral data recorded every 15 seconds. Total number of cow and steer observations were 6080 and 13960, respectively. Observations were conducted in the cooler parts of the day (early morning or late afternoon) and primarily during day 1 on the plot when there was the greatest grazing selection.

Data were analyzed with SAS 8.2© using Proc Mixed. Assumptions of normality and homogenous variances were confirmed using PROC UNIVARIATE and PROC PLOT of the residuals vs. predicted values. All effects were fixed except block (replicate). LSMEANS were computed and LSDs ($P < 0.05$) were used to compare differences across means.

## RESULTS

### Protein and Energy

Shrub quality (CP, NDF, IVTD) ranged from moderately good to excellent and was comparable to alfalfa samples analyzed concurrently (Table 2). Since there was no difference between savanna management treatments (fire vs. control) and there was no interaction with year and species, the combined data is presented in Table 2. Year was significantly different ($P < 0.05$) with CP being higher and NDF lower in 2002 across most species (data not shown). Crude protein level averaged across shrub species was 19.4 and 17.5% on-farm and at YLWA, respectively in 2002 and 12.9 and 12.8% on-farm and at YLWA, respectively in 2001. Neutral

detergent fiber was about 3.5 percentage units lower in 2002 vs. 2001 at each site. Although June precipitation was similar between years and to the 30-yr normal, May of 2002 was dry (2.66" in 2002 vs. 6.16" in 2001) resulting in slower maturing and younger forage at the time of sampling, partially explaining the increased CP and decreased NDF.

On-farm, prickly ash and *Rubus* spp. had the highest CP while multiflora rose had the lowest (Table 2). Prickly ash at YLWA was significantly higher than the other shrubs and gray dogwood ranked the lowest in CP in both years at that site.

Neutral detergent fiber levels of most of the shrubs on-farm and at YLWA were comparable to that of high quality alfalfa with wild parsnip, gray dogwood and gooseberry having the lowest NDF. There is, a minimum amount of fiber needed for proper rumen function and some shrubs, like dogwood, are very low in effective fiber and if the only source of forage, could cause a problem.

Digestible energy, measured as IVTD, was also high across species, averaging 75% and ranging from 64.5% to 84.9% on-farm; prickly ash and wild parsnip (84.2%) were significantly higher than the *Rubus* species and multiflora rose (66.0%). The lower IVTD for *Rubus* spp. might be explained by a higher proportion of stems or juvenile canes mixed in the sample vs. mostly leaves in the sample of the other shrubs. Our observation was that cattle consumed juvenile berry canes but not much stem from other shrubs. At YLWA, IVTD of prickly ash (84.8%) was significantly higher than gooseberry (78.4%). Microorganisms collected from the rumen of Scottish Highland (*Bos taurus* spp.) or Angus (*Bos taurus* spp.) cattle had similar capacity to digest the six shrub species evaluated.

**Macro Minerals (P, Ca, K, Mg)**

Phosphorus concentration in shrubs was not different between years at either YLWA or on-farm (data not shown). However, shrub species showed considerable variation in P. Wild parsnip, followed by prickly ash ranked highest and *Rubus* spp. and multiflora rose ranked lowest in P on-farm, while prickly ash ranked highest and gray dogwood lowest at YLWA (Table 2). Alfalfa typically has 0.21 to 0.33% P, with higher levels in younger plants (Table 2).

Species at YLWA had significantly higher levels of Ca in 2001 than 2002 but year was not significant for on-farm vegetation. Dogwood, low in P and K, ranked highest in Ca concentration. On the farm with acidic soil and low organic matter, Ca levels were very low in *Rubus* spp. Most of the shrub Ca levels fell in the range of immature and mature alfalfa (Table 2).

Potassium concentrations in shrubs were similar over years ($P < 0.05$). Potassium levels in gooseberry at YLWA were higher in 2001 (3.2%) than 2002 (2.6%) suggesting that this species exhibited luxury consumption in a wet spring resulting in soil solution with high available K. Potassium levels of species ranked similar to P levels on-farm (Table 2). Very low K levels were found in gray dogwood (0.91%) and gooseberry had the highest K at YLWA (Table 2).

Prickly ash ranked lowest of all shrubs in Mg at both on-farm and YLWA. Wild parsnip was particularly high in Mg with less difference between the remaining shrubs and all of the shrubs tested higher in Mg than alfalfa (Table 2).

**Cattle Observations**

The Scottish Highland cattle spent the majority of their time (>65%) in the wooded area of the plots and less time in the open, grassy area. Trampling and rubbing of trees and shrubs was common among the cows. They seemed to choose a diverse diet of plants including leaves from shrubs and trees, grasses and forbs (Fig. 1). Cows used their horns to knock down small trees and to open up dense shrub groves. Cows were observed to walk down small trees to reach the leaves. Prickly ash and *Rubus* spp. were browsed most frequently, accounting for over 50% of the total shrubs consumed. The cattle ate leaves of most shrubs present, but consumed minimal amounts on multiflora rose, gooseberry and dogwood, all of which ranked lower in quality than prickly ash and *Rubus* spp. Cows preferred the shrub layer more so than the yearling steers (34 vs. 21%); steers preferring more forbs than shrubs (data not shown). Reasons for this are likely the cows' larger body size and bigger horns allowing them at reach or access more leaves of trees and shrubs. Also, the energy requirements of growing steers are greater than mature cows, and the greater sward density of the forbs could provide greater energy intake.

## DISCUSSION

According to the Nutrient Requirements of Beef Cattle (1996), growing or finishing cattle gaining over 2 lb/day generally need on average 12 to 13% of CP (on a dry matter basis) in the feed they consume. All shrubs were highly digestible and as long as quantity is not limiting, beef cattle would meet their energy requirement. Crude protein and IVTD levels of shrubs in our study were adequate for many classes of cattle.

Calcium and P, important for bones, teeth, and reproduction are required by beef cattle in concentrations from 0.38 to 0.70 and 0.17 to 0.37 % of DM, respectively, depending on class of animal (Beef NRC 1996). All shrubs in our study test sufficient-to-high in Ca, and P levels were sufficient (Table 2). K is an important cation in intracellular fluid and cell functions and is often abundant in forages, with levels above 2% in alfalfa (Table 2). With the exception of multiflora rose and dogwood, which were low-to-deficient in K, the other shrubs tested sufficient-to-high in K. Magnesium, important for many enzyme function and all biosynthetic processes, is needed at levels of 0.10 to 0.20% of DM, increasing from growing or finishing cattle to lactating cows (Beef NRC 1996) and tested slightly higher than alfalfa.

Not only are these species more than adequate for beef cattle nutrition, they are high compared to most other browse species. Mineral concentrations from 14 browse species in northern Mexico were found to be at their highest levels in spring and summer; however, none of them matched the species sampled in our study (Ramirez 2001). With just one sampling period in our study, it is hard to say how mineral levels would change but it seems safe to assume that mineral levels are at their highest in the late spring when soils are moist and microbial decomposition is active. Assuming this, mineral supplementation would be required if dogwood was a major shrub to be grazed since it has such low P and K concentrations in late spring.

Mitchell and Rodgers (1985) working in Idaho had similar findings to our own, and estimated that cattle preferred to spend more time in July in shrubs vs. pasture (70 vs. 30%). Kirby and Stuth (1982) and Kirby and Parman (1986) however, reported that grasses dominated (>65%) diets across seasons in esophygeally fistulated beef cattle when grazing mixed prairie or brush managed pastures. Likewise, Rutagwenda et al. (1990) found that cattle grazing in semiarid Kenya, favored grasses, irrespective of season, with > 90% of the total feeding time spent on grasses. It is possible that there may exist palatability differences among various shrubs. For example, high tannin levels common in many tropical shrub species have been shown to reduce intake (Barahona et al., 1997). An explanation for the difference between our findings and these other studies may be due to the longhaired cattle used in our study moving to the cooler, shaded areas of the plots where there is less grass and more shrubs present. Although forage digestibility was similar between Scottish Highland and Angus cattle, Scottish Highland cattle may have greater browsing habits than the more common domestic beef cattle such as Angus or Hereford. Our observations support local belief that this breed is an effective browser. It is not known what other cattle breeds or livestock species would consume if put in a similar environment. Similar to our observations, Mitchell and Rodgers (1985) observed cattle walking down branches of willow (S*alix* spp.) plants so the leaves could be reached and consumed. In a sister study to ours, Harrington and Kathol (in press) reported grazing caused significant reduction in stem density for *Corylus Americana* (hazelnut), *Rubus* spp., prickly ash and others but not for gray dogwood or *Ribes* spp. The small leaf-to-stem ratio of *Ribes* spp. and multiflora rose may account for the lack of grazing effect on stem density but gray dogwood, which does not have thorns and has high leaf-to-stem ratio may have anti-quality factors affecting intake.

## CONCLUSIONS

With the cessation of fire and grazing, natural succession has led to a degraded state of most of the oak savanna that once existed on so many acres in pre-settlement Wisconsin. Managed grazing in these degraded savannas could serve the dual purpose of providing livestock feed and shelter and at the same time restoring oak savanna structure. Shrub forage quality, sampled in early summer was good-to-excellent for most species tested. With the diversity of species that exist in degraded oak savannas and woodlands and associated pastures, cattle should be able to choose the higher quality species to maximize performance. Our expectation is that with repeated grazing episodes, and perhaps some mechanical thinning, light would penetrate the understory, releasing the native vegetation associated with healthy savannas.

## ACKNOWLEDGEMENTS

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**Table 1. Baseline routine soil tests to 15-cm depth from the three study sites.**

| Site | Soil Test P (ppm) | Soil Test K (ppm) | Organic matter % | pH |
|---|---|---|---|---|
| YLWA | 20 | 141 | 6.0 | 7.0 |
| Prairie Oaks | 33 | 153 | 7.6 | 6.8 |
| Creag-is-Daru | 29 | 71 | 2.8 | 4.9 |

**Table 2. Quality of various shrub species from on-farm and YLWA averaged across replicates and years plus alfalfa checks for comparison.**

| Site | Species | %CP | %NDF | %IVTD | %P | %Ca | %K | %Mg |
|---|---|---|---|---|---|---|---|---|
| On-farm | | | | | | | | |
| | *Rubus* spp. | 18.1a | 39.6a | 67.4b | 0.25c | 0.80c | 1.75c | 0.46b |
| | Multiflora rose | 11.7c | 40.1a | 64.5b | 0.25c | 1.46a | 1.48c | 0.35c |
| | Prickly ash | 20.0a | 36.7ab | 84.9a | 0.31b | 1.63a | 2.27b | 0.35c |
| | Wild parsnip | 14.9b | 32.5b | 83.5a | 0.48a | 1.28b | 2.88a | 0.64a |
| | LSD ($P < 0.05$) | 2.7 | 5.6 | 4.8 | 0.05 | 0.18 | 0.44 | 0.03 |
| YLWA | | | | | | | | |
| | Prickly ash | 18.8x | 38.1x | 84.5x | 0.28x | 1.45z | 2.14y | 0.28z |
| | Gray Dogwood | 12.3y | 24.1z | 80.3y | 0.21z | 1.76x | 0.91z | 0.41x |
| | Gooseberry | 14.3y | 30.8y | 78.4y | 0.24y | 1.59y | 2.88x | 0.35y |
| | LSD ($P < 0.05$) | 2.0 | 2.9 | 3.5 | 0.02 | 0.14 | 0.16 | 0.04 |
| Alfalfa Checks | | | | | | | | |
| | Immature | 23.1 | 33.3 | 80.3 | 0.33 | 1.50 | 2.51 | 0.21 |
| | Mature | 16.9 | 46.9 | 70.8 | 0.21 | 1.18 | 2.07 | 0.22 |

1 Different letters in same column show significant differences at $P < 0.05$
2 Checks pertain to lab standards from K. Albrecht's lab tested frequently over 4 years.

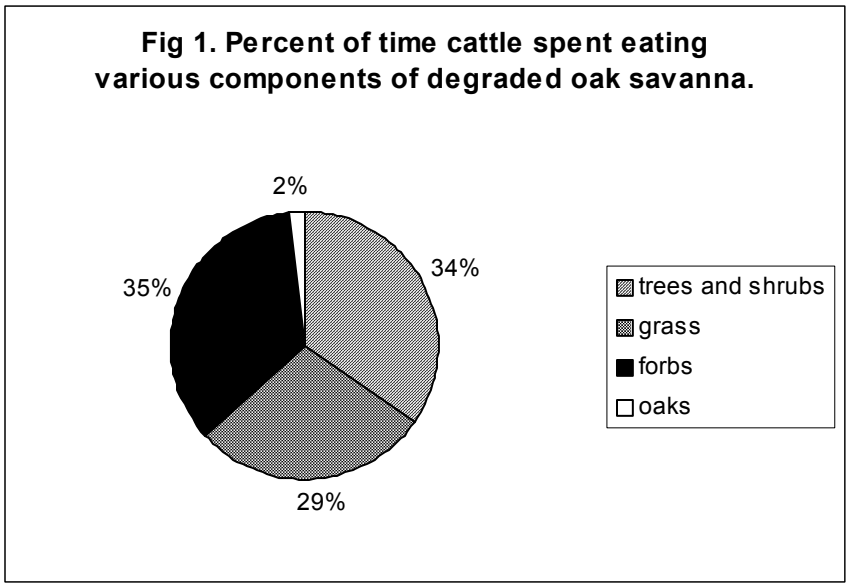
Fig 1. Percent of time cattle spent eating various components of degraded oak savanna.
2%
34%
35%
29%
trees and shrubs
grass
forbs
oaks

1

# USING CATTLE TO REDUCE OAK SAVANNA UNDERSTORY SHRUB ABUNDANCE: STOCKING RATES AND WEIGHT GAINS

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## ABSTRACT

Oak (*Quercus* spp.) savanna, characterized by widely scattered oaks with an understory of prairie species is one of the most endangered native ecosystems in North America. The absence of grazing and burning along with the introduction of tillage agriculture are key factors for the loss of this ecosystem. Our objective was to determine the effectiveness of rotational grazing to reduce the shrub layer in degraded oak savannas. This study took place at 3 sites in southwestern Wisconsin. In this paper we will report on the results of the savanna grazing on the cattle. For 2 summers, cow/calf pairs or yearling Scottish Highland cattle (*Bos taurus* spp.) were placed on 1-acre (0.4 ha) treatment sites for about 2-3 days per month with a rest on grass pasture for one day between replicates. Animal weight gain was satisfactory. During the study, cattle generally gained better in 2002 due to adjusted stocking densities from 2001. Cows that calved prior to the study typically maintained body weight similar to controls while late-calving cows in both groups lost some weight. Dry cows, steers and nursing calves also performed similar to the controls. Body condition scores (BCS) for all classes of cattle were similar between the treatment and control groups over the season, hovering around 5 and 6. Managed grazing with 5 to 7 cow/calf pairs or 12 yearlings per acre, for about 2-3 days per month 2 to 4 times per season reduced the shrub layer in oak savanna while permitting adequate weight gains.

## KEYWORDS

Oak woodland, managed grazing, Scottish Highland cattle

## INTRODUCTION

Oak savanna, characterized by scattered open-grown oak trees, and a groundcover composed of grasses, sedges, wildflowers, and occasionally brush, is the most endangered native ecosystem in North America (Nuzzo 1986, Packard and Mutel 1997). Grassland ecologists attribute the lack of grazing and burning along with the introduction of agriculture as key factors explaining the disappearance of this ecosystem. Restoring oak savanna structure to the remaining fragments of this ecosystem begins with increasing light penetration to the herbaceous ground layer. The overall objective of this study was to determine the effectiveness of rotational cattle grazing to reduce the shrub layer in degraded oak savannas. In this paper we will focus on the impact of grazing oak savanna on the livestock themselves. Shrub forage nutritional value and cattle observation data can be found in Hedtcke et al. (in press). Information on the impact of grazing on the vegetation is presented in a companion paper (Harrington and Kathol, in press).

## STUDY AREA AND METHODS

The pre-settlement landscape of southwestern Wisconsin was a mosaic of vegetation types that ranged from prairie to forest. Tallgrass prairie had few-to-no trees and depended on frequent fires to maintain a grassy landscape. Next was oak savanna, which had scattered open-grown trees but also prairie underneath. Then there was oak woodland, which had more trees, but less than 80% canopy cover. And finally, the mixed hardwood forest itself, with little direct sunlight penetration beneath the tree canopy. Critical to maintaining the former two ecologies was grazing.

This study took place at three sites in southern Wisconsin: Yellowstone Lake Wildlife Area (YLWA) in Lafayette County, owned and managed by the Wisconsin Department of Natural Resources (WDNR); Prairie Oaks Farm (hereafter referred to as Farm 1), also in Lafayette County; and Creag-Is-Daru Farm (hereafter referred to as Farm 2), in Iowa County. Current conditions at the three sites reflect primarily soil and slope differences. Farm 1 is a shrub-infested oak woodland, dominated by bur (*Quercus macrocarpa*) and/or white oak (*Quercus alba*). YWLA was once a savanna that has been highly degraded by encroaching shrubs and invasive species. The Dubuque silt loam soils at these two sites are well drained and high in organic matter. Farm 2 is the least degraded of all sites with significant oak savanna components present. Its soil (Northfield sandy loam > 12% slope) is well drained, shallow, and sandy. Each site had remnant prairie patches with species common to historic tallgrass prairie and oak savanna regions of southern Wisconsin. The soil test values for each site are reported in Table 1. YLWA and Farm 1, which are on fertile soils, were not brought under the plow primarily due to the steep slopes. At Farm 2, the steep, shallow, acidic, less fertile soils are not conducive to row-crop agriculture.

The study was done using a Scottish Highland breed of cattle of which there are currently about 20,000 registered plus an unrecorded number of unregistered animals raised for beef in the USA (American Highland Cattle Association, pers. comm. 2002). This breed has a shorter stature than typical beef breeds but they have similar body weights. They are good browsing animals, and they possess large horns frequently used to knock over small trees and brush. Several local grazers considered these traits and their reported ability to thrive in less than ideal pasture circumstances on the Scottish moors, as advantages for grazing in overgrown oak savannas.

**Treatments and Design.**
At all three sites, the cattle grazed in the oak savanna for about 25 days/month during the summer and were compared to animals grazing only in grass/legume pastures. The design was a randomized complete block design with five replicates at each site. Three-strand high tensile wire fencing was installed around each 1-acre (0.4 ha) plot in the spring of 2001 at all 3 sites. Each plot had an open grassy area at the bottom of the slope with increasingly dense understory beneath the tree canopy upslope.

Grazing occurred during the summer of 2001 and 2002. Cattle were weighed just prior to entering plots in late May and again at the end of the grazing season. Cattle were weighed one at a time using a gated chute set up around a weighing platform under which was a Tru-Test™ load-bar scale with digital readout. Cows and steers were also scored for body condition in 2002 at the beginning and end of the season using a visual BCS system with a scale from 1 to 9, with 1 representing emaciated and 9 meaning obese condition (Whitman, 1975). The same trained cattle handler scored each animal at the time of the weighing.

**Cattle Rotation**
Cattle 'grazed' the savanna plots in each replicate for 4 days and were then placed in a pasture area for one day between replicates. At the end of the 25-days, cattle were returned where they started in the first replicate (Table 2).

**Stocking Rates:**
Stocking rates, expressed as AU/acre (1 AU=1000 lbs live cattle weight or 455 kg) were based on our evaluation of existing forage in late May (Table 3). On-farm, cow/calf pairs and dry cows (about 1000 lbs or 455 kg each) were used while 450-lb (205-kg) steers were used at YLWA. At the same time that the grazing animals were selected, a paired control group on grass/legume pasture was identified to be used as a reference for weight and body condition each summer.

## RESULTS & DISCUSSION

**Cattle Rotation**:
At YLWA, the animals were grazed all summer (4 cycles in 2001; 3 cycles in 2002) while on-farm, there were only two grazing cycles each year (Table 2). The July and August cycles of grazing were eliminated due to dry summer weather. In both years, June rainfall stopped by mid-month, and July rainfall was less than half of the 30-year average.

**Stocking Rates**:
As summarized in Table 3, on Farm 1, 6 cow/calf pairs were rotated through the plots in both years. Based on experience we lowered the stocking rates at the other two sites in the second year. On Farm 2, 6 cow/calf pairs and 3 dry cows were used in 2001 and 4 cow/calf pairs and 2 dry cows were used in 2002. At YLWA, overstocking occurred for cycle 1 of the first year, where we started with 18 steers. Twelve animals were used for the entire 2002 season at YLWA. Our impression is that the 2002 stocking rates (5-7 AU/a) were sustainable and permitted good animal weight gains (Table 4) as well as partial clearing of the shrub layer.

**Animal Performance**

*Cow/calf pairs.* Under good grazing conditions, pregnant beef cows generally lose about 100-150 pounds (45-68 kg) during the first few weeks after calving due to heavy energy demands from peak milk production (National Research Council, 1996). During our study, the treatment cows that calved late or during the study lost on average 92 lbs (42 kg) due to calving and peak lactation compared to a 40-lb (18 kg) loss in the control group (Table 4). Cows that calved prior to the study essentially maintained body weight and condition, similar to controls. Initial BCS were slightly higher in the control group (6.2) than the treatment group (5.2) but both groups maintained their condition at the end of the season.

Weight gains of nursing calves were similar between treatment and control groups (Table 4), with both groups doubling or tripling their birth weight by the end of the season. Most of their nutrition was from milk but some foraging of shrubs and forbs was observed as well.

*Dry cows and steers.* During the 2 seasons, dry cows gained a similar amount of weight on both the oak savanna plots and the control plots. As with the pregnant cows, body scores were similar between the animals grazing in the oak savanna and those on pasture all summer. Final BCS was also similar between groups of 6.6 for the controls and 6.0 for the treatment group. At YLWA, the 12 steers gained weight as well as the controls in 2002 and final BCS was acceptable at 5.3 but the control group gained more condition over the season increasing from 5.0 to 6.5. However, in the first season, due to overstocking and overgrazing on cycle 1, the six steers that remained on the plots only gained 60% of that by the controls (Table 4).

## CONCLUSIONS

Our results indicate that grazing with Scottish Highland cattle have the potential to reduce the shrub layer and begin the process of oak savanna structure restoration. We found that using 5 to 7 cow/calf pairs or 12 yearlings per acre, rotated through the paddocks for about 2-3 days per month 2 to 4 times a year resulted in measurable shrub removal. Generally, the weight gains and condition scores of cattle on treatment plots were adequate and similar to that on the control plots. Due to the heterogeneity of forage production within oak savannas and variability in summer rainfall, managers are advised to carefully monitor the vegetation and livestock as actual stocking rates and duration in the savanna will vary. We recommend further evaluation of this system on larger paddocks with more animals and for several years, before promoting its use as a habitat management option.

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## TABLES

**Table 1. Baseline routine soil tests to 6-inch (15-cm) depth from the three study sites.**

| Site | Soil Test P (ppm) | Soil Test K (ppm) | Organic matter % | pH |
|---|---|---|---|---|
| Farm 1 | 33 | 153 | 7.6 | 6.8 |
| Farm 2 | 29 | 71 | 2.8 | 4.9 |
| YLWA | 20 | 141 | 6.0 | 7.0 |

**Table 2. Cattle rotation schedule at the 3 sites**

| Site | 2001 | 2002 |
|---|---|---|
| Farm 1 | June 1-June 25 | June 1-June 25 |
| | June 26-July 20 | Aug 20-Sept 13 |
| | Sept 17-Oct 10 | |
| Farm 2 | June 1-June 25 | June 1-June 25 |
| | July 1-July 25 | Aug 26-Sept 19 |
| | Sept 15-Oct 8 | |
| YLWA | June 1-June 25 | June 1-June 25 |
| | June 26-July 20 | June 26-July 20 |
| | July 21-Aug 14 | July 21-Aug 17 |
| | Aug 18 -Sept 11 | |

**Table 3. Stocking densities in lbs/a (with number of animals in parenthesis) at the 3 sites.**

| | lbs/acre | |
|---|---|---|
| | 2001 | 2002 |
| Farm 1 | 6717 (6 cow/calf pairs) | 7256 (6 cow/calf pairs) |
| Farm 2 | 8840 (6 cow/calf pairs + 3 dry cows) | 5802 (4 cow/calf pairs + 2 dry cows) |
| YLWA | 8685 (18 yearling steers)[1] | 5064 (12 yearling steers) |

[1] Stocking density was reduced to 6 steers after first grazing cycle.

**Table 4. Cattle weight gain or loss on treatment and control plots.**

| Site | Class of cattle | Treatment (Degraded savanna) | | Control (Grass/legume pasture) |
|---|---|---|---|---|
| | | 2001 | 2002 | 2-yr average |
| On-farm | | ----------lbs/head---------- | | |
| | Lactating cows | | | |
| | Calved early | -18 (n=9) | 50 (n=7) | 65 (n=8) |
| | Calved late | -91 (n=3) | -92 (n=3) | -40 (n=7) |
| | Baby calves | 174 (n=11) | 151 (n=7) | 170 (n=14) |
| | Dry cows | 91 (n=3) | 153 (n=2) | 112 (n=8) |
| YLWA | | | | |
| | Yearling steers | 76 (n=6)[1] | 108 (n=12) | 127 (n=4) |

[1] Initially there were 18 animals on the plots. This was reduced to 6 steers in mid-summer.

# MONITORING CATTLE PERFORMANCE ON PASTURE AT THE KRUSENBAUM FARM.

Janet Hedtcke, Josh Posner and Altfrid Krusenbaum

## INTRODUCTION

After converting from a conventional dairy to a managed-intensive rotational grazing dairy farm in the early 1990's, the Krusenbaums's ('Krusen Grass' Farm) were interested in further improving their labor efficiency to reduce the cost of production and to allow for some vacation time. They implemented seasonal calving so that the majority of their herd was dry during the winter and calved in the spring. To further lighten their load and to minimize capital costs they decided to outwinter the cows, bred heifers, and young stock on the paddocks.

However, by the winter of 1997/98, they were beginning to make some modifications. Although they aimed to have all the cows dry in February, they were more flexible in drying the cows off according to their due date, depending on labor availability. And secondly, they constructed an outwintering shed for the milking string. The former modification was made for reasons of cash flow and total milk production, and the latter for reasons of herd health, cow comfort and more flexible manure management. They now focused their attention on the impact of their outwintering strategies on the bred heifers and young stock.

More specifically, they were concerned about how their herd management decisions were impacting animal weight gain. Was it necessary to separate steers from heifers due to the different levels of aggressiveness of each during grazing? Did crossbreeding their Holsteins with Jerseys result in improved rates of weight gain? Was it necessary to invest in housing for the young stock if winter weight gains were low?

A study in Sweden on behavioral responses of dairy heifers to climate showed that climate had significant effects on main activity and location of the heifers and that heifers adapted their behavior to reduce energy expenditure by spending more time lying in the wooded areas in very cold or windy conditions (Redbo et al., 2001). Knowing this, it was important to provide some protection from the elements so that animals didn't lose a lot of condition. To help maintain condition and weight gain, the replacement cattle were provided high quality round bales or baleage on the paddocks during the winter months. Water was provided in the lot. In extremely cold or windy conditions, animals were supplemented with corn grain and were provided either natural (trees or valley) or artificial windbreaks set up using 2 layers of large round bales.

We decided to ask three questions:

1) Did steers and heifers gain at the same rate?
2) Did Holstein cattle gain at the same rate as Jersey crossbred cattle?
3) Would winter weight gain equal summer weight gain?

This is a report on the first two years of data collection.

## MATERIALS AND METHODS

Bred heifers, weaned calves, and male calves were weighed in late fall at the end of the grazing season and again as the overwintering period ended and the paddocks began to green up (early

Spring). Summer weighing was avoided as to not interfere with conception rates during this delicate phase. The target birthing and breeding schedule for this farm is for the calves to be born in March, pass a first winter as young stock, to be bred in June (at ~14 months) and pass a second winter as bred heifers, and finally give birth and enter the milking string in March (at 23 months). Table 1 summarized the number of animals that entered the study. They are grouped as the calves born in Spring 2002 (only measured over their second winter, ~20 mo.), the calves born in Spring 2003 (weighed over two winter seasons, first as calves (~8 mo.) and then as bred heifers ~20 mo.) and those born in 2004 (at the date of this report, only weighed as calves going through their first winter). Table 2 shows the weighing schedule.

**Table 1. Replacement heifers and steers in the study.**

| Animals born in the spring of: | Holstein heifers | Crossbred heifers | Steers (mixed breeds) | Total Animals |
|---|---|---|---|---|
| 2002 | 11 | 12 | 0* | 23 |
| 2003 | 12 | 22 | 22 | 56 |
| 2004 | 26 | 7 | 23 | 56 |

* steers not weighed

**Table 2. Weighing dates.**

| Fall weighing dates | Early Spring weighing dates |
|---|---|
| December 12, 2003 | March 1, 2004 |
| November 5, 2004 | February 22, 2005 |
| August 25, 2005 | Late February, 2006 (end of study) |

Cattle were brought in off the paddocks the morning they were to be weighed. Supplemental feed was withheld until after weighing. One-by-one, cattle were 'run' across a Tru-Test© load bar scale and loading platform set up beneath a holding chute. Though body condition scoring was not recorded, each animal was observed for problems and thrift while on the platform scale. Using phenotype, breed was assigned to each animal. Because the farm does raise some organic beef, male calves (steers) were included in the second and third cohort.

Data was analyzed with a pair T-test approach for each group using SAS 8.2 Proc Mixed. LSMEANS were used to report the means. There were no gender x season or breed x season interactions so the main effects are averaged across seasons in this report.

## RESULTS AND DISCUSSION

### Heifer vs. Steer Weight Gain

Looking at the unbred heifers and steers, weight gain of steers, although arithmetically higher, wasn't statistically consistently higher from year to year (Table 3). We would like to get another year of data before basing a decision on separating males and females into different grazing groups.

| **Table 3. Average daily weight gain as a function of gender.** | | | |
|---|---|---|---|
| Year | Class of cattle | Winter1 | Summer2 |
| | | lbs/day | |
| Calf2003 | Unbred Heifer | 1.37 | 1.51 |
| | Steer | 1.50 | 1.57 |
| *p-value* | | *0.1043* | *0.3018* |
| | | | |
| Calf2004 | Unbred Heifer | 1.22 | 1.46 |
| | Steer | 1.26 | 1.55 |
| *p-value* | | *0.4946* | *0.1044* |

**Overwintering period and the effect of breed**

*Bred Heifers:* Bred heifers (Calf2002) were weighed going through their second winter at about 1050 lbs/animal or 75% of their mature weight (Table 4). By the end of their second winter, some bred heifers had already calved and thus were moved to the milking string. Although the Holstein heifers tended to be heavier than the crossbreds there was no effect of breed on average weight.

The following winter (2004-2005), another set of bred heifers (Calf2003) was weighed. Similar to Calf2002 group, breed was not significant factor in average body weight at the start of the winter but by late February the Holstein heifers were heavier. It is interesting to note that this group performed better in a harsher winter of 04/05 (1.82 lb/day) than did Calf2002 during the previous milder winter (1.36 lb/day) ($p<0.0025$). Although the animal weight gain was very different in these two winters prior to calving, DHIA herd records show that the Krusenbaum heifers calve at an average age of 24 months of age, and a median age of 23 months (Nordlund, pers comm. 2005).

*Yearling heifers:* The young stock at 8-9 months old averaged 475 lbs the first year (Calf2003) and 430 (Calf2004) the second year going into their first winter and came out of winter season (~12 mo. of age) at 584 (Calf2003) and 559 (Calf2004) lbs on average (Table 5). As with the bred heifers there was generally no effect of breed on animal weights going into the winter or coming out of the winter. These animals were small compared to industry standards where the desirable weights at 14 months (breeding age) are between 825-875 lbs for Holstein heifers and 580-600 lbs for Jerseys (Crowley et al., 1991; Hoffman, 1997). Vargas et al (1998) actually found a significant effect of heifer weight at 13 months on age at first calving. They reported that the chance of calving was consistently higher for heifers with higher body weights at 13 months, and it decreased linearly from the top to the lowest quartiles. Although somewhat light, DHIA records show a very high rate of conception for the 1st-calf heifers at nearly one service per conception, exceeding their goal of 1.5 services per conception.

| **Table 4. Bred heifer body weights—winter weight gains** | | | | |
|---|---|---|---|---|
| | Calf2002 | | Calf2003 | |
| | Dec. 12, 2003 | March 1, 2004 | Nov. 5, 2004 | Feb. 22, 2005 |
| | Start of 2nd winter | End of 2nd winter | Start of 2nd winter | End of 2nd winter |
| Breed | ----------lbs---------- | | | |
| Holstein | 1058 N=12 | 1162 N=11 | 975 N=12 | 1201 N=10 |
| Jersey Cross | 1048 N=17 | 1173 N=13 | 937 N=22 | 1126 N=21 |
| *Mean* | *1053* | *1168* | *956* | *1163* |
| *p-value* | *0.7936* | *0.8410* | *0.1155* | *0.0245* |

| **Table 5. Young heifers body weights—winter weight gains** | | | | |
|---|---|---|---|---|
| | Calf2003 | | Calf2004 | |
| | Dec. 12, 2003 | March 1, 2004 | Nov. 5, 2004 | Feb. 22, 2005 |
| | Start of 1st winter | End of 1st winter | Start of 1st winter | End of 1st winter |
| | ----------lbs---------- | | | |
| Holstein | 490 N=12 | 600 N=12 | 440 N=26 | 576 N=26 |
| Jersey Cross | 461 N=22 | 568 N=22 | 420 N=7 | 541 N=7 |
| *Mean* | *475* | *584* | *430* | *559* |
| *p-value* | *0.0694* | *0.1345* | *0.4420* | *0.2150* |

| **Table 6. Average daily weight gain of bred and yearling heifers** | | | | | | |
|---|---|---|---|---|---|---|
| Group | Class | Season | Holstein | Jersey-Hol. Cross | Mean | Pr > F |
| | | | Average daily gain (lb/day) | | | |
| Calf2002 | Bred heifer | Winter '03-04 | 1.27 | 1.45 | 1.36 | 0.5343 |
| Calf2003 | Bred heifer | Winter '04-05 | 1.97 | 1.74 | 1.82 | 0.1304 |
| Calf2003 | Yearling heifer | Winter '03-04 | 1.39 | 1.35 | 1.37 | 0.7239 |
| Calf2004 | Yearling heifer | Winter '04-05 | 1.25 | 1.22 | 1.24 | 0.6450 |
| | | | | | | |
| Calf2003 | Yearling heifer | Summer '04 | 1.51 | 1.51 | 1.51 | 0.9887 |
| Calf2004 | Yearling heifer | Summer '05 | 1.51 | 1.26 | --- | 0.0033 |

In Table 6 the animal measurements are "standardized" by presenting their average daily weight gain. Industry standards are approximately 1.8 lb/day for pure Holstein heifers and 1.5 lbs/day for pure Jerseys (Crowley et al., 1991). As with total weights, breed was not significant in all but one case (summer '05). The winter weight gain of 2004-2005 for the yearling heifers was low (1.24 lb/day) and worthy of concern (Table 6). During that winter temperature fluctuated above and below freezing allowing for both rain and snow events. Intervals of freezing and thawing cycles created ice sheets and muddy paddocks. In the first week of January 2005, over 2" of rain fell which caused many problems and headaches for the cattle and paddock condition was

damaged. Winterkill of both grass and legume was prevalent. Animals had a hard time walking in the icy conditions, which likely negatively impacted feed and water intake.

**Weight gains for the young heifers: 1st winter season vs. 2nd grazing Season**

Due to confounding effect of fetus growth with the bred heifer growth, we only looked at differences between seasonal weight gain of the young stock. Since the difference between breeds was not significant (Table 6), they are averaged in the comparison of winter and summer weight gains (Table 7). To further increase the number of observations steers are included since, as a group, they did not gain weight at a different rate than the heifers (see Table 3). Based on the first two years of data, we find that the year of measurement is significant (the rough winter of 2004/5 markedly reduced the growth rates of the young animal), and season is significant with winter gains lower than summer gains. The interaction is one mainly of scale as the stock that suffered in the winter, markedly increased their weight gain in the summer, while the less affected animals from the year before kept more similar growth rates in both seasons. Overall, weight gains in the winter were modest (1.33 lb/day). Across breeds, weight gain during the grazing season averaged 1.51 lb/day but weight gain was below the target of 1.8 lb/day.

**Table 7. Seasonal effect on weight gain (lb/d) on 2003 and 2004 young stock (including steers).**

| | Season | | |
|---|---|---|---|
| | Winter1 | Summer2 | *Mean* |
| Group | ----------lb/day---------- | | |
| Calf2003 | 1.42 | 1.53 | *1.47* |
| Calf2004 | 1.24 | 1.49 | *1.36* |
| *Mean* | *1.33* | *1.51* | |

Group*season interaction $p<0.0207$. Both main effects significant at $p<0.01$

## SUMMARY

In this study, the Holstein and Jersey Holstein crosses are gaining weight at the same rate, as are the heifers and steers. At this point, it appears un-necessary to break the young stock out into different groups for summer grazing and winterfeeding. It was found that summer weight gains were higher for young stock (including steers) (1.51 lb/d) than in the two winters already monitored (1.42 and 1.24 lb/d). The heifers in this study were only gaining weight at about 80% of the industry standard of 1.8 lbs/day. Although most research would suggest that these animals would be more difficult to inseminate and calve at a later date, DHIA records indicate that conception rate is above the industry standard of 1.6 and average age at calving is 23 months. From this partial analysis, it appears that the Krusenbaum outwintering strategy permits the young stock, although a bit small to move into the milk string in an orderly fashion. Furthermore, using this outwintering strategy reduces capital investment in housing. However, there is some risk associated with over wintering young stock out on pasture as can be seen from low weight gain of 1.24 lb/d during the winter of 2004-2005. We will continue to monitor the replacement stock performance, which will allow for adapting future management decisions.

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