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

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ABSTRACT

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

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

Our conclusions are the following:

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

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

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

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

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

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INTRODUCTION AND OBJECTIVES

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

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

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

LITERATURE REVIEW

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

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

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

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

MATERIALS AND METHODS

Cropping System Trials and Terminology

Definitions of the terms: crop rotation, crop sequence, phase, cycle and test crop; are consistent with those originated by Cochran (1947) and Yates (1954). Cady (1991) provides a more recent statement of them. By "cropping system" we mean the combination of a crop rotation and a management philosophy. Our use of cropping system is more general than the definition in Cady that a cropping system is the combination of a crop rotation and a set of specific management practices. Substitution of a management philosophy for specific practices allows the flexibility to adjust the practices to the needs of each crop rotation and keep up with rapidly changing technologies such as changes in varieties, weed control, and tillage. We used a panel of farmers and researchers to guide such changes and ensure that they were consistent with the overall philosophy of each system (Posner et al. 1995). Cropping system trials such as these may be viewed as fractions of the full factorial combinations of crop rotations by cultural practices discussed in Patterson and Lowe (1970) and Cady (1991). By choosing only the treatment combinations that are appropriate for each crop rotation, every cropping system is compared near its optimal level and the problem of impractically large, full-factorials trials that Cady warned of

are avoided. This flexibility and efficiency in cropping systems trials comes at a price; that is, the ability to identify specific causes of differences among systems is mostly lost.

Experimental Design and Establishment

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

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

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

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

Sites

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

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

Statistical Analyses

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

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

where

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

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

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

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

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

RESULTS AND DISCUSSION

Crop Yields Over Locations

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

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

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

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

Crop Yields Within Locations

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

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

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

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

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

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

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

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

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

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

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

Because animal production in the form of meat or milk is the ultimate goal of forage production, forage quality is as important as dry matter yield. We determined relative feed value (RFV) as a measure of forage quality and estimated milk production with MILK91 (Undersander et al. 1993). **Tables 4g and 4h** show the results of these observations. Not surprisingly, there was a 23 (ARS) to 35 (LAC) point RFV advantage between forage that was primarily composed of alfalfa versus the companion-seeded option (oats/peas) in the establishment year. The RFV of

the pasture samples was 120 ± 10, which was also significantly lower than for alfalfa in CS4, but not for alfalfa in CS5. However, the differences in RFV were offset by larger dry matter yields so there were no significant differences in estimated milk production between the two systems. Similar offsets occurred, but to a lesser extent, in the other comparisons so there were no significant differences in milk production in any of the comparisons at ARS or LAC.

Crop Yield Variability Over Years Within Locations

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

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

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

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

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

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

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

Crop Yield Trends at Arlington

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

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

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

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

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

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

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

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

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

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

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

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

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

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

CONCLUSIONS

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

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

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

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

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

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

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

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

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

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

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

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

¶ Soybeans planted in 30-inch rows.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Estimated using MILK91 (Undersander et al. 1993)

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

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

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

Estimated using MILK91 (Undersander et al, 1993)

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

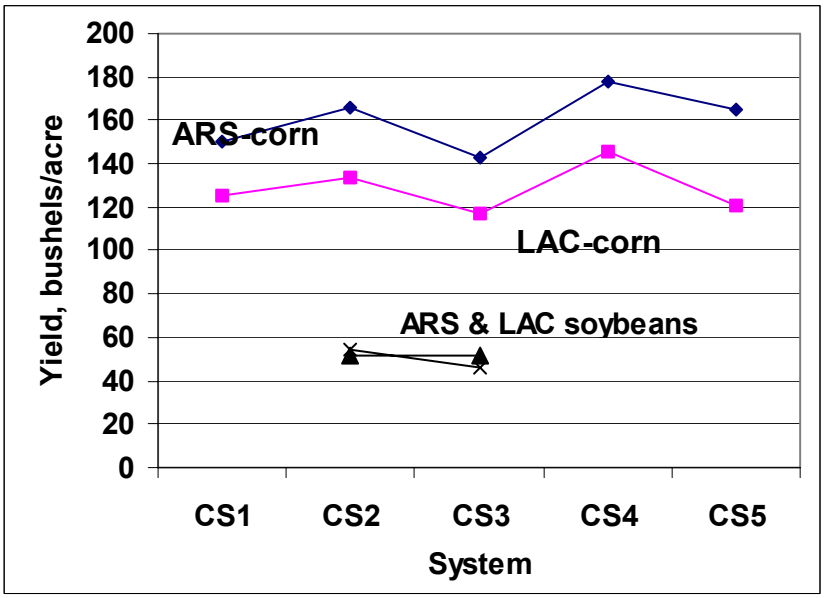

Fig. 1a. Mean yields of corn and soybeans by site and system.
ARS =Arlington Research Station; LAC = Lakeland Agricultural Complex

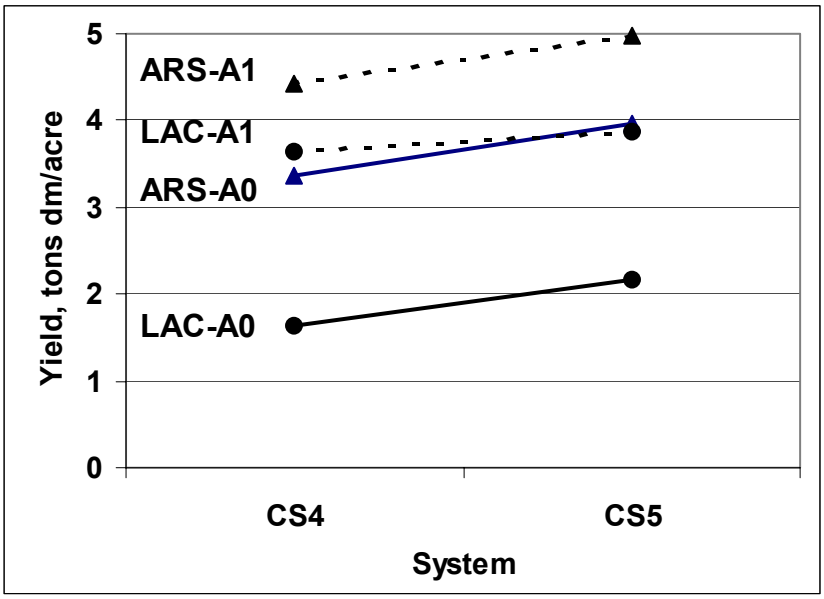

Fig. 1b. Mean forage yields by site and system.
ARS=Arlington Research Station; LAC= Lakeland Agricultural Complex
A1=alfalfa hay year I; A0=alfalfa seeding year

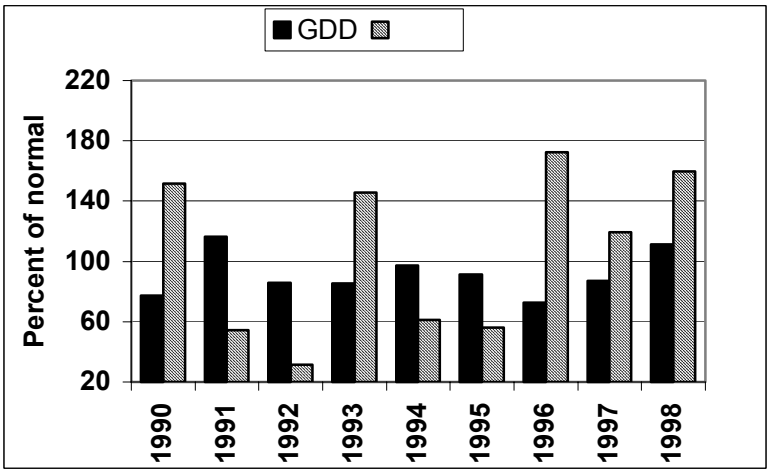

Fig. 2. Lakeland Ag Complex, WI, May plus June Growing Degree Days (GDD, base 50ºF) and May plus June rainfall, as a percentage of the 1971-2002 norms.

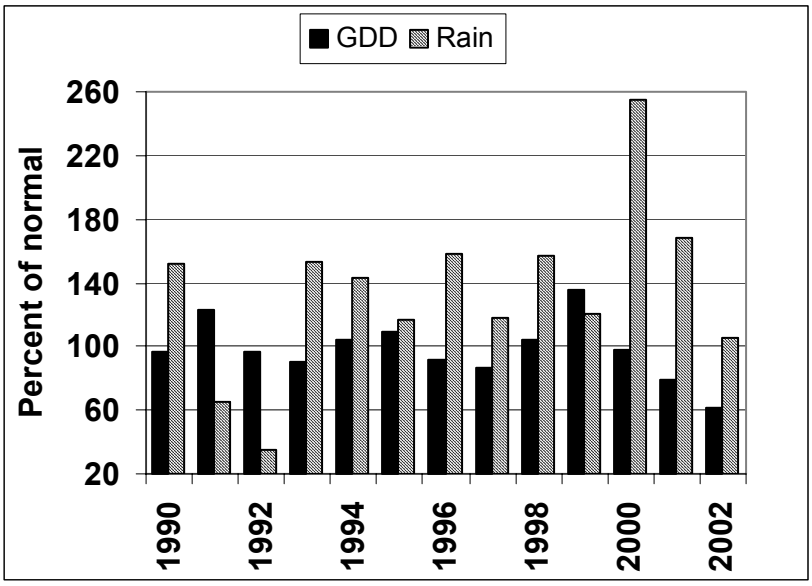

Fig. 3. Arlington, WI, May plus June Growing Degree Days (GDD, base 50ºF) and May plus June rainfall, as a percentage of the 1971-2002 norms.

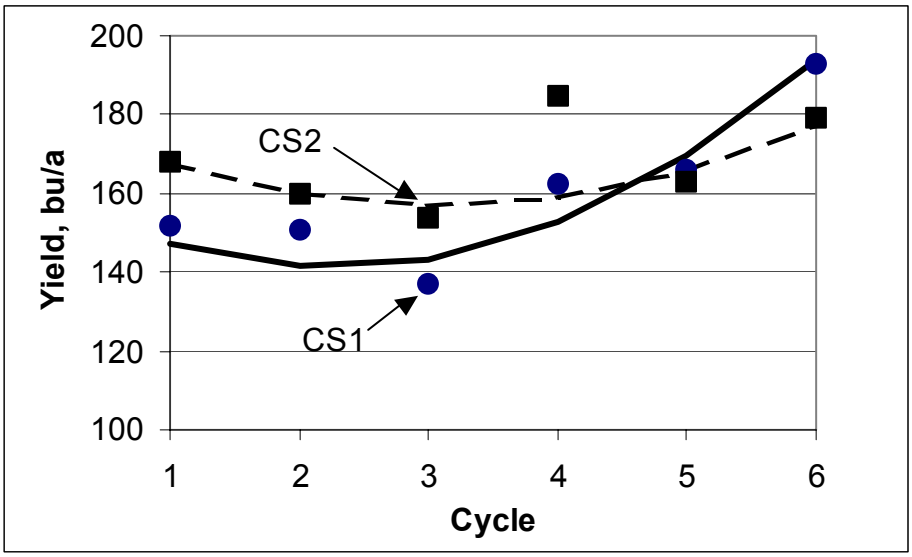

Fig. 4. Trend of corn yields for CS1 and CS2 over cycles at Arlington (n=8). The regression:equation are CS1: Yield = 160.7 – 17.2*Cycle + 3.8*Cycle^2; and CS2: Yield = 180.0 – 14.9*Cycle + 2.4* Cycle^2. Each term in these models is significant at the 10% level or better.

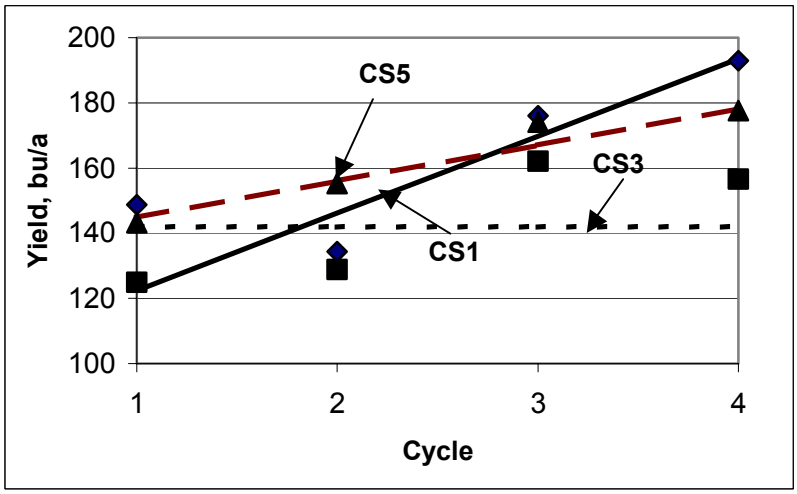

Fig. 5. Corn yield trends for CS1, CS3, and CS5 over cycles (n=12 for Cycles 1-3 and n=8 for Cycle 4). The regression equations are CS1: Yield = 98.7 + 23.7*Cycle; CS3: Yield = 141.9; and CS5: Yield = 133.7 + 11.1*Cycle. Each term in these models is significant at the 1% level.

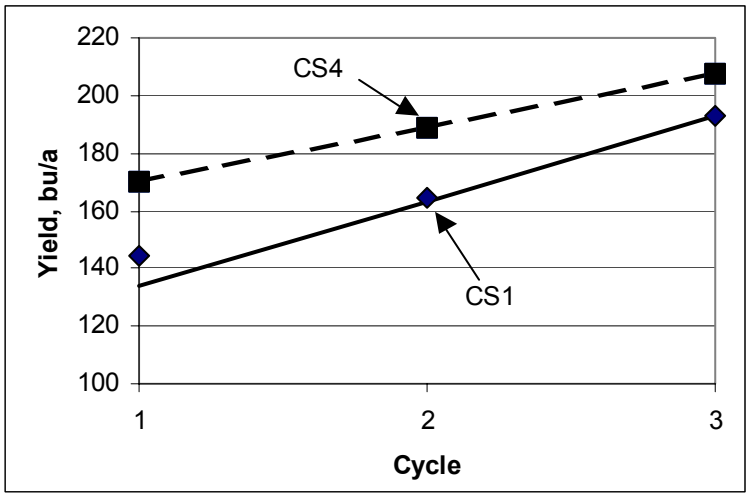

Fig. 6. Corn yields for CS1 and CS4 over cycles (n=16 for Cycles 1-2, n=8 for Cycle 3). The regression equations are CS1: Yield = 103.9 + 29.7*Cycle and CS4: Yield = 151.5 + 18.6*Cycle, each term in the models is statistically significant at the 2% level.

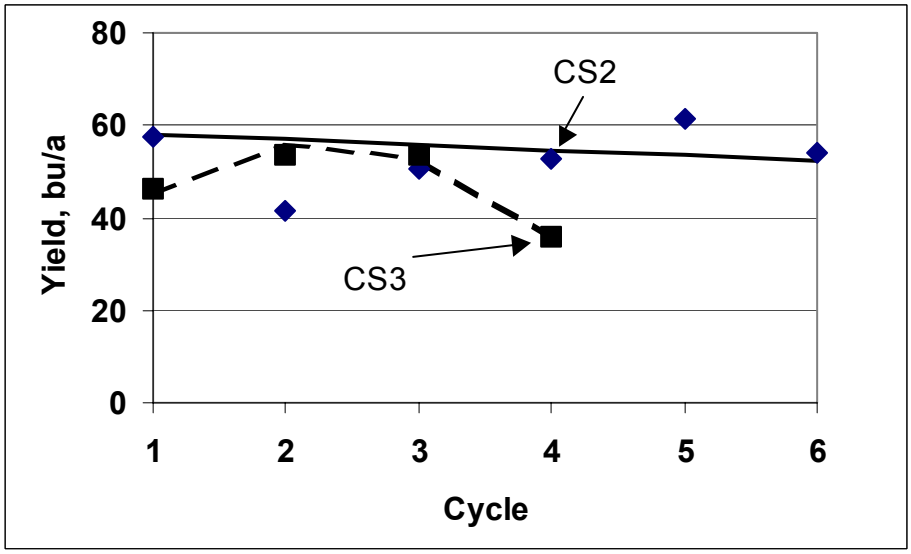

Fig. 7. Trend of soybean yields for CS2 (n=8) and CS3 (n=12) over cycles. The regression equations are CS2: Yield = 59.180 – 1.150*Cycle and CS3: Yield = 20.52 + 31.58*Cycle – 6.94*Cycle^2. The coefficients in both equations are statistically significant at the 1% level.

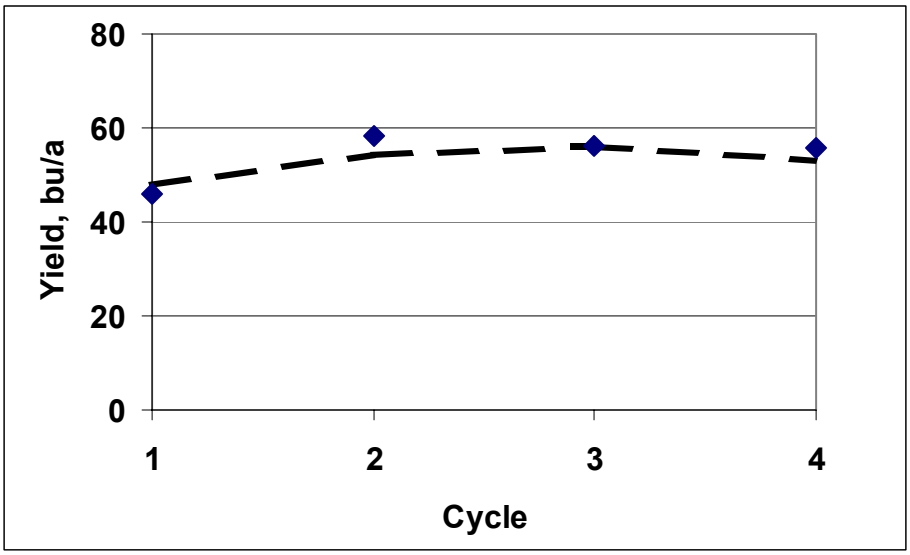

Fig. 8. **Trend of mean wheat yields for CS3 over cycle (n=12).** The regression equation is Yield = 36.46 + 13.87*Cycle – 2.43*Cycle^2. The coefficients are statistically significant at the 5% level.

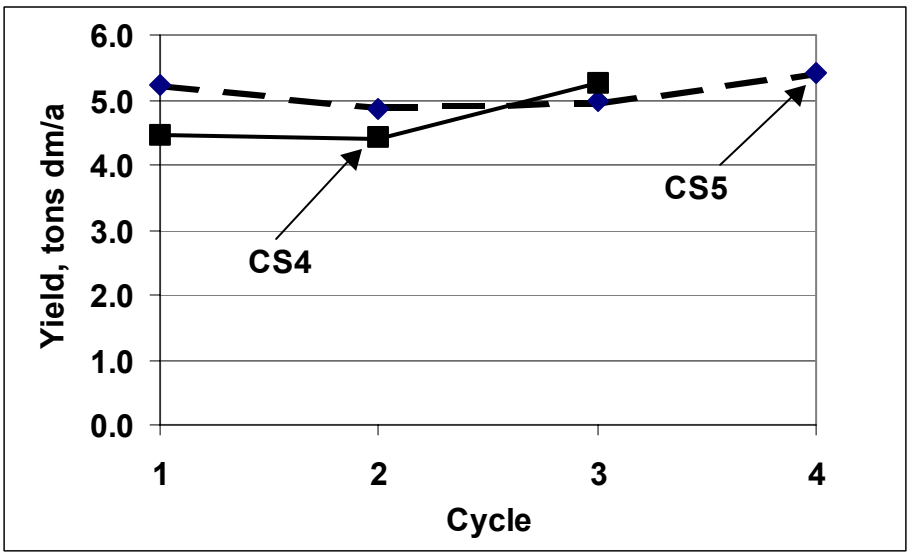

Fig. 9. **Trend of mean 1st year alfalfa yields for CS4 (n=16, except Cycle 2 n=15) and for CS5 (n=12) over cycles**. The regression equation is CS4: Yield = 5.41 –1.40*Cycle + 0.45*Cycle^2. and CS5: Yield = 5.99 – 0.96*Cycle + 0.2049* Cycle^2. The coefficients for both equations are statistically significant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