A Paradox with Herbicide Resistance, Tillage and Semiarid Crop Production

Randy Anderson
USDA-ARS
Brookings, SD

Producers in the Central Great Plains have been using glyphosate (Roundup) extensively to control weeds in no-till systems. In some rotations, glyphosate may be applied several times in one year. However, weeds such as horseweed are developing resistance to glyphosate (Heap 2003). Other weeds are becoming tolerant to glyphosate; tumble windmillgrass, toothed spurge, and wild buckwheat now require double the normal-use rates of glyphosate for control.[1]

Producers, concerned about this trend with weeds, are considering tillage with a sweep plow as an alternative to glyphosate during fallow. They are asking for information on the effect of occasional tillage on weed dynamics. Thus, we summarize the response of weeds to sweep plow tillage compared with no-till. First, we discuss the interaction between tillage and rotation design on weed density, then describe the weed community response to tillage with individual crops. We also suggest possible alternatives to tillage for managing weeds and herbicide resistance.

Tillage and weed density in various rotations

In the early 1990s, three cropping systems studies were started at Pierre and Wall SD, and at Akron CO to evaluate rotations comprised of winter wheat, various warm-season crops, and fallow. After several years, we assessed weed community densities in these studies (Anderson 2003). At all sites, crop and weed management tactics were similar to practices used by producers in the region. The weed community consisted of downy brome, green foxtail, kochia, redroot pigweed, Russian thistle, stinkgrass, and witchgrass.

With all studies, weed density was lower in rotations comprised of 2-year intervals of crops with similar growth periods compared with rotations of shorter duration. For example, at Pierre, weed density in a rotation comprised of two cool-season crops followed by two warm-season crops,

[1]Gail Wicks, personal communications. 2003. North Platte NE.

[dry pea-winter wheat-corn-soybean] was 5 plants/m^2. In contrast, weed density was 12-fold greater in winter wheat-chickpea, averaging 60 plants/m^2. Similar trends occurred at the Wall and Akron sites; weed density was lowest in 4-year rotations comprised of 2-year intervals of cool- and warm-season crops (fallow fits in either category).

However, weed density between 4-year and 2-year rotations differed only three-fold at Wall and six-fold at Akron, contrasting with the 12-fold difference at Pierre (Table 1). The reason for this trend is tillage. At Wall, tillage with the sweep plow incorporated herbicides and fertilizer as well as controlled weeds during fallow, with one to three tillage operations occurring each year; at Akron, tillage occurred only once during the rotation cycle. The study at Pierre was no-till in all years.

Table 1. Impact of tillage on weed density when comparing a 4-year rotation to a 2-year rotation[a] at three locations in the Great Plains. Weed density was assessed at least 8 years after initiation of each study. (Adapted from Anderson 2004).

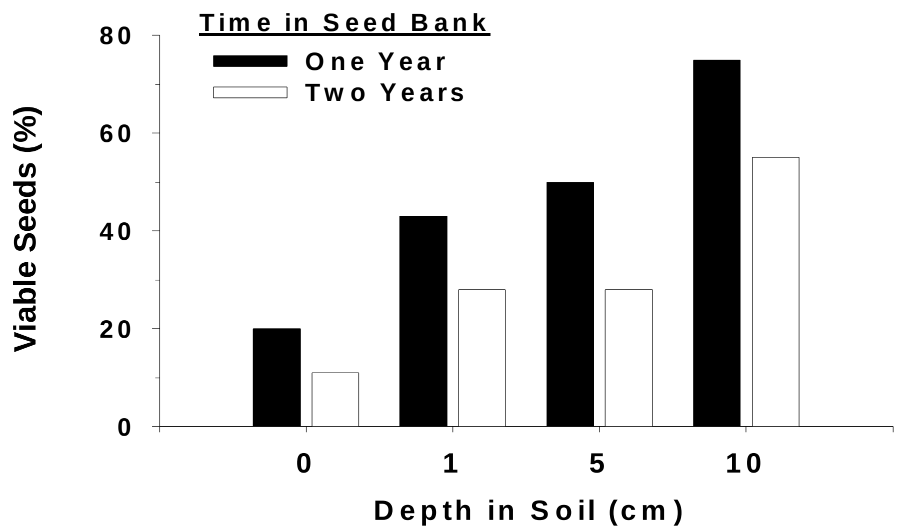
Study site	Frequency of tillage	Magnitude of difference in weed density between 4-year vs. 2-year rotations
Wall	One to three times/year	3-fold
Akron	Once/rotation cycle	6-fold
Pierre	No tillage	12-fold

[a]Rotations compared were winter wheat-corn-sunflower-spring wheat vs. winter wheat-proso millet at Wall, winter wheat-corn-proso millet-fallow vs. winter wheat-proso millet at Akron, and winter wheat-corn-soybean-dry pea vs. winter wheat-chickpea at Pierre.

Arranging cool- and warm-season crops in 2-year intervals helps weed management because it favors the natural loss of viable seeds in soil. For example, less than 10% of green foxtail seeds are viable after 2 years in soil. In the 4-year rotation, control strategies in the 2-year interval of cool-season crops prevent seed production of green foxtail, thus, natural loss of viable green foxtail seeds in soil during this 2-year interval reduces potential seedling density in future years more than 90%.

But, tillage prolongs seed survival by burying seeds in soil. Green foxtail survival after 2 years is greater than 50% when seeds are buried 10 cm in soil, contrasting with less than 10% of seeds surviving when they remain on the soil surface (Figure 1). Even when green foxtail seeds are buried only 1 cm in soil, survival is still two-fold greater after 2 years compared with seeds remaining on the soil surface. The higher seed bank density results in more green foxtail seedlings in following years. This trend with seed bank dynamics and tillage occurs with both cool- and warm-season weeds (Egley and Williams 1990).

Figure 1. Impact of seed depth in soil on survival of green foxtail in the semiarid prairies of Canada. (Adapted from Thomas et al. 1986).



Tillage between winter wheat and summer annual crops

When we started evaluating rotations that included summer annual crops with winter wheat, we compared no-till to stubble mulch, the conventional practice used by producers. With stubble mulch, the sweep plow controls weeds during fallow; usually two to three operations occur after winter wheat harvest and before planting a summer annual crop the next year. Weed density was always 35 to 50% higher in corn, sunflower, or proso millet in stubble mulch compared with no-till (Anderson 1999).

Tillage increases weed density by placing seeds in more favorable sites in soil, thus stimulating germination and seedling establishment. Tillage also reduces quantity of crop residues on the soil surface. High levels of crop residues can reduce weed establishment 15 to 40% by altering environmental conditions related to germination or physically impeding seedling growth (Crutchfield et al. 1986). Yet, our studies show that even with high crop residue levels, seedling density still increases with tillage (Anderson 1999). Tillage apparently alters the weed seed-soil interaction such that seedling emergence increases regardless of residue quantity on the soil surface.

Because winter survival of weed seeds is two-to five-fold less on the soil surface than when buried in soil (Figure 1), we wondered if delaying initial tillage with the sweep plow until the next spring would minimize differences in weed density between tillage systems. To test this idea, we compared weed density in proso millet between no-till and sweep plow tillage, but with the initial tillage occurring just before planting proso millet in early June (Anderson 2000). Our goal was to favor natural loss of weed seeds during winter before tilling. The previous crop was winter wheat and the weed community was primarily redroot pigweed.

Even with delay of tillage until spring, however, redroot pigweed density still was six-fold greater after tillage compared with no-till (Table 2). The greater loss of weed seeds over winter did not compensate for increased seedling emergence due to tillage. A further consequence of tillage is that 48,300 seeds/m^2 of redroot pigweed were added to the seed bank, more than nine-fold greater than occurred with no-till. An intriguing trend was that redroot pigweed was more productive in the tilled system; one plant produced 1,930 seeds in proso millet grown after tillage, contrasting with 1,280 seeds per plant in no-till proso millet. We attribute reduced productivity of redroot pigweed in no-till to more vigorous crop growth, as grain yield of proso millet in weed-free conditions was 18% greater in no-till compared with the tilled system. No-till provides a more favorable environment for proso millet than stubble mulch, which improves its competitiveness with redroot pigweed.

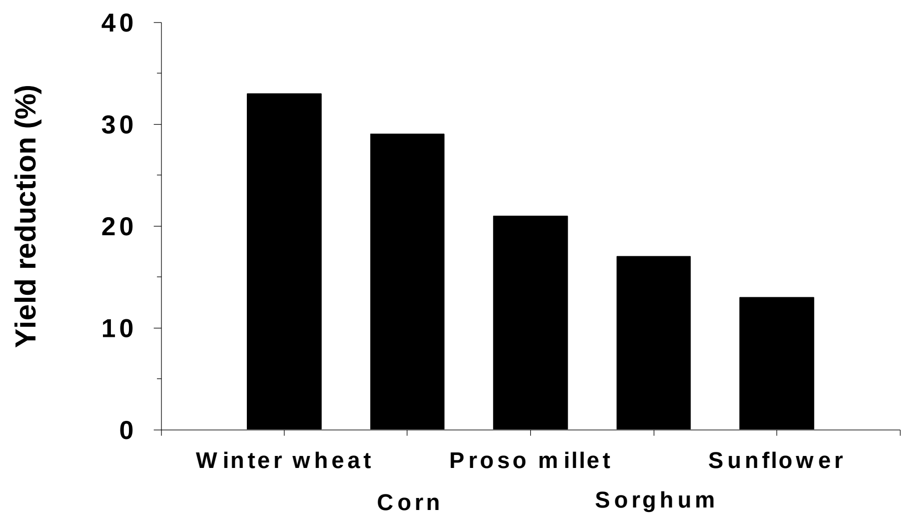
Table 2. Redroot pigweed density and seed production in proso millet, as affected by tillage. Data were averaged across 4 years. (Adapted from Anderson 2000).

Tillage system	Density/m^2	Seed production/m^2	Seeds/plant
Till	25	48,300	1,930
No-till	4	5,100	1,280
Reduction in no-till	84%	89%	34%

Crops yield less after tillage in a semiarid climate

As found with proso millet, crops yield less after sweep plow tillage. Compared with no-till, yield loss in tilled systems for warm-season crops ranged from 29% for corn to 13% with sunflower (Figure 2). With winter wheat, tilling four to six times with the sweep plow during the 14-month fallow reduced yield more than 30% compared with no-till.

Figure 2. Yield reduction in the Central Great Plains when comparing tilled systems to no-till. All crops were planted after winter wheat. (Adapted from Anderson 2004).



One reason why crops yield less after tillage is less favorable water relations. Maintaining crop residues on the soil surface with no-till improves precipitation storage efficiency as well as reduces soil water evaporation (Peterson et al. 1996). Tillage, by burying crop residues, lowers the efficiency of precipitation use by crops in this semiarid climate.

A paradox with tillage as a management tactic to minimize selection pressure

Producers can replace glyphosate applications with occasional tillage, but in the semiarid Great Plains, this option may be detrimental to crop production. First, tillage increases weed density in following crops, which may lead to higher herbicide inputs to manage weeds. Second, crop growth and yield is less after tillage. Thus, herbicides needed for weed management in no-till are less becoming effective due to resistant weeds, yet tillage minimizes the benefits of residue conservation and intensive cropping.

However, producers have alternatives to tillage, especially if an integrated management plan with multiple tactics is used to minimize selection pressure on the weed community. A key component for managing weed resistance is rotations comprised of a diversity of crops. This diversity provides more opportunities for producers to rotate herbicides with different modes of action. Also, if rotations include crops with different planting dates, the timing of glyphosate applications can be varied across years in relation to a specific weed's emergence period, thus reducing selection pressure on that weed. In addition, diverse rotations with no-till have lowered weed community density such that some crops, such as proso millet, do not need herbicides for weed control in the Central Great Plains (Anderson 2000). Thus, selection pressure for resistance is eliminated in that crop.

During fallow, an alternative to tillage may be green fallow, where a crop is grown only for vegetative growth before being killed with herbicides. If green fallow suppresses weed emergence and growth for 6 to 8 weeks, then producers could vary the timing of glyphosate use. The interval of green fallow suppression could be related to periods of glyphosate use in previous years.

If producers choose to till, it would be least detrimental if tillage precedes winter wheat during fallow. Tilling once approximately 3 to 4 months before planting winter wheat does not affect winter wheat yield compared with no-till (Anderson et al. 1999). Weeds emerging after tillage can easily be controlled with herbicides before planting winter wheat. However, if several tillage operations occur before planting winter wheat, yields can be reduced 35% (Figure 2).

Literature Cited

Anderson, R. L. 1999. Cultural strategies reduce weed densities in summer annual crops. Weed Technology 13:314-319.

Anderson, R. L. 2000. A cultural systems approach eliminates the need for herbicides in semiarid proso millet. Weed Technology 14:602-607.

Anderson, R. L. 2003. An ecological approach to strengthen weed management in the semiarid Great Plains. Advances in Agronomy 80:33-62.

Anderson, R.L. 2004. Impact of sub-surface tillage on weed dynamics in the Central Great Plains. Weed Technology 18:(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. Journal of Production Agriculture 12:95-99.

Crutchfield, D. A., G. A. Wicks, and O. C. Burnside. 1986. Effect of winter wheat (*Triticum aestivum*) straw mulch level on weed control. Weed Science 34:110-114.

Egley, G. H. and R. D. Williams. 1990. Decline of weed seeds and seedling emergence over five years as affected by soil disturbance. Weed Science 38:504-510.

Heap, I. 2003. The International Survey of Herbicide Resistant Weeds. [Online] www.weedscience.com [accessed October 16, 2003].

Peterson, G. A., A. J. Schlegel, D. L. Tanaka, and O. R. Jones. 1996. Precipitation use efficiency as affected by cropping and tillage systems. Journal of Production Agriculture 9:180-186.

Thomas, A. G., J. D. Banting, and G. Bowes. 1986. Longevity of green foxtail seeds in a Canadian prairie soil. Canadian Journal of Plant Science 66:189-192.