Tillage, Rotations, and Weed Populations

by Randy Anderson

SCIENCE

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Crop residue retention has changed rotational practices in the central Great Plains. Winter wheat >>summerfallow has been the prevalent rotation since the 1930s. However, maintaining crop residues on the soil surface improves precipitation storage in the soil such that producers can grow more crops in succession before fallow is needed.[1] Producers now grow corn (*Zea mays*), sunflower (*Helianthus annuus*), sorghum (*Sorghum bicolor*), or proso millet (*Panicum miliaceum*) in rotation with winter wheat and fallow.

The benefits of crop residues are closely related to their quantity on the soil surface. One study on the Great Plains found that precipitation storage during fallow increased 1 cm (0.4 inch) for every 1,000 kg/ha (892 lbs/a) of winter wheat residues,[2] while another study reported that corn grain yield increased 5 to 8% for each additional 1,000 kg/ha of winter wheat residues.[3] Because crop residues often improve crop performance, some producers seek to maximize residue quantity on the soil surface.

After 18 years, the weed community differed between the two tillage systems, with density of all species being less in no-till.

When winter wheat producers and scientists first recognized the value of residue preservation in the 1950s, they developed tillage implements such as the sweep plow or rod weeder, which led to the "stubble mulch" system. With stubble mulch, weeds are controlled during fallow with a sweep plow, which consists of V-shaped blades that sever plant roots at a tillage depth of 5 to 8 cm (2 to 3 inches). Each operation buries only 10% of crop residues because of low soil inversion, contrasting with tillage by a tandem disk or moldboard plow that buries 60 to 100% of crop residues. Crop residue management is further improved with no-till systems, where herbicides replace tillage for weed control during fallow. Some producers in the region now rely completely on no-till systems for crop production.

Photo by Doug Palen.

Prickly lettuce & marestail are two species difficult to control with glyphosate.

Producers, however, are concerned about herbicide-resistant weeds in the central Great Plains. When "eco-fallow" was first developed, producers relied on atrazine to control weeds during fallow. Now, biotypes of kochia (*Kochia scoparia*), green foxtail (*Setaria viridis*), redroot pigweed (*Amaranthus retroflexus*) and barnyardgrass (*Echinochloa crusgalli*) are resistant to atrazine.[4]

Glyphosate also is used for weed control during fallow because of favorable economics and cropping flexibility. However, weed population shifts have led to a greater prevalence of species that require higher rates for control. For example, horseweed (or marestail, *Conyza canadensis*), toothed spurge (*Euphorbia dentata*), tumble windmillgrass (*Chloris verticillata*), and wild buckwheat (*Polygonum convolvulus*) are increasing in some producer fields. These species require substantially higher rates of glyphosate for control.[5]

Because of resistant weeds and species shifts, input costs for weed control during non-crop periods are escalating,

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

2 B.W. Greb, 1983, Water conservation: Central Great Plains, in *Dryland Agriculture*, ed. H.E. Dregne & W. O. Willis, American Society of Agronomy.

3 G.A. Wicks, D.A. Crutchfield & O.C. Burnside, 1994, Influence of wheat (*Triticum aestivum*) straw mulch and metolachlor on corn (*Zea mays*) growth and yield, *Weed Sci.* 42: 141-147.

4 J.S. Holt & H.M. LeBaron, 1990, Significance and distribution of herbicide resistance, *Weed Technol.* 4: 141-149.

5 Gail Wicks, personal communication.

as herbicide alternatives to glyphosate or atrazine are more expensive. For economic reasons and resistance management, some no-till producers are reconsidering tillage as an alternative weed control option, and they want to know the impact of occasional tillage on weed populations. Tillage affects weed dynamics because burial of weed seeds in soil influences seed germination and survival in the seed bank.[6] For example, one operation with the sweep plow increased seedling emergence of downy brome (*Bromus tectorum*) and jointed goatgrass (*Aegilops cylindrica*) two-fold compared with a no-till system during the first year after tillage.[7] Increased seedling emergence reflects the sweep plow's placement of weed seeds into more favorable sites for germination.

To help producers assess the value of tillage in managing herbicide resistance, we reviewed recent research in the central Great Plains that quantified weed dynamics and crop response to systems involving tillage compared with no-till. We also discuss possible alternatives to tillage in devising cropping systems that minimize selection pressure for resistant weeds.

Photo by Matt Hagny.

The need for keeping those unwanted species at bay: Here, a patch of pigweed seedlings stunted the corn. The weeds were sprayed out at spike, and again a few weeks before this photo—when pressure is severe, that's not enough. The corn crop is fine elsewhere in the field.

Weed Density: Rotations Key

With the region's prevalent winter wheat >>fallow rotation, producers have struggled to control winter annual grasses, especially downy brome.[8] Over a series of decades, Charles Fenster (agronomist with U.Neb. at Scottsbluff) and Gail Wicks (weed scientist with U.Neb. Extension at N. Platte) explored various management systems in winter wheat >>fallow for downy brome control.[9] They compared a range of tillage systems, including stubble mulch and no-till, and found that downy brome continued to infest winter wheat regardless of management during fallow. They noted that environmental conditions, such as timing of precipitation after winter wheat planting, influenced downy brome density as much as tillage system.

A team led by Jim Moyer, a weed scientist with Agri-Food Canada (Lethbridge), in an extensive review of various tillage systems in winter wheat, found similar results in that downy brome was prominent in both "conservation" and conventional tillage.[10] ("Conservation tillage" was defined on the basis of crop residue quantities on the soil surface, and included both reduced-till and no-till systems.) They also reported that other weed species have been shown to increase in both systems, and they suggested that this trend might reflect short-interval rotations comprised of only one or two crops. The authors hypothesized that weed densities may *decrease* in conservation tillage if rotations were comprised of several crops and sequenced across a longer duration.

The results of another research team in the central Great Plains support this hypothesis.[11] This team examined long-term dynamics of the winter annual grasses, jointed goatgrass and feral rye (*Secale cereale*), in winter wheat as affected by tillage and rotation. These species were prominent in winter wheat >>fallow with both sweep plow tillage and no-till after 8 years. If warm-season crops such as sunflower or proso millet were added to the rotation, jointed goatgrass and feral rye were almost eliminated. Their density in rotations that included a warm-season crop was reduced by a factor of over 100 compared to the winter wheat >>fallow rotation. The 2-yr interval between winter wheat crops reduced weed density because of greater loss of viable seeds in the seed bank.

Gail Wicks further examined the impact of a 2-yr interval on weeds in a winter wheat >>sorghum >>fallow rotation in western Nebraska, assessing both cool- and

[6] R.J. Froud-Williams, R.J. Chancellor & D.H. Drennan, 1984, The effects of seed burial and soil disturbance on emergence and survival of arable weeds in relation to minimal cultivation, *J. Appl. Ecol.* 21: 629-641. H.A. Roberts, 1981, Seed banks in soils, *Adv. Appl. Biol.* 6: 1-55.

[7] R.L. Anderson, 1998, Seedling emergence of winter annual grasses as affected by limited tillage and crop canopy, *Weed Technol.* 12: 262-267.

[8] G.A. Wicks & D.E. Smika, 1990, Central Great Plains, in *Systems of Weed Control in Wheat in North America*, ed. W.W. Donald, Weed Science Society of America.

[9] C.R Fenster, C.E. Domingo & O.C. Burnside, 1969, Weed control and plant residue maintenance with various tillage treatments in a winter wheat-fallow rotation, *Agron. J.* 61: 256-259. C.R. Fenster & G.A. Wicks, 1982, Fallow systems for winter wheat in western Nebraska, *Agron. J.* 74: 9-13.

[10] J.R. Moyer, E.S. Roman, C.W. Lindwall & R.E. Blackshaw, 1994, Weed management in conservation tillage systems for wheat production in North and South America, *Crop Protection* 13: 243-259.

[11] O. Daugovish, D.J. Lyon & D.D. Baltensperger, 1999, Cropping systems to control winter annual grasses in winter wheat (*Triticum aestivum*), *Weed Technol.* 13: 120-126.

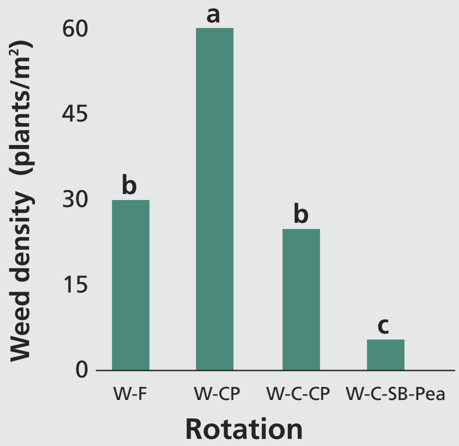
warm-season weed species. This study compared no-till with a tilled system of sweep plow operations as needed for weed control during non-crop periods; weeds were controlled in-crop with herbicides.[12] The weed community consisted of downy brome, barnyardgrass, green foxtail, kochia, redroot pigweed, Russian thistle (*Salsola iberica*), stinkgrass (*Eragrostis cilianensis*), and witchgrass (*Panicum capillare*). After 18 years, the weed community differed between the two tillage systems, *with density of all species being less in no-till.* For example, downy brome density was reduced by a factor of five in no-till compared with the sweep plow system. Similar trends occurred with other species, with densities in no-till reduced by factors of three to five.

These studies suggest that tillage favors weeds.

Expanded Rotational Studies

With improved moisture conditions in no-till systems, producers are seeking to minimize fallow by including more warm-season crops in the rotation. Therefore, in the early 1990s, several cropping systems studies were started in the central Great Plains to evaluate rotations comprised of winter wheat, various warm-season crops, and fallow. Eight to eleven years after initiation of the studies, we assessed weed community changes for studies located at Pierre, SD, Wall, SD, and Akron, Colorado.[13] At all sites, crop and weed management tactics were similar to practices used by producers in the region. The weed community at these sites was similar to the rotation study in Nebraska, except barnyardgrass was not present.

In all three studies, weed density was reduced in longer rotations based on 2-yr phases of crops with similar growth periods, as compared with rotations of shorter duration. For example, at Pierre, various rotations were comprised of cool-season crops such as winter wheat and dry pea (*Pisum sativum*), and warm-season crops such as corn, soybean, and chickpea (*Cicer arietinum*). Planting of warm-season crops usually occurred in early May, whereas dry pea was planted in late March or early April. Averaged across all phases of the rotation, weed density in a 2-year rotation of winter wheat >>fallow (W-F) was 31 plants/m^2, with downy brome being the main weed species (see graph). With a winter wheat >>chickpea rotation (W-CP), weed community density increased to 60 plants/m^2 and included summer annual weeds such as green foxtail, stinkgrass, witchgrass, and redroot pigweed, as well as downy brome. In winter wheat >>corn >>chickpea (W-C-CP), downy brome was rarely observed, but density of summer annual weeds was 25 plants/m^2. A 4-yr rotation comprised of two cool-season crops, dry pea and winter wheat, followed by two warm-season crops, corn and soybean (W-C-SB-Pea), reduced weed community density to only 5 plants/m^2. Weed density in the 4-yr rotation was reduced by a factor of 12 compared with W-CP, and reduced by a factor of five compared with W-C-CP.



Weed density in four rotations of a cropping systems study, Pierre, South Dakota. The study was initiated in 1990; weed community was assessed after the final weed management tactic occurred in each crop in 2000 and 2001. Means represent weed density averaged across all crops within each rotation across both years; bars with the same letter are not significantly different based on Fisher's LSD test (0.05). Abbreviations: W = winter wheat; CP = chickpea; C = corn; F = fallow; SB = soybean; and Pea = dry pea. (Adapted from Anderson, 2003.)

Similar results occurred at the other sites: weed density was lowest in 4-yr rotations with long intervals between crop species. Winter wheat >>proso millet, or winter wheat >>corn >>proso millet had weed densities several-fold higher than rotations such as spring wheat >>winter wheat >>corn >>sunflower at Wall, and winter wheat >>corn >>proso millet >>fallow at Akron.

Depleting the Seed Bank

Arranging cool- or warm-season crops into multi-year cycles helps weed management because it favors the natural loss of viable seeds in soil. Survival of weed seeds in soil follows a typical trend, with rapid loss of viable seeds in the first 2 years after shedding.[14] With green foxtail

[12] G.A. Wicks, D.E. Smika & G.W. Hergert, 1988, Long-term effects of no-tillage in a winter wheat (*Triticum aestivum*)-sorghum (*Sorghum bicolor*)-fallow rotation, *Weed Sci.* 36: 384-393.

[13] R.L. Anderson, 2002, Designing rotations to favor natural benefits, in Proceedings: 2002 No-Till on the Plains Winter Conference (Salina KS, 21-22 Jan. 2002), No-Till on the Plains Inc. R.L. Anderson, 2003, An ecological approach to strengthen weed management in the semiarid Great Plains, *Advances in Agronomy* 80: 33-62.

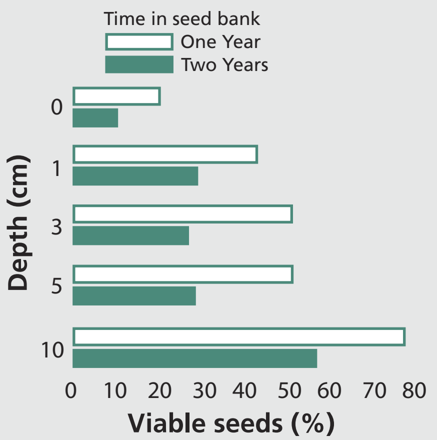
[14] G.H. Egley & R.D. Williams, 1990, Decline of weed seeds and seedling emergence over five years as affected by soil disturbance, *Weed Sci.* 38: 504-510. Roberts, 1981.

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

Impact of rotations and tillage on differences in weed density. The 4-year rotations had fewer weeds than 2-yr rotations at all sites, although the magnitude of the difference varied. Cropping systems studies show that rotations can be designed to reduce weed community density by 30 to 90 percent or more; tillage lessens this rotational effect by burying weed seeds and prolonging their survival in soil. The studies at Akron, CO and Pierre, SD were started in 1990; the study at Wall, SD was initiated in 1994. Weed community density was assessed in the 8th year of the studies at Akron and Wall, and in the 11th year of the study at Pierre. 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. (Adapted from Anderson 2002, 2003.)

and downy brome, less than 10% of seeds are viable after 2 years on the surface.[15] In the 4-yr rotation, control strategies in the 2-yr phase of cool-season crops prevents seed production of warm-season weeds, whereas seed production of cool-season weeds is prevented during the 2 years of warm-season crops. Thus, if weed seeds are not added to the seed bank, the natural loss of viable weed seeds during the 2-yr span can reduce potential seedling density in future years more than 90%.

However, we were surprised that impact of rotation design on weed density differed greatly among the three sites. Weed densities between 4-yr and 2-yr rotations differed only three-fold at Wall and six-fold at Akron, contrasting with the 12-fold difference at Pierre. This contrast in weed density does not reflect differences in weed community composition, as the prominent weeds at all sites were downy brome, green foxtail, kochia, redroot pigweed, Russian thistle, stinkgrass, and witchgrass.



Impact of seed depth in soil on longevity of green foxtail. Study conducted in the semi-arid prairies of Canada. (Adapted from Banting et al., 1973; Thomas et al., 1986).

A key difference among the studies was tillage frequency. 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 once during the rotation cycle. The study at Pierre was no-till in all years. Differences among rotations at the three sites suggest that *tillage decreases the impact of rotation on weed populations.* A second trend with these studies also suggests that tillage favors weeds. Weed community density was assessed in nine rotations at both Wall and Pierre; averaged across all rotations, weed density was six-fold greater at Wall.[16]

Tillage with the sweep plow lessened the beneficial effect of the 2-yr break by prolonging weed seed survival in the seed bank.

Tillage usually stimulates a flush of seedlings by placing some weed seeds in more favorable sites in the soil for germination.[17] However, burial of weed seeds by tillage also prolongs their survival over time because soil protects dormant seeds from environmental extremes.[18] For example, green foxtail seed survival after 2 years was greater than 50% when seeds were buried 10 cm (4 inches) in soil, contrasting with less than 10% of seeds surviving when they remained on the soil surface.[19] Even when green foxtail seeds were buried only 1 cm (0.4 inch) or 5 cm (2 inches) in soil, survival was still two-fold greater after 2 years compared with seeds remaining on the soil surface. This trend also occurs with other species. One study found that wild oat (*Avena fatua*) seed survival over winter was five times greater when seeds were buried 5 cm deep compared with seeds lying on the soil surface.[20] Other scientists found similar results with summer annual weeds.[21]

An understanding of weed seed survival helps explain other findings. Initial research on the interaction of

[15] Anderson, 2003.
[16] Anderson, 2003.
[17] Roberts, 1981.
[18] G.H. Egley, 1986, Stimulation of weed seed germination in soil, in *Reviews of Weed Science* 2: 67-89, Weed Science Society of America. Froud-Williams et al., 1984.
[19] J.D. Banting, E.S. Molberg & J.P. Gephardt, 1973, Seasonal emergence and persistence of green foxtail. *Can. J. of Plant Sci.* 53: 369-376. A.G. Thomas, J.D. Banting & G. Bowes, 1986, Longevity of green foxtail seeds in a Canadian prairie soil, *Can. J. of Plant Sci.* 66: 189-192.
[20] G.R. Sagar & A.M. Mortimer, 1976, An approach to the study of the population dynamics of plants with special reference to weeds, *Adv. Appl. Biol.* 1: 1-47.
[21] Egley & Williams, 1990.

Photo by Matt Hagny.

Low soil disturbance, long rotations, and competitive crops are important for getting a grip on weeds. This photo was taken more than 30 days after wheat harvest, but no herbicides had been applied since harvest. Further, no herbicides were applied in-crop. This was second-year wheat in a long rotation—an excellent stand & good fertilizer management helped. Notably, other fields in the area with thinner wheat or shorter rotations had plenty of weeds.

weeds and tillage reported that weed densities, especially annual grasses, usually were greater in no-till systems.[22] However, other studies found that this trend does not always occur.[23] The Jim Moyer team cited numerous examples where a certain weed species responded differently to tillage from one study to the next.[24]

To better predict weed population changes within a tillage system, Charles Mohler (weed scientist at Cornell) developed a mathematical model based on published data.[25] For seedling emergence within a no-till system, a much higher percentage will emerge in Year 1 after seed shed, compared to Year 2 or Year 3. In contrast, emergence after tillage is more balanced among years (the tapering off of emergence is not as great in Years 2 and 3). Consequently, weed seedling emergence in no-till would be substantially less during later years compared to tilled systems because the surface seed pool in no-till is depleted by emergence and mortality. However, this trend occurs only if weed seed entry to the surface seed bank is prevented during this period.

The density trends observed with the rotation studies in the central Great Plains agree with the model's prediction for no-till. Seed production of cool-season weeds is prevented during the 2-year span of warm-season crops, thus eliminating seed entry to the seed bank during those years. Similarly, seed production by warm-season weeds is avoided during the cool-season crop phase. The 2-yr break favors the natural decline of weed seed density in the seed bank. However, with the weed community at these sites, tillage with the sweep plow lessened the beneficial effect of the 2-yr span by prolonging weed survival in the seed bank.

Residue Suppression of Weeds

A benefit of crop residues on the soil surface is that weed establishment is reduced.[26] Crop residues suppress weed establishment in a variety of ways, such as altering environmental conditions related to germination, physically impeding seedling growth, or inhibiting germination and growth by allelopathy.[27] Compared to a bare soil surface, 1,700 kg/ha of residue reduced weed density 17%, whereas 6,800 kg/ha of residue reduced weed density more than 80% (see graph).

In a study[28] at Akron, CO evaluating cultural practices for control of winter annual grasses in winter wheat, we noted that quantity of winter wheat residues remaining after harvest varied among cultural systems. Winter wheat grown with standard practices left approximately 4,000 to 4,500 kg/ha of crop residues on the soil surface after harvest. In contrast, winter wheat produced 6,000 to 6,500 kg/ha of crop residues with a competition-enhancing system comprised of a higher seeding rate, taller cultivar, and N fertilizer banded with the seed.

Because tillage may stimulate weed emergence,[29] we wondered if the extra crop residues produced with the enhanced-competition system in winter wheat could minimize

Green foxtail seed survival after 2 years was greater than 50% when seeds were buried 10 cm (4 inches) in soil, contrasting with less than 10% surviving when remaining on the soil surface. Even when buried only 1 cm (0.4 inch), survival was still two-fold greater after 2 years. This trend also occurs with other species.

[22] R.J. Froud-Williams, D.H. Drennan & R.J. Chancellor, 1983, Influence of cultivation regime on weed floras of arable cropping systems, *J. Appl. Ecol.* 20: 187-197. F. Pollard & G.W. Cussans, 1981, The influence of tillage on the weed flora in a succession of winter cereal crops on a sandy loam soil, *Weed Res.* 21: 185-190.

[23] D.A. Derksen, G.P. Lafond, A.G. Thomas, H.A. Loeppky & C.J. Swanton, 1993, Impact of agronomic practices on weed communities: tillage systems, *Weed Sci.* 41: 409-417.

[24] Moyer et al., 1994.

[25] C.L. Mohler, 1993, A model of the effects of tillage on emergence of weed seedlings, *Ecol. Applic.* 3: 53-73.

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

[27] Crutchfield et al., 1986. Wicks et al., 1994.

[28] R.L. Anderson, 1997, Cultural systems can reduce reproductive potential of winter annual grasses, *Weed Technol.* 11: 608-613.

[29] Roberts, 1981.

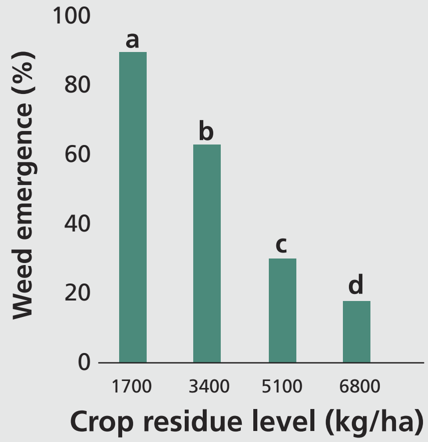
tillage-induced weed emergence. To test this hypothesis, we compared two winter wheat production systems (higher residue levels versus standard practices) for impact on weed density in corn, sunflower, or proso millet planted the following year.[30] We also compared tillage and no-till during the time span after wheat harvest and before planting the warm-season crops in both production systems of winter wheat. Tillage plots were tilled twice with the sweep plow in the fall after winter wheat harvest, followed by one tillage operation in the spring. In no-till, herbicides controlled weeds during the period between winter wheat harvest and planting. The weed community was comprised primarily of green foxtail, kochia, redroot pigweed, Russian thistle, and witchgrass.

As expected, the high-residue system reduced weed emergence 35 to 50% among the three warm-season crops compared with the normal-residue-level system in no-till. However, our hypothesis that extra crop residues would mask the effect of tillage on weed emergence was proven false. For example, weed density in corn declined from 108 seedlings/m^2 in the normal residue level with tillage to 76 seedlings/m^2 in no-till (see graph). Density declined further to 62 seedlings/m^2 in the high-residue treatment with no-till. However, tillage in the high-residue system increased weed density from 62 to 102 seedlings/m^2, thus eliminating the crop residue effect on emergence. Similar results occurred with sunflower and proso millet. Burial of residues and weed seeds by tillage apparently altered the weed seed/soil interaction such that weed emergence was increased regardless of residue quantity on the soil surface.

Photo by Doug Palen.

Redroot pigweed. From Anderson's data, pigweeds can produce over 48,000 seeds per square meter (~11 square feet), even with good crop competition. No wonder the weed populations can 'blow up' in a hurry.

Because weed seed loss is high when seeds are left on the soil surface over winter,[31] we hypothesized that delaying the initial tillage with the sweep plow until the next spring may minimize the differences in weed density between tillage systems. Therefore, we compared weed density in proso millet between no-till and sweep plow tillage, with the initial tillage occurring 4 weeks before planting proso millet in early June.[32] Our goal was to favor the natural loss of weed seeds during winter before tilling. The previous crop was winter wheat grown to produce high quantities of crop residues, and the weed community was primarily redroot pigweed and tumble pigweed (*Amaranthus albus*).



Suppression of weed seedling density as affected by quantity of winter wheat residue on the soil surface (tillage eliminates this effect). Data represent weed emergence from March through September, and are averaged across two sites and two years in western Nebraska. Bars with the same letter are not significantly different based on Fisher's LSD test (0.05). (Adapted from Crutchfield et al., 1986.)

Even with delay of tillage until spring, however, pigweed density still was six-fold greater after tillage compared with no-till. The greater loss of weed seeds over winter did not compensate for increased seedling emergence due to tillage. The density of pigweeds in the tilled system reduced proso millet grain yield 17%, but weed interference did not affect grain yield in no-till. A further consequence of tillage was that the pigweed plants infesting proso millet produced 48,300 seeds/m^2, more than nine-fold greater than pigweed seed production in the no-till system.

Less Yield after Tillage

Another consequence of tillage is that crops yield less when tillage with the sweep plow occurs in the period before planting. Compared with no-till, yield loss in tilled systems for warm-season crops ranged from 29% for corn to 13% with sunflower. Sorghum and proso millet also yielded less after tillage. With winter wheat, where four to six operations with the sweep plow occurred during the fallow period, yield was reduced more than 30% compared with no-till.

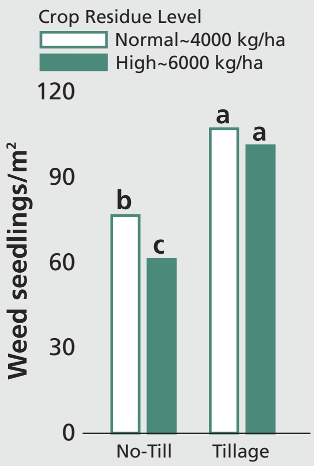
One reason why crops yield less after tillage is less favorable moisture conditions. For example, available soil water at planting time for winter wheat was 7 cm (2.8

[30] R.L. Anderson, 1999, Cultural strategies reduce weed densities in summer annual crops, *Weed Technol.* 13: 314-319.
[31] Egley & Williams, 1990. Sagar & Mortimer, 1976.
[32] R.L. Anderson, 2000, A cultural systems approach eliminates the need for herbicides in semiarid proso millet, *Weed Technol.* 14: 602-607.

inches) less after stubble mulch fallow compared with a no-till system.[33] No-till systems increase soil water because crop residues improve precipitation infiltration as well as reduce water evaporation from the soil surface.[34] Tillage, by burying crop residues, reduces efficiency of precipitation storage in this semiarid climate.

Implications for Weed Management

Producers are adjusting their cropping systems to address herbicide resistance. Tillage is one option to reduce herbicide selection pressure on the weed community. However, tillage with the sweep plow may increase weed density in crops and reduce crop yield. Tillage before planting warm-season crops may force producers to increase inputs for weed control in the crop because of higher weed density.



Effect of winter wheat residue and tillage on weed density in corn. Averaged across 3 years. Bars with the same letter are not significantly different based on Fisher's LSD test (0.05). (Adapted from Anderson, 1999.)

No-till systems provide other options for producers to manage herbicide resistance. The diversity of crops that can be grown because of no-till provides more opportunities for producers to rotate herbicides with different modes of action.[35] In addition, producers following rotations comprised of multi-year phases of both cool- and warm-season crops have lowered weed community density such that herbicide inputs can be reduced 50%.[36] In 4-yr rotations with no-till, some crops, such as proso millet, do not need in-crop herbicides for weed control.[37]

Nevertheless, a serious obstacle in no-till systems is weed control during fallow; producers are seeking options to reduce glyphosate or atrazine use during fallow. Herbicides with different modes of action that effectively control weeds during fallow, but with costs similar to glyphosate or atrazine, would be helpful. Another option is green fallow, where a cover crop is grown only for vegetative growth before being killed with herbicides. For example, sweetclover (*Melilotus officinalis*) grown over winter reduced weed density 75 to 97% during fallow, compared with conventional fallow.[38] In the central Great Plains, however, cover crop growth required for that level of weed suppression reduced winter wheat yield because of excessive water use.[39] In contrast, wheat yields were not affected if a green fallow crop such as dry pea was grown in the spring for only 6 weeks.[40] If green fallow could suppress weeds for part of the season, producers may be able to reduce selection pressure by glyphosate on the weed community. The timing of green fallow suppression could be related to periods of peak glyphosate use in previous years.

Producers following rotations comprised of multi-year phases of both cool- and warm-season crops have lowered weed community density such that herbicide inputs can be reduced 50%.

A further consideration related to tillage is health and productivity of the soil. Maintaining crop residues on the soil surface increases soil organic matter as well as minimizes erosion.[41] The winter wheat >>fallow system based on tillage has reduced soil organic matter levels more than 50% during the last 100 years; loss of organic matter reflects the low quantity of crop residues returned to the soil when growing only one crop every 2 years. In contrast, no-till systems are improving soil health in the central Plains region, as interactions among more favorable water relations, crop residue production, and intensive cropping are continually improving soil organic matter levels and crop performance.[42] Tillage disrupts this soil regeneration by its detrimental effect on crop residue conservation and water relations.

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

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