Are Some Crops Synergistic to Following Crops?

Randy L. Anderson*

ABSTRACT

Because of improved water management, producers in the Great Plains are diversifying their crop rotations. A benefit of crop diversity is that some crop sequences can increase grain yields. Along with yield benefits, we also have noted that water use efficiency (WUE) of some crops can be improved by preceding crops. For example, WUE of winter wheat (*Triticum aestivum* L.) and proso millet (*Panicum miliaceum* L.) is improved if corn (*Zea mays* L.) is included in the rotation. If crops respond favorably to rotation, they either increase plant capacity and resource use or improve resource use efficiency (synergism). We suggest that the soil environment remaining after some crops, such as corn or legumes, synergistically improves growth efficiency of following crops. However, synergism appears to be specific between crops. We also suggest that synergism among crops would be assessed most accurately in long-term cropping systems studies.

Producers are changing their crop rotations in the Great Plains. A stimulus for this change is no-till production systems and residue conservation, which has improved water relations for crop growth (Peterson et al., 1996). With no-till systems, land productivity has been almost doubled compared with intensively tilled systems (Anderson et al., 1999).

Producers gain an ancillary benefit when adding more crops to their rotations; crop diversity often improves grain yield, a response referred to as the rotation effect (Crookston, 1995). This yield response has been attributed to a multitude of factors, such as changes in soil moisture levels, nutrient cycling and availability, soil structure, soil microbial community, or pest infestations (Higgs et al., 1990).

To help producers plan new rotations, several long-term cropping systems studies were started in the Great Plains during the 1980s, including a study at Akron, CO (Anderson et al., 1999). After several years, we noticed some unusual trends with WUE and crop sequences in the Akron study; this paper describes those trends and relates them to other published data. Our objective is to encourage scientists to evaluate resource use efficiency of crops as affected by preceding crops.

Corn May Improve Water Use Efficiency of Winter Wheat and Proso Millet

During 1994 through 1999 at the Akron cropping systems study, winter wheat yielded 10% more in winter wheat–corn–fallow (W-C-F) compared with winter wheat–fallow (W-F). We initially attributed this yield benefit to the longer interval between winter wheat crops in W-C-F suppressing root diseases of winter wheat (Cook and Veseth, 1991). However, we were surprised that winter wheat yields did not differ between W-F and winter wheat–proso millet–fallow (W-M-F).

When we examined water use of winter wheat in these rotations, we noted an unusual trend with WUE; winter wheat was more efficient at converting water into grain with W-C-F than with W-M-F (Fig. 1). For example, 300 mm of water use by winter wheat would yield 3930 kg ha^{-1} in W-C-F, contrasting with only 2940 kg ha^{-1} of grain with W-M-F. With W-C-F, winter wheat produces 34% more grain than with W-M-F with the same water use.

We wondered if nutrient status could cause this difference in WUE; however, N management was based on annual soil tests and target yield goals (Anderson et al., 1999). Phosphorus needs were adequate as P was banded with winter wheat seed at planting. Also, we did not observe any pest issues that would explain this difference. We further noted that WUE of winter wheat in W-M-F was similar to W-F; thus, we hypothesized that presence of corn in the rotation improved WUE of winter wheat.

We also observed in our study that corn exerts a similar effect on proso millet WUE (Anderson, 2004b). Averaged across 4 yr, proso millet yielded 300 kg ha^{-1} more in winter wheat–corn–proso millet (W-C-M) compared with winter wheat–proso millet (W-M) (Table 1). We initially speculated that water use would explain this difference; yet, soil water level at planting time and crop water use by proso millet were similar in both rotations. With W-C-M, proso millet was 24% more efficient at converting water into grain, as WUE increased from 75 kg ha^{-1} cm^{-1} with W-M to 93 kg ha^{-1} cm^{-1} with W-C-M (Table 1).

As with winter wheat, we did not feel that this trend with proso millet could be attributed to nutrient differences; our nutrient management was based on annual soil tests and target yield goals. We then considered if the yield difference was related to frequency of proso millet cropping and disease management; however, proso millet yield did not differ among W-M, W-M-F, and winter wheat–proso millet–sunflower (*Helianthus annuus* L.)–fallow (data not published). We were unable to explain why, but when corn was present in the rotation, WUE of winter wheat and proso millet was improved.

Insight Gained from Other Studies

To understand this trend, we searched the literature for other examples of WUE responding to crop se-

USDA-ARS, 2923 Medary Ave., Brookings, SD 57006. Received 24 June 2004. *Corresponding author (randerson@ngirl.ars.usda.gov).

Published in Agron. J. 97:7–10 (2005).

Abbreviations: NUE, nitrogen use efficiency; W-C-F, winter wheat–corn–fallow; W-C-M, winter wheat–corn–proso millet; W-F, winter wheat–fallow; W-M, winter wheat–proso millet; W-M-F, winter wheat–proso millet–fallow; WUE, water use efficiency.

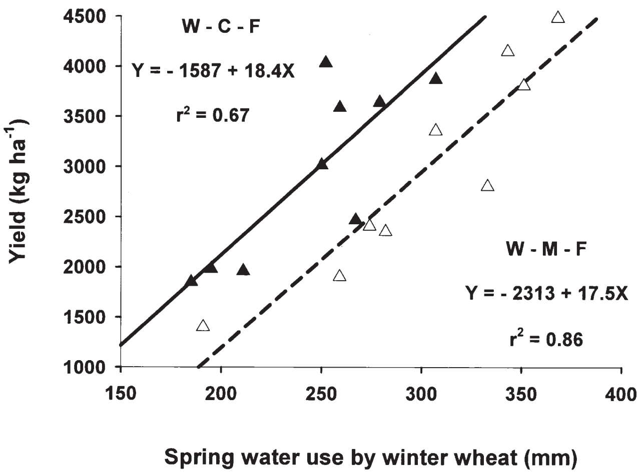

Fig. 1. Grain yield–water use relationship for winter wheat grown in two rotations, wheat–corn–fallow (W-C-F: black triangles and solid line) and winter wheat–proso millet–fallow (W-M-F: white triangles and dashed line). Data are averaged across 3 yr; study conducted at Akron, CO (adapted from Anderson, 2002).

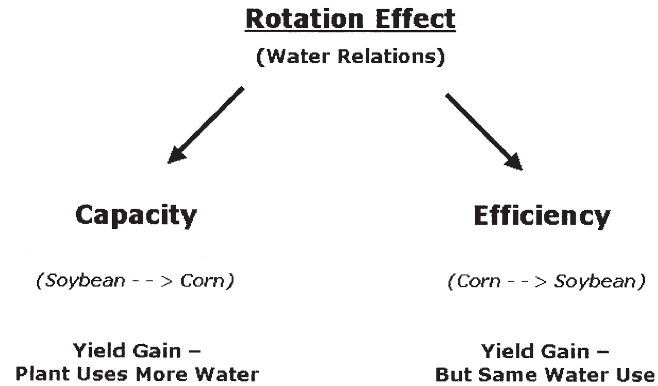

Fig. 2. Different responses by corn and soybean to the rotation effect in Minnesota (based on concepts described in Copeland et al., 1993; Crookston, 1995; and Anderson, 2004a).

quences. First, we reviewed *Limitations to Efficient Water Use in Crop Production* (Taylor et al., 1983); several chapters in this monograph discussed impact of crop manipulations on WUE, but effect of previous crop and rotational sequence were not mentioned. Taylor (1983) suggested that root exudates from some plants could benefit root growth of following crops; however, he felt that knowledge gaps related to the interaction of plant compounds, root growth of crops, and microorganisms made it difficult to predict responses.

We then examined a series of studies by Crookston and associates in Minnesota designed to identify the cause of the rotation effect in soybean [*Glycine max* (L.) Merr.] and corn (Crookston, 1995). Both corn and soybean yielded 15 to 20% more grain when rotated with each other compared with monocultures of either crop, but yield gain reflected different crop responses to the rotation effect (Fig. 2). When soybean preceded corn, corn produced a larger plant and used more water to increase grain yield compared with continuous corn (Copeland et al., 1993; Crookston et al., 1991). In contrast, soybean following corn used the same amount of water as continuous soybean, yet yield was 15% greater; soybean plant size did not change. Thus, WUE of soybean increased if corn was the previous crop compared with soybean, whereas WUE of corn was not influenced by previous crop.

Table 1. Impact of previous crop on proso millet yield and water use; data averaged across 4 yr. Asterisk indicates that treatment means were significantly different between rotations for that agronomic factor (0.05 level of probability) (adapted from Anderson, 2004b).

Agronomic data	W-M†	W-C-M‡
Grain yield, kg ha^{-1}	2020	2320*
Available soil water at planting, cm	14	13
Water use, cm	27	25
Water use efficiency, kg ha^{-1} cm^{-1}	75	93*

† W-M, winter wheat–proso millet.
‡ W-C-M, winter wheat–corn–proso millet.

A similar trend occurred with nutrient uptake. Quantifying accumulation and concentration of 10 nutrients in both crops, Copeland and Crookston (1992) found that corn used more nutrients when producing more yield in the corn–soybean rotation. Soybean, however, did not accumulate more nutrients; soybean was more efficient in using nutrients as well as water when following corn compared with a monoculture of soybean. Thus, corn responded to rotation by increasing its use of resources, whereas soybean in rotation increased growth efficiency to produce more grain with the same resource use. Schneekloth et al. (1991) reported a similar response of corn to rotations with three irrigation regimes; WUE of corn did not differ between continuous corn and winter wheat–corn–soybean. Yield increase due to rotation reflected higher water consumption.

Another intriguing finding by the research team in Minnesota was corn responded the same to rotation whether soybean, sunflower, or alfalfa (*Medicago sativa* L.) was the previous crop (Porter et al., 1997). They suggested that broadleaf crops eliminated a negative effect of corn to itself as a preceding crop. In the same study, however, sorghum [*Sorghum bicolor* (L.) Moench] was not beneficial for corn like broadleaf crops.

Another example of increased plant capacity due to crop sequencing occurs in Western Australia where oilseeds are planted before winter wheat for disease management. Angus and van Herwaarden (2001) found that winter wheat yields more after oilseeds compared with winter wheat because of greater soil water extraction rather than improved WUE; yield gain reflected more water use. Crop diversity helps winter wheat increase its plant capacity for yield because of improved root growth. With the capacity response, however, if extra water is not available, winter wheat yield is not increased by crop diversity.

Based on results from the Akron, CO and Minnesota studies, we suggest that corn may leave a soil environment that, in some way, improves growth efficiency of some following crops. However, this beneficial interaction appears to be specific between crops. Corn was favorable for soybean, winter wheat, and proso millet; yet, Schmidt and Frey (1988) found that corn was not beneficial for sorghum in a study where groundnut (*Arachnis hypogaea* L.) increased sorghum yield 23% compared with continuous sorghum or corn–sorghum.

Concept of Synergism

As we considered the interaction of corn with WUE of following crops, we noted similarity with the concept of synergism used in pest management (Gressel, 1990). Compounds known as synergists, such as adjuvants, are often mixed with pesticides to improve their efficiency. The cause of synergism by these compounds involves numerous factors, and in some cases, the cause is not known. Also, synergists are specific for pesticides; a synergist may improve efficiency of only a few pesticides. We suggest this concept also describes the interaction among crops where growth efficiency is improved. We are unsure of the cause of this response, whereas synergism among crops also appears to be specific to individual crops.

Other Examples of Possible Synergism among Crops

We have described examples of corn synergism to subsequent crops, but other crops, especially legumes, also may be synergistic to subsequent crops. For example, dry pea (*Pisum arvense* L.) improved WUE of winter wheat compared with winter wheat, proso millet, or fallow preceding winter wheat (Anderson, 2002). Rice (1983, p. 34) found that roots of dry pea release growth-promoting compounds that stimulate photosynthesis of barley (*Hordeum vulgare* L.).

Legumes can improve N use efficiency (NUE) of some cereal crops (Raun and Johnson, 1999), but the level of effect varies among legume species (Badaruddin and Meyer, 1994). A similar variation occurred among legumes improving NUE of pearl millet [*Pinnisetum glaucum* (L.) R. Br.] in India (Praveen-Kumar et al., 1997). Sometimes, however, legumes do not improve NUE, as noted by Copeland and Crookston (1992) with soybean preceding corn.

Crop sequencing also can affect N fixation by legumes. In a study comparing 4-yr sequences where cereal crops were rotated with an oilseed and a legume crop, Matus et al. (1997) found that N fixation by lentil [*Lens culinaris* (L.) Medikus] increased 10% if canarygrass (*Phalaris canariensis* L.) was the preceding crop rather than spring wheat. Canaryseed may be synergistic to *Rhizobium* spp. efficiency with lentil.

Benefit of Synergism in Great Plains Crop Production

Since the settlement of the Great Plains, producers have invested considerable resources in water management, relying on fallow, residue conservation, and limited cropping choices to moderate the impact of variable precipitation (Greb, 1983). Producers may be able to further improve water conversion into grain if crop sequences that improve WUE were known.

To identify synergistic crop interactions, we encourage scientists involved with long-term rotation studies in the Great Plains to measure resource use efficiency in conjunction with crop yield. We are concerned that short-term studies may not detect synergism among crops. With the Akron, CO, cropping systems study, synergism between corn and winter wheat or proso millet did not appear until after several years of rotations were completed. Stevenson and van Kessel (1996), examining the beneficial effect of dry pea on spring wheat across several sites, found that crop management practices in the year preceding dry pea influenced spring wheat response to dry pea.

It may be difficult to identify the cause of synergism. Wright (1990) suggested that the rotation effect reflects a complex interaction among numerous soil and plant factors, whereas Crookston (1995), after 15 yr of research, suggested that the cause of the rotation effect may never be completely explained. We perceive a similar situation with crop synergism. Even if the cause of synergism among crops is not known, identifying crop sequences that improve WUE or NUE will help producers integrate this benefit into their production systems.

REFERENCES

Anderson, R.L. 2002. Designing rotations to favor natural benefits. p. 7–14. *In* Proc. No-Till on the Plains Conf., Salinas KS. 25–26 Jan. 2002. No-Till on the Plains Assoc., Wamego, KS.

Anderson, R.L. 2004a. Benefits of crop sequencing. p. 9–17. *In* Proc. No-Till on the Plains Conf., Salinas KS. 27–28 Jan. 2004. No-Till on the Plains Assoc., Wamego, KS.

Anderson, R.L. 2004b. Improving sustainability of semiarid cropping systems. J. Sustain. Agric. (in press).

Anderson, R.L., R.A. Bowman, D.C. Nielsen, M.F. Vigil, R.M. Aiken, and J.G. Benjamin. 1999. Alternative crop rotations for the central Great Plains. J. Prod. Agric. 12:95–99.

Angus, J.F., and A.F. van Herwaarden. 2001. Increasing water use and water use efficiency in dryland wheat. Agron. J. 93:290–298.

Badaruddin, M., and D.W. Meyer. 1994. Grain legume effect on soil nitrogen, grain yield, and nitrogen nutrition of wheat. Crop Sci. 34:1304–1309.

Cook, R.J., and R.J. Veseth. 1991. Wheat health management. Am. Phytopathol. Soc. Press, St. Paul, MN.

Copeland, P.J., R.R. Allmaras, R.K. Crookston, and W.W. Nelson. 1993. Corn–soybean rotation effects on soil water depletion. Agron. J. 85:203–210.

Copeland, P.J., and R.K. Crookston. 1992. Crop sequence affects nutrient composition of corn and soybean grown under high fertility. Agron. J. 84:503–509.

Crookston, R.K. 1995. The rotation effect in corn. p. 201–215. *In* D. Wilkerson (ed.) Proc. Annu. Corn Sorghum Res. Conf., 50th, Chicago, IL. 6–7 Dec. 1995. Am. Seed Trade Assoc., Alexandria, VA.

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.

Greb, B.W. 1983. Water conservation: Central Great Plains. p. 57–72. *In* H.E. Dregne and W.O. Willis (ed.) Dryland agriculture. Agron. Monogr. 23. ASA, CSSA, and SSSA, Madison, WI.

Gressel, J. 1990. Synergizing herbicides. Rev. Weed Sci. 5:49–82.

Higgs, R.L., A.E. Peterson, and W.H. Paulson. 1990. Crop rotations: Sustainable and profitable. J. Soil Water Conserv. 45:68–70.

Matus, A., D.A. Derksen, F.L. Walley, H.A. Loeppky, and C. van Kessel. 1997. The influence of tillage and crop rotation on nitrogen fixation in lentil and pea. Can. J. Plant Sci. 77:197–200.

Peterson, G.A., A.J. Schlegel, D.L. Tanaka, and O.R. Jones. 1996. Precipitation use efficiency as affected by cropping and tillage systems. J. Prod. Agric. 9:180–186.

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.

Praveen-Kumar, R.K. Aggarwal, and J.F. Power. 1997. Cropping systems: Effects on soil quality indicators and yield of pearl millet in an arid region. Am. J. Altern. Agric. 12:178–184.

Raun, W.R., and G.V. Johnson. 1999. Improving nitrogen use efficiency for cereal production. Agron. J. 91:357–363.

Rice, E.L. 1983. Pest control with nature's chemicals. Univ. of Oklahoma Press, Norman.

Schmidt, G., and E. Frey. 1988. Crop rotation effects in northern Ghana. p. 775–777. *In* P.W. Unger et al. (ed.) Proc. Challenges in Dryland Agric. Conf., Bushland TX. 15–19 Aug. 1988. Texas Agric. Exp. Stn., College Station.

Schneekloth, J.P., N.L. Klocke, G.W. Hergert, D.L. Martin, and R.T. Clark. 1991. Crop rotations with full and limited irrigation and dryland management. Trans. ASAE 34:2372–2380.

Stevenson, F.C., and C. van Kessel. 1996. The nitrogen and non-nitrogen rotation benefits of pea to succeeding crops. Can. J. Plant Sci. 76:735–745.

Taylor, H.M. 1983. Managing root systems for efficient water use: An overview. p. 87–113. *In* H.M. Taylor, W. A. Jordan, and T. R. Sinclair (ed.) Limitations to efficient water use in crop production. ASA, CSSA, and SSSA, Madison, WI.

Taylor, H.M., W.A. Jordan, and T.R. Sinclair. 1983. Limitations to efficient water use in crop production. ASA, CSSA, and SSSA, Madison, WI.

Wright, A.T. 1990. Yield effect of pulses on subsequent cereal crops in the northern plains. Can. J. Plant Sci. 70:1023–1032.