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# Alternative Crop Rotations for the Central Great Plains

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**Winter wheat (*Triticum aestivum* L.) is the most common dryland crop grown in the central Great Plains. Producers in this region include fallow in the rotation to minimize yield variability due to erratic precipitation. However, fallow degrades soil quality by increasing erosion potential and loss of organic matter. Fortunately, minimum-till production systems and residue management improve water use efficiency by plants, thus producers can crop more frequently. We evaluated eight rotations comprised of various sequences of winter wheat (W), corn (*Zea mays* L.) (C), proso millet (*Panicum miliaceum* L.) (M), sunflower (*Helianthus annuus* L.) (S), and fallow (F) in comparison to W-F at Akron CO. Our goal was to identify rotations that can replace W-F to minimize the frequency of fallow. The soil was a Weld silt loam (Aridic Paleustoll). Continuously cropping with W-C-M and W-M almost doubled total grain yield compared with the conventional system of W-F. Other rotations such as W-C-F, W-C-S-F, and W-C-M-F yielded >60% more on an annualized basis than W-F. Winter wheat yield increased with longer time intervals between wheat crops. Sunflower yielded the most when grown only once every 4 yr; more frequent cropping favored diseases. Sunflower reduced yield of the following crop, especially during dry years. Yield variability was highest with corn and sunflower, whereas proso millet showed the least variability. Producers can manage yield variability by diversifying crops in the rotation, as annualized yield variability of W-M and W-C-M was similar to W-F. With residue maintenance and minimum tillage, producers can crop more frequently, thus increasing land productivity while minimizing the frequency of fallow in this semiarid region.**

SINCE THE 1930S, W-F has been the prevalent cropping system in the central Great Plains (Hinze and Smika, 1983), as producers rely on fallow to minimize impact of erratic precipitation on grain production (Greb, 1983). However, fallow degrades soil quality by increasing erosion potential and loss of organic matter (Peterson et al., 1993). A second negative consequence of W-F is that considerable water is wasted. At Akron, CO, where yearly precipitation is 16.5 in., wheat consumes 14 in. of water to produce 45 bu/acre of grain (Nielsen and Halvorson, 1991). Thus, W-F uses only 42% of precipitation received over 2 yr for crop growth. The remainder of precipitation is lost primarily by evaporation, and in some years, by percolation beyond the rooting depth of wheat.

Minimum-till production systems have changed water relations in our agroecosystem by maintaining more crop residue on the soil surface (Smika, 1990). The residue moderates soil temperature and increases precipitation infiltration, subsequently increasing precipitation storage (Smika and Unger, 1986) and water use efficiency of crops (Peterson et al., 1996). Thus, with minimum-till, more intensive cropping is possible in the central Great Plains. A winter wheat-summer crop-fallow rotation has been productive, with crops such as proso millet (Shanahan et al., 1988), corn (Smika et al., 1986), or grain sorghum [*Sorghum bicolor* (L.)Moench] (Norwood et al., 1990) planted after wheat. In addition, longer rotations with three crops in 4 yr, such as W-C-M-F, are also successful (Peterson et al., 1993). These alternative rotations increase land productivity and net return, yet reduce financial risk compared with W-F (Dhuyvetter et al., 1996). Another potential crop for this region is sunflower (Anderson et al., 1996). A regional processing plant for sunflower and other oil seeds in western Kansas now ensures a local market.

Continuous cropping can be successful with no-till in the semiarid northern Great Plains if a diversity of crops are used (Black et al., 1981). In the central Great Plains, continuous wheat has been examined (Norwood et al., 1990), but

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**Abbreviations:** C, corn; CT, conventional-till; F, fallow; M, proso millet; NT, no-till; RT, reduced-till; S, sunflower; W, winter wheat.

Table 1. Grain yield of wheat (W), corn (C), proso millet (M), sunflower (S), and rotations at Akron, CO, averaged over 4 yr (1994–1997). Fallow is designated as F, and annualized yield and gross returns represent yield of all crops divided by number of years in rotation, including fallow.

| Rotation | Wheat | Corn | Proso millet | Sun-flower | Annualized rotation yield | | Gross return |
|---|---|---|---|---|---|---|---|
| | lb/acre | | | | | % of W-F | $/acre |
| W-F (CT) | 1720 | -- | -- | -- | 860 | 100 | 48 |
| W-F (RT) | 2670 | -- | -- | -- | 1340 | 156 | 75 |
| W-F (NT) | 2550 | -- | -- | -- | 1280 | 149 | 72 |
| W-C-F | 2750 | 2200 | -- | -- | 1650 | 192 | 81 |
| W-M-F | 2660 | -- | 1730 | -- | 1460 | 170 | 77 |
| W-S-F | 1940 | -- | -- | 610 | 850 | 99 | 59 |
| W-C-M-F | 2780 | 2290 | 1740 | -- | 1700 | 198 | 82 |
| W-C-S-F | 2660 | 1930 | -- | 900 | 1370 | 160 | 81 |
| W-M | 1240 | -- | 1930 | -- | 1590 | 185 | 80 |
| W-C-M | 1520 | 2060 | 1830 | -- | 1800 | 209 | 84 |
| M-S | -- | -- | 1090 | 460 | 780 | 91 | 51 |
| LSD (0.05) | 325 | 220 | 255 | 260 | 250 | | |

this rotation often leads to a buildup of root diseases (Cook and Veseth, 1991) and winter annual weeds (Anderson, 1994), often resulting in crop failure. Continuous cropping may succeed in this region if rotations include low water use crops such as proso millet (Shanahan et al., 1988). Another advantage of rotating crops is that yields are generally greater than in monoculture (Kurtz et al., 1984; Porter et al., 1997), a response termed the "rotation effect." This yield response has been related to a multitude of factors, including improved soil physical characteristics and reduced root diseases (Crookston et al., 1991). Minimum-till systems enhance this rotation effect, however, certain crops in rotations can be detrimental to following crops through increased pest problems or high soil water depletion (Pierce and Rice, 1988).

This study evaluated cropping systems composed of various sequences of winter wheat, corn, proso millet, sunflower, and fallow, including continuous cropping. Our goal was to identify rotations that can replace W-F to minimize and possibly eliminate fallow.

## MATERIALS AND METHODS

### Site Description

Nine crop rotations (Table 1) were established in 1990 on a Weld silt loam at Akron, CO. The soil's organic matter level ranges from 0.5 to 1.5% in the top 2 in. Water holding capacity of the top 5 ft is 9.6 in., with potential rooting depth of >5 ft. The site's long-term average precipitation is 16.5 in./yr, with 80% occurring between 1 April and 30 September. About 25% of the annual precipitation is received as snow, whereas 29% occurs in July and August, a critical period of plant development for summer annual crops. Average daily temperature for the year is 48°F, ranging from 25°F in January to 73°F in July. Open pan evaporation for April through September is 61 in.

The experimental design was a randomized complete block with three replications. Plot size was 30 ft by 100 ft. All phases of each rotation were present every year. We analyzed data from 1994 to 1997, with the growing seasons during 1990 to 1993 used to allow rotation effects to develop (Cady, 1991). Yearly precipitation during 1994 to 1997 was 17.4 in., 105% of the 90-yr mean, and ranged from 12.8 to 20.7 in.

Table 2. Cultural practices for establishing winter wheat, corn, proso millet, and sunflower at Akron, CO. For varieties, P represents Pioneer Hi-Bred Seed International and T represents Triumph Seed Company, Inc. In 1997, the wheat variety Akron replaced TAM 107.

| Cultural data | Winter wheat | Corn | Proso millet | Sunflower |
|---|---|---|---|---|
| Variety | TAM 107 | P-3732 | Sunup | T-546 |
| Planting date range | 20–30 Sep | 1–12 May | 5–15 June | 1–10 June |
| Seeding rate, seeds/acre | 860 000 | 15 200 | 830 000 | 18 000 |
| Row spacing, in. | 8 | 30 | 8 | 30 |
| Harvest date range | 1–20 July | 7–25 Oct | 5–20 Sep | 1–20 Oct |

### Agronomic Practices

Cultural practices used for establishing each crop are listed in Table 2. We used minimum tillage with all rotations except W-F, where we compared three tillage systems: conventional-till (CT), reduced-till (RT), and no-till (NT). Conventional-till consisted of three to six sweep plow operations as needed for weed control during fallow. For RT and NT, atrazine + clomazone were applied at 0.5 + 0.3 lb/acre after wheat harvest. Weeds were controlled the next summer by one to three sweep plow operations in RT and by repeat applications of glyphosate at 0.5 lb/acre in NT. Minimum tillage with other rotations consisted of sweep plowing to incorporate herbicides with sunflower or to eliminate perennial grasses.

With all crops following wheat, atrazine + clomazone were applied after wheat harvest. The following spring, glyphosate was applied to eliminate weeds at planting for corn and proso millet. For weed control in corn, atrazine and dimethenamid (2-chloro-*N*-((1-methyl-2-methoxy)ethyl)-*N*-((2-4-dimethyl-thien-3-yl)-acetamide) at 0.8 + 0.8 lb/acre were applied at planting. Dicamba and 2,4-D at 0.3 + 0.4 lb/acre were applied at the two to three leaf stage of proso millet to control broadleaf weeds.

For sunflower, granular ethalfluralin was applied at 1.3 lb/acre 2 wk before planting and incorporated with two passes of the sweep plow. In 1996 and 1997, carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) at 0.3 lb/acre was banded with sunflower seed at planting for insect control.

Weed control was initiated the following spring after corn, proso millet, or sunflower harvest. If fallow was next in sequence, weeds were controlled with one sweep plow operation in June, followed by repeat applications of glyphosate as needed until winter wheat planting. If a crop was next in sequence, the in-crop weed control practices described above for each crop were used.

Fertilizer N was applied to each plot according to soil tests obtained each year and projected crop yield. Soil profiles were sampled in 12-in. increments to a depth of 6 ft. The N source was ammonium nitrate, broadcast before planting the crop. For wheat only, 15 lb P/acre (11-52-0) was banded with the seed at planting.

Plant available soil water was measured during the first week of March for winter wheat, and at planting for corn, millet, and sunflower. Soil water was measured by time-domain reflectometry in the 0 to 12 in. layer, and with a neu-

Table 3. Available soil water, to a depth of 6 ft, each spring for winter wheat (W), and prior to planting for corn (C), proso millet (M), and sunflower (S) in various rotations, at Akron, CO, 1994 to 1997.

| Rotation | Wheat | Corn | Proso millet | Sunflower |
|---|---|---|---|---|
| | in. | | | |
| W-F (CT) | 4.0 | – | – | – |
| W-F (RT) | 5.9 | – | – | – |
| W-F (NT) | 6.7 | – | – | – |
| W-C-F | 6.1 | 6.9 | – | – |
| W-M-F | 5.8 | – | 6.6 | – |
| W-S-F | 3.3 | – | – | 4.5 |
| W-C-M-F | 6.3 | 7.0 | 6.9 | – |
| W-C-S-F | 4.5 | 6.0 | – | 5.5 |
| W-M | 3.0 | – | 6.8 | – |
| W-C-M | 3.7 | 6.8 | 6.3 | – |
| M-S | – | – | 3.9 | 4.2 |
| LSD (0.05) | 1.6 | NS | 2.0 | NS |

tron probe at 18, 30, 41, 53, and 65 in. below the soil surface.

Grain yield was determined by harvesting 500 sq ft of winter wheat and millet, and two rows 80 ft long in corn and sunflower. Grain sample weight was adjusted to 12.5, 15.5, 12, and 10% for winter wheat, corn, proso millet, and sunflower, respectively, to account for seed moisture differences at harvest.

To calculate gross return among rotations, we used the average monthly price at harvest for each crop: winter wheat, \$3.35; corn, \$2.25; proso millet, \$0.047/lb; and sunflower, \$0.11/lb (Christy Pruitt, USDA-Agricultural Marketing Service, Greeley, CO 80631, 1998, personal communication). Data were expressed on an annualized basis to include the fallow investment in land area.

### Statistical Analysis

Data were analyzed with analysis of variance, with rotations and years analyzed as fixed effects. Individual error terms for years were homogenous, and a year × treatment interaction did not occur, therefore data were averaged over years. Treatment means were compared with either Fisher's protected LSD or Duncan's New Multiple Range Test at the 0.05 level of probability. Yield variability was calculated by dividing the standard deviation of yearly means by the treatment mean, and expressed as a percentage. Variability was calculated for each crop in its highest yielding rotation, and for the W-F (RT), W-M, W-C-M, and W-C-M-F rotations, using annualized yield.

## RESULTS AND DISCUSSION

### Rotation Comparison

Wheat yielded 1720 lb/acre in conventional-till W-F, the prevalent cropping system in the region (Table 1). Wheat in RT and NT systems yielded > 2500 lb/acre, almost 50% more than W-F (CT). The W-F systems with less tillage stored more precipitation in the soil than the CT system (Table 3), subsequently increasing yields. This yield response reaffirms the value of minimizing tillage for crop production in this semiarid region (Greb, 1983; Peterson et al., 1996).

To compare rotations, we expressed yield on an annualized basis, which includes fallow land area in the yield computation. Four rotations, W-C-M, W-C-M-F, W-C-F, and W-M yielded at least 80% more than conventional-till W-F (Table 1). With appropriate crop choice, continuous cropping appears promising, as W-C-M yielded 209% of conventional-till W-F. However, this region may not have the biological potential to support continuous cropping with high water use crops like sunflower, as M-S yielded only 43% of W-C-M.

Rotations with the highest annualized yield, W-C-F, W-C-M-F, W-M, and W-C-M, also had the highest gross return (Table 1). One exception, however, was the W-C-S-F rotation, where the high price for sunflower seed increased gross return to levels similar to the higher yielding rotations. Compared with W-F (CT), gross return was increased 70% with the more intensive rotations.

### Individual Crop Response

#### *Winter Wheat*

Wheat yield did not differ among rotations if preceded by fallow, except with W-S-F and conventional-till W-F where wheat yielded less (Table 1). Sunflower impact on wheat yield will be discussed later, whereas reduced yield in conventional-till W-F compared with yields in the RT and NT systems reflects less available soil water during the growing season (Table 3).

Wheat response to rotation and crop sequencing was related to seasonal precipitation. In 1995, a year of above-normal precipitation during the wheat growing season, wheat yield did not increase with a 2-yr interval between wheat crops (W-C-F or W-M-F) compared with W-F (RT or NT), but yield increased 13% with a 3-yr interval, as with W-C-M-F (Fig. 1). Furthermore, diversifying the rotation by adding a broadleaf crop, sunflower in W-C-S-F, increased wheat yield 23%. Thus, increasing the time interval between wheat crops in combination with crop diversity maximized the rotation effect on wheat yield.

Producers are seeking crop sequences that eliminate fallow before winter wheat without severe yield losses. Wheat

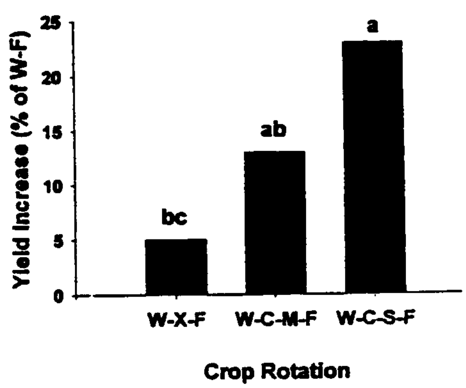


Fig. 1. Yield of winter wheat at Akron, CO, as affected by rotation in 1995. W-X-F is the average of W-C-F and W-M-F. Means differences were determined with the Duncan's New Multiple Range Test at the 0.05 level of probability. Bars with the same letter are not significantly different and the letter c signifies that rotation yield did not differ from W-F (average of RT and NT).

yield in W-C-M did not differ from W-F (CT); in contrast, wheat in W-M yielded only 72% of W-F (CT) (Table 1). These results demonstrate that with appropriate crop sequencing and minimal tillage, wheat yields will not be drastically reduced in continuous cropping.

### *Corn*

Corn yields were greatest in W-C-F or W-C-M-F (Table 1), whereas corn in W-C-M and W-C-S-F yielded 10% less than in W-C-M-F. We are unable to explain why yields in W-C-M and W-C-S-F were lower, since soil water at planting did not differ among rotations (Table 3).

Corn yield varies with amount of precipitation received during silking (Westgate and Boyer, 1986). Our corn yield ranged from 600 to 4680 lb/acre over years. In 1997, when precipitation during July was only 40% of normal, drought stress led to poor pollination and subsequently a yield of only 600 lb/acre. In contrast, precipitation was 125% of normal during tasseling and pollination in 1996, resulting in corn yield of 4680 lb/acre. Because of below-normal precipitation during pollination in 3 of the 4 yr of our study, corn yield was lower than the long-term average of 3200 to 3500 lb/acre at the Central Great Plains Research Station (Nielsen et al., 1996; Smika et al., 1986).

### *Proso Millet*

Proso millet yield did not differ whether following wheat or corn, with yields ranging from 1730 to 1930 lb/acre (Table 1). Following sunflower, however, yield was reduced 44% compared with proso millet yield in W-M, because of less soil water available for crop growth (Table 3). This yield response of proso millet demonstrates the negative impact sunflower can have on the next crop in sequence.

### *Sunflower*

Yield of sunflower was highest in the W-C-S-F rotation, but sunflower yielded 32% less in W-S-F and 49% less in M-S (Table 1). In 1996, phoma (*Phoma macdonaldii* Boerma) infested sunflowers in M-S and W-S-F. This soil-borne fungus infests and weakens the stem, eventually causing plants to lodge (Guyla et al., 1994). We counted number of lodged plants at harvest in 1996 and 1997. Greater than 40% of sunflower plants lodged in M-S and W-S-F in both years, thus reducing sunflower yield. No lodging occurred in W-C-S-F. To control phoma and other soil-borne root diseases, sunflower should be grown only once every 4 yr (Guyla et al., 1994).

Sunflower can reduce yield of subsequent crops, even after a fallow period. For example, wheat yielded 30% less in W-S-F than in W-C-M-F (Table 1). We speculate that sunflower stems weakened by phoma in W-S-F lodged earlier during the noncrop period, thus minimizing snow catch during winter and subsequently, soil water levels (Table 3). Secondly, sunflower extracts more water from the soil profile than other crops (Black et al., 1981), thus leaving less water in the soil for future crops.

Surprisingly, wheat yield in W-C-S-F did not differ from W-C-M-F, when averaged over 4 yr (Table 1). However, sunflower effect on wheat yield with W-C-S-F varied with precipitation received during the wheat growing season. During two growing seasons of winter wheat that received above normal precipitation, wheat yield increased more than 11% with both W-C-S-F and W-C-M-F compared with W-F (average of RT and NT) (Fig. 2). In contrast, during two growing seasons with below normal precipitation, wheat yield decreased 8% in W-C-S-F, whereas wheat yield was not reduced in W-C-M-F. Part of this response in the dry years may be related to difference in soil water use by proso millet and sunflower. Wheat yielded more in W-C-S-F than in W-S-F (Table 1), which we attribute to improved snow catch by sunflower stalks after harvest in W-C-S-F, as sunflower lodging did not occur in this rotation.

### Yield Variability

Fallow was adopted by producers because of extreme variability of wheat yield due to erratic precipitation. This experience leads producers to perceive that more intensive cropping will increase yield variability. Among the four crops in our study, corn and sunflower yields were the most variable; standard deviation of yield was 53 and 69% of the yearly mean for corn and sunflower, respectively (data not

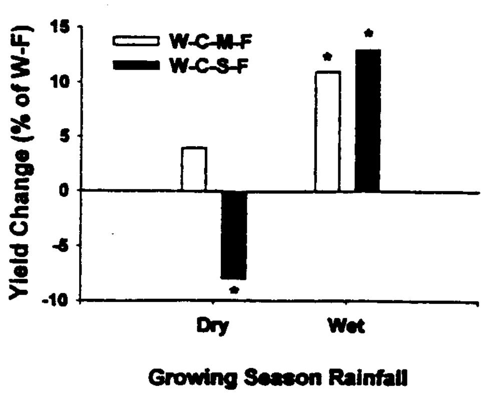


**Fig. 2. Yield of winter wheat at Akron, CO, as affected by rotation and rainfall levels, 1994 to 1997. An asterisk indicates that means within growing season rainfall categories differed significantly ($P$ > 0.05) from yield in W-F (average of RT and NT).**

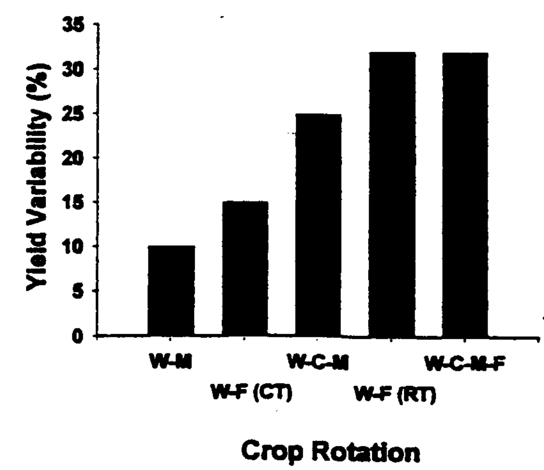


**Fig. 3. Annualized yield variability of five rotations at Akron, CO. Variability was calculated as standard deviation of yearly annualized means divided by the rotation's overall mean.**

shown). Wheat's variability was 27%, whereas proso millet varied 15%. This was expected, as corn and sunflower are more responsive to precipitation near flowering than proso millet or wheat (Lyon et al., 1995).

Diversifying crops in the rotation, however, minimized annualized yield variability, which we calculated by dividing standard deviation of yearly annualized means by the rotation's overall mean. During the 4 yr of our study, variability of wheat yield with conventional-till W-F was 15%, whereas W-F (RT) yield varied 32% (Fig. 3). Surprisingly, yield variability of W-M was only 10%, less than either W-F system, and W-C-M's variability of 27% was less than either W-F (RT) or W-C-M-F. From a land area perspective with annualized yield, continuous cropping did not increase yield variability compared with W-F.

Our study demonstrates that continuous cropping is possible, if tillage is minimized and rotations include low water use crops such as proso millet or forages. Continuous cropping will enable producers to protect their soil resource from erosion (Doran et al., 1996) and improve soil quality (Bowman et al., 1996), thus favoring agricultural sustainability of the central Great Plains.


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## Research Question

Since the 1930s, winter wheat-fallow has been the prevalent crop rotation for the semiarid Central Great Plains. Because available water is usually the most limiting resource, producers rely on fallow to minimize the impact of erratic precipitation on grain production. However, fallow degrades soil quality by increasing erosion and loss of organic matter.

Development of minimum-till production systems has altered the water relations in our agroecosystems. Minimizing tillage leaves more crop residue on the soil surface, subsequently increasing precipitation storage and water use efficiency of crops. Thus, with minimum-till systems, more intensive cropping is possible in the central Great Plains.

This study evaluated cropping systems composed of various sequences of winter wheat (W), corn (C), proso millet (M), sunflower (S), and fallow (F), including continuous cropping. Our goal was to identify rotations that may be successful alternatives to W-F.

## Literature Summary

With reduced-till systems, several crops have been successful in a wheat-summer crop-fallow rotation in this region, including proso millet, corn, and grain sorghum. In addition, longer rotations with three crops in 4 yr, such as W-C-M-F, are also successful and have increased land productivity by 70%. Another potential crop for this region is sunflower. Economic analysis indicates that these alternative rotations increase net return and reduce financial risk.

With no-till systems, continuous cropping has been successful in the semiarid northern Great Plains. In the central Great Plains, continuous wheat has been tested, but this practice leads to a buildup of root diseases and winter annual weeds, often resulting in crop failure. However, continuous cropping may succeed in this region if a diversity of crops is used, especially crops with low water use such as proso millet.

## Study Description

| | | | |
|---|---|---|---|
| Rotations: | W-F | W-C-F | W-M-F |
| | W-S-F | W-C-M-F | W-C-S-F |
| | W-M | W-C-M | M-S |

Location: Akron CO
Reporting Period: 1994–1997.
Yearly precipitation: 16.9 in. during the study, 16.5 in. long-term average.
Soil: Weld silt loam (fine, smectitic, mesic Aridic Paleustoll)
Tillage: Minimum with all rotations, except W-F, where conventional-till (CT), reduced-till (RT) and no-till (NT) were compared.

## Applied Questions

**Can producers crop continuously in the drier regions of the central Great Plains?**

The prevalent cropping system in the region, conventional-till W-F, yielded 1720 lb/acre. Two continuous cropping rotations, W-C-M and W-M, yielded at least 80% more than conventionally tilled W-F on an annualized yield basis. In

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contrast, M-S y...ded less than W-F. Thus, with appropriate crop choice, continuous cropping appears promising. However, this region may not have the biological potential to support continuous cropping with high water use crops like sunflower.

**By cropping more frequently, will yield variability increase?**

Fallow was adopted by producers in the 1930s because of the extreme variability of yield due to erratic precipitation. Thus, producers are concerned that more intensive cropping will lead to more yield variability. In our study, yield variability was high with individual crops, however, at the rotation level, diversifying crops minimized yield variability. Variability of wheat yield in W-F ranged from 15 to 32% among tillage systems (Fig. 1). In contrast, annualized yield variability with W-M was only 10%, whereas W-C-M's variability was 27%. This demonstrates that on a land area basis with annualized yield, continuous cropping does not increase overall yield variability.

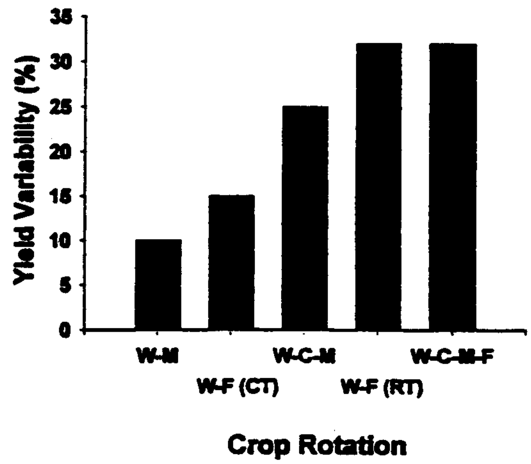


**Fig. 1. Annualized yield variability of five rotations at Akron, CO. Variability was calculated as standard deviation of yearly annualized means, divided by the rotation's overall mean.**