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# Long-Term Tillage Effects on Seed Banks in Three Ohio Soils[1]

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*Abstract.* Soils from long-term tillage plots at three locations in Ohio were sampled to determine composition and size of weed seed banks following 25 yr of continuous no-tillage, minimum-tillage, or conventional-tillage corn production. The same herbicide was applied across tillage treatments within each year and an untreated permanent grass sod was sampled for comparison. Seed numbers to a 15-cm depth were highest in the no-tillage treatment in the Crosby silt loam (77 800 $m^{-2}$) and Wooster silt loam (8400 $m^{-2}$) soils and in the grass sod (7400 $m^{-2}$) in a Hoytville silty clay loam soil. Lowest seed numbers were found in conventional-tillage plots in the Wooster soil (400 $m^{-2}$) and in minimum-tillage plots in the Crosby (2200 $m^{-2}$) and Hoytville (400 $m^{-2}$) soils. Concentration of seeds decreased with depth but the effect of tillage on seed depth was not consistent among soil types. Number of weed species was highest in permanent grass sod (10 to 18) and decreased as soil disturbance increased; weed populations were lowest in conventional tillage in the Hoytville soil. Common lambsquarters, pigweeds, and fall panicum were the most commonly found seeds in all soils. Diversity indices indicated that increased soil disturbance resulted in a decrease in species diversity. Weed populations the summer following soil sampling included common lambsquarters, pigweeds, fall panicum, and several species not detected in the seed bank. Nomenclature: Common lambsquarters, *Chenopodium album* L. #[3] CHEAL; fall panicum, *Panicum dicotomiflorum* Michx. # PANDI; corn, *Zea mays* L.

*Additional index words.* No-tillage, minimum tillage, weed shifts.

## INTRODUCTION

The weed seed bank, comprised of viable seeds in the soil or on its surface, is the principal source of annual weeds in field crops. Size and composition of the seed bank as well as aboveground weed flora reflect past and present weed, crop, and soil management (24). Reducing the size of the weed seed bank has been a long-term goal of weed management strategies, especially for fields cropped continuously (28). Additions and losses of seeds from the seed bank are affected by physical, biological, and management factors that interact over time to result in shifts in weed flora (5).

Soil physical and fertility conditions are important in establishment of weed seed banks (15). Soil physical properties that influence freezing and thawing, rates of drying, and surface cracking can affect seed dormancy and depth distribution. Large differences in frequency of species within seed banks have been reported in surveys of soils differing in texture and organic matter (4, 22).

Tillage affects species composition and depth distribution of seeds in soil (18). As tillage intensified, weed species associated with intensive cropping increased in importance (27). Twelve percent of the viable seed bank emerged after a shallow cultivation or deep plowing, compared to 8% from uncultivated soil (2). After 9 yr of tillage treatments, the most uniform depth distribution occurred with deep (36- to 41-cm) plowing; rotary hoe cultivation concentrated seeds in the top 15 cm of soil (27). Most seeds were in the unaggregated soil fraction with reduced tillage, while conventional tillage incorporated seeds into larger aggregates and deeper layers of soil (23).

The interaction of herbicides with tillage and cultivation practices has altered the size and nature of seed banks (17, 24). The seed bank was reduced 98% after atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] was applied to cornfields for 6 yr (28). Continued use of triazine herbicides in cornfields in Ontario altered weed species composition and resulted in large increases in triazine-resistant weeds (5). When triazines were applied consecutively to cornfields for 16 yr in England, the seed bank decreased 96% and number of species was reduced by half (25).

Most studies on effects of cultural practices on weed seed banks have been limited to one soil type, a single rotation, or a few growing seasons; however, 4 to 10 yr are required for tillage systems to reach equilibria in yield, weed populations, and soil characteristics (10). Tillage studies initiated in Ohio in 1962 provide a unique opportunity to document long-term effects of tillage systems on corn yield and soil properties. Changes in soil chemical (C, N, P, and pH) and enzymatic components after 18 to 19 yr of continuous conventional-, minimum-, and no-tillage corn have been reported (8, 9) as have differences in arthropod communities (29). Corn grain yields were similar among tillage treatments after 22 yr, as long as weeds were controlled, except for reduced yields with no-tillage on a poorly drained soil (11).

The objective of this study was to determine the long-term effects of tillage and continuous corn production on the size, distribution, and composition of the seed bank in three soils in Ohio.

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[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

## MATERIALS AND METHODS

Experiments were begun in 1962 on a Crosby silt loam (Aeric Ochraqualf) at South Charleston (west-central Ohio), a Wooster silt loam (Typic Fragiudalf) at Wooster (northeastern Ohio), and in 1963 on a Hoytville silty clay loam (Mollic Ochraqualf) at Hoytville (northwestern Ohio). The Crosby soil is somewhat poorly drained, the Hoytville soil has poor drainage when wet but cracks when dry, and the Wooster soil is well drained. A more detailed description of the soil and site characteristics was reported by Dick and Van Doren (11).

Corn was grown continuously with three tillage treatments. Conventional tillage (CT)[4] consisted of moldboard plowing 20 to 25 cm deep followed by at least two other 10-cm-deep secondary tillage operations before planting. Minimum tillage (MT)[4] had the same moldboard plowing in the spring with no further tillage prior to planting. In 1983 MT plots were tilled with a paraplow to a depth of 35 cm. Since 1985 only a chisel plow has been used prior to planting. No-tillage (NT)[4] plots received no tillage except that accomplished with a coulter-type planter. Tillage was performed in the spring at the Wooster and Crosby sites and in the fall at the Hoytville site. Postemergence cultivation (5 cm deep) was used occasionally in MT and CT plots as needed at the Wooster and Crosby sites. During the 6-yr interval prior to 1962 and 1963, the Wooster site had been in grass meadow with no tillage, the Crosby site was in a corn-soybean rotation with plowing and disking for each of the 6 yr, and the Hoytville site was in a corn-oats-meadow rotation with plowing and disking during 4 of the 6 yr.

Corn was planted in rows 102 cm apart from 1967 to 1972 and 76 cm since 1973. Plants were thinned to a common population when they reached a height of about 4 cm. Plots were 5 by 210 m at Wooster and Crosby sites, and 6 by 30 m at the Hoytville site. Treatments were arranged in a randomized complete block design with four replications at the Wooster and Crosby sites and three replications at the Hoytville site. A border surrounding each site (15 m wide) and between replications (9 m) was maintained as a permanent tall fescue (*Festuca arundinacea* Schreb.) sod throughout the study period.

Some management variables, other than tillage, were changed during the study to conform to accepted agronomic practices. Fertilizer was applied based on soil test recommendations, with the same rates of N, P, and K applied to each tillage treatment. Lime was broadcast as required to maintain a pH of 6.0 in the Ap horizon. Herbicides and rates altered somewhat over time depending on need for weed control, with the goal of attaining adequate and equivalent weed control in all treatments. Briefly, atrazine, simazine (6-chloro-*N*,*N*′-diethyl-1,3,5-triazine-2,4-diamine), or cyanazine {2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile} have been applied every year at rates from 1.1 to 4.5 kg ha$^{-1}$. Amitrole (1*H*-1,2,4-triazol-3-amine) was applied the first 5 yr of the study, and dicamba (3,6-dichloro-2-methoxybenzoic acid) and either linuron [*N*′-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea] or alachlor [2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl)acetamide] were applied at label-recommended rates between 1967 and 1984. Glyphosate [*N*-(phosphonomethyl)glycine] was applied for preplant weed control in NT beginning in 1974, but paraquat (1,1′-dimethyl-4,4′-bipyridinium ion) was used at some sites beginning in 1983. Metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] was applied at the Crosby site since 1984. 2,4-D [(2,4-dichlorophenoxy)acetic acid], bentazon [3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide], and bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) were applied when needed to control broadleaf weeds. The same herbicides and rates were applied to each tillage treatment within a given location and year. Herbicides applied between 1985 and 1989 are listed in Table 1. Details of other changes in corn hybrids, fertilizer rates, and insecticides and a complete listing of herbicides have been documented (11, 12, 13).

Soil samples were obtained in November 1989 to determine the seed bank composition. Twenty samples per plot were taken at random within an area the width of three corn rows and the length of the center one-third of the plot. Soil cores, 3.5 cm in diameter, were divided into 0- to 5-, 5- to 10-, and 10- to 15-cm depths and the 20 samples from each depth were pooled.

The soil was air dried and sieved through a 2-mm screen to break up large soil peds. The entire sample, minus large rocks and root fragments, was spread in 22-cm-square trays and watered twice daily in a greenhouse. The greenhouse thermostat was set to maintain a temperature of 22 ± 5 C, with no artificial lighting. Weed seedlings that emerged were identified, counted, and removed. Seedlings of questionable identity were transplanted into pots and grown until their identity could be verified. Watering continued for 1 week after seedling emergence ceased; then the soil was air dried, thoroughly mixed, and rewetted to permit further germination. This process was repeated four times or until no more seedlings emerged.

Seeds remaining in the soil samples were physically separated using procedures similar to those described by Ball and Miller (1). Dispersion of soil was accomplished with sodium hexametaphosphate (50 g L$^{-1}$) and sodium bicarbonate (25 g L$^{-1}$) and constant stirring for 5 min. This slurry was poured onto a 250-μm sieve through which clay and silt were washed. The remaining sand and organic matter were added to a solution of magnesium sulfate (125 g L$^{-1}$) and the organic material, including seeds, was decanted. Seeds were counted and identified with the aid of a dissecting microscope and the seed identification key of Delorit (7). Seeds resisting gentle pressure with forceps were considered viable (26).

Weed density in the field plots was determined in August 1989. A 0.25-m$^2$ quadrat was placed at 16 random locations within the same area in each plot from which soil samples were taken. Weeds within the quadrat were counted by species. Each stem of perennial weeds was considered an individual.

[4]Abbreviations: CT, conventional tillage; MT, minimum tillage; NT, no tillage.

*Table 1.* Rates of herbicides applied to long-term tillage corn plots since 1985[a].

| Location and year | Paraq | Glyph | Atraz | Cyana | Simaz | Alach | Metol | Linur | 2,4-D | Bentaz | Bromox |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | kg ai ha$^{-1}$ | | | | | | | | | | |
| Wooster: | | | | | | | | | | | |
| 1985 | | 0.6 | 1.7 | 2.8 | | | | | | | |
| 1986 | | 0.6 | 1.7 | 2.8 | | | | | | | |
| 1987 | 0.8 | | 2.2 | 2.2 | | 2.2 | | | | | |
| 1988 | | | 2.2 | 2.2 | | | 2.2 | | | | |
| 1989 | 1.6 | | 1.1 | 2.2 | | | 2.2 | | 0.6 | 0.3 | |
| Crosby: | | | | | | | | | | | |
| 1985 | 0.6 | | | 3.3 | | | 3.3 | | | | |
| 1986 | | 0.8 | 2.2 | 2.2 | 1.1 | | 2.8 | | 1.1 | | |
| 1987 | | 0.8 | 1.7 | 1.7 | | | 2.8 | | 1.1 | | |
| 1988 | | 0.8 | 0.8 | 2.5 | | | 2.2 | 1.1 | 1.1 | | |
| 1989 | | 0.8 | 0.8 | 2.5 | 1.1 | | 2.8 | | | | |
| Hoytville: | | | | | | | | | | | |
| 1985 | | 1.1 | 2.2 | 2.2 | | 2.2 | | | | 1.1 | 0.4 |
| 1986 | | 0.8 | 2.2 | 2.0 | | 2.2 | | | | | |
| 1987 | | | 1.3 | 2.8 | | 2.1 | | | | | |
| 1988 | | | 1.9 | 2.2 | | 2.2 | | | 1.1 | | |
| 1989 | | 0.6 | 3.5 | 3.8 | | | 2.2 | | 1.1 | | 0.4 |

[a]Paraq = paraquat; Glyph = glyphosphate; Atraz = atrazine; Cyana = cyanazine; Simaz = simazine; Alach = alachlor; Metol = metolachlor; Linur = linuron; Bentaz = bentazon; Bromox = bromoxynil.

Seed bank data (counts of seedlings from the germination procedure plus seeds from the extraction process) and weed density in the field were converted to numbers per m$^2$. Seed bank species composition data were used to calculate indices of species diversity and heterogeneity (20). The Shanon-Wiener heterogeneity function was calculated as

$$H = -\sum_{i=1}^{s} (P_i)\ (\log_2 P_1)$$

where $P_i$ is the proportion of the sample belonging to the $i^{th}$ species and s is the number of species in the sample. Simpson's diversity index, using the same variables, was calculated as

$$D = 1 - \sum_{i=1}^{s} (P_i)^2$$

Data were subjected to analysis of variance to determine differences among tillage treatments, with locations analyzed separately. Where appropriate, depth was included in the model as a fixed effect. Grass sod was not originally included as a treatment and was therefore not randomized within blocks. However, the area of sod sampled was the same as that for corn plots and sample locations were chosen at random; thus, data for sod were included in the statistical analyses.

## RESULTS AND DISCUSSION

**Seed bank size.** Size of the seed bank differed among soils and tillage treatments (Table 2). Highest seed density was found in the Crosby soil where 77 800 seeds m$^{-2}$ were measured in NT. Seed density was lowest (400 m$^{-2}$) in CT at Wooster and MT at Hoytville. This range in seed bank size is similar to the 600 to 80 000 range reported in a review by Roberts (24), but less than the 2080 to 130 300 range for continuous irrigated corn (28). The most consistent finding among sites was a higher seed population in NT than MT or CT. Lower seed numbers in MT and CT than in NT may be due to better weed control in these tillage treatments (see later reference to Table 6) and to the stimulatory effect of tillage in inducing weed seed germination (2). Seed numbers in sod were higher than in tillage plots at the Hoytville site but were intermediate among treatments at the other sites. Differences among sites can be attributed in part to differences in tillage timing, postemergence cultivation, and previous vegetative cover in addition to differences in soil type.

**Vertical distribution.** Seed number differed significantly ($P = 0.01$) with tillage and sample depth and there were

*Table 2.* Number of seeds per m$^2$ to a depth of 15 cm in three soils following 25 to 26 yr of continuous corn with three tillage systems or permanent grass sod[a].

| Tillage treatment | Seeds | | |
|---|---|---|---|
| | Wooster | Crosby | Hoytville |
| | no. m$^{-2}$ | | |
| No-till | 8400 | 77 800 | 2100 |
| Minimum till | 4800 | 2 200 | 400 |
| Conventional till | 400 | 5 400 | 900 |
| Grass sod | 1000 | 4 800 | 7400 |
| LSD (0.05) | 2500 | 4 500 | 1500 |

[a]Values are means of 4 replications at Wooster and Crosby sites and 3 replications at the Hoytville site.

interactions among tillage, depth, and soil. The concentration of weed seeds was highest, or tended to be, in the top 5 cm of soil and decreased with depth in all tillage treatments and soils (Figure 1). Distribution with depth in sod was similar at all locations, with 70 to 78% of seeds in the top 5 cm, 14 to 20% at the 5- to 10-cm depth, and 5 to 10% at the 10- to 15-cm depth. Over 90% of seeds were concentrated in the top 5 cm in NT and MT at Wooster and in NT at the Crosby site.

Depth distributions in CT at the Wooster and Crosby sites were similar, with 72 to 77% of seeds in the top 5 cm, 12 to 13% in the 5- to 10-cm depth, and 10 to 16% in the 10- to 15-cm depth. A greater concentration of seeds in the upper 5 cm for NT compared to CT was consistent at each site. This difference may be due to the lack of physical movement of seeds in NT compared to CT plots. Higher concentrations of hydrogen ions, organic carbon, N, P, and enzyme activity in the top 5 cm of the soil profile reported for NT compared to CT at these sites (8, 9) could have long-term effects on the seed bank. These changes in soil chemical and biological properties could influence herbicide activity, weed seed dormancy, and weed growth, resulting in differences in weed population dynamics among tillage treatments. Depth distribution was more uniform in the Hoytville soil than the other soils, with 64, 55, and 47% of seeds in the top 5 cm in NT, MT, and CT, respectively, and 12% at the 10- to 15-cm depth in each of these treatments. This difference in the Hoytville soil may be attributed to the large cracks that form when this lakebed clay soil dries, allowing freshly produced weed seeds to be deposited deeper than in the other soils.

Seed depth profiles do not agree with seed depth distributions simulated for continuous tillage (6) or observations of Roberts and Stokes (27) following 9 yr of tillage treatments. Those authors reported higher seed concentrations in the 5- to 20-cm depth than in the surface 5 cm for plowed (20-cm-deep) soil. Where a rigid tine was used they found vertical distributions similar to those reported here for CT and MT. Our results are in general agreement with other studies, where moldboard plowing resulted in uniform seed distribution in the top 7.6 cm and decreases with depth, while continuous chisel plowing resulted in 85% of seeds in the top 5 cm (14). Differences among these findings may be due to time of sampling relative to time of tillage. Our samples were obtained in the fall, after most weeds had shed seeds, while the simulations of Cousens and Moss (6) and the observations of Roberts and Stokes (27) were based on vertical distribution of seeds immediately following spring tillage.

**Species composition.** Thirty-nine weed species were identified in the seedbank or in the field, plus pigweeds (*Amaranthus* spp.) which were not separated into species. Common and Latin names of weeds found in this study are listed in Table 3. Over 90% of each seed bank among tillage treatments and soils was comprised of six or fewer weed species with four species being common to all three sites (Table 4). The weeds included, in different combinations for each seed bank, common lambsquarters, pigweeds, fall panicum, giant foxtail, Pennsylvania smartweed, velvetleaf, and eastern black nightshade. Common lambsquarters, pigweeds, fall panicum, and giant foxtail were the most common weeds found at all three sites but common lambsquarters was the only species present in each tillage treatment. Common lambsquarters constituted 34 to 93% of the total seed bank across all locations and consistently made up a greater percentage of the seed bank in CT and MT than in NT.

Pigweeds and fall panicum were the next most abundant species among sites and tillage treatments. Where present, pigweeds comprised 3 to 33% and fall panicum from less than 1 to 38% of the seed bank. Percentage of the total seed bank comprised of pigweeds or fall panicum was not associated with any single tillage treatment, although fall panicum was more abundant in NT than in MT or CT at the Wooster site.

Giant foxtail was found in all tillage treatments at the Wooster and Hoytville sites but was present only in the NT at the Crosby site. It comprised, where present, 1 to 18% of the seed bank. It consistently formed a higher percentage of the seed bank in NT than in CT. Pennsylvania smartweed was present only at the Wooster and Hoytville sites and comprised, where present, 1 to 8% of the total seed bank.

Velvetleaf and eastern black nightshade were found only in NT and were not present at all soil sites. Velvetleaf comprised from less than 1 to 25% of the NT seed bank at the Crosby and Hoytville sites, respectively, while eastern black nightshade accounted for 7% of the NT seed bank at the Wooster site.

The number of species forming the majority of the seed bank became more numerous as tillage intensity decreased. One to three of the weeds discussed above formed 92 to 95% of the seed bank in CT and MT treatments, whereas three to five of those weeds accounted for the same percentage in the NT treatments.

Seed bank composition in the tillage treatments was similar to that reported by others in that the majority of seeds was comprised of only a few species (21). Seed banks developed under corn-dry bean-sugarbeet rotations in Colorado and Nebraska were dominated by common lambsquarters and redroot pigweed (*Amaranthus retroflexus* L.) which together comprised 86% of the seed bank in Colorado and 76% of the seed bank in Nebraska (28, 30). Common lambsquarters is one of the dominant weeds in seed banks of the cool temperate regions while *Amaranthus* species are among the weeds dominating seed banks throughout the warm temperate regions (24). Prolific seed production and seed longevity associated with these two weeds, as well as their adaptability to different crop environments, may be important factors responsible for their predominance in temperate-region seed banks (16).

Similar to findings among tillage treatments, common lambsquarters was present in soil underlying grass sod at all sites and constituted from 15 to 75% of the total seed bank. The remainder of the sod seed banks at the three sites was distributed somewhat evenly among numerous other weed species with no one species making up more than 10% of the total seed bank. Major weeds found in tillage treatments and a number of other weeds not found in any tillage treatments were present in the sod seed bank at each site.

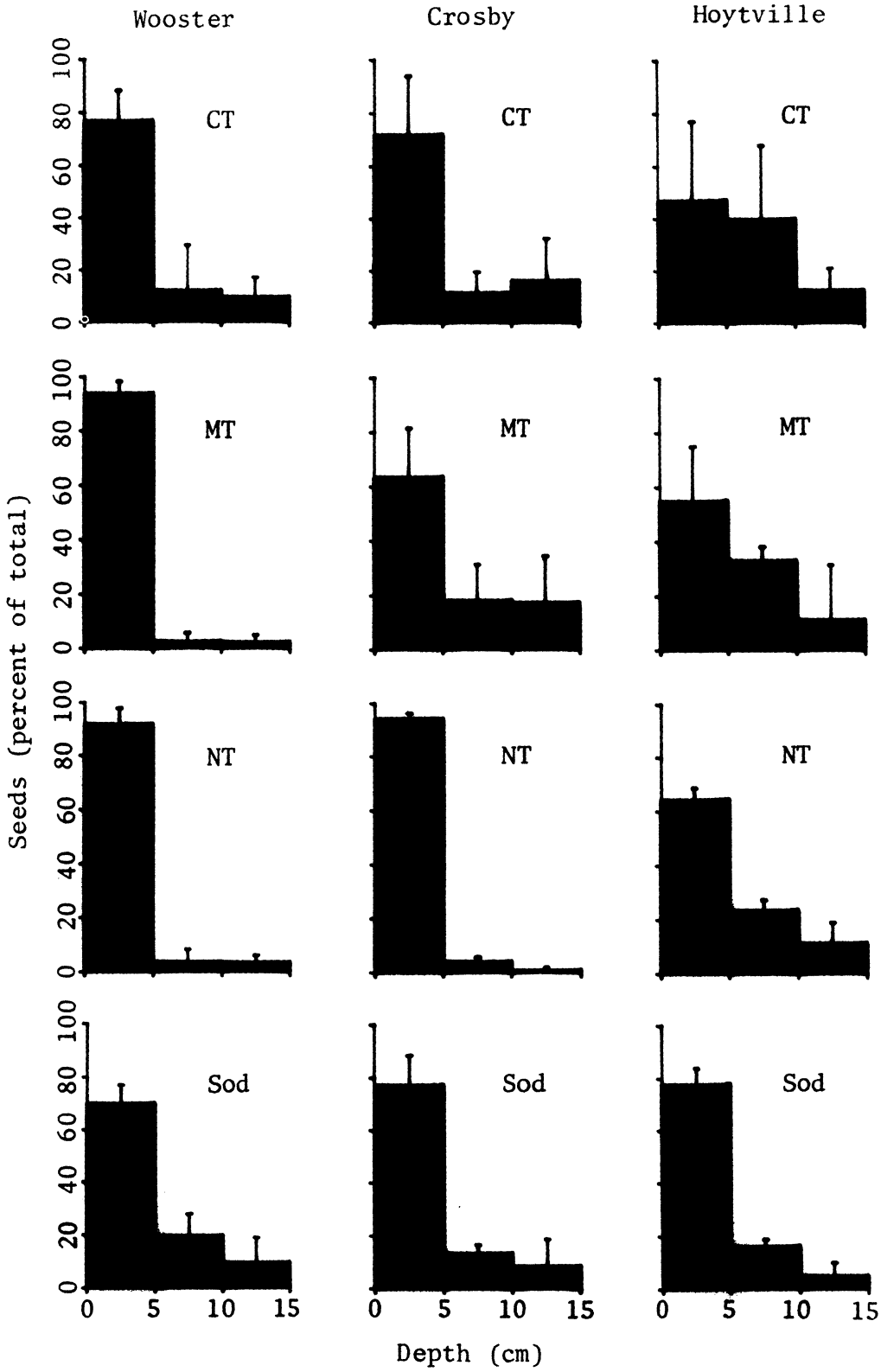


*Figure 1.* Depth distribution of weed seeds after 25 yr of grass sod, no-tillage (NT), minimum tillage (MT), and conventional tillage (CT) at Wooster, Crosby, and Hoytville sites. Data are percent of total seed number to a depth of 15 cm. Vertical lines are standard deviations.




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*Table 3.* Common names, scientific names, and five-letter Bayer code for weeds identified in this study.

| Common name | Scientific name | Bayer code |
|---|---|---|
| Buckhorn plantain | *Plantago lanceolata* L. | PLALA |
| Canada thistle | *Cirsium arvense* (L.) Scop. | CIRAR |
| Carolina geranium | *Geranium carolinianum* L. | GERCA |
| Coltsfoot | *Tussilago farfara* L. | TUSFA |
| Common chickweed | *Stellaria media* (L.) Vill. | STEME |
| Common lambsquarters | *Chenopodium album* L. | CHEAL |
| Common purslane | *Portulaca oleracea* L. | POROL |
| Carpetweed | *Mollugo verticillata* L. | MOLVE |
| Dandelion | *Taraxacum officinale* Weber in Wiggers | TAROF |
| Eastern black nightshade | *Solanum ptycanthum* Dun. | SOLPT |
| Fall panicum | *Panicum dicotomiflorum* Michx. | PANDI |
| Field pennycress | *Thlaspi arvense* L. | THLAR |
| Giant foxtail | *Setaria faberi* Herrm. | SETFA |
| Hemp dogbane | *Apocynum cannabinum* L. | APCCA |
| Henbit | *Lamium amplexicaule* L. | LAMAM |
| Honeyvine milkweed | *Ampelamus albidus* (Nutt.) Britt. | AMPAL |
| Kentucky bluegrass | *Poa pratensis* L. | POAPR |
| Large crabgrass | *Digitaria sanguinalis* (L.) Scop. | DIGSA |
| Mouseear chickweed | *Cerastium vulgatum* L. | CERVU |
| Musk thistle | *Cauduus nutans* L. | CRUNU |
| Nimblewill | *Muhlenbergia schreberi* J. F. Gmel. | MUHSC |
| Pennsylvania smartweed | *Polygonum pensylvanicum* L. | POLPY |
| Pigweeds | *Amaranthus* spp.[a] | |
| Prickly lettuce | *Lactuca serriola* L. | LACSE |
| Prostrate knotweed | *Polygonum aviculare* L. | POLAV |
| Purple deadnettle | *Lamium purpurem* L. | LAMPU |
| Red clover | *Trifolium pratense* L. | TRFPR |
| Red sorrel | *Rumex acetosella* L. | RUMAA |
| Sheperdspurse | *Capsella bursa-pastoris* (L.) Medik. | CAPBP |
| Slender rush | *Juncus tenuis* Willd. | IUMTE |
| Spotted spurge | *Euphorbia maculata* L. | EPHMA |
| Sulfur cinquefoil | *Potentilla recta* L. | PTLRC |
| Tall fescue | *Festuca arundinacea* Schreb. | FESAR |
| Thymeleaf speedwell | *Veronica serpyllifolia* L. | VERSE |
| Virginia copperleaf | *Acalypha virginica* L. | ACCVI |
| Velvetleaf | *Abutilon theophrasti* Medik. | ABUTH |
| White clover | *Trifolium repens* L. | TRFRE |
| Witchgrass | *Panicum capillare* L. | PANCA |
| Yellow rocket | *Barbarea vulgaris* R. Br. | BARVU |
| Yellow woodsorrel | *Oxalis stricta* L. | OXAST |

[a]Pigweeds were not separated beyond the genus due to difficulties in distinguishing species in the seed and seedling stage; redroot pigweed (*A. retroflexus* L. # AMARE), tumble pigweed (*A. albus* L. # AMAAL), and smooth pigweed (*A. hybridus* L. # AMACH) are found throughout Ohio.

Numbers for seed density can be calculated by multiplying percentages of various species in Table 4 times the total seed number (Table 2). Although CT and MT seed banks had a higher percentage of common lambsquarters than NT seed banks, the actual number of common lambsquarters seeds per unit soil volume was lower in CT and MT than NT, due to the low number of total weed seeds in the seed banks of CT and MT compared to NT (Table 2). This was also true for nearly all other major weeds. The greater abundance of common lambsquarters in CT and MT in terms of percentage of the total seed bank may be due to factors in these two tillage systems that discourage growth and reproduction of other weeds rather than factors that favor growth of common lambsquarters. The possibility that some of the increase in the common lambsquarters population may be due to triazine resistance development is being investigated.

Several weed species present in NT were absent from MT and CT and were also common in the sod. These weeds included winter annuals, biennials, and simple perennials (Table 4). Together, these weeds made up 53 to 62% of the total weeds found in NT but not in MT or CT. None of these weeds is apt to reproduce well under one or more annual tillage events in spring or fall due to their times of emergence and reproduction or, in the case of the perennial weeds, due to their reduced ability to regenerate vegetatively following tillage. Summer annual weeds that were present in NT, but not in MT or CT, included velvetleaf, eastern black nightshade, witchgrass, Virginia copperleaf, and carpetweed. Reasons for their presence only in NT are not clear. Occasionally, such common weeds as pigweeds, giant foxtail,

*Table 4.* Seed bank composition (15 cm deep) in three soils after 25 to 26 yr of continuous corn with three tillage treatments or grass sod[a].

| | Seed bank composition[b] as affected by soil and tillage treatment[c] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wooster | | | | Crosby | | | | Hoytville | | | |
| Species | NT | MT | CT | Sod | NT | MT | CT | Sod | NT | MT | CT | Sod |
| | % | | | | | | | | | | | |
| Buckhorn plantain | 0 | 0 | 0 | 6 | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Canada thistle | . . . | . . . | . . . | . . . | + | 0 | 0 | 0 | . . . | . . . | . . . | . . . |
| Carolina geranium | . . . | . . . | . . . | . . . | 1 | 0 | 0 | 6 | . . . | . . . | . . . | . . . |
| Carpetweed | . . . | . . . | . . . | . . . | + | 0 | 0 | 4 | 0 | 0 | 0 | 5 |
| Coltsfoot | 2 | 0 | 0 | 0 | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Common chickweed | 1 | +[c] | 0 | 3 | 1 | 0 | 0 | 1 | . . . | . . . | . . . | . . . |
| Common lambsquarters | 34 | 56 | 66 | 15 | 79 | 93 | 93 | 46 | 43 | 59 | 85 | 75 |
| Common purslane | + | 1 | 2 | 1 | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Dandelion | 0 | + | 0 | 7 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Eastern black nightshade | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | . . . | . . . | . . . | . . . |
| Fall panicum | 38 | 5 | 17 | 4 | 10 | 4 | 7 | 10 | + | + | 0 | + |
| Field pennycress | 0 | + | 0 | 1 | 0 | 0 | 0 | 1 | . . . | . . . | . . . | . . . |
| Giant foxtail | 10 | 2 | 1 | 6 | 3 | 0 | 0 | 2 | 17 | 18 | 7 | 7 |
| Henbit | + | 1 | 0 | 10 | 2 | 0 | 0 | 1 | . . . | . . . | . . . | . . . |
| Kentucky bluegrass | + | 0 | 1 | 2 | 1 | 0 | 0 | 4 | 0 | 0 | 0 | 3 |
| Large crabgrass | 0 | + | 0 | 5 | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Mouseear chickweed | 0 | 0 | 0 | 3 | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Musk thistle | + | 0 | 0 | 0 | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Nimblewill | 0 | 0 | 0 | 5 | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Pennsylvania smartweed | 1 | 1 | 2 | 3 | . . . | . . . | . . . | . . . | 8 | 4 | 0 | 2 |
| Pigweeds | 5 | 33 | 10 | 2 | 6 | 3 | 0 | 6 | 7 | 18 | 7 | 2 |
| Prickly lettuce | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | 0 | 0 | 0 | + |
| Prostrate knotweed | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | 0 | 0 | 0 | 2 |
| Purple deadnettle | 0 | 0 | 0 | + | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Red clover | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Red sorrel | 0 | 0 | 0 | + | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Shepherdspurse | . . . | . . . | . . . | . . . | 0 | 0 | 0 | 5 | . . . | . . . | . . . | . . . |
| Slender rush | 0 | 0 | 0 | 1 | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Spotted spurge | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | 0 | 0 | 0 | + |
| Sulfur cinquefoil | . . . | . . . | . . . | . . . | 0 | 0 | 0 | 6 | 0 | 0 | 0 | + |
| Tall fescue | 1 | 1 | 1 | 4 | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Thymeleaf speedwell | 0 | 1 | 0 | 5 | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Velvetleaf | . . . | . . . | . . . | . . . | + | 0 | 0 | + | 25 | 0 | 0 | 1 |
| Virginia copperleaf | 1 | 0 | 0 | 10 | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| White clover | 0 | 0 | 0 | 1 | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Witchgrass | + | 0 | 0 | 2 | + | 0 | 0 | + | . . . | . . . | . . . | . . . |
| Yellow rocket | . . . | . . . | . . . | . . . | 0 | 0 | 0 | 4 | . . . | . . . | . . . | . . . |
| Yellow woodsorrel | 1 | 0 | 0 | 3 | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |

[a]Values are means of 4 replications at Wooster and Crosby sites and 3 replications at the Hoytville site.

[b]+ indicates species present at less than 1%; dots indicate species was not found at that site; 0 indicates species was found at the site but not in the treatment.

[c]NT = no-till; MT = minimum till; CT = conventional tillage; sod = permanent grass sod; see text for additional details of treatments.

fall panicum, and Pennsylvania smartweed were absent from MT or CT (especially CT) while present in NT. Again, reasons for the absence of these specific weeds in MT and CT are not clear, although greater overall species diversity with reduced tillage is not uncommon (19). The use of both tillage and herbicides in MT and CT may have resulted in such low populations of these weeds that their seeds were not detected with the sampling methods used in this study.

Seeds of 19 weed species were present in sod but were not present in any tillage treatments at the three sites. The majority of these weeds were biennials, perennials, or winter annuals, with only 21% of the seed being summer annuals. The biennials and simple perennials found in sod could be controlled with tillage, since none of the perennials present in sod had creeping roots capable of surviving repeated tillage. Weed species in sod not present in NT may have been controlled in NT by the herbicides applied and/or continuous annual interference from corn. Winter annuals were vulnerable to fall or spring tillage before they could reproduce in MT and CT and to herbicides applied preplant in NT. Summer annuals found only in the sod included carpetweed, spotted spurge, and prostrate knotweed. Absence of these small, prostrate species in corn plots may be due to spring tillage, herbicides, shading by corn, and competition from other weeds.

**Species diversity.** Indices were calculated using seed bank species composition to measure species diversity (Table 5).

*Table 5.* Species diversity indices for seed banks following long-term tillage treatments on three soils in Ohio[a].

| | Species diversity value[b] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Wooster | | | Crosby | | | Hoytville | | |
| Tillage | s | H | D | s | H | D | s | H | D |
| Conventional | 4.6 | 1.3 | 0.4 | 4.0 | 0.3 | 0.1 | 3.0 | 0.5 | 0.2 |
| Minimum | 5.3 | 0.7 | 0.3 | 4.0 | 0.3 | 0.1 | 4.0 | 1.3 | 0.5 |
| No-till | 10.1 | 1.8 | 0.7 | 7.0 | 0.2 | 0.1 | 5.7 | 1.5 | 0.6 |
| Sod | 17.7 | 3.7 | 0.9 | 14.8 | 2.3 | 0.6 | 10.3 | 1.6 | 0.5 |
| LSD (0.05) | 1.1 | 0.6 | 0.2 | 1.9 | 0.5 | 0.2 | 3.0 | NS | NS |

[a]Values are means of 4 replications at Wooster and Crosby sites and 3 replications at the Hoytville site.

[b]s = mean number of species; H = Shanon-Weiner heterogeneity function; D = Simpson's diversity index; larger values of s, H, and D signify greater diversity.

*Table 6.* Weed populations in August 1989 at three sites where corn has been grown for 25 to 26 yr with three tillage treatments[a].

| | Weed population as affected by soil and tillage[b] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Wooster | | | Crosby | | | Hoytville | | |
| Species | NT | MT | CT | NT | MT | CT | NT | MT | CT |
| | no. $m^{-2}$ | | | | | | | | |
| Common lambsquarters | 760 | 132 | 28 | 667 | 22 | 20 | 0 | 0 | 0 |
| *Amaranthus* species | 990 | 212 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| Fall panicum | 256 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Giant foxtail | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Pennsylvania smartweed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Velvetleaf | 0 | 0 | 0 | + | 0 | 0 | 26 | 0 | 12 |
| Dandelion | 0 | 0 | 0 | 3 | 1 | 1 | 4 | 0 | 0 |
| Canada thistle | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 7 | 0 |
| Hemp dogbane | 0 | 0 | 0 | + | + | 0 | + | 0 | 0 |
| Honeyvine milkweed | 0 | 0 | 0 | 1 | + | 0 | 0 | 0 | 0 |

[a]Values are means of 4 replications at Wooster and Crosby sites and 3 replications at the Hoytville site.

[b]NT = no-till; MT = minimum tillage; CT = conventional tillage.

The most consistent finding at each location was the relationship of species and amount of soil disturbance. As soil disturbance increased, species numbers decreased. The grass sod seed bank had three to four times as many species as CT plots. Number of species in NT was greater than in CT or MT but less than in sod, except at the Hoytville site where the number of species among tillage treatments did not differ significantly. Similar interpretations of species can be made from the Shanon-Weiner (H) and Simpson (D) indices. However, the trend with degree of soil disturbance was less clear. The Shanon-Weiner index gives greater weight to rare species while Simpson's index gives greater weight to common species (20). This explains the greater range of H-values compared to D-values. The indices support the concept that species diversity decreases with continued disturbance.

Greater species diversity was observed in all treatments (including the sod) at the Wooster site than at the Crosby or Hoytville sites. Species diversity was least apparent at the Hoytville site. Six years prior to initiation of these long-term studies, the Wooster site had been in meadow with NT during the six years, the Crosby site had been in a corn-soybean rotation with yearly tillage, and the Hoytville site had been cropped in a corn-oats-meadow rotation with tillage during 4 of the 6 yr. Some of the greater species diversity observed at the Wooster site may be due to long-lasting effects of its cropping history prior to the initiation of the experiment.

Fall or spring tillage disturbs niches which can be occupied by weeds with a winter annual, biennial, or perennial life cycle. Winter annuals require the fall, winter, and early spring months to become established and reproduce. Some weeds, such as purple deadnettle (*Lamium purpureum* L. # LAMPU), are obligate winter annuals that germinate in the fall (3). Fall or spring tillage would effectively disrupt reproduction by this species. Similarly, biennials and perennials with little or no ability to regenerate from fragmented roots require undisturbed soil to complete their reproduction. Fewer weed species in CT and MT in this study are likely due to the absence of niches in these environments for weeds with non-summer annual life cycles.

**Summer weed flora.** Weed densities in August 1989 (Table 6) were higher in NT than in MT or CT at all three sites. This may explain the high numbers of weed seeds observed in NT compared to MT and CT. The weeds observed in August represent those that survived weed control operations performed during the growing season. Long-term effects from a lack of secondary tillage (i.e., postemergence cultivation) and/or reduced herbicide effectiveness in NT compared to MT and CT may have contributed to the greater number of weeds observed in NT (19). Postemergence cultivation was occasionally used in MT and CT at the Wooster and Crosby sites (but not in 1989). This may have aided in overall weed control in these tillage treatments in previous years at those two locations.

Common lambsquarters densities in NT plots at the Wooster and Crosby sites were 5 to 15 times higher than in MT and CT. At Hoytville, no common lambsquarters was observed in any tillage treatment. Pigweeds were observed in MT and NT at the Crosby and Hoytville sites but were not observed in CT at any of the sites, despite the presence of seeds in the seed bank. Fall panicum was present in MT and NT at the Wooster site, but not in CT where seed numbers in soil were 40 $m^{-2}$, or any treatments at the other sites, even where soil seed numbers were high at the Crosby site. Other weeds present in the summer flora, but whose seeds were not found in soil, where dandelion, Canada thistle, hemp dogbane, and honeyvine milkweed. All four are perennials and the latter three are creeping perennials. Lack of seed in soil may be related to the often low rate of seed production and low seed viability that is associated with many creeping perennial weeds compared to annual and biennial weeds (16). For example, Canada thistle is dioecious; if plants of both sexes are not present in the field, seed production is unlikely to occur.

Summer flora data agree with findings by others (19) that small-seeded species such as common lambsquarters, pig-

weeds, and fall panicum tend to predominate as tillage is reduced. However, velvetleaf, a relatively large-seeded weed that has been observed to decrease in NT (19), was present in high numbers in our long-term NT plots, both in the summer flora and in the seed bank. This finding does not support the concept that NT generally favors small-seeded weeds and discourages large-seeded weeds. The shift towards common lambsquarters and fall panicum observed in NT may be related to reduced efficacy of weed control methods used in no-till which allowed weeds with prolific seed production to increase rapidly in population. No relationship was found in the seed bank composition of the three tillage treatments between weed seed size and tillage intensity.

Biological factors and differential physical disturbance probably account for some of the seed bank and summer flora differences among tillage treatments. Previous studies in these long-term tillage plots and elsewhere have shown an accumulation of organic C, N, and P in the top 5 cm in NT (8, 12, 13, 19). Acidity was also higher at the soil surface in NT due to nitrification of ammonium from fertilizer and organic matter (8, 10). The combination of low pH and high organic constituents under NT may have reduced herbicide effectiveness, which would result in higher weed populations, greater weed seed production, and hence larger weed seed banks in NT compared to CT. Accumulation of organic and inorganic components in the soil surface layer in NT may create a zone of increased biological activity characterized by high levels of bacteria, fungi, soil enzymes, insects, and earthworms (10). This unique environment may have affected such factors as weed seed dormancy, species adaptation, and prevalence of weed predators and pathogens, which could have altered weed population dynamics.

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