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

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

## ABSTRACT

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

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

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

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

---

J.L. Posner and J.L. Hedtcke, Dep. of Agronomy, Univ. of Wisconsin, 1575 Linden Dr., Madison, WI 53706; J.O. Baldock, AGSTAT, 6394 Grandview Rd., Verona, WI 53593. Major funding provided by the W.K. Kellogg Foundation's Integrated Food and Farming Systems program and federal appropriation from the Agricultural Research Service (ARS) Integrated Farming Systems program. Received 9 Feb. 2007. *Corresponding author (jlposner@wisc.edu).

Published in Agron. J. 100:253–260 (2008).
doi:10.2134/agronj2007.0058

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

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

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

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

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

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

¶ Only soil insecticides were used.

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

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

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

§§ The alfalfa in Phase 1 of CS4 was sole seeded; the alfalfa in Phase 1 of CS5 was companion seeded with the oat–pea mix.

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

## MATERIALS AND METHODS

### Cropping System Trials and Terminology

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

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

### Design and Establishment of the Experiment

The ongoing WICST experiment consists of six cropping systems, replicated four times and situated at two locations in southern Wisconsin (the second site was terminated in 2002). Three cash-crop (typical of specialized grain farms) and three forage-crop systems (typical of livestock–crop farms) were selected for study based on crop diversity and level of external inputs (Posner et al., 1995). Specifically, the cash grain systems were a high-external input, continuous corn (CS1) system; a moderate-external input, corn–soybean (CS2) system, and an organic corn–soybean–winter wheat with frost-seeded red clover (*Trifolium pretense* L.) (CS3) system (Table 1). Forage systems include a high-input, corn–alfalfa (*Medicago sativa* L.) system (CS4); an organic inputs system of corn, alfalfa, oat (*Avena sativa* L.) plus field pea (*Pisum sativum* L.) mix, followed by a year of alfalfa hay (CS5); and a rotationally grazed pasture (CS6) seeded to a mixture of red clover, timothy (*Phleum pratense* L.), brome grass (*Bromus inermis* L.), and orchardgrass (*Dactylis glomerata* L.) (Table 1). The key differences in cultural practices among the systems are described in Table 1. The organic grain and organic forage systems (CS3 and CS5) could not be certified organic, because they lack a 10-m buffer zone around each plot, and the same field machinery was used interchangeably on both conventional and the organic plots without previous cleaning. Also, before 2002 we used conventional, not certified organic seed. Except for these discrepancies, these grain and forage plots meet all the (other) USDA requirements for a certified organic system (USDA, 2007).

The trials were established in 1989 with all 24 ha at each location planted to corn to improve the uniformity of crop history and to allow baseline measurements to be made. Some of the baseline variables, especially yield, were used to block the trial into a four-block randomized complete block design with one replication of the 14 total phases in the six cropping systems placed in each block. Instead of starting all crops in all rotations in the first year, a staggered start was used so that each phase of each rotation was replicated in time as well as space (Posner et al., 1995; Loughin, 2006). After the stagger was completed in 1992, every phase was present every year for all the crop rotations, thus meeting a core requirement of a crop rotation trial (Cady, 1991). The large, 0.3-ha plots allowed field work to be done with farm scale equipment. Grain and dry matter yields were measured by first running the harvest wagons across a farm scale and then taking several small samples that were composited and then frozen. Grain crop samples were analyzed for moisture, protein levels, and nutrient content (P and K), while forage samples (both hay and pasture) were tested with near infrared spectrophotometry (NIRS) to determine relative feed value (RFV) (Rohweder et al., 1978). In the rotational grazing system, randomly selected samples (4 × 0.5 $m^2$) were hand-cut each week with a shears at ground level just before grazing by the heifers (Marten, 1989). Additional details on the design and conduct of the WICST trial are provided in Posner et al. (1995).

## Locations and Analytical Methods

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

## Statistical Analyses

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

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

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

The analyses outlined above did not use the staggered start to estimate both a fixed effect of years (e.g., technological advances) and a random effect of years (e.g., weather effects) (Loughin, 2006). This deviation from optimal analyses occurred because in staggered starts for studies involving crop rotations there is an additional fixed effect of time due to agroecological factors, namely cycle. The differing cycle lengths among the cropping systems in this study made it very difficult to estimate all three time effects at once and especially difficult to ascertain the random effect of years because that effect was nested within the various cycles. Furthermore, preliminary analyses showed that the weather related effects of years were much larger than the cycle effects. Based on these considerations, we ignored the effect of cycle in this paper, but plan to report on it in a later article. In completing the analyses combined over locations and years without regard to cycles, we found that examining the effect of years within sites in more detail would be useful for a few crops. For these cases, we omitted the terms and indices involving location from the above model to conduct these analyses. The latter analyses also allowed us to include the data through 2002 at Arlington.

## RESULTS AND DISCUSSION

### Test Crops

#### Fixed Effect of Cropping Systems

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

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

#### Fixed Effects of Location and Cropping System × Location

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

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

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

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

† Significant at the 0.10 probability level.

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

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

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

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

‡ Organic systems.

§ Standard error of the mean.

#### Random Effects of Year, Block, and Their Interactions

Table 4 presents the variance components for the four test crop yields as a measure of the variability across the random factors in the analyses (Littell et al., 1996). While there are some interesting features in the first four rows of Table 4, we have focused on the year × system (row 5) and year × system × location (row 6) interactions that measure how consistently the cropping systems performed across years and year-site combinations. With the four test crops, the three-way interaction was larger than the two-way interaction and statistically significant using the likelihood ratio test. This indicates that further analyses to explain the variability is warranted and that it might be best done on individual sites. This was a fortuitous result because it allowed us to include the additional years (1999–2002) available at Arlington. We did not have to examine forage crop yields in more detail because the estimated year × system variance components for both forage crops were zero (Table 4, row 5), which means the differences in forage production between the organic and conventional systems were very stable across years. However, the results for the two grain crops were not consistent across years as manifested by the moderately large and statistically significant variance components for year × system (Table 4). This variability fit our observations of the trials that there was a large range in annual grain yields in the organic systems depending on how favorable the weather was for mechanical weed control. Others have reported similar observations (Liebhardt et al., 1989; Porter et al., 2003). Consequently, we attempted to quantify this effect in more detail as part of the within-site analyses using the method of separating the results into logical groups (that is, ones with different responses and hopefully smaller variance components) as outlined by Littell et al. (1996).

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

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

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

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

** Significant at the 0.01 probability level.

† NS, not significant at the 0.10 probabiliy level.

‡ Significant at the 0.10 probability level.

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

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

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

### Logical Groups for Corn at Elkhorn and Arlington

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

### Logical Groups for Soybean at Elkhorn and Arlington

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

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

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

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

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

‡ Small grain: w = wheat and o = oat.

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

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

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

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

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

## Nontest Crops

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

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

## Correspondence with Previous Results and Implications

This report on the WICST adds a substantial number of site-years to the compilation of field trials comparing organic and other low-input cropping systems to conventional cropping systems in the northern tier states (Table 7). In addition, combining the WICST outcomes with the previous information gives rise to a clear pattern that shows weed control in the low input systems is a key contributor to the observed differences. Specifically, when there is a problem controlling weeds in the low-input systems, corn yields reported from these trials ranged from 72 to 84% of the corn yields in the conventional systems. Similarly, when there is a problem controlling weeds in the low-input systems, soybean yields in those systems ranged from 64 to 79% of the soybean yields in the conventional systems. However, when low-input weed control was successful, corn yields in the low-input system were 98 to 114% of the conventional corn yields and low-input soybean yields were 94 to 111% of conventional soybean yields (Table 7). This pattern did not appear to be a factor in non row-crop yields because none of the reports mentioned weed control and the low-input system production was 90 to 100% of that in conventional systems (Table 7). Thus, we conducted or found 37 site-years of comparisons of low-input to conventional corn, and of these, only 11 had depressed yields that averaged 75% of conventional corn due to difficulty controlling weeds in the low-input systems. In the other 26 site-years, the mean yield of the low-input corn was 101% of the mean for conventional corn. Correspondingly, researchers have compiled at least 39 site-years of low-input to conventional soybean comparisons. In 15 of those 39 cases, there was a problem controlling weeds in the low-input systems, and low-input soybean only yielded 73% of the conventional soybean. However in the other 24 cases, the low-input soybean averaged 97% of conventional soybean.

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

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

## CONCLUSIONS

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

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

## REFERENCES

Aldrich, S.R. 1978. Organic farming can't feed the world. World Agric. 28:17–19.

Altieri, M. 1987. Agroecology: The scientific basis of alternative agriculture. Westview Press, Boulder, CO.

Avery, D.T., and A. Avery. 1996. Farming to sustain the environment. Hudson Briefing Pap. 190. Hudson Institute, Indianapolis, IN.

Baldock, J.O., and R.B. Musgrave. 1980. Manure and mineral fertilizer effects in continuous and rotational crop sequences in central New York. Agron. J. 72:511–518.

Barbash, J.E., G.P. Thelin, D.W. Kolpin, and R.J. Gilliom. 2001. Major herbicides in ground water: Results from the National Water-Quality Assessment. J. Environ. Qual. 30:831–845.

Batte, M.T., D.L. Forster, and F.J. Hitzhusen. 1993. Organic agriculture in Ohio: An economic perspective. J. Prod. Agric. 6:536–542.

Berardi, G.M. 1978. Organic and conventional wheat production: Examination of energy and economics. Agro-Ecosystems 4:367–376.

Cady, F.B. 1991. Experimental design and data management of rotation experiments. Agron. J. 83:50–56.

Cacek, T., and L. Langner. 1986. The economic implications of organic farming. Am. J. Alt. Agric. 1:25–29.

Cochran, W.G. 1947. Some consequences when the assumptions for the analysis of variance are not satisfied. Biometrics 3:22–38.

Council for Agricultural Science and Technology. 1990. Alternative agriculture: Scientists' review. CAST Spec. Publ. 16. CAST, Ames, IA.

Crosson, P., and J. Ostrov. 1990. Sorting out the environmental benefits of alternative agriculture. J. Soil Water Conserv. 45:34–41.

Crosson, P. 1989. What is alternative agriculture? Am. J. Alternative Agric. 4:28–32.

Delate, K., and C.A. Cambardella. 2004. Agroecosystem performance during transition to certified organic grain production. Agron. J. 96:1288–1298.

Doll, J.D., S. Alt, R. Graef, and J.L. Posner. 1999. Weed seed bank changes: 1990–1998. The Wisconsin Integrated Cropping Systems Trial. Available at www.cias.wisc.edu/wicst/pubs/weedseed.htm (verified 30 Oct. 2007). Univ. of Wisconsin, Madison.

Felstehausen, H. 1986. Decline of farming in Wisconsin. Wisconsin Acad. Rev. 33:44–50.

Frye, W.W., and G.W. Thomas. 1991. Management of long-term field experiments. Agron. J. 83:38–44.

Gish, T.J., and A. Sadeghi. 1993. Agricultural water quality priorities: A symposium overview. J. Environ. Qual. 22:389–391.

Harwood, R.R. 1985. The integration efficiencies of cropping systems. p. 64–75. *In* T.C. Edens et al. (ed.) Sustainable agriculture and integrated framing systems: 1984 Conference Proceedings. Michigan State Univ. Press, East Lansing.

Harwood, R.R. 1990. A history of sustainable agriculture. p. 3–19. *In* C.A. Edwards et al. (ed.) Sustainable agricultural systems. Soil and Water Conserv. Soc., Ankeny, IA.

Helmers, G.A., M.R. Langemeier, and J. Atwood. 1986. An economic analysis of alternative cropping systems for east-central Nebraska. Am. J. Alternative Agric. 1:153–158.

Hildebrand, P.E. 1990. Agronomy's role in sustainable agriculture: Integrated farming systems. J. Prod. Agric. 3:285–288.

Keeney, D. 1990. Sustainable agriculture: Definition and concepts. J. Prod. Agric. 3:281–285.

Klepper, R.W., W. Lockeretz, B. Commoner, M. Gertler, S. Fast, D. O'Leary, and R. Blobaum. 1977. Economic performance and energy intensiveness on organic and conventional farms in the Corn Belt: A preliminary comparison. Am. J. Agric. Econ. 59:1–12.

Krall, J.M., and G.E. Schuman. 1996. Integrated dryland crop and livestock production systems on the Great Plains: Extent and outlook. J. Prod. Agric. 9:187–191.

Lee, L.K. 1992. A perspective on the economic impacts of reducing agricultural chemical use. Am. J. Alternative Agric. 7:82–88.

Liebhardt, W.C., R.W. Andrews, M.N. Culik, R.R. Harwood, R.R. Janke, J.K. Radke, and S.L. Rieger-Schwartz. 1989. Crop production during conversion from conventional to low-input methods. Agron. J. 81:150–159.

Liebman, M., and A.S. Davis. 2000. Integration of soil, crop and weed management in low-external-input farming systems. Weed Res. 40:27–47.

Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS system for mixed models. SAS Institute, Cary, NC.

Lockeretz, W., G. Shearer, and D.H. Kohl. 1981. Organic farming in the Corn Belt. Science 211:540–546.

Lockeretz, W., G. Shearer, R. Klepper, and S. Sweeney. 1978. Field crop production on organic farms in the Midwest. J. Soil Water Conserv. 33:130–134.

Loughin, T.M. 2006. Improved experimental design and analysis for long-term experiments. Crop Sci. 46:2492–2502.

Madden, J.P. 1989. What is alternative agriculture? Am. J. Alternative Agric. 4:32–34.

Mader, P., A. Fliessbach, D. Dubois, L. Gunst, P. Fried, and U. Niggli. 2002. Soil fertility and biodiversity in organic farming. Science 296:1694–1697.

Marten, G.C. (ed.). 1989. Grazing research: Design, methodology and analysis. CSSA Spec. Publ. 16. CSSA and ASA, Madison, WI.

Melander, B., H.A. Rasmussen, and P. Barberi. 2005. Integrating physical and cultural methods of weed control: Examples from European research. Weed Sci. 53:369–381.

National Oceanic and Atmospheric Administration. 2007. State inventory. Available at www5.ncdc.noaa.gov/climatenormals/clim81/WInorm.txt (accessed 17 Apr. 2006; verified 30 Oct. 2007). NOAA, Washington, DC.

National Research Council. 1989. Alternative agriculture. National Academy Press, Washington, DC.

Oberle, S.L., and M.R. Burkart. 1994. Water resources implications of Midwest aagroecosystems. J. Environ. Qual. 23:4–8.

Parr, J.F., and S.B. Hornick. 1992. Agricultural use of organic amendments: A historical perspective. Am. J. Alternative Agric. 7:181–189.

Porter, P.M., J.G. Lauer, W.E. Lueschen, J.H. Ford, T.R. Hoverstad, E.S. Oplinger, and R.K. Crookston. 1997. Environment affects the corn soybean rotation effect. Agron. J. 89:441–448.

Porter, P.M., D.R. Huggins, C.A. Perillo, S.R. Quiring, and R.K. Crookston. 2003. Organic and other management strategies with two and four year crop rotations in Minnesota. Agron. J. 95:233–244.

Posner, J.L. 1990–2002. Wisconsin integrated cropping system trial annual technical reports: 1–9. Univ. of Wisconsin, Madison.

Posner, J.L., M.D. Casler, and J.O. Baldock. 1995. The Wisconsin integrated cropping system trial: Combining agro-ecology with production agronomy. Am. J. Alternative Agric. 10:98–107.

Rodale, R. 1985. Past and future of regenerative agriculture. p. 312–317. *In* T.C. Edens et al. (ed.) Sustainable agriculture and integrated farming systems: 1984 Conference Proceedings. Michigan State Univ. Press, East Lansing.

Rodale, R. 1990. Finding the middle road on sustainability. J. Prod. Agric. 3:273–276.

Rohweder, D.A., R.F. Barnes, and N. Jorgensen. 1978. Proposed hay grading standards based on laboratory analysis for evaluating quality. J. Anim. Sci. 47:747–759.

SAS Institute. 1999. SAS OnlineDoc. Version 8. SAS Institute, Cary, NC.

Shrader, W.D., W.A. Fuller, and F.B. Cady. 1966. Estimation of a common N response function for corn (Zea mays) in different crop rotations. Agron. J. 58:397–401.

Smith, R.G., and K.L. Gross. 2006. Weed community and corn yield variability in diverse management systems. Weed Sci. 54:106–113.

Undersander, D.J., T.H. Howard, and R. Shaver. 1993. Milk per acres spreadsheet for combining yield and quality into a single term. J. Prod. Agric. 6:231–235.

University of Wisconsin Extension. 1996–2006. How much fertilizer do your animals produce? Bull. A3601. Available at http://learningstore.uwex.edu/How-Much-Fertilizer-Do-Your-Animals-Produce-P105C20.aspx (accessed 17 Apr. 2006; verified 30 Oct. 2007). Univ. of Wisconsin, Madison.

USDA. 1981. Land resource regions and major land resource areas of the United States. Agric. Handb. 296. U.S. Gov. Print. Office, Washington, DC.

USDA. 2007. National organic program. Available at www.ams.usda.gov/nop/NOP/standards.html (accessed 11 Jan. 2007; verified 30 Oct. 2007). USDA, Washington, DC.

Wagner, R.E. 1990. Finding the middle road on sustainability. J. Prod. Agric. 3:277–280.

Weil, R.R. 1990. Defining and using the concept of sustainable agriculture. J. Agron. Educ. 19:126–130.

Wisconsin Agricultural Statistics Service. 1991–1998. Wisconsin statistics. Available at www.nass.usda.gov/wi (accessed 26 Sept. 2006; verified 30 Oct. 2007). USDA-NASS, Washington, DC.

Yates, F. 1954. The analysis of experiments containing different crop rotations. Biometrics 10:324–346.