Weed Science, 1992. Volume 40:654–659

# Weed Seedbank Response to Tillage, Herbicides, and Crop Rotation Sequence[1]

DANIEL A. BALL[2]

*Abstract.* **Changes in the weed seedbank due to crop production practices are an important determinant of subsequent weed problems. Research was conducted to evaluate effects of primary tillage (moldboard plowing and chisel plowing), secondary tillage (row cultivation), and herbicides on weed species changes in the soil seedbank in three irrigated row crop rotational sequences over a 3-yr period. The cropping sequences consisted of continuous corn for 3 yr, continuous pinto beans for 3 yr, or sugarbeets for 2 yr followed by corn in the third year. Cropping sequence was the most dominant factor influencing species composition in the seedbank. This was partly due to herbicide use in each cropping sequence producing a shift in the weed seedbank in favor of species less susceptible to applied herbicides. A comparison between moldboard and chisel plowing indicated that weed seed of predominant species were more prevalent near the soil surface after chisel plowing. The number of predominant annual weed seed over the 3-yr period increased more rapidly in the seedbank after chisel plowing compared to moldboard plowing unless effective weed control could be maintained to produce a decline in seedbank number. In this case, seedbank decline was generally more rapid after moldboard plowing. Row cultivation generally reduced seedbanks of most species compared to uncultivated plots in the pinto bean and sugarbeet sequences. A simple model was developed to validate the observation that rate of change in the weed seedbank is influenced by type of tillage and weed control effectiveness. Nomenclature: Corn, *Zea mays* L.; pinto beans, *Phaseolus vulgaris* L.; sugarbeets, *Beta vulgaris* L.** *Additional index words:* **Weed shifts, reduced tillage, conservation tillage, population dynamics, modeling, KCHSC, AMARE, CHEAL, SOLSA, SETVI, ERACN.**

## INTRODUCTION

Patterns of disturbance in agricultural ecosystems influence species composition of weed plant communities. Agroecosystems are characterized as highly disturbed, so plant species inhabiting these sites are adapted to and respond to the disturbance regime (4, 21, 31, 35). Changes in agricultural management practices alter the pattern of disturbance and produce changes in the weed plant community over time. Several workers have documented the effect of different crop/weed management practices on changes in weed flora (1, 9, 12, 16, 18, 19, 30, 34) and the weed seedbank (3, 7, 25, 26). Many weed infestations in cropping systems arise from the weed seedbank, so changes in the seedbank due to agricultural management practices ultimately result in changes in observed weed flora. However, seedbank changes must be of sufficient magnitude to produce detectable changes in weed flora since only a small percentage of seed residing in soil is expressed as flora during any given growing season (13, 22).

Tillage and crop rotational sequences are two primary practices that have an impact on weed seedbanks. Cropping sequence, in turn, dictates type and time of tillage, as well as herbicide use patterns which influence weed seedbank composition (3, 5, 6, 26, 28). Recognizing the importance of tillage practices and cropping sequence in altering species composition in the weed seedbank can lead to improved strategies for weed management.

## INFLUENCE OF TILLAGE ON WEED SEEDBANKS

It is widely recognized that primary tillage influences distribution of weed seed in the soil tillage layer (10, 11, 22). Inversion tillage such as moldboard plowing results in burial of a large proportion of seed in the tillage layer. Noninversion tillage methods such as chisel plowing leave a greater proportion of seed near the surface. Figure 1 illustrates vertical distribution of weed seed in the soil after different primary tillages. These data are from a study conducted on the weed seedbank of irrigated cropping systems (1) and represent typical seed distribution patterns after moldboard and chisel plowing. It also has been postulated that moldboard plowing turns seed up to the surface at the same time it buries other seed, but this has not been documented. The increased proportion of weed seed left near the surface after chisel plowing compared to moldboard plowing produces a greater potential for weed germination and establishment. This greater potential for weed infestation in chisel or other noninversion tillage systems requires increased weed management inputs to prevent development of unacceptable weed problems.

Secondary tillage such as row cultivation during the growing season also has an influence on seedbank numbers and species composition. In a 3-yr study of irrigated row crops (3), cultivation eliminated weeds between the row which reduced seed production and influenced seedbank number. However, the impact of row cultivation on seedbank composition was dependent on cropping sequence. Cultivation reduced weed seed numbers in a continuous dry bean (*Phaseolus vulgaris* L.) sequence where herbicidal weed control alone was inadequate. Effect of cultivation was not evident, however, in continuous corn (*Zea mays* L.) where herbicidal weed control was adequate. Row cultivation

[1]Received for publication May 23, 1992, and in revised form October 9, 1992. Oregon Agric. Exp. Stn. Tech. Paper No. 9831.

[2]Asst. Prof., Oregon State Univ., Columbia Basin Agric. Res. Ctr., P.O. Box 370, Pendleton, OR 97801.

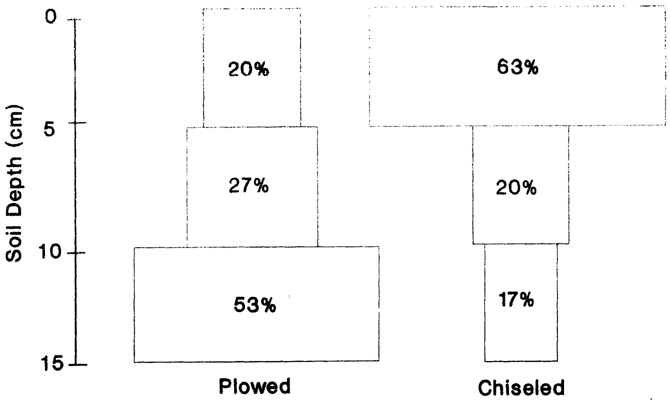


*Figure 1.* Influence of primary tillage on vertical distribution of total weed seed to a 15-cm depth in the soil after a dry bean crop (1). LSD (0.01) for plow NS and for chisel 34.5%.

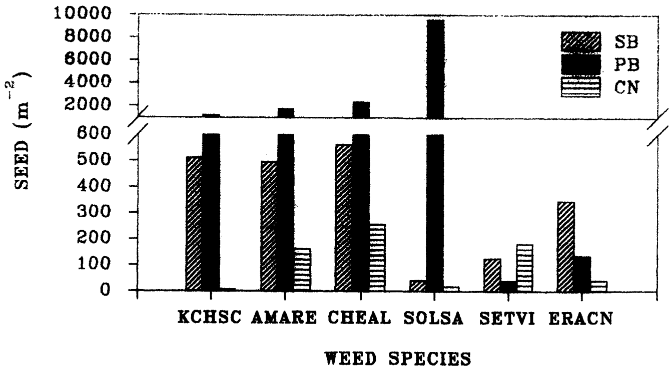


*Figure 2.* Influence of cropping sequence on predominant weed species to a 15-cm depth in the seedbank. SB = 2-yr sugarbeet, 1-yr corn; PB = 3-yr pinto beans; and CN = 3-yr corn. KCHSC = kochia, AMARE = redroot pigweed, CHEAL = common lambsquarters, SOLSA = hairy nightshade, SETVI = green foxtail, ERACN = stinkgrass (3).

produced less soil disturbance than primary tillage which resulted in less influence on the seedbank than from primary tillage.

Tillage influences the longevity of weed seed in the soil (8, 17, 32, 33, 36). Seed buried in the soil remains viable longer than seed near the surface, and this increased longevity varies according to species (23, 24). Persistence of weeds in the seedbank can influence ability of a weed species to cause economic losses in agricultural systems and prolong weed infestations over several growing seasons.

### INFLUENCE OF CROP ROTATION ON WEED SEEDBANKS

Over a several year period, the most dominant factor influencing species composition in the seedbank and weed flora is cropping sequence. Crop sequences dictate both time and type of tillage operations and herbicides used. Weed species selection due to crop rotation has been reported by several workers (14, 15, 29).

In a 3-yr study, designed to evaluate the influence of crop rotation, primary tillage, and herbicide input level on the weed seedbank (3), changes in seedbank number and species composition occurred in the top 15 cm of soil due to cropping sequence and herbicide use (Figure 2). A sequence of 3-yr continuous pinto bean production became dominated by broadleaf weeds, particularly hairy nightshade (*Solanum sarrachoides* Sentner). A 3-yr continuous corn rotation had fewer total weed seed, but the seedbank contained a large proportion of green foxtail (*Setaria viridis* (L.) Beauv.) and common lambsquarters (*Chenopodium album* L.). A third sequence of sugarbeets (*Beta vulgaris* L.) for 2 yr followed by corn produced a weed seedbank dominated by kochia [*Kochia scoparia* (L.) Schrad.], redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters, and stinkgrass [*Eragrostis cilianensis* (All.) E. Mosher].

### INFLUENCE OF HERBICIDE USE ON WEED SEEDBANKS

Herbicides also influence seed number and species composition of the seedbank. Certain species decrease in the seedbank and others increase depending on herbicide use (26). Herbicides selected for use are partly dictated by chosen crop rotation sequences. In general, weed selection will be in favor of species that are less susceptible to applied herbicides. This in turn ultimately dictates species composition of the seedbank. Other researchers have reported a steady decline in total seedbank densities in plots receiving repeated herbicide applications (6, 28). However, weed seed numbers increased rapidly after herbicide use was discontinued. In the 3-yr study summarized in Figure 2, the selection of hairy nightshade in the pinto sequence, kochia in the sugarbeet sequence, and green foxtail in the corn sequence, was partly due to tolerance of these weeds to herbicides used in the cropping sequences.

### RATE OF CHANGE IN THE WEED SEEDBANK AS INFLUENCED BY TILLAGE AND WEED MANAGEMENT INPUTS

Differential rates of change among weed species in the seedbank will eventually be expressed as changes in weed flora. Management practices such as primary tillage and weed control influence rate of change in individual weed species in the seedbank. In a study of conservation tillage systems for winter wheat (*Triticum aestivum* L.) production in the Pacific Northwest, weed seedbank numbers increased more rapidly after chisel plowing than moldboard plowing[3].

In the 3-yr study previously discussed (3), each cropping sequence was given an annual moldboard plow or chisel plow subtreatment, and the rate of change in seedbank number was influenced by this primary tillage (Table 1). Post harvest soil samples were taken from the top 15 cm of soil after primary tillages were preformed in November of each year. Weed seed were physically extracted (2) and identified. With some

[3]F. L. Young, USDA-ARS, Pullman, WA. Personal communication.

*Table 1.* Influence of primary tillage on seedbank measured to a soil depth of 15 cm in three cropping sequences, 1985–1987[a] (3).

| Crop[b] | Weed[c] | Plow 1985 | Plow 1986 | Plow 1987 | Chisel 1985 | Chisel 1986 | Chisel 1987 | Interaction probability[d] |
|---|---|---|---|---|---|---|---|---|
| | | no. $m^{-2}$ | | | | | | |
| SB | KCHSC | 1260 a | 1260 a | 330 a | 10 120 a | 8 520 a | 690 b | .0001 |
| | AMARE | 80 a | 160 a | 330 a | 150 c | 1 300 a | 660 b | .0004 |
| | CHEAL | 270 a | 330 a | 520 a | 750 b | 1 650 a | 600 b | .0002 |
| | SOLSA | 20 | 20 | 40 | 40 | 130 | 40 | NS |
| | SETVI | 60 a | 20 a | 20 a | 30 b | 90 b | 230 a | .001 |
| | ERACN | 1 a | 1 a | 120 a | 1 b | 10 b | 570 a | .0004 |
| | OTHER | 180 | 260 | 30 | 390 | 1 230 | 120 | — |
| | TOTAL | 1870 a | 2050 a | 1390 a | 11 480 a | 12 930 a | 2 910 b | .0001 |
| PB | KCHSC | 390 a | 20 a | 350 a | 1 190 b | 170 c | 2 070 a | .05 |
| | AMARE | 510 | 370 | 690 | 3 640 | 6 500 | 2 890 | NS |
| | CHEAL | 2530 | 1200 | 1520 | 7 680 | 5 210 | 3 210 | NS |
| | SOLSA | 30 a | 370 a | 2110 a | 470 b | 1 980 b | 17 030 a | .0001 |
| | SETVI | 50 | 20 | 40 | 100 | 40 | 40 | NS |
| | ERACN | 1 a | 0 a | 30 a | 1 b | 0 b | 240 a | .0004 |
| | OTHER | 230 | 80 | 0 | 260 | 190 | 40 | — |
| | TOTAL | 3470 a | 2060 a | 4740 a | 13 340 b | 14 090 b | 25 520 a | .03 |
| CN | KCHSC | 10 | 5 | 0 | 40 | 30 | 7 | NS |
| | AMARE | 190 a | 100 a | 50 b | 240 a | 100 b | 270 a | .03 |
| | CHEAL | 200 | 70 | 100 | 370 | 130 | 410 | NS |
| | SOLSA | 30 | 10 | 5 | 10 | 10 | 30 | NS |
| | SETVI | 90 a | 20 a | 30 a | 70 b | 50 b | 330 a | .0002 |
| | ERACN | 4 | 4 | 20 | 4 | 7 | 60 | NS |
| | OTHER | 480 | 620 | 30 | 490 | 720 | 3 | — |
| | TOTAL | 1000 a | 830 a | 230 b | 1 220 a | 1 000 a | 1 110 a | .03 |

[a]Data are averaged across all cultivation and herbicide input levels. Means within a tillage type and weed species followed by the same letter are not significantly different at the 0.05 level as determined by LSD (0.05).

[b]SB = 2 yr sugarbeet and 1 yr corn, PB = continuous dry bean, CN = continuous corn.

[c]KCHSC = kochia, AMARE = redroot pigweed, CHEAL = common lambsquarters, SOLSA = hairy nightshade, SETVI = green foxtail, ERACN = stinkgrass, OTHER = all other species.

[d]Probability level for the primary tillage by year interaction.

exceptions, where seedbank number increased over the 3-yr period, the increase occurred more rapidly with chisel plowing than with moldboard plowing. Conversely, where seed numbers declined over the 3 yr, rate of decline was more rapid with moldboard plowing. The exception to a more rapid decline with moldboard plowing was for species with short seed longevity in the soil, especially where weed control was maintained adequately.

For example, in a sequence of continuous pinto beans for 3 yr, adequate weed control could not be maintained, and there was an increase in total weed seed numbers. In 3 yr, this increase was more rapid with chisel plowing compared to moldboard plowing (Figure 3). This also was evident with the predominant weed, hairy nightshade. Conversely, in continuous corn for 3 yr, acceptable levels of weed control were maintained, and total weed seedbank numbers declined. In the top 15 cm of soil, total seed number declined more rapidly with annual moldboard plowing than annual chisel plowing (Figure 4). This was not evident, however, in green foxtail, a predominant species in the corn sequence. This species was poorly controlled after chisel plowing after 3 yr and increased in the seedbank, while other, more easily controlled species declined or remained unchanged (Table 1). Green foxtail increase, again, was more rapid with chisel plowing. An exception to the premise of a more rapid seedbank decline from moldboard plowing occurred with 2 yr of sugarbeet and

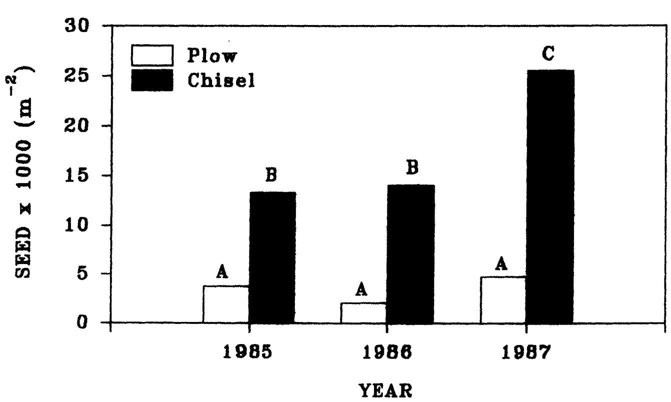


*Figure 3.* Influence of primary tillage over 3 yr on total seedbank to a 15-cm depth in the pinto bean sequence. Data represented by bars with the same letter within tillage type do not differ at P > 0.05 (3).

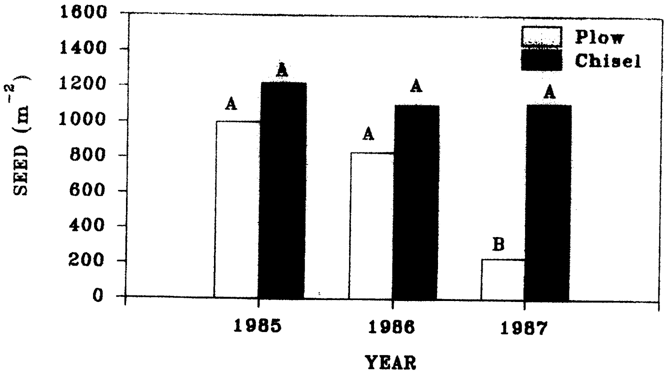


*Figure 4.* Influence of primary tillage over 3 yr on total seedbank to a 15-cm depth in the corn sequence. Data represented by bars with the same letter within tillage type do not differ at P > 0.05 (3).

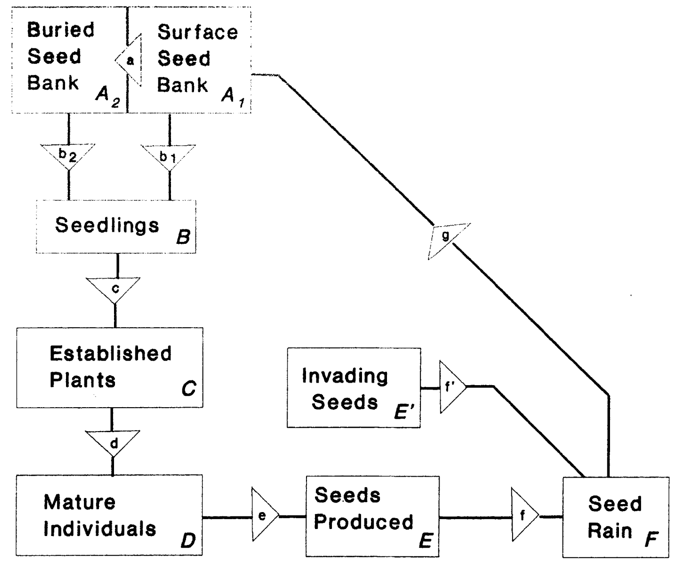


*Figure 5.* A generalized life table for an annual weed species reproducing from seed. $A_2$ through F are six intermediate life stages. Small letters represent interphase multiplier variables of seed survival that control seed number in each life stage and may range from 0 to 1.

1 yr of corn. Between 1985 and 1986, increases in seedbank density were more pronounced with chisel plowing. However, between 1986 and 1987, seed of several species including kochia, common lambsquarters, and redroot pigweed declined more rapidly with chisel plowing (Table 1). In this year, the crop changed from sugarbeets to corn. It is possible that leaving seed near the surface with chiseling allowed greater germination and subsequent control with corn herbicides, thereby depleting the seedbank. This suggests that reduced tillage rather than moldboard plowing will provide seedbank reductions if effective weed control can be maintained in each rotational crop.

The differential change in seed number between plowing and chiseling has other implications for weed management in conservation tillage systems. Unfortunately, chisel-based tillage systems will allow difficult-to-control weeds to build up at a rapid rate. Higher rates of seed increase due to chiseling point to the need for increased weed management in conservation tillage systems. Also, a weed infestation may respond more slowly to weed control in chisel plow systems, unless control is highly effective.

## MODELING THE RATE OF CHANGE IN THE SOIL SEEDBANK

Difficulty in substantiating the interaction between factors influencing seedbank population dynamics makes it beneficial to model this system to gain a better conceptual understanding of the contributing processes. A simple model of weed seedbank dynamics developed by Sagar and Mortimer (27) has been used to explain changes in wild oat (*Avena fatua* L.) plant population density as influenced by management practices (20). This same conceptual model was used to provide a mechanistic explanation of observations on seedbank change from the 3-yr study discussed above (3).

Figure 5 illustrates a model of the different life stages of a typical annual weed species reproducing from seed. The proportion of individuals progressing through each life stage is dependent on several environmental and genetic factors. Using this model, a simple computer program was written to calculate seedbank changes over a 4-yr period. Several hypothetical scenarios were created to illustrate the influence of primary tillage, weed control effectiveness, and seed longevity on rate of change in the weed seedbank.

Change in the surface seedbank density through one life cycle was calculated based on number of individuals progressing through each of six intermediate life stages (modules $A_2$ through F, Figure 5). In the model, seed number in each life stage is controlled by nine interphase multiplier variables. The surface seed population, $A_1$, changes in response to seed production and survival from the previous generation. An overwinter mortality multiplier variable (g) accounts for overwinter mortality of seed, thereby allowing calculation of seedbanks over successive generations. The various multiplier variables represent mortality factors (0 to 100%) between each life stage during a growing season.

Calculated seedbank population over a 4-yr period based on several hypothetical scenarios of weed growth is presented in Table 2. Assumptions included an initial surface seed density ($A_1$) of 10 000 $m^{-2}$, moldboard plowing burial of 60% (a = 0.4) of the seed (from Figure 1), and a seedling emergence (B) of 2% ($b_1$ = 0.02, $b_2$ = 0.0). In the first scenario, good control of 95% (c = 0.05) was assumed which limited the number of seedlings that would become established plants. Other assumptions included no self-thinning (d = 1.0), a hypothetical per plant seed production of 1000 (e) with all seed reaching the soil surface (f = 1.0), and no seed immigration (f' = 0.0). In this first scenario, overwinter mortality was assumed to be 30% (g = 0.7), with overwinter mortality unaffected by burial depth. Using all of the above assumptions in the simulation, it was observed that if good weed control was obtained over the 4-yr simulation, seedbank

*Table 2.* Simulated changes in weed seedbank to a depth of 15 cm as influenced by primary tillage and weed control effectiveness. Long-lived weed seed[a].

| Year | Seedbank as affected by primary tillage type and weed control | | | |
|---|---|---|---|---|
| | Moldboard plow | | Chisel plow | |
| | Good control | Poor control | Good control | Poor control |
| | no. $m^{-2}$ | | | |
| 0 | 10 000 | 10 000 | 10 000 | 10 000 |
| 1 | 4 000 | 24 000 | 7 000 | 42 000 |
| 2 | 2 240 | 47 040 | 6 860 | 144 060 |
| 3 | 1 250 | 92 200 | 6 720 | 494 130 |
| 4 | 700 | 180 710 | 6 590 | 1 694 850 |

[a]Influence of tillage on longevity of long-lived seed assumed to be negligible with 30% overwinter mortality for both moldboard and chisel plow.

*Table 3.* Simulated changes in weed seedbank to a depth of 15 cm as influenced by primary tillage and weed control effectiveness. Short-lived weed seed[a].

| Year | Seedbank as affected by primary tillage type and weed control | | | |
|---|---|---|---|---|
| | Moldboard plow | | Chisel plow | |
| | Good control | Poor control | Good control | Poor control |
| | no. $m^{-2}$ | | | |
| 0 | 10 000 | 10 000 | 10 000 | 10 000 |
| 1 | 4 000 | 24 000 | 1 960 | 42 000 |
| 2 | 1 920 | 40 320 | 550 | 41 160 |
| 3 | 920 | 67 740 | 140 | 40 340 |
| 4 | 440 | 113 800 | 150 | 39 530 |

[a]Influence of tillage is assumed to produce substantial differences in seed longevity with 40 and 80% overwinter mortality for both moldboard and chisel plow, respectively.

density declined (Table 2). In a similar simulation with an assumption of chisel plow burial of only 30% (a = 0.7), with good weed control, a decrease of the seedbank population also occurred (Table 2), but less rapidly than moldboard plowing, which is in general agreement with actual 3-yr field observations presented in Table 1.

A second simulation was run assuming all the same parameters for both moldboard and chisel plowing as described above, with the exception of an assumption of poor weed control of 70% (c = 0.3). The results indicated a general increase in seedbank density over the 4-yr period (Table 2), but the increase was more rapid with chisel plowing (a = 0.7) than moldboard plowing (a = 0.4). Again, these results are in general agreement with trends observed in the 3-yr field study.

## MODELING THE INFLUENCE OF SEED LONGEVITY ON SEEDBANK CHANGES

A notable exception to the premise of more rapid seedbank decline due to moldboard plowing was previously mentioned in the 3-yr study in the cropping sequence consisting of 2 yr of sugarbeets and 1 yr of corn. In this situation the rapid decline of kochia was observed with chisel plowing. This was possibly due to short longevity of kochia seed near the surface as is the case after chisel plowing (36). The computer program based on the model in Figure 5 was used to simulate a high mortality rate of 80% (g = 0.2) in the overwintering population if chiseling was employed, but less overwinter seed mortality of 40% (g = 0.6) if moldboard plowing was used. All other interphase variables were as previously described. Simulation results for a 4-yr period are presented in Table 3. The simulated rate of change for 4 yr in the seedbank (Table 3) shows that increased seed mortality due to surface placement of seed resulted in a decline in the seedbank over the 4-yr simulation period, if good weed control was maintained. This suggests that if good weed control can be obtained in a chisel plow system, depletion of a short-lived species in the seedbank will be more rapid than with conventional moldboard plowing.

## IMPLICATIONS FOR WEED MANAGEMENT

Adoption of reduced tillage has been limited by problems associated with poor weed control. Recognition that reduced tillage accelerates buildup of seed of weed species less susceptible to applied herbicides points to the importance of maintaining acceptable levels of weed control in reduced-tillage systems beyond that necessary in systems utilizing moldboard plows. Placing greater emphasis on weed management in conversion to conservation tillage systems will improve chances of a successful conversion. Failure to adjust weed management inputs with conservation tillage can result in rapid development of weed problems. It is also likely that development of herbicide-resistant weed populations will be more rapid in reduced-tillage systems due to the potential for rapid seedbank increases when control cannot be maintained.

From the previous discussion it also seems possible that tillage system and crop rotational sequences could be integrated to accelerate decline of problem weeds in the seedbank. Minimum tillage to leave seed near the surface coupled with effective crop rotation/herbicide regimes could accelerate depletion of problem weed species from the seedbank.

## LITERATURE CITED


1. Ball, D. A. 1987. Influence of tillage and herbicides on row crop weed species composition. Ph.D. Dissertation, Univ. Wyoming. Laramie, WY. 157 pp.
2. Ball, D. A. and S. D. Miller. 1989. A comparison of techniques for estimation of arable soil seed banks and relationship to weed flora. Weed Res. 29:365–373.
3. Ball, D. A. and S. D. Miller. 1990. Weed seed population response to tillage, and herbicide use in three irrigated cropping sequences. Weed Sci. 38:511–517.
4. Bazzaz, F. A. 1983. Characteristics of populations in relation to disturbance in natural and man-modified ecosystems. Pages 259–275 *in* H. A. Mooney and M. Gordon, eds., Disturbance and Ecosystems, Components of Response. Springer-Verlag, Berlin.
5. Burnside, O. C. 1978. Mechanical, cultural and chemical control of weeds in a sorghum-soybean rotation. Weed Sci. 26:362–369.
6. Burnside, O. C., R. S. Moomaw, F. W. Roeth, G. A. Wicks, and R. G. Wilson. 1986. Weed seed demise in soil in weed-free corn production

across Nebraska. Weed Sci. 34:248–251.

7. Cardina, J., E. Regnier, and K. Harrison. 1991. Long-term effects on seed banks in three Ohio soils. Weed Sci. 39:186–194.
8. Chepil, W. S. 1946. Germination of weed seeds II. The influence of tillage treatments on germination. Sci. Agric. 26:347–357.
9. Donaghy, D. I. and E. H. Stobbe. 1972. Weed population response to zero-tillage. Proc. North. Cent. Weed Control Conf. 27:41.
10. Fay, P. K. and W. A. Olson. 1978. Technique for separating weed seed from soil. Weed Sci. 26:530–533.
11. Froud-Williams, R. J., R. J. Chancellor, and D.S.H. Drennan. 1983. Influence of cultivation regime upon buried weed seeds in arable cropping systems. J. Appl. Ecol. 20:199–208.
12. Fryer, J. D. and R. J. Chancellor. 1970. Evidence of changing weed populations in arable land. Pages 958–964 *in* Proc. 10th Br. Weed Control Conf.
13. Harper, J. L. 1977. The seed bank. Pages 83–110 *in* Population Biology of Plants. Academic Press, London.
14. Hume, L., S. Tessier, and F. B. Dyck. 1991. Tillage and rotation influences on weed community composition in wheat in southwestern Saskatchewan. Can. J. Plant Sci. 71:783–789.
15. Johnson, C. W. and H. D. Coble. 1986. Crop rotation and herbicide effects on the population dynamics of two annual grasses. Weed Sci. 34:452–456.
16. Miller, S. D. and J. D. Nalewaja. 1985. Weed spectrum change and control in reduced-till wheat. Pages 11–14 *in* North Dakota Farm Res.
17. Miller, S. D., J. D. Nalewaja, and G. Gillespie. 1985. Wild oats seed longevity and production. Pages 15–18 *in* North Dakota Farm Res.
18. Pollard, F. and G. W. Cussans. 1977. The influence of tillage on the weed flora of four sites sown to successive crops of spring barley. Pages 1019–1028 *in* Proc. Br. Crop Prot. Conf.—Weeds. 1976.
19. Pollard, F. and 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.
20. Radosevich, S. R. and J. S. Holt. 1984. Pages 86–89 *in* Weed Ecology: Implications for Vegetation Management. John Wiley and Sons, New York.
21. Reiners, W. A. 1983. Disturbance and basic properties of ecosystem energetics. Pages 83–98 *in* H. A. Mooney and M. Godron, eds. Disturbance and Ecosystems, Components of Response. Springer-Verlag, Berlin.
22. Roberts, H. A. 1963. Studies on the weeds of vegetable crops. III. Effects of different primary cultivations on the weed seeds in the soil. J. Ecol. 51:83–95.
23. Roberts, H. A. 1964. Emergence and longevity in cultivated soil of seeds of some annual weeds. Weed Res. 4:296–307.
24. Roberts, H. A. and P. A. Dawkins. 1967. Effect of cultivation on the numbers of viable weed seeds in soil. Weed Res. 7:290–301.
25. Roberts, H. A. 1981. Seed banks in soils. Adv. Appl. Biol. 6:1–55.
26. Roberts, H. A. and J. E. Neilson. 1981. Changes in the soil seed bank of four long-term crop/herbicide experiments. J. Appl. Ecol. 18: 661–668.
27. Sagar, G. R. and A. M. Mortimer. 1976. An approach to the study of the population dynamics of plants with special reference to weeds. Appl. Biol. 1:1–47.
28. Schweizer, E. E. and R. L. Zimdahl. 1984. Weed seed decline in irrigated soil after six years of continuous corn and herbicides. Weed Sci. 32:76–83.
29. Slife, F. W. 1976. Pest ecosystem models, other important ecosystems—weed populations. Pages 193–195 *in* Modeling for Pest Management: Concepts, Techniques, and Applications. U.S.A./USSR. Michigan State Univ., East Lansing.
30. Triplett, G. B. and G. D. Lytle. 1972. Control and ecology of weeds in continuous corn grown without tillage. Weed Sci. 20:453–457.
31. Vogl, R. J. 1980. The ecological factors that produce perturbation-dependent ecosystems. Pages 63–94 *in* J. Cairns, ed. Recovery Process in Damaged Ecosystems. Ann Arbor Sci. Publ., Ann Arbor, MI.
32. Wicks, G. A. and B. R. Somerhalder. 1971. Effects of seedbed preparation for corn on distribution of weed seed. Weed Sci. 19: 666–668.
33. Wilson, B. J. 1972. Studies of the fate of *Avena fatua* seeds on cereal stubble, as influenced by autumn treatment. Pages 242–247 *in* Proc. 11th Br. Weed Control Conf.
34. Wrucke, M. A. and W. E. Arnold. 1985. Weed species distribution as influenced by tillage and herbicides. Weed Sci. 33:853–856.
35. Young, J. A. and R. A. Evans. 1976. Responses of weed populations to human manipulations of the natural environment. Weed Sci. 24: 186–190.
36. Zorner, P. S., R. L. Zimdahl, and E. E. Schweizer. 1984. Effect of depth and duration of seed burial on kochia (*Kochia scoparia*). Weed Sci. 32:602–607.