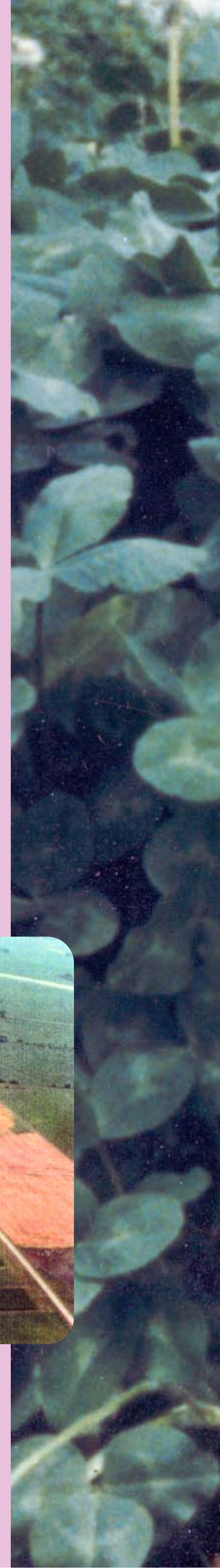
Comparing Upper Midwestern farming systems

Results from the first 10 years of the Wisconsin Integrated Cropping Systems Trial (WICST)



Executive Summary

The WICST question:

By increasing cropping system diversity, is it possible to simultaneously
- reduce potential negative environmental impacts of farming
- lower input levels
- maintain or increase productivity
- maintain or increase profitability

The WICST experiment:

We designed a total of six cropping systems based on common existing farming practices to evaluate these issues in 1989. To ensure the relevance of the results for a commercial farm setting, our plots were large (0.8 a) and field operations were performed with conventional farm machinery. Our cropping systems were not simply rotations, but rotations combined with management strategies that were guided by a particular philosophy (e.g., minimizing purchased chemical inputs). Because of the importance of both animal-based and cash grain systems in Southern Wisconsin, we included three cash grain and three forage systems of varying levels of crop diversity and inputs. The trial took place at two sites: one with heavy and relatively poorly drained soils (Lakeland in Walworth County), the other with lighter and better drained soils (Arlington in Columbia County) to capture some of the variability of regional conditions.

An aerial view of the Arlington plots.

CS1 — continuous corn (low diversity, high-purchased-input system)
CS2 — corn-soybeans (moderate diversity, moderate-purchased-input system)
CS3 — corn-soybeans-wheat/red clover (high diversity, low-purchased-input system)
CS4 — corn-alfalfa-alfalfa-alfalfa (low diversity, high-purchased-input system)
CS5 — corn-oats/alfalfa-alfalfa (moderate diversity, low-purchased-input system)
CS6 — rotational grazing (high diversity, low-purchased-input system)

Gross margins Summary Stats

Site-averages ($/a):

	ARS	LAC
CS1	165	88
CS2	201	172
CS3	188	151
CS4	221	163
CS5	232	153

Rankings of Cash Grain Cropping Systems

	Profitability	Productivity	Environment
Best	CS2	CS2	CS3
Next Best	CS3	CS1	CS2
Worst	CS1	CS3	CS1

Rankings of Forage Cropping Systems

	Profitability	Productivity	Environment
Best	CS4 and CS5	CS4	CS6
Next Best	*	CS5	CS5
Worst	*	CS6	CS4

What we found:

No single system "won" in every measure.

The cash grain and forage systems can be ranked as shown in the chart at left. Keep in mind that differences between systems in any given measure were not necessarily large.

We were not able to compare the profitability of rotational grazing with the other stored forage systems due to the complexity of this animal/forage system.

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The trade-offs.

The no-till corn-soybean system (moderate-purchased-input, CS2) had the best yields and highest gross margins (crop income less variable costs—seed, fertilizer, fuel) at both sites. The low-purchased-input rotation (CS3) that added a small grain and cover crop to the corn soybean system was the best system from an environmental standpoint but was slightly (9%) less profitable. The corn and soybeans in CS3 were 14% less productive than the simpler no-till corn soy system (CS2). Among the forage systems, rotational grazing was the most environmentally benevolent system and produced (on average) 87% of the dry matter of CS4 and CS5. On the other hand, the most productive system (CS4, intensive alfalfa) was the least environmentally benign. The low-purchased-input forage system (CS5) was again a solid all-around performer, equaling the highest input system in profitability, with only slightly lower yields, but better environmental performance.

Cultivation of wide-row soybeans on CS3.

Specializing in a single crop is costly.

The continuous corn system experienced high input costs ($164/a direct costs versus $123 for CS2 and $76 for CS3), had erratic and only fair corn yields (135 bu/a compared with CS2's 147 bu/a and CS3's 124 bu/a), showed unimpressive economic performance (average gross margins of $127/a versus $187/a for CS2 and $170/a for CS3) and engendered high environmental costs. The primarily alfalfa system (CS4) was a much better economic performer than continuous corn, but achieved little that the more diverse forage system (CS5) did not. The alfalfa system also experienced more trouble with pests and had a poorer environmental performance, particularly as regards potential nitrate leaching.

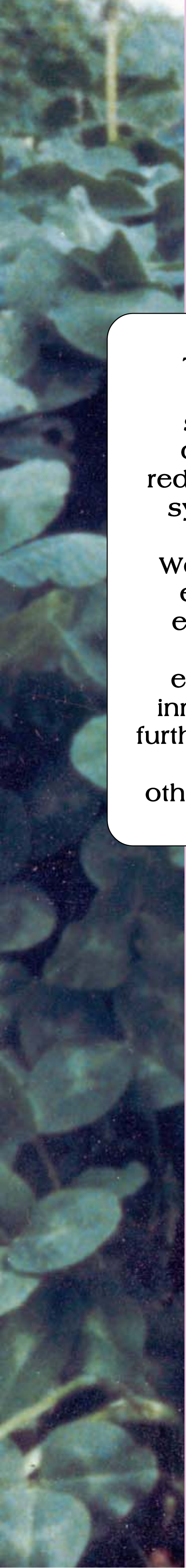
Lower input systems are better for the environment.

The environmental advantages of the lower input systems generally included greater energy efficiency (better energy output/input ratios), reduced groundwater contamination, lower pesticide use and soil that was slightly "healthier" in some measures. Rotational grazing (CS6), in particular, stood out positively in a number of measures, e.g., soil ecology, soil conservation, nitrate leaching.


Dairy heifers on rotationally grazed plots—CS6.

Lower input systems are not "riskier" than the higher input systems.

The lower input systems did not show significantly greater yield or profitability variation than the higher input systems. They did encounter different sources of risk however, stemming primarily from the challenges of mechanical weed control in wet weather. Labor use in the low-input cash grain system was also higher. The no-till corn and soybean system used the least amount of labor resulting in a savings of nearly 25% compared to continuous corn and 64% compared to the three-phase rotation In addition, two bottlenecks occur in CS3: one in early summer while rotary hoeing and cultivating, the second in the fall when combining soybeans and planting wheat.



Leguminous cover crops are a viable alternative to purchased nitrogen fertilizer.

A typical stand of red clover or hairy vetch will supply about 100 lbs. of nitrogen per acre and offer several agronomic and environmental benefits with modest additional cost (mainly seed) compared to inorganic nitrogen.

The WICST project shows that diversified, reduced-input systems are promising. We hope our experience encourages others to experiment, innovate and further explore these and other options.

Forage rotations outperformed cash grain rotations.

Assuming a ready market for hay, the alfalfa-based systems (CS4 and CS5) were more profitable than the cash grain systems, produced high yields with fewer inputs, and were more environmentally benign than the cash grain systems.

We can't always "have it all," but WICST shows we can do better.

Farmers in the Upper Midwest have a range of production options available to them. Those who wish to reduce their impact on the environment should be able to do so with little or no economic sacrifice by adopting diversified systems with appropriate management strategies. Management strategies which emphasize the long-term health of the resource base and system profitability (rather than yield) can be achieved by significantly reducing purchased chemical inputs. Some farmers may be willing and able to substitute labor and managerial inputs for purchased chemical inputs, thereby further reducing potential negative environmental impacts. More drastic reductions in purchased chemical inputs (such as what we tried on CS3 and CS6) will almost certainly lower productivity compared to the most productive systems, but the economic results may be similar to or only modestly lower than higher-input systems. Organic management of the low-purchased-input systems — if organic price premiums continue — offers the potential for significantly enhanced profitability of these systems.

Management is key to success.

With any given cropping system, there are many possible management philosophies and strategies. While our underlying philosophy remained the same for each system over of the course of the trial, our specific management tactics evolved over time as we gained familiarity with the strengths, weaknesses and potentials of each under various conditions. In order to boost the productivity of the lowest input cash grain system, we shifted from flying on the wheat to adopting shorter cycle soybean varieties and drilling in the wheat. Also, we tried food-grade soybeans and organic management on some plots. As no-till drills became more popular in the region, we shifted to an entire no-till system for the higher input corn-soybean system. What is important is not adherence to a rigid formula for success, or adoption of a particular set of practices or crops, but designing a cropping system and management philosophy appropriate to a given situation, and continuing to fine-tune it with prioritizing long-term health, productivity, and profitability.

We dedicate this report to the memory of our much-respected colleague, Dan Forsythe, Manager of the Lakeland Agricultural Complex, who was tragically killed in a car accident in the spring of 2000.

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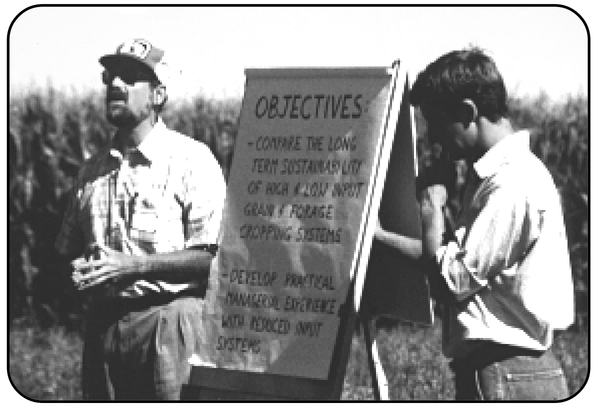
Introduction



Josh Posner and Jim Stute discuss WICST experiment at Arlington Field Day.

The Wisconsin Integrated Cropping Systems Trial (WICST) project was born in response to dissension within the agricultural community between those who feel the United States has the most successful food production system in history, and those who consider it unsustainable in one or more aspects. To frame the debate somewhat simplistically, on one side are the proponents of conventional agriculture who feel that the production practices adopted after World War II — the widespread use of purchased fertilizers and pesticides — have given us a highly productive and efficient system that needs no apology. On the other side were those who believe that agriculture is in need of fundamental changes. This camp argues for a "new agricultural paradigm" in which agriculture would more closely mimic natural processes and ecosystems; some proponents even urge wholesale adoption of organic production methods. Advocates of change generally focus on sustainability (environmental, economic, social or some combination of the three) as the goal. Between these poles are those who advocate fine-tuning conventional agriculture through Best Management Practices (BMPs)[1]. The BMPs specify fertility and pest management protocols for a range of cropping and livestock systems, and are continuously being developed by many state Departments of Agriculture and agricultural colleges nationwide.

The WICST team recognized the importance of this controversy to the future of Wisconsin agriculture, and the need for an inclusive debate informed by sound data on the production, economic and environmental implications of a range of cropping and livestock systems. Several important questions needed to be answered:

- Would low-purchased-input systems have unacceptably low yields?
- Would they be unprofitable or too labor-intensive?
- How far could Best Management Practices get us environmentally?
- Were the environmental impacts of conventional systems as bad as the critics said?

In short, how would systems relying on different mixes of inputs stack up against each other environmentally, economically, and agronomically?

The group's goal was to become an "honest broker" in addressing these questions. WICST hoped to become a forum where interested parties could compare side-by-side trials and see the costs, benefits and trade-offs of the different systems for themselves. As one of the project founders put it, "We wanted to have a place where the nozzle-heads and the granola-heads could come together and talk!" The team designing the trials ultimately expanded to include not only researchers, but crop consultants, farmers, County Extension personnel, and the Michael Fields Agricultural Institute, a non-profit research, education and advocacy organization for sustainable agriculture.

In 1989, two primary sites for the study were chosen: the Arlington Agricultural Research Station in Columbia County (affiliated with the University of Wisconsin) and the Lakeland Agricultural

Complex in Walworth County (the county-owned farm). In addition, several interested farmers offered their farms as experimental sites for "satellite trials," meant to explore particular questions in more depth in a commercial farm setting[2].

Management decisions for the Trial have been made by two overlapping groups. At annual winter meetings project staff from both sites, extension personnel, collaborating researchers from several disciplines, experimental farm employees, and the advisory committee make overriding or "big picture" decisions. Day-to-day management decisions are made by experimental farm employees and other project staff, in consultation with the broader group when the situation warrants.

WICST Project Steering Committee

(see Appendix 3 on page 31 for full list of collaborators)

University of Wisconsin-Madison College of Agricultural and Life Sciences
Michael Fields Agricultural Institute
Center for Integrated Agricultural Systems (UW-Madison)
UW Cooperative Extension Service
Lakeland Agricultural Complex (Walworth County Farm)
Arlington Agricultural Research Station (UW-affiliated)
AGSTAT (Agricultural and Statistical Consulting)
USDA-ARS National Dairy Forage Research Center (UW-Madison)

Advisory Board Members

(current and past; * marks those serving in 1999)

*Ron Doetch (grain originator; Walworth County)
Brad Franz (producer, Columbia County)
Norm Harris (producer, Columbia County)
Ken Hershleb (producer, Dane and Columbia Counties)
*Roger Jacobsen (producer, Walworth County)
*Altfrid Krusenbaum (producer, Walworth County)
Roger Peters (producer, Walworth County)
*Steve Pinnow (producer, Walworth County)
*Ron Schoepp (producer, Columbia County)
*Ken Schroeder (producer, Columbia County)
*Bill Stangel (crop consultant, Jefferson County)
Charles Weeks (producer, Rock and Walworth Counties, and northern Illinois)

Researcher Jim Stute at field day with Secretaries of Ag, Lakeland, 1997

For additional information about the Wisconsin Integrated Cropping Systems Trial, contact Josh Posner at the UW-Madison Department of Agronomy at 608-262-0876, e-mail jlposner@facstaff.wisc.edu; or call John Hall at Michael Fields Agricultural Institute at 262-642-3303, e-mail jhall@mfai.org

Cropping System Descriptions

The team set up two sets of comparisons[3]: 1) three cash grain systems; and 2) three production systems focusing on feeding livestock[4]. Each set of comparisons offered a "high purchased input" system, a "moderate purchased input" system, and a "low purchased input" system. The cropping systems were not just rotations — they were rotations combined with management practices appropriate to those rotations. Most management decisions for CS1, CS2, and CS4 followed BMPs. There were no BMPs for systems with little to no purchased inputs. BMPs were developed as a response to apparent overuse of agro-chemicals. The plot sizes were designed to be large enough — 0.8 acres — so that conventional farm equipment could be used for all field operations. *(See Appendix 1 on page 28 for detailed management protocols of the six systems.)*

Cash Grain Systems

Cropping System 1: Continuous corn

This monoculture system was established as the "extreme" case, the minimum plant diversity system. At the time the trial was started, roughly 30% of Wisconsin's corn acreage was devoted to continuous corn (corn grown for three consecutive years or more in the same field) in part because of federal price support programs[5]. Continuous corn was expected to be — and is — the highest purchased input system in the trials, relying on manufactured fertilizers and chemical and mechanical weed and pest control. We use reduced tillage (chisel plow) to reflect current production practices.

Cropping System 2: Corn-soybeans

This moderate-input, two-crop rotation is prevalent in the upper Midwest. The two-crop rotation breaks up some pest cycles and reduces the need for nitrogen fertilizer in corn. Chemical as well as occasional mechanical weed control is used on corn. The system started out with no-till corn and conventionally tilled, drilled soybeans. Since 1994, in part because of the increasing popularity of no-till beans, the whole system has been no-till[6]. Since the Trial began in 1989 however, new variants of corn root worms and soybean nematodes, and increased problems with white mold in soybeans suggest that this two-phase rotation may no longer be adequate for control of these problems; this argues for consideration of other, longer rotations.

No-till driling corn into soybean stubble, CS2.

Cropping System 3: Corn-soybeans-wheat/red clover

This cropping system has the longest and most diversified rotation, with four different crops in three years. Adding the small grain (winter wheat) to the system permits the introduction of a cover crop (red clover). The cover crop offers ground cover in the fall and winter and reduces or eliminates the need for nitrogen fertilizer for corn. Wheat, as a winter annual, breaks up the cycles of warm season annual weeds which can become a problem in corn-soy systems. Wheat also can act as a "nitrogen sponge" in the fall and spring, reducing potential leaching. Finally, by lengthening the time between soybean crops this rotation may address the increased difficulties many farmers are experiencing with white mold in soybeans. This system receives no manure or

Cultivating soybeans on CS3.

chemical fertilizers, and relies as much as possible on mechanical weed control. "Rescue" treatments of herbicides have been used in some years.

Red clover puts on abundant growth after wheat harvest on CS3.

Forage-based Systems

Cropping System 4: "Green Gold"[7] (alfalfa-alfalfa-alfalfa-corn)

This conventional system is our least diverse, highest-purchased-input forage-based system. We use a highly productive, disease-tolerant alfalfa planted without a companion crop, and harvest it intensively (three to five times per year), depending on the vigor of the stand. This system relies on both manure and purchased fertilizers for fertility, and herbicides and insecticides as needed for pest control. Our goal with this system is the production of a high quality hay.

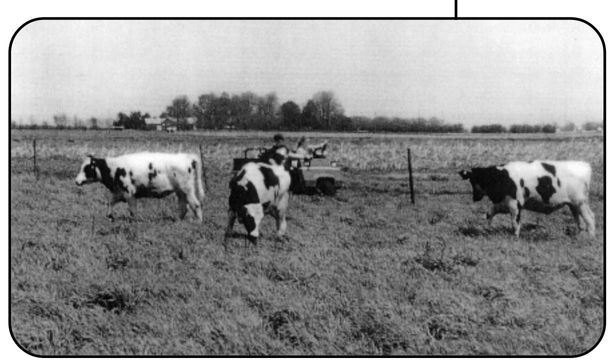
Harvesting forage on WICST plots.

Cropping System 5: Corn-oats/alfalfa-alfalfa

This moderately diverse, rapid turn-around system more closely equalizes the proportions of cereal and legume crops (maximizing the alfalfa nitrogen credits for corn), and is used by many organic dairy farmers. The oats help suppress weeds in the alfalfa, and are generally harvested as oatlage. To improve the protein content of the oatlage, we added peas to the mix after the first couple of years. We also added perennial ryegrass and red clover to the alfalfa at that time to improve dry matter production. This was particularly effective on the wet Lakeland soils. We selected this system as a low-purchased-input dairy forage rotation that could be of particular interest to farmers trying to grow more corn or corn silage, a common concern among dairy farmers considering herd expansion. We expected the three-cut system would result in good quality hay, though rarely surpass relative feed values of 140. We also expected this system to leach less nitrate than Cropping System 4.

Cropping System 6: Rotational grazing

The soils at both of WICST's research sites in southern Wisconsin were formed under tallgrass prairie vegetation. We hypothesized that this high plant diversity grazing system, somewhat mimicking the natural vegetation, would be the lowest purchased input and most environmentally benign of our six systems. With electric fencing we subdivided the grazing plots into temporary paddocks and moved heifers[i] through them at a rate that allowed for timely consumption of available forage, and adequate rest to assure good regrowth. If the pasture began to mature before the heifers could be moved onto it, the plots were hayed. Each fall the plots were evaluated for legume content and if low, the plots were frost seeded with red clover the subsequent winter. Recognizing the limitations of trying to replicate this complex system on small paddocks[8], a satellite trial has been conducted for 10 years on a 150 acre neighboring farm in Walworth County *(see the Outreach and Outgrowths section on page 25 for a description of this project*). At the time the WICST trials started, a small but growing minority of farmers practiced rotational grazing, and it received only limited attention in the research community. Today about 23 percent of Wisconsin dairy farmers use Management Intensive Rotational Grazing on some part of their farm[9].



Dairy heifers grazing cool-season grasses on pasture plots in CS6.

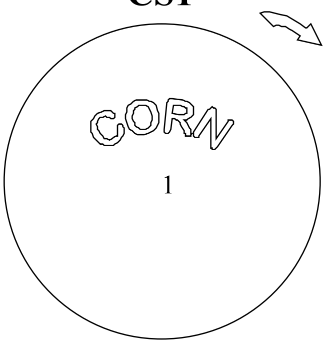
[i] *Dairy heifers were used instead of dairy cows at both sites due to the distance between the paddocks and the dairy.*

Rotation Diagrams

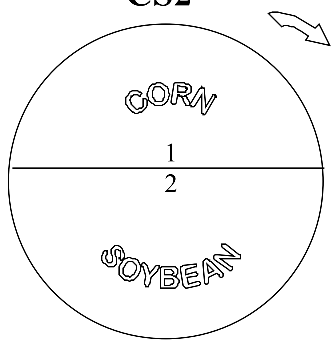
Schematic drawing of cropping systems in the Wisconsin Integrated Cropping Systems Trial. Numbers within circles represent year of rotation.

Cash Grain Cropping Systems:

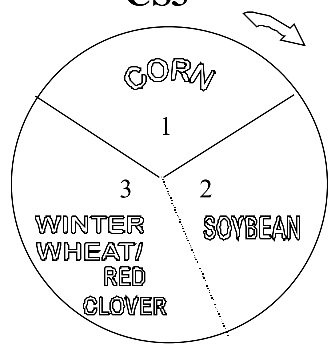
CS1



CS2

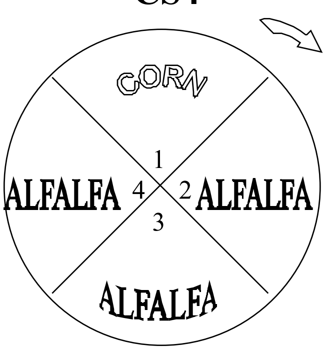


CS3

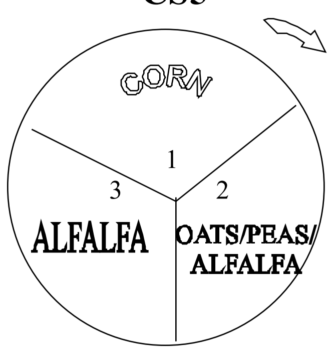


Forage-based Cropping Systems:

CS4



CS5



CS6

Cropping System Yields

A frequent criticism of low-input and organic systems is that they result in unacceptably low yields. With the world's population now at 6 billion, and expected to reach 7 billion in another 12 years, many argue that we need to obtain higher, not lower yields if we are to avert widespread food shortages[10]. Some observers believe that reducing agricultural inputs means setting yields back to where they were in the 1940s. Defenders of low-input and organic systems, on the other hand, assert that claims of yield reductions under organic systems — once a 4-5 year transition is accomplished — are exaggerated or false, and that modern crop genetics and equipment make historical yields just that—historical, and inapplicable under modern production systems.

In this section we discuss the yields of individual crops within each WICST cropping system. This is the simplest way to address the question of productivity. However, our greater objective is to integrate the cropping phases and ultimately discuss the system's overall profitability and impact on the environment; we refer readers to subsequent sections for these discussions.

What then, do WICST's data suggest about yields in systems with varying degrees of crop diversity, pesticide inputs and sources of plant nutrients?

Grain Yields 1992-1999 (bu/a)

Arlington		**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**Avg**
CS1	Corn	144	124	178	143	131	129	196	170	152
CS2	Corn	150	130	190	168	140	158	213	163	164
	Soybeans	30	53	43	58	54	52	64	59	52
CS3	Corn	99	87	188	156	84	148	198	156	139
	Soybeans	38	53	44	63	60	49	52	31	49
	Wheat	45	29	61	68	45	54	58	57	52
	Wheat straw (ton/a)	0.34	1.44	1.44	1.22	1.55	0.97	0.58	0.63	1.02
CS4	Corn	NA*	165	197	168	151	159	227	190	179
CS5	Corn	112	119	199	157	154	155	205	182	167

Lakeland		**1992**	**1993**	**1994**	**1995**	**1996****	**1997**	**1998**	**1999**	**Avg**
CS1	Corn	119	100	177	151	42	113	165	72	117
CS2	Corn	126	101	184	150	40	154	172	106	129
	Soybeans	47	49	63	55	40	58	68	51	55
CS3	Corn	73	78	187	131	45	134	129	90	108
	Soybeans	52	32	47	59	27	49	45	51	45
	Wheat	26	22	51	70	***	57	47	50	46
	Wheat straw (ton/a)	0.00	2.20	1.87	1.23	0.70	1.10	0.91	1.17	1.31
CS4	Corn	NA*	113	211	154	64	160	172	133	144
CS5	Corn	102	81	198	144	57	151	93	128	122

* All phases of the 4-year rotation were not planted until 1993 due to the staggered start, i.e., one more plot is brought into the rotation each year until every phase of the rotation is present every year.
**Heavy spring rains and poorly drained soils prevented corn planting until July 1 on all systems.
***Wheat did not survive the winter, so oats were planted in the spring, yielding 76.9 bu.
****1 bu corn=56 lbs.; 1 bu soybeans=60 lbs.; 1 bu wheat=60 lbs.; 1 bu oats=32 lbs.

Forage Yields 1993-1999 (ton dry matter/a)

Arlington		1993	1994	1995	1996	1997	1998	1999	Avg 93-99 ton/a	RFV*
CS4	Alfalfa seeding	3.27	3.21	3.19	1.57	3.56	2.63	2.27	**2.81**	**143**
	Alfalfa haylage I	3.93	4.56	4.02	4.16	5.08	4.30	4.49	**4.36**	**143**
	Alfalfa haylage II	3.25	3.68	2.24	3.78	4.50	4.13	4.06	**3.66**	**148**
CS5	Seeding, 1st cut	**	1.84	1.91	1.61	2.43	4.29	2.60	**2.45**	**105**
	Seeding, 2nd cut	**	1.53	1.30	1.07	2.24	1.38	2.09	**1.60**	**121**
	Alfalfa haylage I	4.65	5.30	4.89	4.42	4.99	4.45	5.49	**4.88**	**142**
CS6	Pasture ***	2.18	3.86	2.17	1.67	1.84	2.94	2.21	**2.41**	**128**

Lakeland		1993	1994	1995	1996	1997	1998	1999	Avg 93-99 ton/a	RFV*
CS4	Alfalfa seeding	-	2.37	1.24	0.15	1.45	3.12	****	**1.67**	**157**
	Alfalfa haylage I	2.88	4.12	4.47	4.26	1.33	4.53	3.23	**3.55**	**145**
	Alfalfa haylage II	2.61	4.05	3.34	3.74	3.38	4.32	3.31	**3.54**	**148**
CS5	Seeding, 1st cut	0.68	2.96	1.51	**	0.97	1.08	****	**1.40**	**110**
	Seeding, 2nd cut	0.75	0.53	0.00	0.63	1.35	1.90	****	**0.86**	**122**
	Alfalfa haylage I	3.38	3.82	4.62	4.35	3.00	4.86	****	**4.03**	**140**
CS6	Pasture***	2.54	4.08	3.58	*****	*****	1.36	1.63	**2.64**	**118***

*Relative feed value (RFV) is a measure of hay quality. High producing cows need hay with an RFV of 140, while heifers and dry cows can use hay with a RFV between 115 and 125.The RFV has been weighted on yield across the season. RFV is reported on a weighted basis and is determined by yield and quality of each cut.
**The oats were harvested as grain, yielding 62 bu/a at Arlington in 1993, and 54.3 bu/a at Lakeland in 1996.
*** Dry matter production in CS6 was estimated by animal weight gain (an indirect measure) and hay production when we hayed a paddock.The RFV was calculated once a week for the actual forage the animals were consuming.The lower RFV on CS6 is due to high grass composition of the sward; reed canarygrass is the primary grass at LAC since the 1997 reseeding. Also, CS6's RFV is a seasonal average which includes a period of low forage quality when grasses are heading out (mid- June).
****Several changes were made in the plots at Lakeland in 1999 so that the yields for CS4 and CS5 are not comparable with those of previous years.
*****The pasture plots were not grazed, due to flood conditions which ruined the sward, and an unsuccessful initial attempt at reseeding in 1996 and 1997.

Rotating crops can improve yields while enabling a reduction in inputs. Simply rotating corn produced a 9 bu/a yield advantage over continuous corn[11]. Furthermore, our longest cash grain rotation (CS3) used very few purchased chemical inputs, and after the first two years generally achieved yields comparable to continuous corn.

Corn grown in forage rotations yields more than corn in cash grain rotations. Growing corn following leguminous forages resulted in a 18 bu/a advantage over growing it in a cash grain rotation (comparing average yields of CS1-3 versus CS4-5). We suspect that this is a result of the soil conditioning effects of the alfalfa and manure and its role in interrupting the lifecycles of corn pathogens and pests.

Very-low-purchased-input systems will, in our experience, result in somewhat lower average yields than moderate-purchased-input systems. Average corn yields in CS3 were 84% of CS2 corn yields from 1992-1999 across both sites. This is an important reduction, but it is not the dramatic loss that some observers have feared. Soybean yields in CS3 were 89% of those in CS2. Our CS3 wheat yields were 98% of the Walworth and Columbia county average (we presume that the county average reflects yields obtained in higher input systems). Among the forage systems, corn yields in the low-purchased-input (CS5) system were 89% of corn yields in the higher-purchased-input CS4. Most often, weeds were the cause of low yields in the lowest input systems. Rainy weather which prevented timely cultivation and rotary hoeing was most often the cause of the weed problems.

To find out how the lowest input cash grain system (CS3) would perform with slightly higher levels of inputs (starter fertilizer and some herbicides) we ran superimposed trials to test these effects. *(See the next section for further discussion.)*

The low input forage system (CS5) produced 78% of the dry matter ofthe high-purchased-input system (CS4) , and had a lower relative feed value. However, the average economic return of both systems was very similar (see Economic section on page 16 for further details). Overall, forage from CS4 had an average RFV of 147 (143-157) which makes excellent feed for high producing cows. In CS5 the average value was lower (123) and the range greater (105-142). Much of this feed would have been used for mid- to late lactating cows and growing heifers. Offtake from the grazed paddocks was lower than in the mechanically harvested systems and average feed quality was also lower (RFV of 122).

Harvesting forage onWICST plots.

The systems were not substantially different in terms of yield variability. This was an unexpected finding. We predicted that yield variability would be greater in the lower input systems. In fact, however, there was no statistical difference in the yield variability among corn, soybean or alfalfa phases, in spite of the fact that each system relied on very different input levels.

The benefits of redesigning a monocrop system are greater than the benefits of trying to fine-tune it. We used Best Management Practices for continuous corn — which represents an improvement over the way it is often produced. Input levels were high for comparatively unimpressive yields. Under Freedom to Farm there is a reduced but still significant number of farmers who try to grow continuous corn on their best land, in the belief that this will bring them the highest returns. If we can draw one unambiguous conclusion from the WICST project, it is that there is little yield (or, as we will discuss later, economic) justification for fine-tuning continuous corn. We can do better, and we should.

Modifications to the Low-purchased-input Cash Grain System (CS3)

We initially envisioned CS3 as a low-input system, relying on no synthetic fertilizers, but using post-emergence herbicides to prevent major crop losses when cultural and mechanical weed control failed. As we gained experience with this system, we decided to try several modifications on satellite plots.

The "chem-lite" option: In this system, we lowered the barrier to herbicide use, using a post-emergence herbicide as soon as it appeared that it would be profitable to so. We also applied sidedress nitrogen if a soil test indicated it would increase economic returns. For example, if cover crops performed poorly the year before, or if the early growing season conditions were slowing nitrogen release from the cover crops, we applied sidedress nitrogen based on results from the pre-sidedress test. We ran the comparison between CS3 and the chem-lite modification from 1995 to 1999 at Arlington.

Comparison of crop yields, bu/a, 1995-1999*

	chem-lite	Low Input (CS3)	Prob>F**
Corn	163	144	1%
Soybeans	56.2	52.3	10%
Wheat	57.0	55.7	NS

*two replicates

**this figure indicates the probability that the difference in yields was due to chance.

Corn yields averaged 19 bu/a higher in the chem-lite system (1% significance), soybean yields were four bushels better (10% significance) and wheat yields were similar. In the case of both corn and soybeans, yield variability was reduced due to the addition of modest levels of inputs. In the case of the cool spring of 1996, nitrogen additions to the chem-lite corn resulted in far better yields than CS3 corn (150 vs. 74 bu/a), and due to abundant rain in the spring of 1999, post emergence herbicide in the chem-lite system resulted in better soybean yields than we were able to achieve with mechanical weed control (50 vs. 32 bu/a).

The organic option: We note that organic premiums for some crops can make the agronomic risks of organic production more tolerable today than they were in 1989. Starting in 1999 we decided to run CS3 as a completely organic system[ii]; we will report results in a future publication.

Weeds, Weed Seeds, and Weed Management

Most farmers and researchers have long believed that letting a large weed seed bank build up in the soil will doom a field to heavy weed pressure — and alternatively, that controlling the buildup of weed seeds in the soil is a major part of prevention of weed problems. These related beliefs have probably prevented some producers from experimenting with lower-purchased-input production systems.

WICST has intensively studied weed seed and weed populations in the six cropping systems[12], and has determined that the relationship between weed seedbanks and weed pressure is not as simple as many believe. We have also experimented with various weed control techniques, comparing various ways of rotary hoeing and the value of post-emergence herbicides in CS3. Here are our major conclusions.

Weed seed numbers in the soil are only weakly correlated with subsequent weed pressure. Plots with outstanding (and non-chemical) weed control have occurred in soils with heavy weed seed banks and plots with heavy weed seed banks have seen seed numbers fall over time even with no herbicide use. Our three cash grain systems have very different levels of weed seeds in the soil, but weed control in soybeans in both CS2 and CS3 is usually good to excellent. The lowest input system (CS3) does often have more weed pressure in the corn than the higher input systems do, and corn yields have sometimes been reduced as a result.

There are many factors affecting the relationship between the number of seeds in

[ii] *Our system will not be certifiable, since our plot layout does not permit sufficiently wide buffer zones. However, we will follow organic practices in every other way, and calculate gross margins using organic prices.*

the soil and eventual weed pressure in a field.


Cultivation of soybeans on CS3.

- **The cropping system we choose**: A system like continuous corn must rely on fairly aggressive weed control measures, including herbicides, cultivation and tillage. In a more diversified system, one or more of the crops planted may compete well with weeds or effectively interrupt the buildup of some weed species. It is important that the crops be of different growing patterns, offering a change of environment for the weeds, for this to work well. We note that a forage phase works particularly well to reduce weed pressure. Mechanical weed control in the corn years of our forage systems is as effective as chemical weed control in our cash grain systems.
- **The way the crops are managed**: We plant wide-row soybeans in our lowest input cash grain system so that we can cultivate them. We also delay planting of corn and soybeans to permit better pre-plant mechanical weed control. In our no-till corn-soybean system this is not an option, so we plant narrow row soybeans to better compete with the weeds.
- **The producer's expertise with mechanical weed control**: Our ability to rotary hoe and row cultivate improved markedly over time.
- **The weather**: This is the big factor we can't control. Our most variable weed control occurs in our lowest input cash grain system. We have had years of outstanding weed control, and years when weed pressure definitely affected yields because early summer rains interfered with the mechanical weeding operations.

Weed seedbank evolution across six cropping systems, 1990-1998

	Weed seeds per square foot		
Cropping system	**1990-92**	**1993-95**	**1996-98**
CS1	205	277	355
CS2	244	401	370
CS3	467	935	728
CS4	294	281	254
CS5	508	436	254
CS6	468	272	350

With a good crop rotation and aggressive mechanical weed control (generally 2 rotary hoeings and 2 cultivations) producers could avoid using herbicides a majority of the time.

However, there are some years when cultural and mechanical weed control cannot prevent significant weed problems. In these cases, use of post-emergence herbicides can offer a reliable weed control back-up plan that reduces the risks of low-input production. In order to measure the economic costs of exclusive reliance on mechanical weed control, we superimposed post-emergence spraying on subplots within CS3 corn and soybeans for four years at both locations. In four of the 16 crop situations, returns to post-emergence herbicide was high (>$35/a), in four

Rotary hoeing advice (see Appendix 4 for further details on rotary hoeing):

Increase planting rates by at least 10% if you plan to control weeds mechanically with a rotary hoe and cultivation. Timing is crucial—rotary hoeing 5 to 10 days after planting is optimal. A second pass may be needed a week later, when above ground corn height is 0.5 to 1 inch. **Drive accurately.** If wet weather prevents the first hoeing, a double pass at the optimum time for a second hoeing works well. The two passes should be in opposite directions.

Greenhouse experiment of weed seedlings from soil of WICST plots.

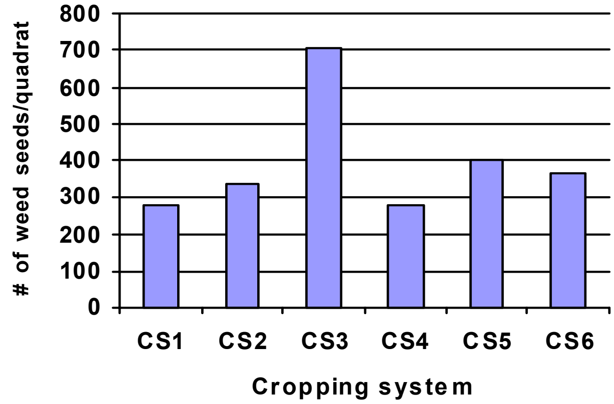
situations returns were modest (>$5/a but < $35/a) and in half of the cases, returns were low (<$5/a) or negative. The higher prices for organic crops can however offset yield losses due to weeds. Over the past few years certified organic premiums have been $5-10/bu for soybeans, $1-1.50/bu for corn, as well as for wheat.

The number of weed seeds per quadrant after the corn phase (except in CS6), 1990-98. See Appendix 4: Management Tips for Low-Purchased-Input Production on page 32 for our research and recommendations on rotary hoeing.

Nutrient Balances and Soil Test Levels

WICST has monitored the status of available potassium and phosphorus under the various cropping system since the start of the Trial. Because leaching and other losses are generally minimal with these two nutrients, changes in soil test levels should be directly related to inputs (fertilizer and manure) and output (crop removal).

The number of weed seeds per quadrat after the corn phase (except in CS 6), 1990-98.



The average initial soil test phosphorus (STP) and soil test potassium (STK) levels at the start of the trial were very high at both WICST sites (see table on next page). Generally speaking it is considered that there is no response to fertilizer if STP is above 30 ppm and STK above 140 ppm for these rotations on the medium textured soils of southern Wisconsin. As a result, except for the advantages of starter fertilizer placement next to the seed in cool soils on the high input systems, no fertilizer was added during the first years of the trial. As mentioned earlier, manure additions on the forage systems (CS4 and CS5) were based on the estimate that at current stocking rates, dairy herds produced an average of 10 ton of manure per tillable acre. As can be seen, STP and STK in almost all the treatments had dropped by the fall of 1999 but remained excessively high for soil phosphorus and was approaching "high" levels for potassium after a full after nine seasons of intensive cropping. The major exceptions were CS4 and CS5 at Lakeland where forage yields were modest and the drier pack-manure used on the plots were higher in total phosphorus and potassium per ton than at Arlington. The grazing plots at Lakeland also saw an actual increase in STP and STK since they were heavily manured in 1996 prior to reseeding the paddocks.

Fall soil sampling on WICST plots.

Soil test P and K over course of WICST trial at both sites.

Lakeland Soil Test Phosphorus

	1989	1994	1999	Avg. Annual Budget[1]
	ppm			lbs. P/a/yr.
CS1	66	95	49	-8
CS2	59	68	41	-10
CS3	64	50	34	-12
CS4	76	54	69	29
CS5	53	65	65	25
CS6	63	46	61	-

Lakeland Soil Test Potassium

	1989	1994	1999	Avg. Annual Budget[1]
	ppm			lbs. K/a/yr.
CS1	196	219	147	-5
CS2	178	183	135	-25
CS3	195	153	124	-35
CS4	148	158	158	70
CS5	163	137	147	52
CS6	181	132	205	-

Arlington Soil Test Phosphorus

	1989	1994	1999	Avg. Annual Budget[1]
	ppm			lbs. P/a/yr.
CS1	105	91	80	-1
CS2	98	79	69	-17
CS3	105	63	55	-17
CS4	115	82	80	3
CS5	110	83	72	-1
CS6	114	84	68	-

Arlington Soil Test Potassium

	1989	1994	1999	Avg. Annual Budget[1]
	ppm			lbs. K/a/yr.
CS1	257	228	217	-14
CS2	199	199	181	-42
CS3	236	165	149	-44
CS4	277	152	154	-87
CS5	250	163	125	-93
CS6	266	157	202	-

[1]Average annual difference between inputs and off-take.

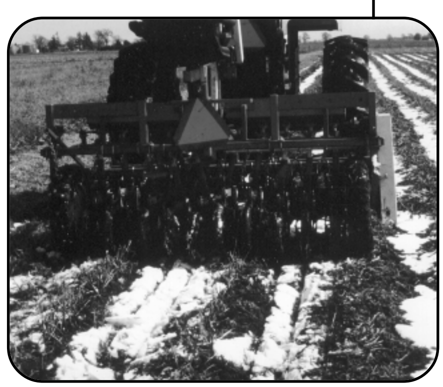
Cover Crops

Cover crops have been a major focus of WICST. They can play a key role in diversifying and reducing purchased inputs in many cropping systems that include a small grain (wheat, oats or barley) or canning crops (sweet corn, peas and beans). In addition to evaluating the agronomic and management aspects of numerous possible cover crops for the upper Midwest, the Trial has evaluated their value as a nitrogen source for corn. WICST has also conducted numerous on-farm and on-station trials of several cover crops[13], and in recent years has worked to fine-tune management and reduce risks associated with relying on cover crops for nitrogen.

The two most successful cover crops we studied were medium or common red clover and hairy vetch. By fall freeze both usually contained nearly 100 lbs. of N/a in the tops and roots. Other cover crops studied included sweet clover, oats, dormant and non-dormant alfalfa, berseem clover and annual medic.

Cover crops were sensitive to soil conditions. The cover crops we worked with were more successful on silt loams than sandy loams, and establishment was inconsistent on the more poorly drained Lakeland site.

Red clover worked best frost seeded into winter wheat in our CS3. Seed is broadcast onto frozen and cracked soil in mid-March after snow melt. Seedlings remain relatively small until wheat harvest, at which time they have full sunlight and three months to grow and fix atmospheric nitrogen. Total nitrogen accumulation typically exceeds 100 lbs./a by the end of the growing season. *(Companion seeding with oats has also been successful;* *see Outgrowths on page 25* *for further information on the Small Grains Initiative.)*



Frost seeding red clover into frozen ground on CS3.

"I like vetch for erosion control, nitrogen, and what it does for the soil… Economically, I'd say the vetch has paid for itself in all but one year, when it was real dry and we had a poor stand."
—**Norm Harris, producer and WICST collaborator**

Hairy vetch can be successfully planted after wheat harvest and produce appreciable biomass and nitrogen yields. On the two occasions (out of 18 site-years of the trial) when the red clover failed to establish well, the vetch produced an average of 115 lbs./a of nitrogen, providing an excellent "back-up plan" that reduces one of the potential risks of relying on a companion-seeded cover crop for nitrogen. We note, however, that on droughty soils, late July plantings can be riskier than frost seeding. *(See Appendix 4 for further tips on cover crop management.)*

Cover crops can provide most or all of the nitrogen required by corn growth. Trials to determine whether supplemental nitrogen was worthwhile found that additional nitrogen (either starter or sidedressed) produced a significant yield increase only about one-fourth of the time. The exceptions always occurred during years with cool springs, when there is a slow release of legume nitrogen. We recommend that producers perform the pre-sidedress nitrate test if the cover crop growth was modest or the spring particularly cool, and use sidedress nitrogen accordingly. (When justified, sidedress nitrogen was more economic than starter in our trials.)

Legume nitrogen is made available to corn in a timely fashion. Except in particularly cool springs, legume nitrogen release is generally well timed to correspond with nitrogen uptake in corn.

Cover crops provide substantial erosion control benefits. Cover crops generally provided 80-100% soil coverage minimizing the erosive impact of fall rain within a month of planting.

Cover crops can be managed economically. When the cost of purchased nitrogen is low, the value of the nitrogen alone does not usually justify the cost of a legume. However, other benefits (e.g. reduced herbicide use, improved yield of other crops, reduced risk of nitrate leaching, improved soil texture, diminshed erosion potential and reduced fossil fuel use) make cover crops more attractive *(see Economics-Modified Systems on for further discussion of the economics of cover crops)*. As energy prices increase, cover crops become increasingly more attractive.

Jim Stute demonstrates the vigor of various cover crops at Lakeland, 1993.

Total biomass and N in foliage and roots in late fall at Arlington and Lakeland, 1991-1999.

Arlington

Year	Legume	Lbs. DM/a	Total lbs. N/a
1991	Red clover	4456	128
1992	Red clover	3918	110
1993	Red clover	4125	119
1994	Hairy vetch	4459	146
1995	Red clover	3407	100
1996	Red clover	5049	147
1997	Hairy vetch	2110	84
1998	Red clover	4458	109
1999	Red clover	7607*	265
Mean		4399	134

Lakeland

Year	Legume	Lbs. DM/a	Total lbs. N/a
1991	Red clover	1585	45
1992	Red clover	6300	161
1993	Red clover	3911	123
1994	Red clover	2422	67
1995	Red clover	3585	97
1996	Red clover	2359	67
1997	Not available	-	-
1998	Not available	-	-
1999	Red clover	7005	161
Mean		3881	103

*Moist late summer conditions and a delayed killing frost resulted in abundant cover crop growth.

Economic Analysis

For our economic analysis we scaled up from acre plots to an appropriately sized whole farm. This involved setting prices and defining farm size, machinery set, and other assumptions appropriate for each system.

The chart below shows the gross margins of CS1-5 for 1992-1999, separated by location. The gross margin analysis removes fixed costs from consideration—which may vary greatly from operation to operation. The gross margin represents the dollars available to cover overhead costs (capital, land, labor and management). We estimate that a cash grain farmer would need approximately $200 to cover these costs. Anything above that amount would be considered the farmer's return to investment (profit).

Gross Margins ($/a)[1,2 3]

ARS	1992	1993	1994	1995	1996	1997	1998	1999	Avg
CS1	115	102	193	266	179	139	210	117	165
CS2	116	179	147	313	219	227	244	161	201
CS3	98	160	211	304	228	205	187	107	188
CS4	na[4]	170	263	212	205	254	255	186	221
CS5	na[4]	222	261	230	230	246	260	178	232

LAC	1992	1993	1994	1995	1996	1997	1998	1999	Avg
CS1	81	-13	150	280	-55	127	158	-25	88
CS2	131	151	224	272	68	248	207	76	172
CS3	88	127	208	308	70	240	49	117	151
CS4	na[4]	66	261	211	87	127	228	na[5]	163
CS5	na[4]	78	218	194	123	164	139	na[5]	153

[1] Gross margins are calculated by taking the gross revenue per acre (yield times price at harvest) minus variable costs of production (seed, fertilizer, pesticides, drying costs, fuel, and repairs).

[2] We did not include any on-farm storage of grains, and simply used the average prices for southeast Wisconsin during the month of harvest. Hay prices were based on the average relative feed value (RFV) for CS4-5 for 1993-96, which was 144. This RFV was assigned a price of $80/ton DM. Any actual deviations in RFV from 144 were used to adjust the forage price by adding or subtracting $1 per ton per RFV point. Farm size was fixed at 1200 acres for the cash grain systems and 150 acres for the forage based systems. Labor prices rose steadily from $6.01 to $7.35/hr (1993-1999) and were based on Agricultural Statistics Service data.

[3] These tables exclude CS6, rotational grazing. The combination of small plots and the complexity of managing the animal-forage interaction made it difficult to conduct a meaningful gross margins analysis on this system.

[4] na=not available: All phases of the 4-year rotation were not planted until 1993 due to the staggered start.

[5] na=not available: Changes in the cropping systems at Lakeland in 1999 make comparison with previous years inappropriate.

Continuous corn was the least profitable system studied. Modest corn yields and very high costs resulted in continuous corn being the least profitable cropping system studied.

There was a modest difference ($17/a) between the gross margins of the standard no-till corn and soybean system (CS2) and the low-external-input corn-soybean-wheat system (CS3). Although CS2 was more productive, its higher costs resulted in the two systems having only modestly different gross margins.

There was no difference in profitability between the "green gold" intensive alfalfa production system (CS4) and the low input, rapid-turn around dairy rotation (CS5).

Systems based on forage rotations (CS4 and CS5) were more profitable than systems based on cash grain rotations (CS2 and CS3) at Arlington but were equal at Lakeland.

Gross margins Summary Stats

Site-averages ($/a):

	ARS	LAC
CS1	165	88
CS2	201	172
CS3	188	151
CS4	221	163
CS5	232	153

Variability associated with the gross margins was highest in continuous corn, lowest in the forage systems, and intermediate in the corn-soybean and corn-soybean-wheat systems.

During the 1990s, prices for corn, soybeans and wheat generally varied together, so that diversification had only a modest buffering effect on farm income. While many believe that diversifying production will protect producers against price variability, we found that the prices of corn, soybeans and wheat were in fact highly correlated (Pearson correlation 0.88-0.93).

Labor Analysis

Financial analysis only addresses part of the economic reality facing farmers. Labor is a production input that is unlike others because it is more frequently subject to shortages. Consistent labor shortages can usually be alleviated by hiring full-time help, decreasing acreage, increasing machinery size or hiring custom operators.

The labor analysis for the cash grain systems was performed assuming a 1,200 acre operation, a specific equipment set for each cropping system, and a maximum period during which certain field operations could be performed with acceptable agronomic outcomes. Major conclusions are as follows.

The no-till corn and soybean system (CS2) used the least amount of labor (564 hr/1200 a). This system resulted in a savings of nearly 20% compared to continuous corn (701 hr/1200 a).

When weed control of the low-input corn-soybean-wheat system (CS3) consisted of approximately 2 rotary hoeings and 2 cultivations, it required 925 hr/1200 a, or 64% more labor than the no-till corn-soybean system. In addition, two bottlenecks occur in CS3: one in early summer while rotary hoeing and cultivating, the second in the fall when harvesting soybeans and planting wheat.

Measuring red clover height to determine nitrogen credit at plowdown.

Economics of Cover Crops

Farmer collaborators with the WICST project initially cited cost as their number one concern about using cover crops to replace synthetic nitrogen. WICST has studied several systems to determine whether cover crops can be an economically competitive source of nitrogen. Major findings are as follows:

If the sole benefit of the cover crop were nitrogen, purchased synthetic nitrogen would be more economical when energy prices are low. The legume nitrogen plus the "rotation effect" generally makes the cover crop systems comparable to or only slightly less profitable than the systems relying on synthetic nitrogen. However, when the price of N fertilizer is high, cover cropping becomes more attractive. In addition to comparing CS2 and CS3, we compared a corn-oat-corn rotation with a corn-oat/red clover-corn rotation and a corn-oat/hairy vetch-corn rotation. We found that the gross margins of the cover crop systems were comparable to the corn-oat system that relied on synthetic nitrogen. Companion seeded red clover was generally more economical than vetch, due primarily to lower seed and establishment costs.

Measuring canopy height of hairy vetch in fall.

There are excellent agronomic and economic reasons for farmers to experiment with cover crops. Our research suggests that cover crops are more economical than many farmers realize, and they offer clear benefits for soil quality, reduced nitrate leaching, and a way to expand corn-soybean rotations for pest and disease control.

Economics of Modified Systems (chem-lite)

The chem-lite system produced sufficiently more grain than CS3 to pay for the additional inputs. In fact, the net return to labor, management, and capital for a 1000 acre chem-lite Farm was $14,000 more than for the same size CS3 Farm ($34,092/yr. versus $20,043/yr.). Sensitivity analyses showed that fertilizer N prices would have to increase nearly 6-fold to reduce the chem-lite return to the level of the CS3 Farm. For an organic system to match the net returns of the chem-lite system would require price increases of 6% across the board. Actual certified organic premiums in SE Wisconsin have been much higher and range from 25 to 50% for corn and wheat to 200% for soybeans.

Water Quality

Ground and surface water pollution from agriculture has farmers, researchers, and policy makers concerned. Upper Midwest farmers are increasingly being told they are at least partly responsible for hypoxia in the Gulf of Mexico[14], eutrophication of lakes, contaminated wells, and the increasing cost of treating municipal water supplies to make them fit to drink. While there are numerous potential pollutants originating from agricultural fields, nitrates and atrazine in well water and phosphorus in runoff are the most common problems in Wisconsin[15].

Nitrates

Since 1990 WICST has measured nitrate-N concentrations in the perched water table[iii] at Lakeland through a set of 18 shallow (12 feet) tube wells established under the plots. There were also two check well under adjoining grassy areas. Samples have been taken from each of the wells 7 times from 1992-1998[16]. As a second measure, the team also sampled fall nitrates under the plots at both sites to 2 feet in depth between 1990 through 1999. From late fall until early summer, the hydrologic balance is downward, recharging the groundwater. Therefore, soluble nitrates in the soil profile tend to move toward the water table during this period. Major conclusions follow:

The average concentrations of nitrate and nitrite-N in the groundwater under the cash grain systems mirrored the levels of purchased inputs used in the systems. Continuous corn, with its relatively heavy applications of inorganic nitrogen, leached the most nitrate on average, and led to well water nitrate concentrations nearly 2 times the safe level for drinking water (safe level set at 10 parts per million, or 45 ppm NO_3[17]). The no-till corn-soybean rotation leached less, hovering around the enforcement standard, and the low-purchased-input corn-soybean-wheat/red clover system leached slightly less than that. It appears that even best management practices can result in significant nitrate leaching.

All of the systems leach a significant amount of nitrate if shallow wells were to be used for drinking water. Rotational grazing was best, averaging 8.2 ppm nitrate-N in the well water between 1996 and 1998. However, all the systems are close to producing nitrate contamination that exceeds drinking water standards. Presumably, some of this nitrate ends up where it is not wanted.

Nutrient budgeting is necessary whatever the source of nitrogen. Although the corn phase in CS4 and CS5 received little to no synthetic Nitrogen, soil nitrate levels were the highest (134 and 117 lb NO_3-N /a to 2 ft depth) of any of the other phases in the trials. (As a point of reference, soil samples from grass buffer strips between the plots contained about 70 lb of NO_3-N/a to 2 foot depth.) Apparently, the combination of legume nitrogen and manure resulted in this being a "nitrogen-rich" phase. Although following alfalfa and before planting corn is a common window of opportunity in the dairy rotation to apply raw manure, more nitrogen mineralizes than can be used by the corn crop which consequently can be leached to groundwater.

Researcher Janet Hedtcke samples water from monitoring wells on WICST plots.

[iii] *A perched water table rests on top of an impervious layer; at Lakeland the impervious layer is 1.5-2 meters below the surface. The water table that would be used for drinking water is deeper than this.*

Nitrate and Nitrite-N Concentrations in Groundwater at the Lakeland Agricultural Complex, parts per million (ppm), 1996-1998.[1]

	04/23/96	04/09/97	11/13/97	11/16/98	Avg.
CS1	28	24	20	19	23
CS2	14	10	11	8	11
CS3	11	11	8	9	10
CS4	9	12	16	13	13
CS5	9	9	11	6	9
CS6	9	7	7	10	8
check	3.9	empty	0.1	-	2.0

[1] We collected data starting in 1991, but the values did not appear to be stabilized until 1996. In all systems except CS4 there was a dramatic decline in leached nitrates between 1991-1996; we suspect the high starting levels reflected prior management of the site, and that the more stable rates of 1996-1998 more closely reflect the true nitrate leaching potential of each of the systems. Figures are the mean of three samples taken from the same phase of each cropping system and mean value of the two check wells.

Fall Soil Nitrates, NO_3-N lb/acre in 0-2 ft, 1996-1999.

Arlington Agricultural Research Station[1]

	1996	1997	1998	1999	Avg.
CS1	74	89	119	67	87
CS2	110	105	75	67	89
CS3	46	89	73	53	65
CS4	62	118	83	71	83
CS5	61	103	79	78	80
CS6	83	76	73	48	70

We started collecting data in 1993, but report only the years since 1996 for comparison with the well water data.

Lakeland Agricultural Complex

	1996	1997	1998	1999	Avg.
CS1	143[1]	115	61	63	96
CS2	64	103	64	51	70
CS3	54	94	62	50	65
CS4	92	126	79	57	89
CS5	70	120	72	70	82
CS6	94	175[2]	74	53	99

[1] Heavy flooding delayed corn planting until early July, reducing yields and hence increasing fall soil nitrates. Excluding this year gives average soil nitrates for this system of 79.8.
[2] In 1997 the pasture plots were heavily manured but not grazed due to weather and sward conditions, leading to very high soil nitrate levels. Excluding this year gives average soil nitrates of 73.5.

Mechanisms of Leaching

Recent research on the WICST plots[18] focuses on how chemicals leach through soils. The major findings are as follows:

Soil Organic Matter by Cropping System Averaged over Both Sites, 1998

System	% Organic matter
CS1	4.75
CS2	4.83
CS3	4.75
CS4	5.11
CS5	5.25
CS6	5.69

See the following section for a further discussion of soil biodiversity under the six cropping systems

Under normal conditions, chemicals can move from the surface to the groundwater in one growing season. In a separate study, a bromide tracer was applied to the Lakeland WICST plots in 1991, and was found in the water table (approximately 3 feet depth) within one season under all cropping systems[19].

Under certain conditions, soils can develop flow-paths that permit rapid leaching of soluble chemicals into tile drains. When soils are relatively dry, water-borne chemicals are transported through small, crooked paths ("pores") slowly, and may be either degraded or taken up by plants before they leach out of the root zone. However, when the soils become more saturated, other, faster flow paths become hydraulically active. The water bypasses the smaller crooked pathways in favor of larger, straighter and more continuous channels which develop. These flow paths permit very rapid leaching of soluble chemicals into tile drains. For example, our research shows that surface applied nitrate could reach tile drains buried at 1 m within as little as 16 minutes. Once these flow paths are established, even a very gentle rainfall (1/8 inch/hour for 10 hours) can cause around 5% of newly applied nitrate to leach out from the root zone.

Soil Quality

Soil Health

The WICST team developed a "*Soil Health Scorecard*" based on structured interviews with 28 Wisconsin farmers in Walworth and Columbia Counties[20] and conducted a number of chemical, physical and biological tests on the soils in the cropping systems trial. The goal was to evaluate the changes in soil characteristics under the different systems between 1990 and 1997.

The major differences that emerged are as follows:

- **Soil test levels of phosphorus and potassium have been dropping** in the low input CS3 system compared to the high input CS1 system. However, after 10 years soil test levels are still in the normal to very high range.
- **Soil pH** was slightly lower — soil was more acidic — under continuous corn than the other systems. Dropping pH may result in irreversible changes in the nutrient holding capacity (cation exchange capacity) of the soil.
- The pasture showed better **soil aggregation** than the other systems.
- **Earthworm** numbers and types of earthworms present in the soil varied by system. *(See page 22 for further discussion.)*
- The most biologically complex cropping systems (CS3 and CS6) showed an increase in **microbial biomass** over time, while the least diverse system (CS1) showed a reduction.

Abundant earthworm levels indicate healthy soil. Earthworm populations were compared across the 6 cropping systems of WICST.

- Total soil **organic matter** increased in the pasture plots (CS6) at both sites over the course of the study, so that it was significantly higher than in the other systems by 1997.
- The mean soil **organic matter** in the forage systems was 12% higher than the mean for the cash crop systems by 1998.
- The areas of highest surface **compaction** occurred in CS3 due to intensive mechanical weed control.

Overall Conclusion: Few significant differences in soil quality/health emerged under the different cropping systems during these first years of the Trial. It must be pointed out that the time frame of the study is very short compared to the 150-year agricultural history of these soils. Furthermore, the soils on which the WICST trial is conducted are among the finest in the world, buffering changes in management and supporting a wide range of cropping systems.

Soil Biodiversity

Extensive research has been conducted on the WICST plots to characterize the communities of soil-dwelling organisms under the different cropping systems. Because little similar work has been done elsewhere, efforts have focused on how to characterize the abundance, diversity and overall "community profile" of soil organisms, including microbes, nematodes, arthropods (insects and spiders) and earthworms.

Our research shows that after 6-8 years in the different cropping systems, the communities of soil organisms do diverge from each other, although the implications of this for the health and long-term productivity of the systems are not necessarily clear. In every group of organisms examined the cropping systems differed from each other over time, sometimes in terms of abundance, sometimes in terms of diversity, and sometimes in terms of the specific species present. (Note that we used molecular techniques so that unculturable microorganisms could be included in our sampling.) To date, the project has identified 20 species of springtails (Collembolas) new to Wisconsin (bringing the total to 52 for the state), and one species "new to science," underscoring how much remains to be discovered in groups which are even less visible. This research is reported at greater length elsewhere (see list of publications at the end of this report)[21].

List of soil chemical, physical, and biological analyses conducted

Nitrate and ammonium nitrogen, pH, extractable phosphorus, exchangeable calcium, magnesium, potassium, cation exchange capacity, particle size distribution, bulk density, total porosity, soil aggregate stability, compaction, percent organic matter, labile carbon, various enzymes, microbial biomass, litter disappearance, corn root growth, studies and earthworm populations, and soil microorganism biodiversity.

Earthworms: The four species of earthworms found on the WICST plots can be broadly classified into two different groups based on where they live in the soil. Three species are topsoil-dwelling earthworms (technically called endogeics) that create horizontal burrows in the top 25 cm of the soil, and one species is a subsoil-dwelling earthworm (the nightcrawler or anecic) that creates one or two burrows that can extend 3 meters into the soil profile. The primary factors affecting earthworm populations appear to be tillage and manure application but the two groups respond differently.

Topsoil-dwelling earthworms: These earthworms did not appear to be directly affected by tillage intensity because their abundance did not fluctuate during the different phases of the same rotation regardless of the amount of tillage. However, the use of manure did result in more topsoil-dwellers. The manure-receiving, forage-based systems had twice the number as the cash-grain systems. Abundance ranged from 31 to 460 earthworms/m^2.

Subsoil-dwelling earthworms: Populations of these earthworms correspond directly to the amount of tillage in the system. Of the six systems, the no-till corn-soybean system had the highest number and continuous corn the lowest. Abundance ranged from 0 to 43 earthworms/m^2.

Soil Erosion

The WICST project has not directly measured soil erosion on plots, largely because our plots are located on land with little erosion potential. However, we note that our work with cover crops, detailed on pages 13-15, is of significant interest to those concerned about erosion that might occur after the harvest of small grains and short season crops. The recently Revised Universal Soil Loss Equation reflects the benefits of cover crops. This has offered producers a new incentive to consider systems that include a small grain and cover crop (like CS3), and has given us renewed motivation to find ways to adapt cover crop use to a variety of commercial farm settings.

Expected soil loss from WICST systems (based on Universal Soil Loss Equation, 1990)

	ton/a							
Land slope	**Slight (2% w/ 200 ft run)**				**Moderate (8% w/ 400 ft run)**			
Conservation practice	**contouring**		**no contouring**		**contouring**		**no contouring**	
Soil erosivity	**low**	**high**	**low**	**high**	**low**	**high**	**low**	**high**
CS1	1	1	1	2	7	9	12	16
CS2	1	1	1	2	7	9	11	15
CS3	1	1	1	1	5	7	8	11
CS4	<1	1	1	1	3	4	5	7
CS5	<1	<1	1	1	3	4	5	6
CS6	<1	<1	<1	<1	2	2	2	2

Energy Inputs and Outputs

The consumption of non-renewable energy in agriculture is an issue that waxes and wanes in the public interest. When fuel prices are high, input prices go up and the agricultural community flirts with the idea of moving to lower input cropping systems. When thinking about energy use, one can imagine two performance criteria, the actual energy purchased into the system, as well as the ratio of output to input, or an efficiency ratio. As can be seen from the table, inputs are highest in the cash grain systems and within enterprise types, the more diverse systems require less purchased energy. Following in the same path, the ratio

Purchased inputs for CS1.

of output to input is highest in the forage based systems and the most efficient systems are the more diverse ones.

Energy Inputs and Outputs (Mcal/a) on WICST Plots, 1992-1999

	Arlington			Lakeland		
System	**Total input**	**Total output**	**Avg O/I ratio**	**Total input**	**Total output**	**Avg O/I ratio**
CS1	2316	17074	7.4	1913	13178	6.9
CS2	1463	13119	9.0	1303	11825	8.7
CS3	992	10937	11.0	753	9587	12.0
CS4	660	15382	23.3	636	12240	19.2
CS5	665	17276	26.0	640	12541	19.6
CS6	290	11571	40.0	304	12158	40.0

Outreach

Fundamental to the concept of WICST was that it would serve as an outdoor, living laboratory and backdrop or forum for a greater discussion about the future of Wisconsin agriculture. Today each site averages about 350 visitors a year as well as numerous field trips from nearby schools. In addition, WICST has contributed comments to the editorial pages of local newspapers and produced a newsletter. The focus on small grains led to a second specialized newsletter "Oatlink" that served to give producers latest production and marketing tips.

UW Extension's Lee Cunningham disseminates WICST information.

The WICST project has spawned several efforts focused on implementing or enlarging on insights gained from the Trial. These projects are described below.

Krusenbaum Farm Project:

Farmers and researchers tour the WICST plots at the annual Agronomy Field Day.

Recognizing the difficulty of representing a rotational grazing system on small experimental plots, WICST early on decided to study the system in greater depth at a nearby farm. Altfrid and Sue Krusenbaum started farming in 1990, and in that year members of the WICST project and others formed a team to study their operation. Between 1992 and 1995 the Krusenbaums experimented with (and eventually adopted on all their production acreage) management-intensive rotational grazing. They also decided to switch to a mostly seasonal milking operation, and outwintering of the cows to reduce the work load. In 1996 they built a New Zealand-style milking parlor. Between 1990 and 1997, they expanded their herd from 37 to 120 cows. Several times a year various researchers (in economics, dairy science, dairy forage, soils, agronomy, agro-ecology) meet with the farm family to discuss the progress of the farm, results of data analysis, and past and upcoming management decisions. The result is an in-depth portrait of a complex and evolving dairy enterprise[iv]. For further information contact Altfrid Krusenbaum at akrusenb@elknet.net or Josh Posner at the UW Department of Agronomy at jlposner@facstaff.wisc.edu

Small grains are an important addition to a cropping system to help break up disease and pest cycles common in the corn-soybean rotation.

Small Grains Initiative (SGI):

Based on our largely positive experience with CS3, the SGI promotes the inclusion of small grains and cover crops in corn-soy rotations. Working with about 40 producers in Wisconsin, Illinois, Iowa and Minnesota, the project offers technical assistance, a participant stipend for record keeping, site visits, newsletters, a producer manual, participant workshops, and some marketing assistance to growers who agree to plant a small grain and cover crop on at least 20 acres. Most producers plant either oats or wheat, and use either frost seeded or companion seeded red clover. Data is collected from each producer on agronomic, economic and environmental measures, and results are disseminated to participants and other interested parties. Initiated in 1997, the program is funded largely by North Central Sustainable Agriculture Research and Education (SARE) program and the federal Fund for Rural America (FRA). For further information contact John Hall at Michael Fields Agricultural Institute at jhall@mfai.org or Josh Posner at jlposner@facstaff.wisc.edu

The Crop Rotations Options Program:

This computer software grew out of our attempts to analyze systematically the effects of changing management practices on whole farm nutrient balances and profitability. The program allows users to consider how various scenarios (enlarging a dairy herd, replacing nitrogen fertilizer with leguminous cover crops, adding or subtracting a farm enterprise, etc.) will affect overall nutrient balances and the bottom line. A user manual and training workshop have been offered to Extension Agents, crop consultants and others interested in using the program with

[iv] *Posner, J.L., G.G. Frank, K.V. Nordlund, and R.T. Schuler. "Constant Goal, Changing Tactics: A Wisconsin Dairy Farm Start-Up." American Journal of Alternative Agriculture, 13 (2): 50-60, 1998.*

clients. For further information contact Jon Baldock at Agstat at agstat@aol.com or Josh Posner at jlposner@facstaff.wisc.edu

Soil Biodiversity Project:

Soil microorganisms such as nematodes seen here, play an important role in agro-ecology.

This project grew in part out of WICST's early findings in soil quality/ health. Funded by the United States Department of Agriculture National Research Initiative, a group of researchers at the University of Wisconsin-Madison and Michael Fields Agricultural Institute began to systematically count and classify soil organisms in the soil under the WICST plots. Large numbers of organisms (some of which have never been identified or named) and large fluctuations in the numbers and mixes of species present in the soil have presented significant analytical challenges. The group is focusing on developing and honing analytical techniques for measuring differences in soil biodiversity. For further information contact either Martha Rosemeyer at rosemeyem@evergreen.edu or jlposner@facstaff.wisc.edu

Organic Matter Budgeter Project:

This Michael Fields Agricultural Institute project aims to help farmers plan farming systems that maintain organic matter in soils while supplying sufficient nitrogen to crops. The budgeter uses both the CENTURY model for organic matter dynamics, and empirical data from WICST and several other sources to establish accurate coefficients for organic matter residue production and turnover. The budgeter is currently being field tested on a number of farms in Wisconsin and Illinois, including some using CS3 type rotations for participation in the Small Grains Initiative. The field tests will allow a comparison of the budgeter predictions to actual field-derived N budgets. Funding for this project has been obtained from the Sustainable Agriculture Research and Education (SARE) program and the Illinois Department of Agriculture. For further information contact Walter Goldstein at MFAI at wgoldstein@mfai.org

Oak Savanna Grazing Project:

Scottish Higland cattle are being studied as an option to restore degraded oak savanna.

Before the advent of modern agriculture, oak savanna was the predominant habitat in much of southern Wisconsin. It is now considered the most endangered habitat in North America. The oak savanna grazing project aims to achieve both environmental and production goals: restoring degraded oak savanna by grazing it with specially selected beef cattle. The rustic Scottish Highland cattle that are used in this project browse shrubs that have invaded most remaining oak savanna—brush that is rejected by other cattle breeds, and that otherwise requires intensive human effort to remove. The meat from these cows is currently being direct-marketed to consumers as organic, "sustainable," "low fat," or otherwise depending on other production practices and meat characteristics. For further information contact Martha Rosemeyer at rosemeym@evergreen.edu or Josh Posner at the UW-Madison Agronomy Department at jlposner@facstaff.wisc.edu

Policy Initiatives:

WICST has participated actively in national and regional policy development initiatives. At the federal level, WICST's experience in interdisciplinary, long-term, systems research was used to guide the development of a federal program to support such research: the Integrated Farming

Systems program. WICST also received one of the first grants made under this program, to continue the core Trial for several more years. Our experience with the Small Grains Initiative has also provided welcome input in numerous regional and national meetings addressing hypoxia in the Gulf, farm profitability, agricultural diversification, environmental aspects of agriculture, and federal farm policy. For further information contact John Hall at Michael Fields Agricultural Institute at jhall@mfai.org

New Directions in WICST:

Farming systems diversity, organic matter and nutrient management and marketing will remain the focus of the WICST program. We will continue to promote the use of the Crop Rotations Option Program (CROP) and Organic Matter Budgeter (OMBS) software to help producers and their advisors estimate the impact of alternative cropping systems on nutrient cycling, soil loss, profits, and organic matter build-up. The new USDA-IFAFS funded "Enhanced integrated nutrient management on dairy farms project," won in collaboration with the USDA Dairy Forage Research Center will allow the team to identify diverse cropping patterns, alternative feed rations and improved manure management systems that minimize nutrient build up. Also a new USDA-NRI funded "The effects of organic manure, grazing and biodynamic growth regulators on an alternative cropping system project," under the leadership of MFAI, will enable the team to continue its evaluation of alternative cropping and nutrient management systems on soil biota.

The production and marketing of small grains, promoting low-chemical and organic systems for specialty soybean and corn markets and research on grass fed dairy and beef herd will continue. Also, thanks to new funding from the Wisconsin Department of Natural Resources, (On-farm restoration of oak savannas using grazing with Highland cattle) the WICST team will be able to continue to expand its focus from crop land to oak savanna and tallgrass prairie restoration. New proposals are now being written to bring the field data collected by the team to the landscape level and with watershed modeling, estimate the impact of alternative farming systems on downstream nutrient loading. Our vision is that this work will assist policy makers in developing incentives to help Upper Midwest producers remain profitable, but reduce environmental impacts, such as nutrient outflow to the Mississippi River Basin causing hypoxia in the Gulf of Mexico.

Appendix 1
Detailed management protocols

CS1 Management protocol:
Philosophy: Low crop diversity, high use of inputs, conventional
Crop Rotation: corn
Variety selection: 105-day relative maturity varieties, upgraded approximately every two years
Tillage: chisel plowing, field cultivation. We aim for a April 25th planting date.
Nutrient management: Fertility is maintained with starter NPK and additional N. The annual N addition is calculated by subtracting pre-plant nitrate test levels from a reference of 160 lbs. N/a. Application rates have ranged from 70 to 160 lbs. N/a/yr., depending on the level of residual spring nitrates. At Arlington N has been added prior to planting as anhydrous ammonium (82-0-0) and at Lakeland, sidedressed as a 28% solution. Various starter fertilizer mixes have been used, applying about 6 lbs. N, 20 lbs. P_2O_5, and 20 lbs. K_2O/a/yr.
Weed and insect control: Weed control has been accomplished using cultivation and herbicides, with a shift towards post-emergence rather than pre-emergence herbicides in recent years. Rootworm insecticide has been applied each year and was effective in all seasons except 1996.

CS2 Management protocol:
Philosophy: Moderate input, somewhat diversified, no-till
Crop Rotation: 1 yr. corn, 1 yr. soybeans
Variety selection: Cultivars of soybean used ranged from mid-Group II (2.4 maturity rating) to late Group I (1.9 maturity rating). In 1998 and 1999 we used a Round-up Ready variety (Asgrow '2301'). We have used the same corn varieties as in CS1.
Tillage and seeding: We started out with no-till corn and conventional-till, drilled soybeans. In 1994 we shifted to using a no-till planter for the soybeans, making the whole system no-till. Our soybean seeding rate increased over time from 150,000 seeds/a initially to our current rate of 225,000 seeds/a.
Fertility: Fertility is maintained with starter NPK (typically 100-180 lbs./a/yr. of 6-24-24) and additional N in the corn as needed. Through 1997, nitrogen fertilizer was applied at the rate of about 120 lbs. N/a/yr. Improved nitrogen crediting rules, beginning in 1998, have resulted in lower N rates. Preplant residual nitrates and a 40 lbs./a soybean credit are subtracted from 160 lbs./a of basic N fertilizer rate for corn. In 1999 the rate applied was approximately 90 lbs. N/a.
Weed and insect control: We rely on cultivation and herbicides for weed control in the corn, burn-down herbicides prior to planting the soybeans, and both pre- and post-emergence herbicides as needed in the soybeans. The narrow rows help shade out weeds during the soybean phase. We have used no insecticides in either phase of the system.

CS3 Management protocol:
Philosophy: Increased management due to greater crop diversity, low input use, and a longer rotation, organic management was implemented in 1998 at Arlington
Crop Rotation: 1 yr. corn, 1 yr. soybean, 1 yr. winter wheat with red clover cover crop. If the winter wheat fails, spring wheat is planted. If the red clover fails, hairy vetch is planted after the wheat harvest.

Variety selection: Soybean maturity group 1.9 is used so wheat can be seeded by the 10th of October. Soft red winter wheat varieties are high yielding, moderately winter hardy, with a medium maturity rating; we have used 'Cardinal,' 'Dynasty,' 'Merrimac' and 'Glacier.' We rely mainly on medium red clover. Generally a 97-day variety of corn is planted in mid-May.
Tillage and seeding: After corn harvest, the field is chisel plowed for soybeans. Wheat is drilled into the soybeans after their harvest. Medium red clover is frost seeded in mid-March at about 20 lbs./a; if a poor stand resulted, hairy vetch was planted in late July. In the fall the clover is undercut and the following spring the field is tilled twice for corn planting, to help control early weeds.
Fertility: No purchased fertilizer or manure is applied. The red clover typically supplies sufficient N for corn production, and the N-credit from soybeans is equivalent to an additional 40 lbs. The drawdown of high soil phosphorus and potassium levels is deliberate. Potassium and phosphorus will be applied if and when needed (after 10 years levels are still adequate; see the section on nutrient management for further discussion).
Weed and insect control: The goal is for at least one cultivation and one to four rotary hoeings per season in the corn and soybeans as weather permits. In the past rescue treatments with post-emergence herbicides were applied when weed pressure was severe — usually because wet weather or over-saturated soils do not permit timely hoeing or cultivating. This has been a particular problem at Lakeland. In the past, Canada thistle and sometimes border rows were sprayed to prevent weeds from creeping in from the edges of the plots.

CS4 Management protocol:

Philosophy: Low crop diversity, high input, strive for very high quality alfalfa hay
Crop Rotation: 1 yr. corn, 3 yrs. alfalfa
Variety selection: The same full season corn variety as is used in CS1 and CS2. Highly disease resistant alfalfa varieties are planted.
Tillage and seeding: The alfalfa is sole seeded. The field is chisel plowed in fall in preparation for corn planting and after and again after corn harvests.
Cutting Schedule: Generally alfalfa is cut twice in the seeding year and 4 times by early September during the established years. Both occasional labor shortages and winter kill result in only 3 cuts.
Fertility: Fertility is maintained with manure applications (20 ton/a, incorporated 2 times in the fall prior to the corn year and the alfalfa establishment year; i.e., 10 ton/yr. over the 4 year rotation), starter NPK in the corn.
Weed and insect control: Herbicide is the primary weed control strategy in the alfalfa, and the only method of weed control during the alfalfa seeding phase. The corn is cultivated once and pre- and/or post-emergence herbicides are used as necessary (such as Lasso and Buctril). Scouting leafhoppers determines the use of insecticides.

CS5 Management protocol:

Philosophy: Moderate to high crop diversity, low input, strive for good quality hay
Crop Rotation: 1 yr. corn, 1 yr. oats, alfalfa, perennial ryegrass and red clover, 1 yr. alfalfa
Variety selection: the same corn variety as CS3 and alfalfa variety as CS4
Tillage and seeding: After corn harvest the field is chisel plowed in the fall, and the disked in the spring before planting. Seeding rates are as follows: Alfalfa (12-15 lbs./a); oats (50 lbs./a); field peas (50 lbs./a); perennial ryegrass (2 lbs./a) and red clover (5 lbs./a).

Cutting Schedule: During the seeding year oatlage mixed with peas, ryegrass and red clover is harvested and usually a cut of alfalfa is taken. During the established year there are three cuts by September 1 and possibly a final cut in November if there has been good regrowth.
Fertility: Fertility is managed with manure applications of 15 ton/a incorporated in the fall at 2 times —once prior to the corn year and once before the alfalfa establishment year (i.e. 10 ton/a/yr. over the entire rotation, the same as CS4).
Weed and insect control: Weeds are controlled early in the alfalfa establishment year primarily with companion-cropped oats, field peas, perennial ryegrass and red clover. Weed control in corn is accomplished primarily with rotary hoeing. Most of the time this system requires no pesticides in either the alfalfa or corn[v].

CS6 Management protocol:

Philosophy: Very low input, high plant diversity, management intensive
Crop Rotation: A timothy, bromegrass, and red clover mixture was seeded in 1990 at both sites. In 1992 some orchardgrass was added. Depending on a fall evaluation of legume content, red clover is frost seeded or drilled in the winter. In 1996 and in 1997 the paddocks were reseeded at Lakeland with a mixture of timothy, perennial ryegrass, red clover and reed canarygrass.
Fertility: Fertility is managed with manure deposition during grazing and the inclusion of red clover in the sward. Corn grain fed to the heifers can be considered a nutrient "subsidy" to the system through the manure. Recently we have added N (one application of 40 lb/a in early summer) to increase forage biomass and therefore grazing days.
Weed and insect control: Weed management is accomplished through grazing and/or clipping at key times (herbicides were used one year at one site.)
Harvesting: The plots have been subdivided in several ways with movable fencing. Alleyways were set up to allow access to a permanent water source. When forage has been excessive, hay has been made, and fed to the animals when forage production lagged. The pastures have required periodic reseeding, particularly after both drought and flood conditions. Animals were temporarily removed under very wet conditions when the sward was being heavily damaged by trampling. In 1999 4 heifers were rotated between the plots.
Animal management: Our goal was to have our 450-500 pound heifers gain weight at the rate of 1.8 to 2 lb/day. Corn supplements were fed to meet this objective. During the initial adjustment phase from confinement feeding to grazing, the heifers have received 4 lbs. grain/head/day. After about 6 weeks, when they are acclimated to the pasture the grain has been reduced to 2 lbs./head/day. Our goal is to keep the heifers on the pasture for 180 days (full growing season) and be ready for breeding the following fall.

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[v] *Since 1992 (when all phases of the rotations were fully up and running) this system has relied on spot spraying for thistles in corn during one year at one site, broadcast herbicide for quackgrass on one plot at one site for one year, and glyphosate in one establishment year of alfalfa at one site for one year. Since 1998, the system has been managed organically at one site.*

Appendix 2
Funders

Early funding was obtained from the UW's Center for Integrated Agricultural Systems (CIAS), Pioneer International Hi-Bred Seed Company, and in-kind donations of labor and supplies from team personnel, the Walworth County Farm Committee, and the UW College of Agricultural and Life Sciences (CALS). In 1991 the project received a substantial four-year grant from the W.K. Kellogg Foundation's Integrated Food and Farming Systems Program. In 1996, the project received a federal appropriation to continue the core trials from the Agricultural Research Service's Integrated Farming Systems program. In recent years funding has been received from several federal and other sources, including the North-Central Sustainable Agriculture Research and Education program (SARE), USDA-National Research Initiative (NRI), USDA-Fund for Rural America (FRA), University of Wisconsin Hatch funds, the Wisconsin Fertilizer Council and the Wisconsin Department of Agriculture, Trade and Consumer Protection. (See the Outreach and Outgrowths Section on pages 24-25 for further discussion of these projects.)

Appendix 3
WICST collaborators

Principle Investigators:

Joshua Posner (UW-Madison Department of Agronomy)
John Hall (Michael Fields Agricultural Institute — MFAI)

Current Collaborators:

Jon Baldock (AGSTAT Agricultural and Statistical Consulting)
David Combs (UW-Madison Department of Dairy Science)
Lee Cunningham (Walworth County UW Extension)
Jerry Doll (UW-Madison Department of Agronomy, UW Extension)
Walter Goldstein (Michael Fields Agricultural Institute)
Janet Hedtcke (UW-Madison Department of Agronomy)
Rick Klemme (UW-Madison Center for Integrated Agricultural Systems)
Sam Kung (UW-Madison Department of Soil Science)
Neal Martin (USDA-ARS National Dairy Forage Research Center-UW-Madison)
Dwight Mueller (Arlington Agricultural Research Station)
Laura Paine (Columbia County UW Extension)
Mark Powell (USDA-ARS National Dairy Forage Research Center-UW-Madison)
Martha Rosemeyer (UW-Madison Department of Agronomy)
Don Schuster (UW-Madison Center for Integrated Agricultural Systems)
Jim Stute (Michael Fields Agricultural Institute)
Daniel Undersander (UW-Madison Department of Agronomy)
Walworth County Board of Supervisors

Former Collaborators:

Scott Alt (UW-Madison Department of Agronomy)
Dan Forsythe (Lakeland Agricultural Complex)
Rhonda Graef (UW-Madison Department of Agronomy)
Katherine Griffith (MFAI and UW-Madison Center for Integrated Agricultural Systems)
Tom Mulder (UW-Madison Department of Agronomy)
Ray Saxby (Columbia County UW Extension)
Jim Schmid (Dane County UW Extension)
Sara Steele (UW-Madison Continuing and Vocational Education)
Alan Wood (Lakeland Agricultural Complex)

Appendix 4
Management Tips for Low-Purchased-Input Production

Rotary Hoeing

WICST looked at several factors that could influence the effectiveness and efficiency of rotary hoeing, including:

- tooth wear (new, slightly worn, very worn);
- hoe weight (with and without 100 pounds added to each row of a 4 row unit);
- hoe speed (6 and 11 miles per hour);
- number of passes (1 and 2);
- use of late hoeing to replace the first row cultivation; and
- two wheels versus one wheel per shank.

The experiments were carried out between 1992 and 1994 at the Arlington Agricultural Research Station in corn phases of corn-alfalfa rotations. Weed biomass, corn height, corn stand, corn yield and kernel moisture at harvest were all measured. Major conclusions are as follows.

- The highest corn yields were achieved using very worn wheels.
- Less worn teeth improved weed control but also reduced the corn stand.
- A double pass improved weed control but also reduced the corn stand.
- A single pass with worn teeth resulted in less weed control but higher yields, suggesting that yield was reduced more by low corn stand than by weed competition in this cropping system.
- Four rotary hoeings and a late row cultivation gave the same results as three hoeings and two cultivations.
- Corn stand reduction from rotary hoeing was not affected by the number of wheels per shank, the hoe weight or hoe speed.

The above results and our experience with rotary hoeing lead us to the following advice:

- Increase planting rates by at least 10% if you plan to control weeds mechanically with a rotary hoe and cultivation.
- Timing is crucial; monitor fields often to check weed growth stage.
- Depending on soil temperatures, rotary hoeing 5 to 10 days after planting is optimal (corn will usually have about a 1 inch sprout at this time). The most mature weeds should be at the "white thread" stage (germinated, with short roots and shoots but no true leaves). A second pass may be needed a week later, when above ground corn height is 0.5 to 1 inch.
- Drive accurately. Weed seeds germinate well in the area compacted by tractor tires. It is best to drive in the planter tracks to avoid compacting new areas.
- If wet weather prevents the first hoeing, a double pass at the optimum time for a second hoeing works well. The two passes should be in opposite directions.

Rotary hoeing on WICST plots.

Cover crop management tips:

Red clover management: Common (not improved) or medium red clover seed from a good source is adequate for cover cropping. It should be seeded at 10-12 lbs./a if companion seeded in a single pass with a small grain, or 15-18 lbs./a if frost seeded into wheat. Frost seeding should usually be done with a broadcast seeder mounted on a small tractor or ATV since the thin layer of frozen soil often cannot support the weight of large equipment. Red clover will tolerate fairly wet, heavy, acidic soils (pH as low as 5.2), and should have P and K in the medium to high range for best results. Red clover should not be planted in the fall because it will not have enough time to fix sufficient nitrogen for the subsequent corn crop. Fall undercutting is recommended, as it offers good ground cover through the winter, nearly 100% winterkill, and ease of corn planting the following April. (While cover crops can add additional dry matter and biologically fixed nitrogen to the system if left to grow in the spring, in wet years they tend to keep the soil wet, and in dry years they tend to rob moisture from the subsequent corn crop.) If harvesting the wheat straw for minimum clover contamination, setting the cutter bar a little higher at harvest time gives good, but not perfect, results.

Hairy vetch management: There are three circumstances which warrant a producer's relying on vetch instead of clover: 1) if frost seeding clover does not fit within a producer's system; 2) if frost seeded red clover fails to establish well; or 3) if the producer wants very clean wheat straw and maximum straw yields[22]. Vetch should be seeded at 25-30 lbs./acres if drilled or 35-40 lbs./ acre if broadcast. It can be planted as late as September 15 but for maximum production, planting immediately after small grain harvest is recommended. It can be successfully established using no-till provided no weeds are present, or following light tillage. It should be planted at least 0.5 inches deep. To reduce establishment costs, seed can be broadcast and incorporated by tillage in a single pass. The seed must be inoculated with the proper rhizobia species. We note that vetch cannot be planted as a companion crop with a small grain because of its climbing habit, which will cause lodging and harvesting difficulties with the small grain. Vetch can be killed in fall or early spring. If vetch overwinters (only likely if it is planted late enough that it does not flower before killing frosts arrive), it will add biologically fixed nitrogen to the system if allowed to grow beyond early May. However, it will also deplete soil moisture. Corn can be no-tilled into vetch residue using burndown herbicide or tillage.

Detailed management information, agronomic data and pros and cons of various cover crops for Wisconsin and the upper Midwest can be found in Legume Cover Crops In Wisconsin: A Guide for Farmers by Jim Stute, Wisconsin Department of Agriculture, Trade and Consumer Protection, ARM publication #55, 1996. Guidelines for using cover crops in rotations with small grains can be found in Farmers Guide & Resource to Quality Small Grains Production by R. G. Doetch, D. Kane, J. Stute, J.L. Posner, and T. Ends, produced at Michael Fields Agricultural Institute in East Troy, WI as part of the Small Grains Initiative, 1999.

Endnotes

[1] The University of Wisconsin Nutrient and Pest Management Program (NPM) had its origins in the project to develop the Best Management Practices for Wisconsin's Department of Agriculture, Trade and Consumer Protection (Nutrient and Pesticide Best Management Practices for Wisconsin Farms. June 1989, Madison, Wisconsin, Department of Agriculture, Trade and Consumer Protection (DATCP) Technical Bulletin ARM-A-3466.
[2] There were seven satellite farms in south-central Wisconsin: one dairy farm implementing rotational grazing, and five farms and an FFA high school demonstration field experimenting with cover crops.
[3] Methodological note: All cropping systems had randomized, replicated plots at the two sites, with each plot surrounded by eight-foot grassy borders. We considered each plot a "field", and managed each according to the specific site characteristics. Thus, a single treatment (eg. "continuous corn") could have four plots with somewhat different levels of inputs, according to soil test results and the like. A "uniformity year" in which corn was planted over the entire experimental area both established base level data on the plots and allowed the researchers to separate the area into relatively uniform blocks to serve as replications. In the cash grain systems we excluded border rows from our investigations to avoid "border effect" alterations of the results. See Posner, Casler and Baldock. 1995. The Wisconsin integrated cropping systems trial: Combining agro ecology with production agronomy. *Am J. of Alt. Agric* 10:3: 98-107.
[4] While many farmers combine cash grain and livestock based systems, specialization is increasingly the trend in Wisconsin. The WICST team wanted its results to be relevant to as many farmers as possible, so we chose to separate these different types of enterprises.
[5] The "Feed Grain" program paid farmers an above-market price for their corn, and in return required them to idle 10 to 35% of their "base" corn acreage (the acreage they had historically devoted to corn production). Dairy farmers also sometimes grow continuous corn on fields near the barn that get heavily manured.
[6] The system relies on a no-till cultivator in the corn phase, and is thus not strictly "no-till."
[7] The name "Green Gold' was coined by UW researcher Dwayne Roweder to describe an alfalfa management system involving high soil test potassium and phosphorus, leaf hopper scouting and spraying, and four cuts a year (five in the final year). This system was heavily promoted during the late 1970s and 1980s.
[8] Production and environmental measurements have been easier to make on this system than a solid economic analysis. Few graziers only raise young stock, the uniformity of the landscape did not give the research managers much flexibility in moving the animals, and the small number of animals (from 6 to 8 heifers) raises questions about the generalizability of the economic analysis. However, the system does provide a valuable contrast with the other systems in several agronomic and environmental measures.
[9] Jackson-Smith, D., and B. Barham. *The changing face of Wisconsin dairy farms: A summary of the PATS' research on structural change in the 1990's.* Program of Agricultural Technology Studies. College of Agriculture and Life Sciences, University of Wisconsin-Madison. Report #7. 25 pages. 2000.
[10] Others respond that a high percentage of the food we produce feeds livestock, not humans, and that the problem of hunger is caused more by the inequities of our global food distribution system than by inadequate production per se. Nevertheless, substantial declines in productivity could carry significant implications for the world's population.
[11] A traditional analysis of variance was performed on the yield data for each crop from 1990-98.
[12] Methodology: In April of each year we sample the soil on all plots that were in corn the previous season, and bring the soil into a greenhouse. We then count the seedlings that sprout through three germination cycles from May to September, calculate the number of seeds per square foot, and determine the relative proportions of grasses and broadleaf weeds. To measure weed biomass, each year from 1993-1997 we cut all weeds taller than 4 inches in subplots in all the corn and soybean fields when the corn is 36 inches tall (usually early July). Weeds are dried and weighed and the proportion of grasses and broadleaves is calculated.
[13] Cover crops: Doetch, Ron, Dan Kane, Jim Stute, Joshua Posner, and Tony Ends. "Farmers Guide and Resource to Quality Small Grain Production." Supported by SARE and FRA. 30pp. 1999.
Mallory, E.B., J.L. Posner, and J.O. Baldock. "Performance, economics, and adoption of cover crops in Wisconsin cash grain rotations: On-farm trials." *American Journal of Alternative Agriculture*. 12(1):2-11, 1998.
Stute, Jim and Joshua Posner. "Synchrony Between Legume Nitrogen Release and Corn Demand in the Upper Midwest." *Agronomy Journal*. 87(6):1063-1069, 1995.

Stute, Jim and Joshua Posner. "Legume Cover Crops as a Nitrogen Source for Corn in an Oat-Corn Rotation." *Journal of Production Agriculture*. 8(3):385-390, 1995.

Stute, Jim. "Legume Cover Crops in Wisconsin: A guide for farmers." WDATCP. ARMPUB 55. 1996.

[14] "Hypoxia" refers to the "dead zone" in the Gulf of Mexico that occurs when nutrient-laden waters from the Mississippi and Atchafalya Rivers reduce the available oxygen of the ocean waters, resulting in a dramatic decrease in the aquatic wildlife that can survive there.

[15] WDATCP. 1989. *Nutrient and Pesticide Best Management Practices for Wisconsin Farms*. UW Extension Bulletin. A-3466 WDATCP Technical Bulletin ARM-1.

[16] Dates were: 12/9/92, 11/23/93, 11/23/94, 4/23/96, 4/9/97, 11/13/97, and 11/16/98.

[17] Wisconsin Department of Natural Resources

[18] Sam Kung, soil physicist in the UW-Madison Soil Science Department, has been investigating leaching and how water travels through the soil under different kinds of rainfall events at the Lakeland Agricultural Complex.

[19] Bromide is a tracer that is often used in leaching studies. It offers a "worst case scenario" since it is negatively charged, and hence repelled by the soil, and (unlike nitrates) does not get incorporated into the bodies of any soil microorganisms. At Lakeland in August after only 7 inches of rainfall, bromide had moved down the profile to 80 cms in all the rotations. By December it was in the shallow groundwater under each of the rotations.

Iragavarapu, Raj et al, 1998, "The effect of various crops on bromide leaching to shallow groundwater under natural rainfall conditions." *Journal of Soil and Water Conservation* 53:2:146-151. Also Iragavarapu, Posner and Bubenzer in WICST Second Report 1992, pp. 65-73.

[20] The Soil Health Scorecard may be obtained by contacting Robin Harris, Dept of Soil Science, UW-Madison, tel. 608/ 263-5691, email rfharris@calshp.cals.wisc.edu

[21] ***Insects:*** Rebek, E. 1998. Cropping system effects on the diversity and abundance of Collembola in Southern Wisconsin. M.S. Thesis. Department of Entomology, UW- Madison.

Rebek, E. J., D.K. Young, and D.B. Hogg. 1999. A list of Wisconsin springtails with new records and annotations (Hexapoda: Parainsecta: Collembola). Great Lakes Ent. 32(1): 51-62.

Microbes: P.A. Selbach, A.S. Yuroff and Hickey, W.J., 2000 submitted. Effects of agricultural cropping systems on solid microbial community structure: Phylogenetic probe analysis. To Soil Biology and Biochemistry.

Gollwitzer, V. 1999. Molecular analysis of ammonia-oxidizing bacteria in Wisconsin agricultural soils. M.S. Thesis. Department of Soil Science, UW-Madison.

Nematodes: MacGuidwin, A., M. Rosemeyer, and T. Lim. 2000 in preparation. The diversity of nematode communities of four established low and high input Midwestern cropping systems over three years. To: Applied Soil Ecology.

[22] We have found that setting the cutter bar a little higher at wheat harvest time gives good, but not perfect, results.

Notes