

Designing Rotations to Favor Natural Benefits

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Anderson received his B.S. and M.S. degrees for South Dakota State University in Agronomy/Weed Science and his Ph.D. from the University of Wyoming in Agronomy/Crop Production. Currently, he is a research leader in Brookings leading a multi-disciplinary team of five scientists in creating new knowledge and concepts in soil health, residue conservation, water, nutrient and weed management, and minimum tillage. Dr. Anderson's research focuses on understanding the ecology of weeds and developing integrated management systems based on ecological weaknesses of weeds. The goal is to minimize herbicide use and input costs. Author of 113 scientific publications, he is known for his leadership and research in weed ecology, alternative crops, and integrated production systems. Anderson spent a number of years at the ARS station in Akron, Colorado prior to his work in Brookings.

Designing Rotations to Favor Natural Benefits

Introduction: Current production systems are struggling with rising input costs and weeds that are resistant to herbicides. Diversifying crops in rotation will enable producers to improve crop yield with adding inputs as well as reduce the population levels of weeds such that herbicide use can be lowered.

I. Rotating crops can increase grain yield

- a. Water use efficiency is improved with rotations
- b. Some crops, especially corn, are synergistic to following crops

II. Rotations help manage plant diseases

- a. Yield increases with longer intervals between growing the same crop
- b. Oilseeds are most responsive to cropping interval

III. Weed density can be reduced in diverse rotations

- a. Greatest impact is if two winter annuals are followed by two summer annual crops
- b. Effect is related to rate death of weed seeds in soil

Close: Arranging crops in a cycle of four accrues multiple benefits for the producers; yields are increased with the rotation effect; whereas weed density is minimized, thus input costs can be reduced.

Designing Rotations to Favor Natural Benefits

Our current crop production approach, relying on rotations with few crops, is generating a series of trends that threaten the economic future of producers. One trend is that production costs continue to increase, yet prices for crop products remain unchanged or are decreasing. To ensure economic survival, producers have been increasing crop inputs with the goal of increasing yields to offset these costs; the final consequence, however, is a crop input treadmill.

A second trend is development of pesticide resistance. Numerous species of insects, plant pathogens, and weeds are now resistant to commonly-used pesticides (Holt and LeBaron, 1990). A further concern is the proliferation of pest-crop associations, where rotations with few crops lead to pests highly adapted to those crops. A striking example occurs with corn. Agrochemicals led producers to grow corn more frequently in their rotations; consequently, corn rootworm (*Diabrotica* spp.) is now so common that crop losses and control costs approach \$1 billion annually (Sutter and Lance, 1991). Similarly in winter wheat, producers struggle to control weeds such as the brome species and jointed goatgrass that have similar life cycles to winter wheat (Wicks, 1984).

Producers can counter these trends by diversifying crop rotations. This approach enables producers to integrate alternative tactics for pest and fertility management, thus possibly reducing input costs. Rotations can be designed to disrupt pest population growth, which reduces need for pesticides (Pedigo, 1995), whereas some sequences of crops improve grain yield and resource-use-efficiency without requiring more management inputs (Kurtz et al., 1984). A diverse crop rotation can accrue natural benefits that will help producers control input costs and avoid accentuating pest problems. The objective of this paper is to examine impact of crop diversity on crop growth and pest management, then suggest guidelines for producers to design rotations that favor the natural benefits of crop diversity.

Positive Interactions Among Crops

Rotating crops can increase grain yield

Diversifying crops in rotation favors the “*rotation effect*”, where rotating crops generally increases yield compared to monoculture (Porter et al., 1997). For example, wheat grain yield is increased 15 to 30% if rotated with broadleaf crops such as dry pea or flax, compared to continuous wheat (Wright, 1990). Rotating corn with soybean also increases grain yield of both crops 10% compared to monocultures of each crop, whereas yields increased 15% if either crop was grown only once in three years (Crookston et al., 1991). The authors suggested adding a third crop to the rotation to accentuate the rotational yield benefits with corn and soybean.

Some crops improve water-use-efficiency of following crops

A long-term rotation study at Akron CO is showing some surprising interactions among crops (Anderson et al., 1999). Corn improves water-use-efficiency of winter wheat. In a wheat-corn-fallow (W-C-F) rotation, wheat produced 3010 kg/ha with 250 mm of water; in contrast, wheat in a wheat-proso millet-fallow (W-M-F) rotation produced only 2060 kg/ha with the same water use (Figure 1). With corn in the rotation, wheat produced 46% more grain with the same water use as wheat in a W-M-F rotation.

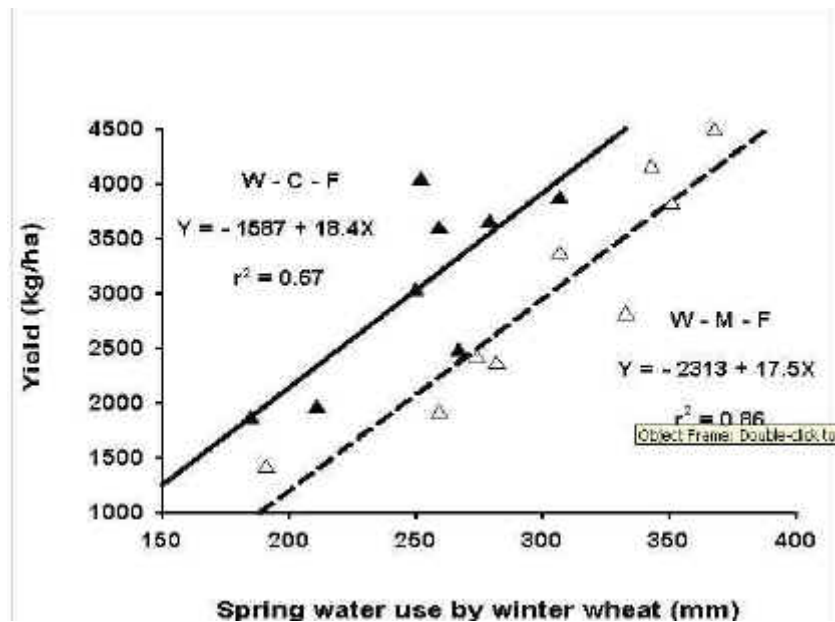


Figure 1. Water use relationships of winter wheat in two rotations: wheat-corn-fallow (W-C-F) and wheat-proso-fallow (W-M-F). Data averaged across three years, Akron CO.

Corn also improves water-use-efficiency of proso millet. During a six-year period, proso grain yield was 2420 kg/ha in winter wheat-corn-proso; in contrast, proso grain yield was 2050 kg/ha in wheat-proso, a decrease of 15%. Water use by proso in these rotations was similar, however, proso was 17% more efficient in converting water into grain when grown after corn compared to wheat. Also, corn's effect on proso was related to growing season precipitation; proso's water-use-efficiency was higher in wet years.

Surprisingly, including fallow in the rotation eliminated corn's effect on proso grain yield and water-use-efficiency. Proso grain yield did not differ in wheat-corn-proso-fallow and wheat-proso-fallow, rotations with the same crop sequence as above, but including fallow. Furthermore, proso grain yield in these rotations was similar to wheat-proso, 15% less than in the wheat-corn-proso rotation. This trend suggests a fallow by crop interaction, as fallow did not eliminate corn's effect on wheat (Figure 1) as occurred with proso.

Diversifying crops accentuates the rotation effect, especially in semiarid climates

It has been difficult to identify the cause of the rotation effect, as it most likely represents a complex interaction of factors such as changes in soil moisture levels, nutrient availability, soil structure, soil microbial community, or pest infestations (Kurtz et al., 1984). However, the rotation effect appears to be a universal phenomenon with appropriate crop sequencing. A guiding principle in designing rotations is to diversify crops as much as possible, especially rotating grass and broadleaf crops. The rotation effect may be especially valuable in semiarid climates, as improved water-use-efficiency with some crop sequences will help producers adjust to drought conditions.

Rotations and Pest Management

Rotation design can help manage plant diseases

Dynamics of some plant diseases are related to how frequently the crop is grown in rotation. To quantify this impact, we can compare crop yields based on "crop interval", which we define as the number of years before the same crop is grown again. For example, the crop interval for winter wheat-fallow is two, whereas in winter wheat-corn-fallow, the crop interval is three for each crop. In our rotation study at

Akron CO, sunflower yields the most when grown once every four years (Figure 2); if grown more frequently, the soil-borne disease phoma (*Phoma macdonaldii* Boerma) severely reduces yield (Anderson et al., 1999). Yields of corn and winter wheat are reduced when grown every two years compared to a four-year crop interval, whereas proso millet is not affected by crop interval.

Corn and winter wheat respond similarly to crop interval in other regions of the U.S. In Minnesota, corn yield is highest when grown once every three years (Porter et al., 1997), whereas winter wheat yield in the Pacific Northwest also is highest with a crop interval of three years (Cook and Veseth, 1991). In the Central Great Plains, devising rotations based on a cycle of four years enables producers to include oilseed crops such as sunflower or canola in rotations, as a four-year crop interval is necessary to prevent serious plant diseases with oilseeds (Bailey 1996).

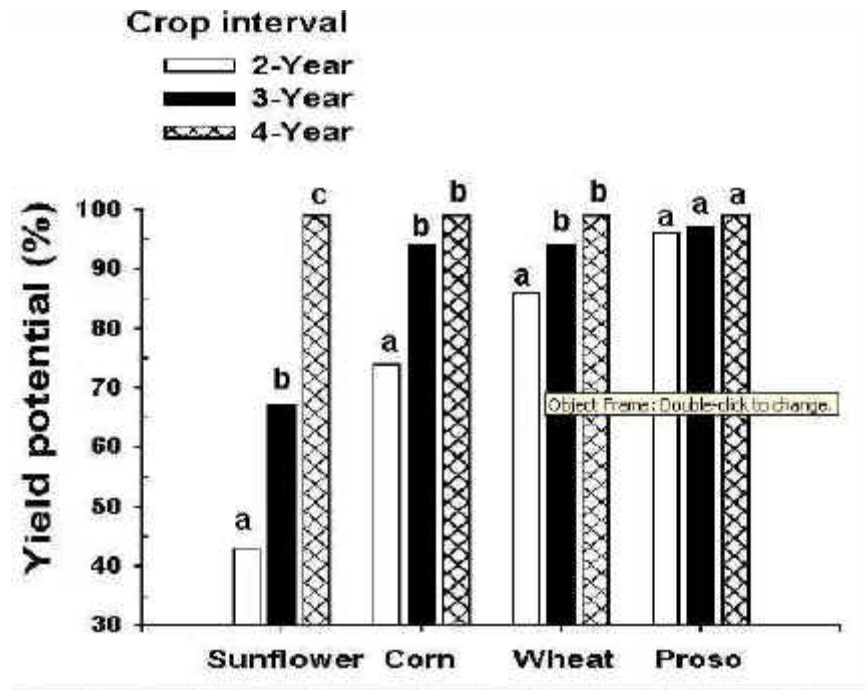


Figure 2. Yield of various crops as affected by crop interval, at Akron CO. Data are averaged across four years; an asterisk signifies that two-year or three-year interval mean differed from four-year mean within each crop.

Rotations can be designed to minimize weed densities

In the rotation study at Akron CO, a series of rotations with winter wheat, corn, proso millet, and fallow contained a range of winter and summer annual crop combinations that enabled us to evaluate impact of rotation design on weed dynamics. Weed biomass was measured in proso of four rotations: continuous proso (M-M), wheat-proso-fallow (W-M-F), wheat-corn-proso (W-C-M), and wheat-corn-proso-fallow (W-C-M-F). Green foxtail and field sandbur proliferated in proso because herbicides used in proso controlled only broadleaf weeds. Conventional herbicides effectively controlled these grasses in wheat and fallow, whereas grass control in corn was approximately 90%.

After eight years, biomass of these grasses was 180 g/m² in continuous proso (Figure 3).

In contrast, weed biomass was six-fold less in W-M-F, a rotation with only one summer crop in three years. Weed biomass in W-C-M was one half of continuous proso (M-M), whereas biomass was three-fold less in W-C-M-F compared with W-C-M. An intriguing finding was that weed biomass did not differ between W-M-F and W-C-M-F, even though W-C-M-F had two summer crops in a row. One similarity

between W-M-F and W-C-M-F is the two-year period without summer crops (winter wheat and fallow). Apparently, this two-year period affected weed dynamics more than two years of summer crops in a row.

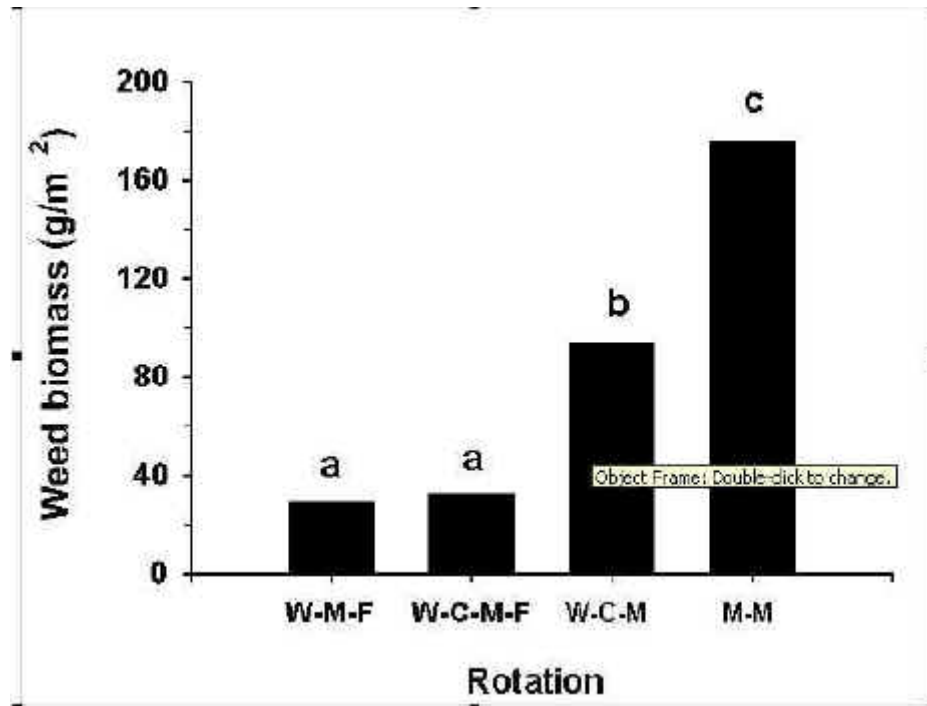


Figure 3. Biomass of green foxtail and field sandbur in four rotations at Akron CO. Study initiated in 1990; biomass measured in 1997 and 1999. Bars with the same letter are not significantly different.

A contributing factor to this trend is length of weed seed survival in soil. The reservoir of weed seed in soil, referred to as the seed bank, is the main source of weed infestation in crops. Seeds in soil either germinate, die of natural causes, or are consumed by soil organisms. Seed density in soil declines rapidly over time, with a dramatic decline occurring during the first two years after seeds enter the seed bank (Egley and Williams, 1990). For example, seed survival of green foxtail and field sandbur is less than 10% after two years in soil (Figure 4). Both W-M-F and W-C-M-F have two years in the rotation when green foxtail and field sandbur can be easily controlled before seed is produced, thus favoring rapid decline of seed density in soil. The two-year interval can reduce future weed seedling density 90%.

The two-year interval provided by summer crops and/or fallow also aids control of winter annual grasses in winter wheat. Seed decline of downy brome is similar to the summer annual grasses, with less than 5% of seed alive after two years in soil. Jointed goatgrass seed persists somewhat longer because its seed is encased within glumes of the spikelet (its dispersal unit). The spikelet protects seed from environmental conditions, yet, within three years, number of viable seeds still declined to less than 5%.

The two-year interval approach is also effective in other agroecosystems. In the Corn Belt, a four-year rotation of corn-soybean-hay-hay prevents green foxtail seed production during the two years of hay (Jordan et al., 1995). Consequently, green foxtail densities are drastically reduced in corn of this rotation compared to continuous corn or corn-soybean rotations, because of seed bank decline during the two years of hay.

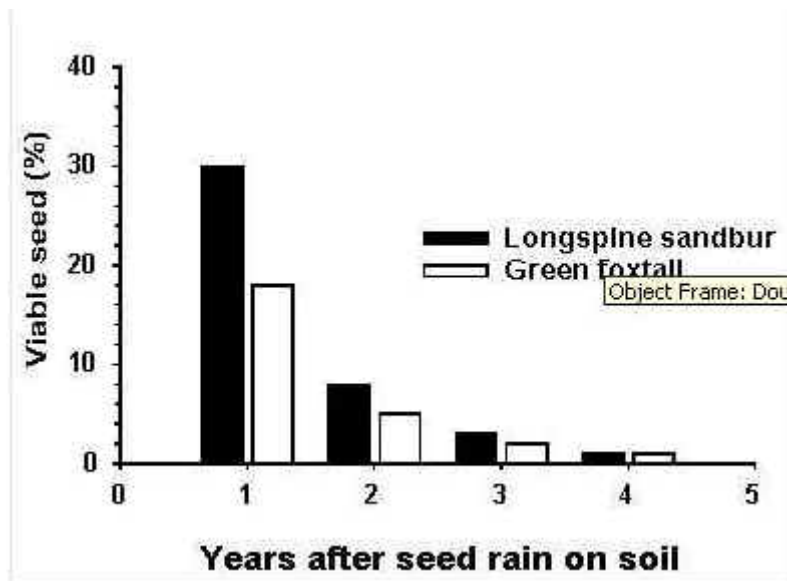


Figure 4. Longevity of seed survival of green foxtail and longspine sandbur, when seed remains in the top three cm of soil.

A second example occurs in the Northern Great Plains (Anderson et al., 1998). Fairy candelabra, a native cool-season species in rangelands, proliferates in no-till spring wheat-fallow. However, a no-till rotation comprised of spring wheat-winter wheat-sunflower eliminates fairy candelabra. Fairy candelabra emerges before sunflower is planted, thus seedlings are easily controlled, whereas winter wheat growth in the spring is more competitive than spring wheat and prevents fairy candelabra seedlings from establishing. Control tactics during the two-year interval between spring wheat crops prevent fairy candelabra proliferation in this rotation.

Designing Rotations to Accentuate Natural Benefits

Our study at Akron CO shows that rotations designed in a cycle-of-four with two winter annual crops followed by two summer annual crops offer multiple opportunities to manage input costs and pests. First, land productivity has been almost doubled compared to the prevalent system of winter wheat-fallow (Anderson et al., 1999). Secondly, because both winter annual and summer annual crops are well adapted in the Great Plains, rotating crops helps manage weeds because growth periods differ considerably between crop types. Prevalent weeds in each crop differ because of lack of similarity in growth periods for weeds; arranging crops in a four-year cycle also favors natural seed decline in soil, thus weed density is reduced in future crops with these combinations.

Producers in the region are seeking rotations with continuous cropping. One promising rotation in our study is winter wheat-corn-proso millet-dry pea, where dry pea is managed either for green fallow, hay, or seed, depending on growing season precipitation. Dry pea is planted in March and harvested before summer annual weeds can produce seed, thus dry pea fits the winter annual crop cycle in managing weeds. Also, different planting dates of dry pea and winter wheat will help producers in managing winter annual grasses.

Rotations comprised of diverse crops offers producers numerous opportunities to manage pests beyond pesticides, thus expanding options for producers to manage pesticide resistance and input costs. Herbicide resistance can be avoided because crop diversity enables producers to rotate herbicides with different modes of action. Also, with lower weed density, cultural systems are more effective, thus allowing producers to eliminate herbicide use in some crops of a rotation (Anderson, 2000). Rotating

crops with different planting dates also disrupts crop-weed associations, thus offering producers another tactic to reduce weed density (Froud-Williams, 1988).

Producers are concerned that adding less profitable crops to the rotation will reduce net farm income; however, diverse rotations can maintain profitability because of reduced input costs. In England, a system based on diverse rotations and ecologically-based pest management was compared to current crop production systems (Jordan et al., 1997). Over a five-year period, crop yield of the diverse system was 10 to 20% less. However, production costs were reduced 32%; thus, overall net income was maintained. Substantial reductions in applied herbicides (26%), fungicides (79%) and insecticides (78%) lowered production costs with the diverse cropping system. A similar study in the Netherlands compared conventional and diverse cropping systems over a 15-year period (Lewis et al., 1997). Pesticide use and input costs were reduced substantially by implementing alternative practices. Yields were lower with the diverse systems, yet reduced input costs led to similar net returns. Furthermore, diversified rotations improved financial risk management.

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