Designing Rotations for a Semiarid Region

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Rotation Design Highlights

1. Determine cropping potential with precipitation use
   Continuous cropping: 80%
   Rotations with fallow: 65%

2. Plan a cycle of 4 years with summer and winter crops to favor the rotation effect and pest management

3. Diversify crops to maximize yield

With improved residue and water conservation techniques, more intensive cropping is now possible in the central Great Plains (16). The USDA-ARS Research Station at Akron, CO initiated a study in 1990 to evaluate several rotations as alternatives to winter wheat-fallow. The study is located on a Weld silt loam, with winter wheat (W), corn (C), proso millet (M), sunflower (S), and fallow (F) combined in various sequences. With all rotations, we use minimal tillage. The site's long-term precipitation average is 16.5 inches per year. Our results demonstrate that this region has a greater cropping potential than W-F, as annualized yield (yield expressed on a land area basis, with fallow included) increased 67% with a W-C-M rotation compared to W-F.

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Before the development of agricultural chemicals, crop rotations were a key component of production systems for fertility and pest management. With no-till systems and more intensive cropping, semiarid producers can now accrue benefits from crop rotations (12). However, certain crops in rotations can be detrimental to following crops through increased pest problems or high water use (17). Therefore, this paper suggests guidelines to design rotations for semiarid regions that maximize rotational benefits yet minimize detrimental effects. Principles related to water use, crop diversity, and length of rotation will be examined in conjunction with data from the ARS crop rotation study.

Rotations: Precipitation Use

In the central Great Plains, available water is usually the most limiting resource. Presently, producers rely on the wheat-fallow (W-F) rotation to minimize the impact of the region's erratic precipitation on grain production. However, W-F wastes considerable water. Wheat consumes 14 inches of water to produce 45 bu/ac of grain (Table 1), thus, the system's precipitation use (SPU: crop water use / fallow + growing season precipitation) for W-F is 14/33 = 42%. The remainder of available water is lost primarily by evaporation, and in some years, by leaching beyond the rooting depth of plants.

No-till systems increase the amount of precipitation available for crop use. In the northern Great Plains, successful rotations with continuous cropping use nearly 80% of precipitation (3). We can achieve similar SPU levels in this region, as our most successful rotation, W-C-M, uses 80% of the precipitation received during the rotation cycle (13+15+12/50= 80% : see Table 1 for water use of various crops). In contrast, if average water use of crops in continuous cropping requires a SPU of 85%, this exceeds our system's limits at Akron. For example, normal yields of C-S would result in a SPU of 85% (28/33). However, corn yields only 12 bu/ac whereas sunflower yields 480 lbs/ac in this rotation, reflecting the shortage of water.

Therefore, producers can use a value of 80% to estimate their system's water supply for continuous cropping. In a 16-inch precipitation zone, producers will have approximately 13 inches of water available for crop use each year. Table 1 also includes the yield change per inch of water used by the crop, thus, producers can plan rotations with potential yield goals for their location.

Table 1. Water use of wheat, corn, sunflower, and proso at Akron (15).

Crop	Average yield	Water use (inches)	Yield/ additional inch
Wheat	45 bu/ac	14	7 bu/ac
Corn	60 bu/ac	15	10 bu/ac
Sunflower	1200 lb/ac	13	160 lb/ac
Proso	2050 lb/ac	12	240 lb/ac

If fallow is included in the rotation, a target SPU for minimal-till systems would be 65%. Successful rotations like W-C-S-F or W-C-M-F both have a SPU near 65%. Rotations such as W-C-F or W-M-F have SPUs of 53 to 59%, which suggests that these rotations may be wasting yield potential because available water is not being used. The target SPU is lower for rotations with fallow because long fallow periods are inefficient in storing precipitation in soil (16).

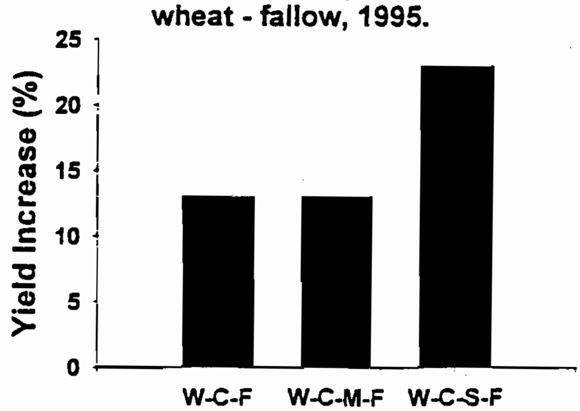
Rotations: Crop Diversity

Because no-till systems increase the amount of available water for crops, producers may consider continuous wheat. However, this practice may hinder crop productivity, as rotating crops generally increase yield compared to monoculture (12, 18). This yield effect was first observed with corn in a corn-soybean rotation, with the beneficial effect related to N supplied by soybean (7). Later, non-N benefits also were recognized, such as reduced root diseases (6, 7). A further consideration is that no-till systems enhance the yield response to rotations (17).

Wheat also responds to the rotational effect (11, 13), mainly due to changes in the soil microbial community and root health of wheat (6). In the Pacific Northwest, grain yield is increased 15% if the time interval between wheat crops is increased from 1 to 2 years.

Similar results occurred in our study in 1995, a year of above-normal precipitation that favored root diseases. Wheat yield increased 13% with the W-C-F rotation compared to W-F (Figure 1). Yield did not change when the time interval increased from 2 to 3 years, if only grass crops were used (W-C-M-F). However, planting a broadleaf crop, sunflower, after corn increased wheat yield 23%.

Figure 1. Wheat yield in alternative rotations compared to wheat - fallow, 1995.



Thus, increasing the time interval between wheat crops in combination with crop diversity (broadleaf crops) maximizes the rotational effect on wheat yield, especially in wet years. Similar time interval and crop diversity effects have been found with corn (18) and proso (2). This rotation effect on yield also increases with time. Since 1994, yield of both wheat and proso have increased 5% per year in W-C-M compared to W-M, reflecting the longer time interval between crops and greater crop diversity.

Rotations: Length

Another consideration related to rotation design is pest management, as producers can minimize pest populations with appropriate crop combinations. With weeds, seeds in the soil are the source for plants establishing in the crop. However, number of live seeds in soil decline at a characteristic rate, due to germination, predation, or death. Green foxtail and field sandbur seed population declines rapidly, with 30% or less of seeds remaining after 1 year (Table 2). After 2 years, less than 10% of seeds of either species are alive. Populations of winter annual grass seed decrease similarly over time, except that jointed goatgrass persists longer than the other species.

Table 2. Longevity of seed survival in soil of four weeds (1, 2, 4, 5, 8).

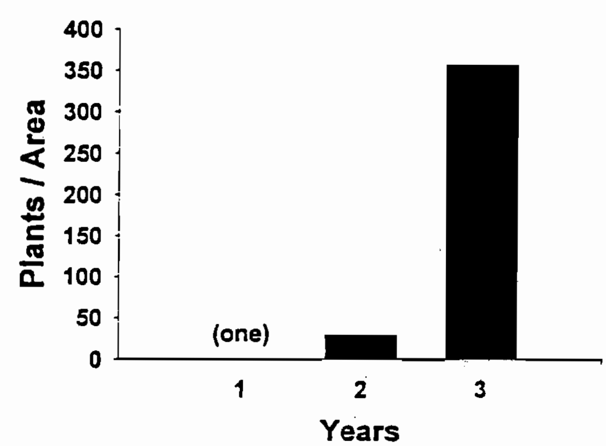
Years in soil	Green Foxtail	Field Sandbur	Downy Brome	Jointed Goatgrass
	% live seed remaining			
1	18	30	20	60
2	5	8	5	25
3	2	3	2	8

By growing winter annual crops for two years and controlling weeds during non-crop periods, producers can reduce seed population of summer annual grasses in soil by > 90%. Conversely, growing summer annual crops for 2 years will reduce the seed bank of jointed goatgrass and downy brome by > 75%. This suggests that a 4-yr cycle with 2 years in winter crops and 2 years in summer crops will favor a decline of weed seed in soil of both winter and summer annual weeds, and subsequently, reduce weed densities in future crops.

Weed populations also demonstrate a characteristic growth rate, as shown with green foxtail. Normally, one green foxtail plant produces approximately 2500 seeds (2), of which 5% of these seeds will emerge the next year (9). Thus, if producers control 85% of the green foxtail plants in year 2, green foxtail density will increase at a rate of 19 times per year (Fig. 2).

This characteristic indicates that with normal management, weeds will require 3 years for extensive population growth to occur. Using the cycle of 4 crops with 2 years in winter crops followed by 2 years in summer crops, producer will minimize future weed populations.

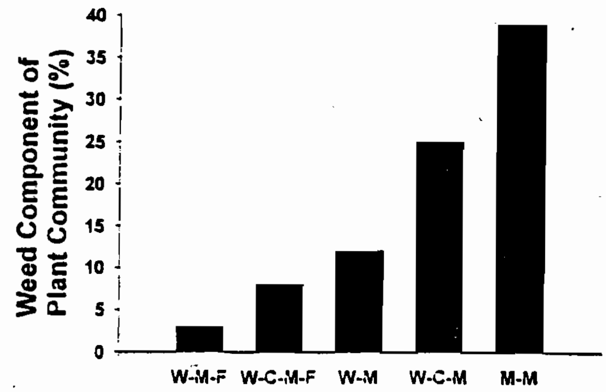
Figure 2. Population growth of green foxtail over time.



This principle is being demonstrated in the Akron rotations study. We determined the weed component of the crop biomass in proso of various rotations. If number of summer crops was greater than winter crops (W-C-M or M-M), weeds comprised 25 to 40% of the plant biomass (Figure 3). In contrast, with W-C-M-F, weeds were only 12% of the total biomass, whereas in W-M-F, with only 1 summer crop in 3 years, less than 3% of the biomass was weeds.

In the central Great Plains where winter wheat is the most prevalent and valuable crop, producers may want to maintain a high percentage of their land base in wheat. Thus, a producer may grow 2 years of winter wheat in a row, a practice that may reduce grain yield in the second year (19).

Figure 3. Weed infestation in proso of various rotations, after 8 years.



However, this yield loss, caused by root diseases (6), also is related to time needed for population growth of the root pathogen. Yield loss in the 2nd year of continuous wheat averages 8%, ranging from 0 to 19% (11, 13, 14, 19). The variation in yield loss is caused by differences in growing season precipitation, with more yield loss in wet years (14). Yield losses continue to increase with time as root pathogen populations increase, as 3 years of continuous wheat lead to 20% yield loss. Thus, if a producer follows a crop cycle of 4 with winter and summer crops, yield loss due to root diseases can be minimized by growing wheat only 2 years in a row.

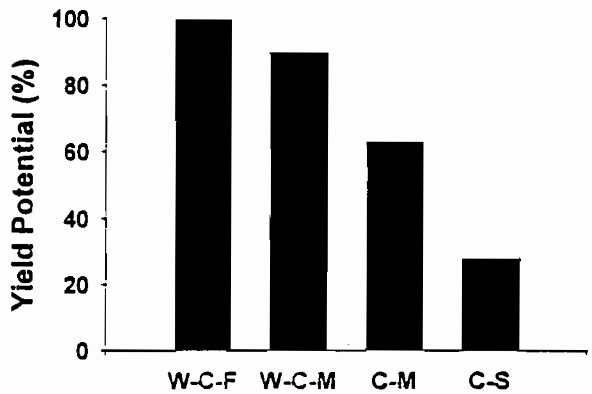
Producers may prefer 2-year rotation cycles in place of 4 years. However, we tested eight 2-year rotations of various combinations of corn, proso, sunflower, and wheat at Akron. Only W-M was successful, with the other seven rotations failing due to either low yields or excessive weed problems. Also, the rotation effect related to time between crops is minimized in 2-year rotations.

Rotations: Crop Sequencing

Crops in sequence can be either favorable or detrimental to the following crop, as shown by crop response to various sequences in the ARS crop rotation study at Akron.

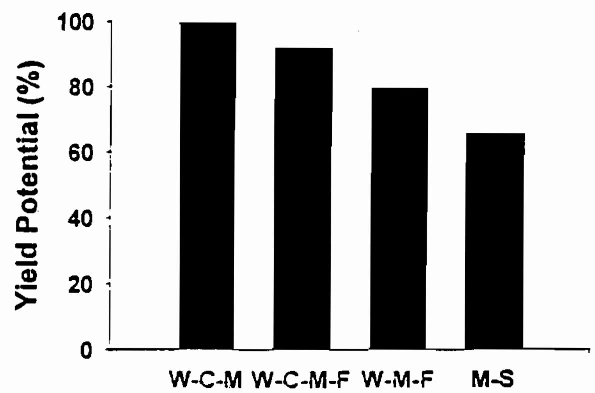
Corn: The most favorable sequence for corn is to follow wheat, such as W-C-F (Figure 4). Corn yield in 2-year rotations such as C-M or C-S was reduced at least 40%. Corn in W-C-M yielded 10% less than in W-C-F, which we attribute to less residue production by wheat planted into proso stubble (20).

Figure 4. Corn yield as affected by crop sequence.



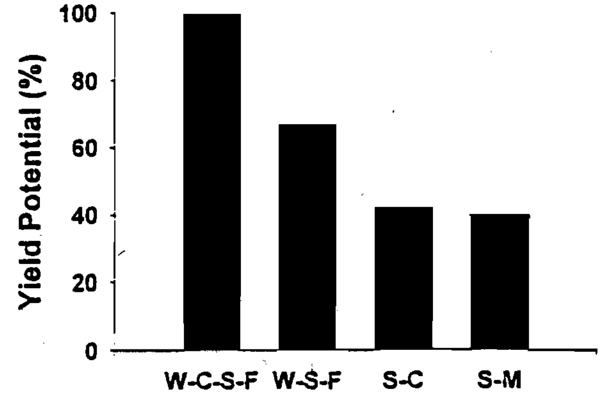
Proso: Proso yield was highest in the W-C-M rotation (Figure 5). Surprisingly, proso yielded less in the W-M-F rotation than in either W-C-M-F or W-C-M. Following sunflower, proso yield was reduced 34%. Compared to corn or sunflower, proso yield was least affected by the previous crop.

Figure 5. Proso yield as affected by crop sequence.



Sunflower: Sunflower yield was highest in the W-C-S-F rotation (Figure 6). Sunflower yielded 60% less in the 2-year rotations, C-S and M-S. Similarly to proso, sunflower yielded 29% less in the 3-year rotation, W-S-F, than with the 4-year rotation W-C-S-F.

Figure 6. Sunflower yield as affected by crop sequence.



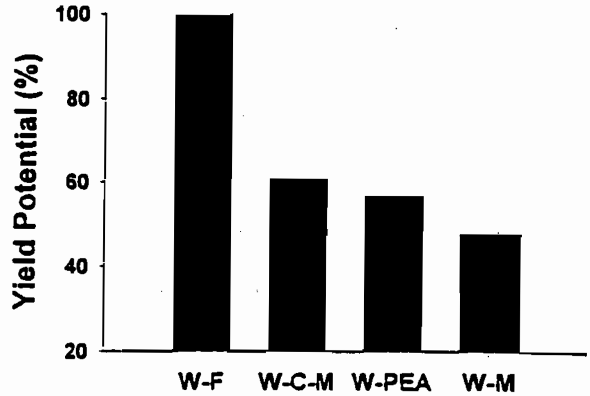
The yield reduction of sunflower in W-S-F and the 2-year rotations was caused partially by phoma. This soil-borne fungus infests the stem, interferes with plant translocation, and weakens the stem (10), which can cause plant lodging. In 1996, over 40% of the sunflower stand in the W-S-F and 2-year rotations lodged, while no lodging occurred in the W-C-S-F rotation. To control phoma and other related root diseases such as sclerotinia, sunflowers should be grown only once every 4 years (10).

Sunflower can impact yield of following crops, even after a fallow period. Wheat yields were 28% less in the W-S-F rotation compared to either W-C-S-F or W-F. We are unable to explain why, but we speculate that sunflower stems weakened by phoma lodge earlier during the non-crop period, thus minimizing the amount of snow catch during winter in the W-S-F rotation.

Both proso and sunflower yielded well when grown after corn in 4-year rotations. Furthermore, both crops yielded more in 4-year rotations than in 3-year rotations with wheat and fallow (Figure 5 and 6). This suggests that sunflower and proso may respond to the time interval between crops, similarly to winter wheat, or that corn has a synergistic effect on following crops.

Wheat: Producers are interested in a crop sequence that eliminates fallow before winter wheat. Compared to wheat yield after fallow, the highest wheat yields in continuous cropping occurred in W-C-M, where yield was 61% of wheat after fallow (Figure 7).

Figure 7. Winter wheat yield as affected by crop sequence.



Wheat yielded 57% of W-F when planted after field pea (PEA), and 48% of W-F when planted after proso in the W-M rotation. The increased wheat yield in W-C-M compared to W-M reflects the rotation effect of more time between crops as well as more crop diversity.

In summary, producers can improve their land productivity and quality by careful crop sequencing, especially in a crop cycle of 4, that maximizes the rotational effect on yield, favors pest management, and increases ecological diversity.

Literature Cited

1. Anderson, R.L. 1994. Management strategies for winter annual grasses in winter wheat. p. 114-122, in Murphy, L.S. (ed.) Proceedings, National Intensive Wheat Management Conference. PPI and FAR, Denver, CO. 157 pages.
2. Anderson, R. L. 1997. Unpublished data from research in progress. USDA-ARS, Central Great Plains Research Station, Akron CO.

3. Black, A. L. and F. H. Siddoway. 1980. Cropping strategies and nitrogen fertilization for efficient water use. Proceedings, USDA-SCS Tillage Symposium. Bismarck, ND. Sept. 9-11, 1980.
4. Burnside, O. C., C. R. Fenster, L. L. Evetts, and R. F. Mumm. 1981. Germination of exhumed weed seed in Nebraska. Weed Sci. 29:577-586.
5. Burnside, O. C., R. G. Wilson, G. A. Wicks, F. W. Roeth, and R. S. Moomaw. 1986. Weed seed decline and buildup in soils under various corn management systems across Nebraska. Agron. J. 78:451-454.
6. Cook, R. J. and R. J. Veseth. 1991. Wheat health management. Am. Phytopathological Society Press, St. Paul, MN.
7. Crookston, R. K., J. E. Kurle, P. J. Copeland, J. H. Ford, and W. E. Lueschen. 1991. Rotational cropping sequence affects yield of corn and soybean. Agron. J. 83;108-113.
8. Dawson, J. H. and V. F. Burns. 1975. Longevity of barnyardgrass, green foxtail, and yellow foxtail seeds in soil. Weed Sci. 23:437-440.
9. Forcella, F., R. G. Wilson, J. Dekker, et al. 1997. Weed seed bank emergence across the Corn Belt. Weed Sci. 45:67-76.
10. Guyla, T., B. Nelson, and A. Lamey. 1994. Diseases. p. 44-62, *in* D. R. Berglund (ed.) Sunflower Production. No. Dak. St. Univ. Ext. Serv. Bull. 25.
11. Hammel, J. E. 1995. Long-term tillage and crop rotation effects on winter wheat production in Northern Idaho. Agron. J. 87:16-22.
12. Kurtz, L. T., L. V. Boone, T. R. Peck, and R. G. Hoeft. 1984. Crop rotations for efficient nitrogen use. p. 295-306 *in* R. D. Hauck (ed.) Nitrogen in Crop Production. American Society of Agronomy, Madison, WI.
13. Larney, F. J. and C. W. Lindwall. 1994. Winter wheat performance in various cropping systems in southern Alberta. Can. J. Plant. Sci. 74:79-86.

14. Lopez-Bellido, L., M. Fuentes, J. E. Castillo, F. J. Lopez-Garrido, and E. J. Fernando. 1996. Long-term tillage, crop rotation, and nitrogen fertilizer effects on wheat yield under rainfed Mediterranean conditions. Agron. J. 88:783-791.
15. Nielsen, D. C. 1995. Water use/yield relationships for central Great Plains crops. USDA-ARS and NRCS Fact Sheet #2-95. Akron CO.
16. Peterson, G. A., A. J. Schlegel, D. L. Tanaka, and O. R. Jones. 1996. Precipitation use efficiency as affected by cropping and tillage system. J. Prod. Agric. 9:180-186.
17. Pierce, F. J. and C. W. Rice. 1988. Crop rotation and its impact on efficiency of water and nitrogen use. p. 21-42 *in* W. L. Hargrove (ed.) Cropping Strategies for efficient use of water and nitrogen. American Society of Agronomy, Madison, WI.
18. Porter, P. M., R. K. Crookston, J. H. Ford, D. R. Huggins, and W. E. Lueschen. 1997. Interrupting yield depression in monoculture corn: comparative effectiveness of grasses and dicots. Agron. J. 89:247-250.
19. Vyn, T. J., J. C. Sutton, and B. A. Raimbault. 1991. Crop sequence and tillage effects on winter wheat development and yield. Can. J. Plant. Sci. 71:669-676.
20. Wicks, G. A., D. A. Crutchfield, and O. C. Burnside. 1994. Influence of wheat straw mulch and metolachlor on corn growth and yield. Weed Sci. 42:141-147.