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# Effect of cultivation and within-field differences in soil conditions on feral *Helianthus annuus* growth in ridge-tillage maize

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## Abstract

Differences in weed population dynamics with respect to within-field heterogeneity are not well documented despite increasing interest in site-specific management of agro-ecosystems. The focus of this study was to determine if mechanical weed management (cultivation) and/or soil factors help to explain observed within-field distributions of feral common sunflower (*Helianthus annuus* L.). The ridges and furrows created by the ridge-tillage system adds additional microsites to existing spatial heterogeneity for soil characteristics such as soil organic carbon (SOC) concentration. Experimental areas were selected on the basis of naturally high or low SOC concentration. Cultivation resulted in 100% mortality of *H. annuus* seedlings growing in the middle of furrows. Cultivation of pre-emergence herbicide treated and no-herbicide ridges resulted in small but statistically significant ( $\alpha = 0.05$ ) reductions in seedling survival. No differences were detected in *H. annuus* canopy height, stem diameter, stem length, or vegetative biomass between high and low SOC environments. Neither total reproductive biomass ( $P = 0.49$ ) nor the biomass of flowers near physiological maturity (an estimate of fecundity;  $P = 0.59$ ) were affected by SOC environment. Late season *H. annuus* lodging was observed to reduce reproductive biomass. Juvenile plants that survived mechanical weed control efforts grew and produced reproductive biomass similarly across SOC environments. The lack of difference in vegetative and reproductive characteristics between high and low SOC environments suggests that SOC (or the edaphic conditions associated with greater or lesser SOC level) was not critical in contributing to the observed distribution of *H. annuus* from juvenile to flowering stages of growth within well-fertilized, irrigated agricultural habitats.

**Keywords:** soil organic carbon, soil organic matter, ridge-tillage, population dynamics, fecundity

## 1. Introduction

Site-specific application of weed management tactics may enhance our ability to manage economic

inputs as well as natural resources. Lindquist et al. (1998) and Johnson et al. (1995) demonstrated potential economic benefits from managing spatially stable weed populations with site-specific herbicide application. Similarly, applying chemical weed

management tactics according to soil characteristics (e.g., sorptive capacity, depth to groundwater, etc.), as opposed to applying a uniform herbicide rate across the field, may reduce the potential for ground or surface water contamination (Mitchell et al., 1996; Prather and Callihan, 1993; Wilson et al., 1993). An intensive soil sampling effort in Iowa demonstrated atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] sorption ( $K_d$ ) ranging from 1.9 to 12.5 within a single 6.25 ha field (Novak et al., 1997). Areas with higher  $K_d$  values would have reduced atrazine bioavailability under uniform application rates. Such differences in soil characteristics may influence seedling survival and, therefore, weed population dynamics (Burton et al., 2004).

If well-managed and coupled with an understanding of the systems' biological components, geographic information systems may help operators compensate for some of the feedback (e.g., adaptive management practiced by farmers familiar with locations and species of weed pests within a field) that is often lacking in larger production systems (Ghersa et al., 1994). Such management of temporally and spatially referenced data has also enabled researchers to examine associations of weedy species with various soil and physiographic factors (Andreasen et al., 1991; Dale et al., 1992; Johnson et al., 1999; Dieleman et al., 2000a, 2000b; Burton et al., 2004, 2005). Depending on the strength of a weed species' association with soil or landscape characteristics (edaphic effects) and the spatial stability of the weed population's distribution (i.e., degree of patchiness, population density constancy and persistence at a location) (Gerhards et al., 1997; Johnson et al., 1996; Wiles et al., 1992; Wilson and Brain, 1991), researchers may be able to identify areas in which a species would likely be most harmful to yield. Similarly, it may be possible to identify where the species would be most recalcitrant in the event of invasion or would likely require application of additional or different management tactics (either in type, magnitude or frequency) for acceptable weed control (Burton et al., 2005). In short, to manage weed populations more efficiently, we must have a more complete understanding of the biology of the weeds within the system and how population dynamics vary with respect to site characteristics.

Although considerable effort has been invested in elucidating demographic processes for some weed species (Gonzalez-Andujar and Fernandez-Quintanilla, 1991; Fernandez-Quintanilla et al., 1987; Lindquist et al., 1995; Naylor, 1972; Sagar and Mortimer, 1976; etc.), few investigations (but see Burton et al., 2004, 2005) have been conducted to test for differences in a species' population dynamics across disparate sub-field environments (e.g., high and low SOC environments) for species known to be associated with particular niche characteristics. Using a multivariate statistical approach, Dieleman et al. (2000b) observed that feral common sunflower (*Helianthus annuus* L.) presence was positively correlated with SOC. Burton et al. (2004) explored the effect of disparate SOC environments on *H. annuus* emergence and early season seedling survival and suggested that (1) differences in SOC may lead to differential survival among *H. annuus* seedlings receiving a pre-emergence herbicide (PRE) treatment of atrazine and acetochlor [2-chloro-*N*-(ethoxymethyl)-*N*-(2-ethyl-6-methylphenyl)acetamide] with 40% higher seedling survival in high SOC environments, and (2) seedling survival was higher in untreated high SOC furrow microsites in the ridge-tillage system than in untreated low SOC environments.

The ridge-till system is widely employed in Nebraska (USA) and many other states for maize, sorghum and soybean production (Klein et al., 1996). The ridges into which the crop is planted are permanent, with ridge tops being truncated prior to or at the time of planting. Mechanical tactics are employed for weed control in the furrow, followed by a "ridging" operation in which soil from the between row space is moved to the base of the crop row (Wicks and Somerhalder, 1971). Truncation of ridges at planting has been observed to remove 31–37% of buried weed seeds from the ridges of continuous maize production systems (Forcella and Lindstrom, 1988a; Forcella and Lindstrom, 1988b). Others report potentially higher levels of weed seed removal from the ridge. Assuming that the top 7.6 cm of soil is moved from the ridges by truncation, the data of Wicks and Somerhalder (1971) indicated that 88% of seeds occurring in the top 15.2 cm of ridges (measured before truncation) are removed from the crop row seedbank. Post-planting cultiva-

tion in the ridge-till system also effectively controls weed seedlings in the furrow (Wicks and Somerhalder, 1971; Wilson, 1993) and resulted in lower average *H. annuus* densities compared to moldboard and disk tillage systems (Wilson, 1993). Cultivation reduced *H. annuus* density by 72% compared to an unmanaged check plot. However, unacceptably high *H. annuus* seedling densities remained (i.e., 125 plants  $10\text{ m}^{-2}$ ). Cultivation in combination with chemical tactics resulted in much lower *H. annuus* densities (i.e., 2 plants  $10\text{ m}^{-2}$ ).

This paper examines the effects of cultivation, ridging, and SOC environment on juvenile *H. annuus* survival in ridge and furrow microsites and compares *H. annuus* vegetative growth from the time of the ridging operation through maize harvest in high and low SOC environments. Reproductive biomass is also compared across SOC environments as an estimate of fecundity.

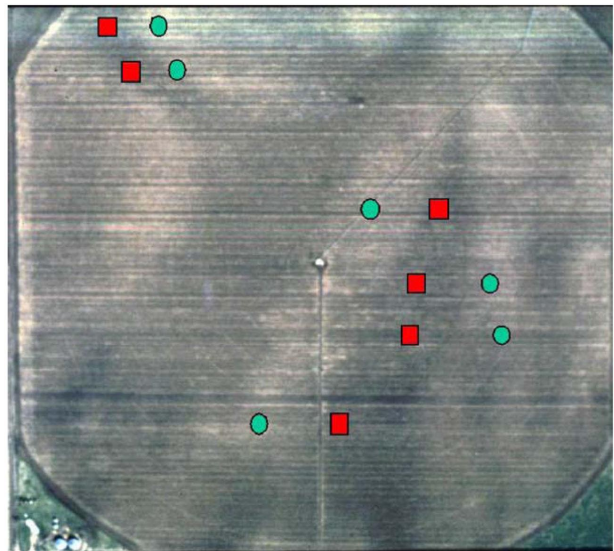
## 2. Materials and methods

### 2.1. Mechanical tactics

Survival of *H. annuus* juveniles was observed by direct count before and after tillage was performed (cultivation, which passed within 7–10 cm of the crop row; and ridging, which moved soil from the furrow to the base of the maize crop) in a continuous maize production field in 1999. The field site was previously described by Burton et al. (2004). Plots consisted of three adjacent subplots, each of which was 1 m of two neighboring 0.76 m crop rows and furrows (subplot area =  $1.52\text{ m}^2$ ). One subplot was selected at random and assigned an herbicide-treatment. Within each subplot, 60 *H. annuus* seeds were planted at 10 cm intervals in each of two between row spaces (furrows) and on both sides of each of two crop rows (ridges), such that a total of 20 seeds were planted to furrows and 40 seeds were planted to ridges in each subplot. Seeds were planted in the ridges 4–6 cm on each side of crop row 1 day after maize planting. Seeds in ridges and furrows were planted to a vertical depth of approximately 4 cm using a small probe to create a 45° angle hole. Pre-emergence herbicide was applied 2 days after crop planting to the appropriate subplots in a 0.38 m band centered on the crop

row at one-half the farmer-applied rate of 2.77 kg ai acetochlor [2-chloro-*N*-(ethoxymethyl)-*N*-(2-ethyl-6-methylphenyl)acetamide] and 1.10 kg ai atrazine per treated ha. A seed pre-treatment of gibberellic acid was used to promote *H. annuus* seed germination and resulted in overall emergence of 68% in no-herbicide plots (Burton et al., 2004).

Effects of tillage on *H. annuus* survival (recruitment) were determined by comparing pre-cultivation seedling number to the number of juveniles that survived cultivation and ridging treatments across high and low SOC levels and herbicide treated and no-herbicide subplots. Cultivation was performed 30 days after maize planting and ridging was performed 1 week later. The experimental design for mechanical tactics was a split-plot with SOC level as main plot and herbicide treatment as the split-plot. Six high-low SOC plot pairs were distributed across the 64 ha field site (Figure 1). Analysis of variance was performed with the MIXED procedure in SAS® System for Windows Version 8 (SAS Institute, Cary, NC). Rodent herbivory resulted in a total of eight missing plant observations (including all of one subplot), all of which were from low SOC environments. These missing plants were treated as missing observations in statistical analyses.



**Figure 1.** Distribution of plots within 64 ha field located near Shelton, NE. Squares represent high SOC locations and circles represent low SOC locations. Plots within a high-low pair occurred in the same crop rows.



## 2.2. Vegetative growth and reproductive biomass

Two days after the ridging operation was completed, four surviving juvenile *H. annuus* plants were randomly selected from furrows in each of the two no-herbicide subplots within each of 12 plots. All other *H. annuus* plants within the subplots were removed. Vegetative and reproductive growth characteristics of *H. annuus* were measured in the high and low SOC environments through maize harvest. Canopy height and stem diameter measurements were made on June 23 (2 days after ridging), July 9 (maize V10), July 23 (maize anthesis), and September 25 (2 days before maize harvest). Canopy height was measured to the nearest 5 cm as the highest point of an undisturbed plant. Since many *H. annuus* plants had lodged during the preceding 2 months, stem length was measured on September 25 in addition to canopy height and stem diameter. Stem length was defined as the overall length of the stem regardless of its angle to the ground (i.e., a plant that was upright would have equivalent values for canopy height and stem length). Maize canopy height was measured as described for *H. annuus* until anthesis, when the tassel was included in the height measurement. Stem diameter was measured with a digital caliper to 0.1 mm at the thickest part of the plant stem. Node number is reported as described by Schneider and Miller (1981), counting each true leaf of >4 cm length or leaf abscission scar.

Each *H. annuus* plant was separated into vegetative (leaves and stems) and reproductive components (flowers and capitula), and dried to constant weight at 70 °C. Flowers were sorted into four classes ( $\leq R5$ , R6, R7, and  $\geq R8$ ) according to phenological development (Schneider and Miller, 1981). Flowers  $\leq R5$  were combined because these flowers were considered unlikely to produce seeds of sufficient resources and vigor to survive under normal conditions if the mother plant was killed during maize harvest. Flowers were combined if  $\geq R8$  because flowers of wild *H. annuus* may begin to shatter before floral characteristics (browning of the base of the capitulum) described by Schneider and Miller (1981) as indicating physiological maturity, R9, were observed.

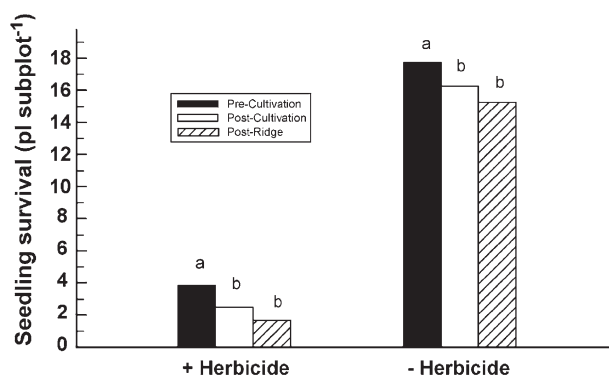
The experimental design for vegetative and reproductive growth characteristics was equivalent

to a randomized complete block with subsampling (higher levels of the original split-plot design were not statistically significant at  $\alpha = 0.05$ ). Analysis of variance for vegetative and reproductive growth characteristics was also performed using PROC MIXED (Littell et al., 1996). Summary statistics for vegetative growth characteristics and reproductive biomass by plant status were calculated using the UNIVARIATE procedure (SAS, 1999).

## 3. Results and discussion

### 3.1. Mechanical weed control

*H. annuus* survival through mechanical weed control tactics (i.e., cultivation and ridging) did not differ significantly ( $P \geq 0.18$ ) between SOC environments. However, cultivation resulted in a reduction in the *H. annuus* juvenile population (Figure 2). All plants occurring in the center of the Furrow were killed by cultivation. Within the PRE treated ridge, survival was reduced ( $P = 0.02$ ) from an initial mean of 3.8 plants subplot<sup>-1</sup> to a mean of 2.5 plants subplot<sup>-1</sup> (Figure 2). The further reduction of *H. annuus* to a mean of 1.7 plants subplot<sup>-1</sup> by ridging was not statistically different from the seedling abundance observed after cultivation ( $P = 0.13$ ). As a consequence of these two operations, the abundance of recruited plants (i.e., the number that



**Figure 2.** Effect of mechanical tactics on *H. annuus* survival in the ridge microsites in herbicide treated and control subplots. Within a treatment, tactics that are annotated by the same letter are not significantly different at  $\alpha = 0.05$ . All seedlings in the furrow microsite were killed by cultivation.

survived all mechanical tactics) was different from the abundance of seedlings (pre-cultivation) that survived the PRE treatment ( $P < 0.001$ ). Control (no herbicide) subplots were similar in terms of the significance of pairwise comparisons of initial seedling abundance (pre-cultivation) and observed abundance following cultivation or ridging (Figure 2). The total actual reduction in juvenile abundance due to mechanical tactics in control subplots (2.6 plants subplot<sup>-1</sup>) was somewhat greater than was observed in herbicide treated subplots (2.1 plants subplot<sup>-1</sup>), but the proportional reduction in observed plant density was smaller (15% versus 55%, respectively). Survival in the control subplots prior to cultivation, after cultivation and after ridging was 17.8, 16.2, and 15.2 plants subplot<sup>-1</sup>, respectively.

Although no differences in weed management outcomes were observed as a consequence of SOC environment in this year, the interaction of soil characteristics and landscape position to produce wet conditions at the time of cultivation can affect weed management outcomes. Areas with wetter soil are sometimes avoided (i.e., left uncultivated) or might result in soil clumps after cultivation that allow re-rooting of weeds that would have been killed under normal (i.e., drier) conditions.

### 3.2. Vegetative growth

Unless otherwise noted, all *H. annuus* growth comparisons were made between subplots not treated with herbicide. Nearly all plants were erect at the 23 July sampling date (maize anthesis) and mean *H. annuus* canopy height (~220 cm) was less

than the ~250 cm mean canopy height of maize (Table 2). Despite >100 cm increase in mean stem length (Table 2) over the mean canopy height at the previous observation date, *H. annuus* mean canopy height did not demonstrate a net increase in canopy height by maize harvest due to bending and lodging of *H. annuus* stems. That is to say, had *H. annuus* plants not lodged or bent, they would have been on average 70 cm taller than the maize crop.

*H. annuus* canopy height, stem length, stem diameter, and node number were not affected by SOC environment (Table 2). This is in part due to the large range of values observed within each SOC environment for each characteristic (Table 1). Vegetative biomass at harvest also did not differ ( $P = 0.40$ ) between SOC environments, with means of 459 and 409 g, respectively. Mean growth characteristic values for high SOC were often, even if only slightly, greater than were observed in low SOC environments. While small differences in growth characteristics can lead to differences in population dynamic outcomes, these differences are small compared to those observed for seedling survival in high and low SOC environments in related experiments (Burton et al., 2004).

In discussing plant vegetative growth, Harper (1977, p. 777) asserts that while there is an advantage conferred to a plant when it intercepts more light than its competitors (and shades its competitors), there is "no intrinsic advantage to the individual from being high (there are some real disadvantages in the amount of non-reproductive tissue to be supported), only an advantage from being higher than neighbors. It is being higher, not just

**Table 1.** Vegetative growth characteristics of feral *H. annuus* at maize harvest (September 25, 1999) when grown in habitats that differed in soil organic carbon (SOC) level

SOC level	Vegetative growth characteristic	N <sup>a</sup>	LS mean	Std error	Range
High	Canopy height (cm)	46 <sup>b</sup>	222	15	60–370
	Stem length (cm)	46	340	6	240–405
	Stem diameter (mm)	46	33.2	1.3	16.6–45.8
Low	Canopy height	37	192	16	10–395
	Stem length	37	328	7	270–410
	Stem diameter	37	31.6	1.4	16.5–46.7

Standard error is standard error of the least squares treatment mean.

<sup>a</sup> N, number of observations in the estimate; LS mean, least-squares mean; Std error, standard error of the treatment mean.

<sup>b</sup> Two of the original 48 plants in the high SOC environments died during the experiment. Although only three plants died in the low SOC environments during the experiment, eight seedlings were eliminated by rodent activity.

**Table 2.** Average canopy height, stem length, stem diameter and node number of feral *H. annuus* growing near maize crop rows in areas of high (H) and low (L) soil organic carbon

Sampling date	Canopy height (cm)		Stem length (cm)		Stem diameter (mm)		Node number	
	H	L	H	L	H	L	H	L
June 23 (post-ridging)	63.9 (4.0)	62.0 (4.1)	-	-	12.7 (0.8)	11.9 (0.9)	12.6 (0.6)	11.5 (0.6)
July 9 (maize V10)	128.6 (6.3)	129.4 (7.2)	-	-	21.2 (1.2)	20.2 (1.4)	22.5 (0.8)	22.0 (0.9)
July 23 (maize anthesis)	217.2 (7.1)	218.3 (7.4)	-	-	24.9 (0.8)	24.0 (0.9)	30.3 (1.0)	29.1 (1.1)
September 25 (maize harvest)	222.2 (14.7)	191.7 (15.8)	340.2 (5.9)	328.1 (6.6)	33.2 (1.3)	31.6 (1.3)	-	-

Standard error of the mean is given in parentheses.

high, that pays.” Resources invested in producing and supporting vertical growth are resources not used in reproductive growth. Our data indicate that there may be other negative repercussions. In Nebraska maize fields, *H. annuus* can grow to overtop the crop by continuing vertical vegetative growth after maize has tasseled. The competitive advantage of a longer period of vegetative growth may, however, leave *H. annuus* at risk of bending, lodging, or stem breakage due to wind exposure and weight—especially as stem stress increases due to increasing reproductive biomass above the shelter of an already tall crop canopy. Plants whose stems cannot support the combined stresses of wind and weight were often partially supported by crop plants, but may fall between rows or crop plants. These plants are shaded by the crop and may suffer broken stems that allow insect infestation (M. Burton, pers. observation). Lodged plants suffered reduced fitness as measured by reproductive biomass (Table 3). In the present experiment, plants that lodged to the ground (i.e., branches and stems were in contact with the soil) usually died and were beginning to decay at harvest. Although rodent activity resulted in eight fewer available seedlings in the low SOC environments at the outset of this experiment, a similar number of plants died in each SOC environment between juvenile and reproductive stages of growth (two and three plants died in high and low SOC environments, respectively).

### 3.3. Reproductive biomass

Survival of *H. annuus* decreased significantly ( $P < 0.01$ ) during the period between July 23 and maize harvest. All juvenile seedlings that were selected after mechanical weed control tactics were still living on July 23. By September 25, some plants had died, suffered broken stems, or were lodged

within the maize canopy. From July 23 to September 25, average plant density declined from 3.82 to 3.39 plants per subplot. Plants that produced little reproductive biomass (i.e., <5 g dryweight) by maize harvest were considered to have failed to produce viable seeds.

Mean total reproductive biomass (floral dry-weight from all reproductive stages) was not different between SOC locations ( $P = 0.49$ ). Mean total reproductive biomass for high and low SOC location was 150 and 134 g, respectively. Since *H. annuus* plants may be killed by maize harvesting equipment, total reproductive biomass may overestimate fecundity. Although *H. annuus* disk flowers develop and are fertilized progressively from

**Table 3.** Average reproductive biomass of feral *H. annuus* by plant status and reproductive biomass phenological categories at crop harvest

Status <sup>a</sup>	Reproductive category	N <sup>b</sup>	Mean	Std error	Range
UPRIGHT	Total	37	187.6	16.9	41.5–465.1
	≥ R7	37	81.4	11.1	0–270.3
BENT	Total	38	166.8	16.4	2.8–359.5
	≥ R7	38	65.2	10.5	0–269.5
LODGED	Total	18	70.7	17.4	0.7–218.1
	≥ R7	18	27.7	9.0	0–120.2
DEAD	Total	8	1.0	1.0	0–8.2
	≥ R7	8	0.6	0.6	0–4.5

Data pooled from all subplots (including four subplots from a related experiment). Plant status was determined as the proportion of canopy height to stem length.

<sup>a</sup> UPRIGHT, proportional height ≥0.70; BENT, ≥0.50; LODGED, <0.50; dead plants were categorized as dead regardless of proportional height observed at harvest.

<sup>b</sup> N, number of observations in the estimate; Std error, standard error of the mean.

the disk perimeter to the center, seeds at the perimeter of R6 flowers were poorly filled and, although fertilized, were considered unlikely to be capable of producing a viable seedling under normal circumstances. Consequently, we tested for an effect of SOC on combined reproductive biomass from the R7 and later phenologies. Again, no effect of SOC was observed ( $P = 0.59$ ) between high and low SOC locations with means of 62 and 55 g, respectively.

#### 4. Conclusions

While *H. annuus* density decreased as a result of mechanical cultivation, the actual magnitude of the decrease was small when juvenile plants were growing near the crop row. Similarly, only small decreases in *H. annuus* plant density were observed during the course of the crop season. The range of total reproductive biomass for untreated *H. annuus* (0–465 g) was similar to that of 23 herbicide treated plants that were allowed to grow in neighboring subplots (0–409 g). Although floral development lagged behind that of the untreated plants (R7–R9 mean of herbicide treated plants was 39 g compared with 61 g for untreated plants), herbicide treated escapes observed elsewhere in the field demonstrated considerable reproductive capacity. Late season (after maize anthesis) lodging of *H. annuus* resulted in decreased reproductive biomass production. Unlike early season survival (Burton et al., 2004), SOC did not affect survival, growth, or reproductive capacity of *H. annuus*. The lack of differences here suggests that SOC's primary role in regulation of *H. annuus* populations in well-fertilized, irrigated maize occurs prior to mechanical cultivation. However, additional multi-year studies should be conducted to confirm this result across a similar or broader range of soil environments and locations.

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