Weed Mortality Caused by Row-Crop Cultivation in Organic Corn–Soybean–Spelt Cropping Systems

Author(s): Charles L. Mohler , Caroline A. Marschner , Brian A. Caldwell , and Antonio DiTommaso
Source: Weed Technology, 30(3):648-654.
Published By: Weed Science Society of America
DOI: http://dx.doi.org/10.1614/WT-D-16-00020.1
URL: http://www.bioone.org/doi/full/10.1614/WT-D-16-00020.1

Weed Technology 2016 30:648–654

Weed Mortality Caused by Row-Crop Cultivation in Organic Corn–Soybean–Spelt Cropping Systems

Charles L. Mohler, Caroline A. Marschner, Brian A. Caldwell, and Antonio DiTommaso*

To assess the effectiveness of interrow cultivation, counts were taken before and after cultivation of corn and soybean during the first two crop rotations in a corn–soybean–spelt organic grain cropping systems experiment. Overall control per cultivation event in soybean was 73%, about equal to the 67% of the interrow area actually covered by cultivator tools. Weed control per cultivation event in corn was higher, and exceeded 91% at later cultivations. The greater weed control in corn relative to soybean, particularly at later cultivations, was probably due to more soil being thrown into the corn row, burying a greater proportion of the weeds. Perennial weeds emerging from roots and rhizomes were less controlled by cultivation events than weeds emerging from seeds. Relatively poor control of perennials was due both to rapid resprouting during the few days between cultivation and assessment and to a lower probability of death in the zone indirectly disturbed by cultivator tools. Seedlings of perennial species suffered greater mortality from cultivation than annual weeds, probably because the low relative growth rate of perennials resulted in small seedlings that were susceptible to cultivation. Common ragweed was less controlled by cultivation than other annual weeds, probably because its heavier seeds produced larger seedlings at the time of cultivation. These larger seedlings were less likely to be buried during hilling-up operations at later cultivations. Counts of weeds before and after individual cultivation events provide insight into the processes affecting weed mortality during mechanical management.

Nomenclature: Common ragweed, *Ambrosia artemisiifolia* L. AMBEL.
Key words: Annual, burial, cultivator, mechanical control, perennial, seedling.

Para evaluar la efectividad de la labranza entre hileras, se tomaron conteos antes y después de la labranza de maíz y soja durante las primeras dos rotaciones de cultivos en un experimento con un sistema orgánico de cultivos para grano maíz–soja–trigo espelta. El control general por evento de labranza en soja fue 73%, casi igual al 67% del área entre hileras cubierta por los implementos del equipo de labranza. El control de malezas por evento de labranza en el maíz fue más alto y excedió 91% con labranzas posteriores. El mayor control de malezas en el maíz en relación a la soja, particularmente con eventos de labranza posteriores, se debió probablemente a que se tiró más suelo sobre la hilera del maíz, enterrando una mayor proporción de las malezas. Malezas perennes emergiendo a partir de raíces y rizomas fueron controladas con los eventos de labranza en menor medida que las malezas emergiendo a partir de semillas. El control relativamente pobre de perennes se debió a su rápida capacidad de rebrote en pocos días entre la labranza y la evaluación y a una menor probabilidad de mortalidad en la zona indirectamente perturbada por las herramientas de labranza. Las plántulas de especies perennes sufrieron mayor mortalidad producto de la labranza que las malezas anuales, probablemente porque la baja tasa de crecimiento relativa de las perennes resultó en plántulas pequeñas que fueron susceptibles a la labranza. *Ambrosia artemisiifolia* fue controlada con la labranza en menor medida que otras malezas anuales, probablemente porque sus semillas más pesadas produjeron plántulas más grandes al momento de la labranza. Estas plántulas más grandes tuvieron una menor probabilidad de ser enterradas durante las operaciones de aporca con labranzas posteriores. Los conteos de malezas antes y después de los eventos individuales de labranza brindaron una visión detallada de los procesos que afectan la mortalidad de malezas durante el manejo mecánico.

Postplanting cultivation for weed control has been a critical component of weed management for centuries. During the second half of the twentieth century, however, research on cultivation largely lapsed as many new synthetic herbicides became available. This lapse in research occurred despite the continued widespread use of cultivation by farmers. Despite the relative lack of academic research on cultivation during this period, many advances in cultivation occurred in the private sector. These included development of cultivator guidance systems, invention of various in-row and near-row cultivating tools, and perfection of a wide variety of

DOI: 10.1614/WT-D-16-00020.1

* Senior Research Associate, Extension Associate, Research Support Specialist, and Professor, respectively, Section of Soil and Crop Sciences, School of Integrative Plant Science, Cornell University, Ithaca, NY 14853. Corresponding author's E-mail: clm11@cornell.edu

harrows specifically designed for weeding (Mohler 2001). During the past 20 yr, cultivation has received renewed attention by researchers due to its continued importance for weed control in vegetables (Melander and Hartvig 1997), its critical role in organic production (Bond and Grundy 2001; Melander et al. 2005), its importance as a component of integrated weed management of herbicide-resistant weeds and other recalcitrant weed problems (Buhler 2002; Mortensen et al. 2012), and the limited range of herbicides available for production of some specialty crops (van der Schans and Bleeker 2006).

Most studies of cultivators and cultivation systems have focused on the number and biomass of weeds present in the crop at some point late in crop growth. Such information is useful for evaluating overall effectiveness of cultivation. However, understanding the impact of individual cultivation events can provide additional insight for improving cultivation practices.

Cultivators kill weeds in three ways: by burying emerged weeds, by dismembering weeds, and by uprooting weeds so that they subsequently desiccate (Mohler 2001). Assessment of weeds before and after cultivation events is necessary to untangle these factors (Cirujeda et al. 2003; Fogelberg and Dock Gustavsson 1999; Kurstjens and Kropff 2001). Mortality rates during cultivation events can also indicate the relative effectiveness of different types of tools and the impact of tools on various types of weed species (Mohler et al. 1997). It also provides a means for evaluating effects of soil conditions on cultivation efficacy (E Gallandt, personal communication). Possibly because of the great labor required to measure weed density before and after many cultivation events, relatively few studies have assessed the impact of individual cultivation events on weed mortality. The approach has been used occasionally in studies of weed harrowing, in which comparisons of crop covering with soil vs. weed mortality are important (Kurstjens et al. 2000; Rasmussen 1991), but the approach is rarer in studies of row-crop cultivation (Mohler et al. 1997). Melander et al. (2012) assessed reduction in biomass of perennial weeds before and after tillage during the fallow period following harvest of spring barley. In this case, however, the assessments were 1 yr apart so that the weeds were in the same stage of their annual growth cycle.

This paper reports results of a 6-yr study on the percentage kill of weeds by row-crop cultivators at first cultivation and at later cultivations in corn and soybean. The purpose of the study was to evaluate the relative effectiveness of interrow cultivation of corn and soybean in three organic cropping systems and to assess the relative impact of cultivation on various taxa and growth forms of weeds.

Materials and Methods

In 2005, an organic grain cropping systems experiment was initiated on a field near Aurora, NY (42.73°N, 76.63°W). The soil is a moderately well-drained, calcareous Lima silt loam (fine-loamy, mixed, mesic Glossoboric Hapludalfs), with partial tile drainage. The field had been used for conventional field crops prior to this experiment.

The experiment employed a 3-yr soybean–spelt/red clover–corn crop rotation with four organically managed cropping systems: (1) high fertility (HF), (2) low fertility (LF), (3) enhanced weed management (EWM), and (4) reduced tillage (RT). The high fertility system received soil fertility inputs based on typical local organic farmer practices for corn, including red clover green manure plus an application of 2 Mg ha^{-1} of composted poultry manure, and application of compost and commercial organic fertilizers approximating chemical fertilizer rates recommended in the Cornell Guide for Integrated Field Crop Management (Cornell Cooperative Extension 2012) for soybean and spelt. The LF system received no fertility inputs other than the red clover green manure and compost or a commercial organic fertilizer applied through the planter for corn, and was otherwise similar to the high fertility system. The EWM system received the same fertility management as LF, but had additional tillage and cultivation. Specific practices included an extra cultivation in corn and soybean if this seemed useful, occasional use of a belly-mounted rather than rear-mounted cultivator to allow closer cultivation to crop rows, moldboard plowing plus disking rather than disking alone before spelt, a 1.5× spelt seeding rate to suppress weeds (1.3× in 2006), and an additional tillage ("false seedbed") before soybean when soil conditions permitted. Unfortunately, the belly-mounted cultivator could only be used occasionally due to mechanical problems with the tractor that carried it. The fourth treatment, RT, received substantially less tillage (mostly ridge tillage) than the other systems, which used moldboard plowing followed by disking and harrowing before corn and soybean. High residue in the RT treatment made tine weeding impossible in the RT system; as a result, the timing of between-row cultivation differed from that of the other systems, making direct comparison of weed mortality rates during particular cultivation events impossible. Consequently, the RT system will not be discussed further in this paper.

Systems were replicated four times in a spatially balanced, randomized block split-plot design (van Es et al. 2007), where the cropping systems were the main plots and two entry points into the crop rotation were the split plots. Plots were 24.4 by 36.6 m to accommodate field scale equipment. Corn and soybean were planted in rows spaced 76 cm apart. Corn was planted at a rate of approximately 72,000 seeds ha^{-1}, and soybean at approximately 470,000 seeds ha^{-1}. Details on tillage, crop varieties, fertility regimens, etc. are provided in Caldwell et al. (2014). Systems were tine-weeded one to three times (usually twice), with the first tine weeding usually occurring before crop emergence.

Systems were cultivated with row-crop cultivators one to three times (usually twice) to reduce weed density and growth. The first cultivation was done with a model 825 John Deere row-crop cultivator (John Deere and Co., Moline, IL) equipped with spring steel S-shanks with 14-cm sweeps on the forward shanks, 12-cm duck-foot shovels on the middle shanks, 18-cm sweeps on the rear shanks, and rolling shields. The final cultivations were done with a cultivator assembled from Brillion high residue cultivator parts (Landoll Corporation, Marysville, KS). This cultivator had three tall, stiff S-shanks per interrow equipped with 14-cm sweeps on the forward shanks, 23-cm sweeps on the rear shank and 34-cm hilling disks. The belly-mounted cultivator was a custom-made four-row machine with trip shanks carrying 18-cm low-crown half sweeps independently on each side of all rows. When the belly-mounted cultivator was used it was followed by one pass of the Brillion cultivator to clean out the row middles. Photographs of these machines can be viewed at: https://weedecology.css.cornell.edu/manage/manage.php?id=43.

Whenever possible, weeds were counted before and after cultivation events during the period 2005 to 2010. One 0.5-m^2 quadrat was randomly placed in each of the four quadrants of each plot. To avoid edge effects, quadrats were only located in the central eight rows and no closer than 4 m from an end of the plot. Quadrats were 76 cm wide and stretched from the center of one interrow to the center of the next. Quadrat positions were permanently fixed for the season by placing a 30 cm red plot marker in the crop row. Counts were taken by species and subsequently grouped by ecological characteristics to simplify analysis and interpretation (Table 1). Perennial broadleaves emerging from roots and rhizomes and yellow nutsedge (*Cyperus esculentus* L.) were enumerated by counting shoots. No perennial grasses were present during the period of the study.

To allow time for weeds to die or reroot and survive following cultivation, we delayed postcultivation counts by a few days. By then, the next cultivation was usually just a few days away. Because the counts generally took a team of four to five workers 2 d to complete, separate counts after the first cultivation and before the next were impractical. Consequently, we developed a procedure in which counts made between cultivations distinguished between old plants that had survived the preceding cultivation and new plants that had emerged following cultivation. Usually, these categories were unambiguous, and comparison with counts from the previous evaluation helped further clarify time of origin.

Crops were usually cultivated twice. When a third cultivation occurred, it took place about 1 wk after the second. In these cases, the second and third cultivations were treated as a single event, with a count taken before the second and after the third cultivation. Because the weed counts were laborious, and timely cultivation was essential for good weed management, counts were sometimes missed. Consequently, counts before and after cultivation events were only available for 11 of the 20 possible crop by cultivation timing (first, later) cases (Table 2). Nevertheless, the data set included 132 treatment by cultivation-timing events spread over 6 yr.

Counts were converted to proportions surviving particular cultivation events, and proportions were transformed by taking the arcsine of the square root of the proportion to increase stability of variance. Data before and after use of the belly-mounted

Table 1. Common names, scientific names, and Bayer codes for the most abundant species in each of the ecological categories that contain more than one species. Species are listed roughly in descending order of their relative abundance within each category. Common ragweed and yellow nutsedge were considered to be in their own ecological categories.

Common name	Scientific name	Bayer code
Annual broadleaves (other than common ragweed)		
Common lambsquarters	*Chenopodium album* L.	CHEAL
Wild mustard	*Sinapis arvensis* L.	SINAR
Ladysthumb	*Polygonum persicaria* L.	POLPE
Yellow woodsorrel	*Oxalis stricta* L.[a]	OXAST
Annual grasses		
Giant foxtail	*Setaria faberi* Herrm.	SETFA
Witchgrass	*Panicum capillare* L.	PANCA
Perennial broadleaves from roots and rhizomes		
Perennial sowthistle	*Sonchus arvensis* L.	SONAR
Smooth groundcherry	*Physalis subglabrata* Mackenzie & Bush	PHYSU
Canada thistle	*Cirsium arvense* (L.) Scop.	CIRAR
Hedge bindweed	*Calystegia sepium* (L.) R. Br.	CAGSE
Horsenettle	*Solanum carolinense* L.	SOLCA
Perennial broadleaves from seed		
Broadleaf plantain	*Plantago major* L.	PLAMA
Dandelion	*Taraxacum officinale* G. H. Weber ex Wiggers	TAROF
Smooth groundcherry	*Physalis subglabrata* Mackenzie & Bush	PHYSU

[a] Yellow woodsorrel is capable of perennation, but in spring-tilled cropping systems in the northeastern United States it behaves almost exclusively as an annual. That is, virtually no individuals survive tillage, essentially all individuals observed after tillage have cotyledons, and surviving plants set seeds before winter. In contrast, species classified here as perennial broadleaves usually produce few or no seeds prior to their first winter.

cultivator in the EWM system were only available for the later cultivation of corn in 2007. A preliminary ANOVA comparing systems for this case showed that none of the six ecological categories had significantly different survival in the EWM system relative to the other two systems. Consequently, data from the EWM system for this case were included in the general analysis. This and the subsequent ANOVA were conducted using SAS Proc GLM (Statistical Analysis System Inc., Cary, NC). Arcsine square-root transformed proportions of weeds surviving row-crop cultivation were subjected to ANOVA. The model included replication and system as main plot factors, cultivation timing (first, later), and crop (corn, soybean) as subplot factors, and weed ecological categories as a sub-subplot factor. Because systems were blocked relative to a soil moisture gradient in the field, replication was considered a fixed effect.

Table 2. Data available for inclusion in the data analysis. The second part of the table gives the number of crop by timing cases in the data set. Each crop by timing case consists of three treatments, each with four replications

Crop	Year	Cultivation timing	
Corn	2005	First	
Corn	2005	Later	
Corn	2007	First	
Corn	2007	Later	
Corn	2008	Later	
Corn	2010	Later	
Soybean	2005	First	
Soybean	2006	First	
Soybean	2008	Later	
Soybean	2009	First	
Soybean	2009	Later	
Cultivation Timing	Corn	Soybean	Total
First	2	3	5
Later	4	2	6
Total	6	5	

Least-squares means from the ANOVA were compared using least significant difference. Least-squares means were back-transformed to proportion of weeds surviving, and these proportions were converted to percentage of weeds killed for presentation. Because data on nearly half of the possible cultivation events were unavailable, attempts to include crop rotation entry point subplot and year (e.g., a repeated-measures design) in the model created an over-specified model from which estimates of least squares means could not be

Table 3. Analysis of variance of the proportion of weeds surviving cultivation. Values were transformed by taking the arcsine of the square root of original values to stabilize the variance.

	df	Significance
Effect		
System[a]	2	0.30
Crop[b]	1	< 0.001
Timing[b]	1	0.20
Crop*Timing[b]	1	0.001
Crop*System[b]	2	0.54
Timing*System[b]	2	0.20
Crop*Timing*System[b]	2	0.96
Ecological group	5	< 0.001
Crop*Ecological group	5	0.15
Timing*Ecological group	5	0.26
System*Ecological group	10	0.18
Crop*Timing*Ecological group	5	0.38
Crop*System*Ecological group	10	0.93
Timing*System*Ecological group	10	0.80
Crop*Timing*System*Ecological group	10	0.27

[a] Tested against System*Replication interaction.
[b] Tested against System*Crop*Timing*Replication.

calculated. Because the data under consideration were proportions surviving cultivation events, carry-over effects from previous years were unlikely. The primary mechanism that could create carry-over effects would be changes in weed density which then affected cultivator effectiveness. However, in this study, system HF had two- to three-fold greater weed biomass in later years than the other two systems (Caldwell et al. 2014), but weed mortality did not differ among systems (Table 3), so we believe that carry-over effects from one year to the next were minimal. Moreover, because all results were either very highly significant ($P < 0.001$) or not even close to significant (Table 3), subtleties of the ANOVA were unlikely to alter the outcomes of the study.

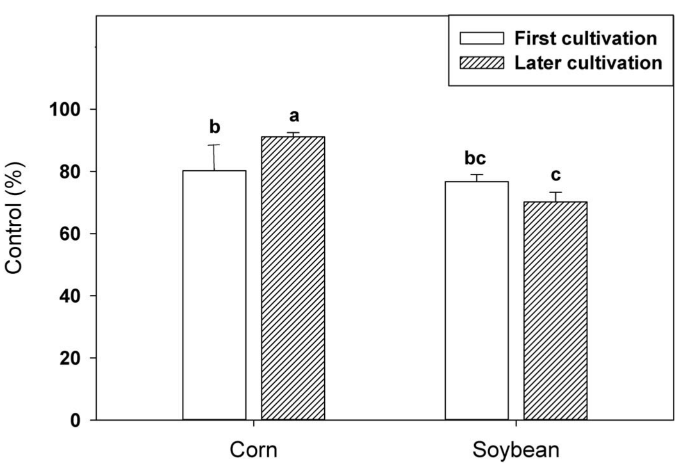

Figure 1. Percentage control of weeds in corn and soybean at the first and later interrow cultivations. Error bars show one positive standard error. Means and standard errors were back-transformed from least-squares means and standard errors of arcsine square-root transformed proportions.

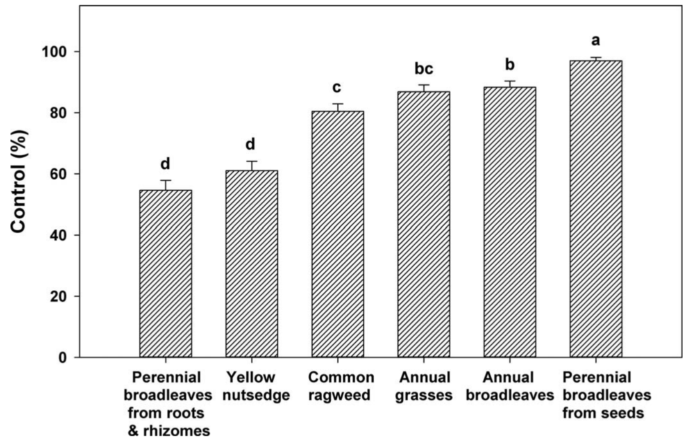

Figure 2. Percentage control of weeds in various ecological groups by interrow cultivation. Data were merged across crop and cultivation timing. Error bars show one positive standard error. Means and standard errors were back-transformed from least-squares means and standard errors of arcsine square root-transformed proportions.

Results and Discussion

The effects of crop (corn vs. soybean), ecological group and the interaction between crop and cultivation timing (first, later) on the survival of weeds during interrow cultivation were all highly significant (Table 3). Weed control by cultivation in corn was better than in soybean, particularly for later cultivations (Figure 1). Better control in corn than soybean at the later cultivations was probably due to the more robust stature of corn, which allowed more soil to be thrown into the crop row to bury weeds. Burying weeds is an effective method for killing weed seedlings, provided the seedlings can be completely buried (Mohler et al., 2016).

Control by cultivation varied greatly among ecological groups (Figure 2). Not surprisingly, control of perennials arising from roots and rhizomes was poorer than for various categories of weeds arising from seeds. Whereas many seedlings along the edge of the zone cut through by the cultivator sweeps were uprooted or buried, few perennial shoots were seriously harmed. Most perennials have storage organs below the 5 to 7 cm cultivated zone, and thus could resprout, within the cultivated interrow area. Although a few perennials present at the postcultivation counts were resprouts, the short interval between cultivation and the subsequent count minimized this effect. Resprouting in the weeks following the last cultivation was substantial in some crop years, and perennials were a major problem in the Organic Grain Cropping Systems Experiment (Ryan et al. unpublished data).

Common ragweed was separated from the other annual broadleaved species because it had a greater seed mass than the other annuals and because it was the most abundant species present in the experiment. Seed mass influences efficacy of mechanical weed management because species with larger seeds grow faster as seedlings (Mohler 1996). Rapid growth of large-seeded species allows more individuals to escape burial (Mohler et al. 2016). Also, a more extensive root system can prevent complete uprooting, particularly along the edge of the cultivated zone, and can facilitate re-establishment when soil and weather conditions allow uprooted weeds to survive for a few days after cultivation.

The ecological group most sensitive to cultivation was perennial species emerging from seeds. Perennial seedlings tend to have lower relative growth rates than annuals, which are adapted for rapid maturation (Grime and Hunt 1975). Consequently, most of the perennial seedlings were tiny at cultivation and thus more easily killed than the annuals (Figure 2).

Although assessments of weed abundance late in the growing season provide a broad picture of the effectiveness of cultivation for weed management, counts before and after cultivation events provide insights into the ecological processes taking place during and shortly after cultivation events. For example, the high biomass of perennials late in the season in the Organic Grain Cropping Systems Experiment (Caldwell et al. 2014), might have been attributed purely to resprouting, whereas the data presented here indicate that escape was also a factor. Although the higher rate of control of perennial seedlings relative to annual seedlings could have been predicted from first principles, we believe the data presented here are the first confirmation of this effect.

Acknowledgments

We thank D. Glabau, M. Park, H. Spalholz, S. Hall, L. Zakrzewski, S. Mulkey, L. Mohler, S. Peever, T. Prado, V. Otero, D. Her, D. Demeree, S. Pietstruska, C. Dykeman, T. Paul, B. Karlovitz, K. C. Alvey, L. Moshman, J. Huang, C. Carlton, and A. Saffer for their assistance with weed sampling. James Frisch constructed the belly-mounted cultivator. This work was supported by grants from the USDA Organic Research and Extension Initiative (Project numbers 2004-51300-02230 and 2009-51300-05586), by a grant from the New York Farm Viability Institute (Project number ARP 08 007), and by funds from the Cornell Agricultural Experiment Station (Multi-State Hatch Projects NE-1000, NE-1026, and NE-1047, Project numbers 125450, 3120006036 NYC-145843 NE1026, and 231327 NYC-125800 NE1047, respectively).

Literature Cited

Bond W, Grundy AC (2001) Non-chemical weed management in organic farming systems. Weed Res 41:383–405

Buhler DD (2002) Challenges and opportunities for integrated weed management. Weed Sci 50:273–280

Caldwell B, Mohler, CL Ketterings QM, DiTommaso A (2014) Yields and profitability during and after transition in organic grain cropping systems. Agron J 106:871–880

Cirujeda A, Melander B, Rasmussen K, Rasmussen IA (2003) Relationship between speed, soil movement into the cereal row and intra-row weed control efficacy by weed harrowing. Weed Res 43:285–296

Cornell Cooperative Extension (2012) 2012 Cornell Guide for Integrated Field Crop Management. Cornell University. http://ipmguidelines.org/fieldcrops/. Accessed November 30, 2012

Fogelberg F, Dock Gustavsson AM (1999) Mechanical damage to annual weeds and carrots by in-row brush weeding. Weed Res 39:469–479

Grime JP, Hunt R (1975) Relative growth-rate: its range and adaptive significance in a local flora. J Ecol 63:393–422

Kurstiens DAG, Kropff MJ (2001) The impact of uprooting and soil-covering on the effectiveness of weed harrowing. Weed Res 41:211–228

Kurstjens DAG, Perdok UD, Goense D (2000) Selective uprooting by weed harrowing on sandy soils. Weed Res 40:431–447

Melander B, Hartvig P (1997) Yield response of weed-free seeded onions [*Allium cepa* (L.)] to hoeing close to the row. Crop Prot 16:687–691

Melander B, Holst N, Rasmussen IA, Hansen PK (2012) Direct control of perennial weeds between crops—implications for organic farming. Crop Prot 40:36–42

Melander B, Rasmussen IA, Bàrberi P (2005) Integrating physical and cultural methods of weed control—examples from European research. Weed Sci 53:369–381

Mohler CL (1996) Ecological bases for the cultural control of annual weeds. J Prod Agric 9:468–474

Mohler CL (2001) Mechanical management of weeds. Pages 139–209 *in* Liebman L, Mohler CL, Staver CP, eds. Ecological Management of Agricultural Weeds. Cambridge: Cambridge University Press

Mohler CL, Frisch JC, Mt. Pleasant J (1997) Evaluation of mechanical weed management programs for corn (*Zea mays*). Weed Technol 11:123–131

Mohler CL, Iqbal J, Shen J, DiTommaso A (2016) Effects of water on recovery of weed seedlings following burial. Weed Sci 64:285–293

Mortensen DA, Egan JF, Maxwell BD, Ryan MR, Smith RG (2012) Navigating a critical juncture for sustainable weed management. BioScience 62:75–84

Rasmussen J (1991) A model for prediction of yield response in weed harrowing. Weed Res 31:401–408

van der Schans D, Bleeker P, eds (2006) Practical Weed Control in Arable Farming and Outdoor Vegetable Cultivation without Chemicals. Publication number 352. Wageningen, The Netherlands: Applied Plant Research. 77 p

van Es HM, Gomes CP, Sellmann M, van Es CL (2007) Spatially balanced complete block designs for field experiments. Geoderma 140:346–352

Received February 7, 2016, and approved May 3, 2016.

Associate Editor for this paper: Steve Fennimore, University of California, Davis.