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Tillage effect on reproductive output by foxtail cohorts in corn and soybean

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Reliable estimates of weed fecundity require determination under ranges of management practices such as differing crops and tillage systems. We measured components of reproductive output per plant (numbers of primary tillers, panicles, and seeds; and sizes of panicles) in three emergence cohorts of green foxtail and yellow foxtail growing among corn and soybean in moldboard plow (MP), chisel plow (CP), ridge till (RT), spring disk (SD), and no till (NT). Differences in emergence between crops and foxtail Cohorts 1, 2, and 3 were 5, 0, and −7 d, respectively. In MP, Cohort 1 of green foxtail produced 2.3 primary tillers and 5.6 panicles per plant, and Cohort 1 of yellow foxtail produced 4.6 primary tillers and 9.0 panicles per plant. Panicle size was variable for both species across tillage systems, crops, and cohorts both years. Green foxtail plants produced the most seeds per plant (3,811) in NT corn, and cohorts did not vary greatly, whereas fecundity was highly variable across tillage systems and cohorts in soybean, where it averaged 3,240 (± 388) seeds per plant. Green foxtail seed number per plant were closely related to panicle numbers per plant for each year in corn ($r^2 = 0.90$) and soybean ($r^2 = 0.78$), and the relationship did not vary among tillage systems. Yellow foxtail seed number per plant was closely related to panicle number per plant, and it was specific for each tillage system in corn ($r^2 = 0.60$ to 0.85) and soybean ($r^2 = 0.65$ to 0.92). Estimates for vegetative and reproductive growth were more reliable for green foxtail than for yellow foxtail across tillage systems, crops, cohorts, and years.

Nomenclature: Green foxtail, *Setaria viridis* (L.) Beauv. SETVI; yellow foxtail, *Setaria pumila* (Poir.) Roem. & Schult. [= *Setaria glauca* (L.) Beauv.] SETLU; corn, *Zea mays* L. ‘Pioneer 3893’; soybean *Glycine max* (L.) Merr. ‘Pioneer 9091’.

Key words: Emergence cohorts, panicles, seed production, tillers.

Among the characteristics used to classify an ideal weed are rapid growth from the vegetative phase to flowering and very high seed output in a wide range of environmental conditions for as long as growing conditions permit (Baker 1974). Several agronomic weeds, mostly annuals that interfere with crop production, fit this description. Many weeds escape control and produce seeds that replenish seed banks and increase the potential for future weed infestations. Seed production by weed escapes is not easily measurable but accounts for the majority of the seeds incorporated into the seed bank each year (Forcella et al. 1996; Norris 1996). Reliable and accurate estimates of seed production by weeds growing in competition with crops are essential if long-term and ecologically based weed control strategies are to be developed (Norris 1996).

Green foxtail and yellow foxtail are important weeds in many crops grown in North America, and they are known to produce numerous seeds (Kegode et al. 1999a, 1999b, 2003; Santelmann et al. 1963; Vanden Born 1971). Because factors regulating foxtail seed production are poorly understood, there is a need to determine the magnitude of seed production of plants that escape control. Such information would improve the ability to predict weed seed production and help improve management decisions because long-term weed management requires maintenance of seed-bank densities as low as possible (Forcella et al. 1992, 1993, 1997).

Time of emergence relative to the crop, and environmental conditions following emergence, influence the growth and competitive nature of foxtails (Blackshaw et al. 1981; Dryden and Whitehead 1963). For example, Knake and Slife (1965) found that seeding giant foxtail (*Setaria faberi* Herrm.) after corn and soybean resulted in reduced giant foxtail biomass compared with foxtail seeded with the crops, particularly in soybean, which provided more shade over the row. Shading can reduce the number of tillers produced by foxtails (Knake 1972). Indeed, plants growing in full sunlight can produce up to five times more tillers than those growing in a crop (Bubar and Morrison 1984).

The adoption of conservation tillage systems in the United States has been advantageous for soil and water conservation, sustaining soil productivity and reducing labor and energy requirements (Unger and McCalla 1980). Consequently, conservation tillage production has increased steadily during the past decade. Conservation tillage practices were used on 26 and 41% of the total cropland area in 1994 and 2004, respectively (CTIC 2005). Conservation tillage is likely to continue increasing in the United States because short- and long-term economic returns favor the adoption of these practices for corn and soybean production on well-drained soils (Al-Kaisi and Yin 2004; Yin and Al-Kaisi 2004).

The effect of tillage practices on the population dynamics of annual weed species is complex and involves several factors. For instance, tillage causes vertical seed movement in agricultural soils (Cousens and Moss 1990; Staricka et al. 1990) resulting in differences in foxtail emergence (Buhler

TABLE 1. Average monthly precipitation and cumulative thermal time (growing degree days; base temperature 10 C), from May 1 to September 17, 1996 and 1997, and the 30-yr mean, at Morris, MN.

	Precipitation			Thermal time		
Month[a]	1996	1997	30-yr mean	1996	1997	30-yr mean
	mm			degree days		
May	116	32	71	102	77	168
June	26	54	94	411	415	435
July	92	115	86	705	634	783
August	57	94	81	911	888	1,093
September	53	37	61	1,003	1,098	1,195
Total	344	332	393	1,003	1,098	1,195

[a] No rainfall or growing degree days recorded in April in either year.

and Mester 1991). Differences in emergence of weeds in relation to crops play a key role in competitive relationships. Weeds that emerge before the crop likely will have a competitive advantage and will produce more biomass and seeds than if they had emerged after the crop. However, even late-emerging weeds produce some seeds that will enter and replenish the seed banks, but levels of seed production of late-emerging weeds are poorly understood.

A shift from intensive tillage systems to reduced tillage systems can cause major changes in weed population dynamics (Buhler 1995). To fully characterize the population dynamics of weeds, a better understanding of weed growth and reproductive characteristics related to tillage practices and emergence timing is necessary. The objective of this study was to determine the influence of tillage system and time of emergence of green foxtail and yellow foxtail on per plant primary tiller production, panicle production and size, and seed production in corn and soybean cropping systems.

Materials and Methods

General Field Procedures

This study was conducted in 1996 and 1997 at Morris, MN, in an Aastad clay loam soil (Pachic Udic Haploboroll; fine, loamy, mixed). The plots were originally established in 1978 to study the long-term effects of tillage systems on soil properties in corn–soybean rotations. The experimental design was a randomized complete block in a split–split plot arrangement with two replications. Tillage system was the whole plot factor, crop was the split plot factor, and cohort was the split–split plot factor. Plot size was 9 by 18 m and consisted of 12 crop rows. The six center rows were used as the experimental area from which cohort plants were selected.

The tillage systems included MP, consisting of fall moldboard plow followed by a field cultivator in spring; CP, consisting of fall chisel plow followed by a field cultivator in spring; SD, consisting of spring disk and harrow; RT, consisting of a horizontal disk that truncated ridges in spring (ridges were reformed during interrow cultivation); and NT. Depth of tillage was 25 to 30 cm for MP, 15 to 20 cm for CP, and 10 to 15 cm for SD and field cultivation.

Corn plots were sown with 'Pioneer 3893' seed at the rate of 74,000 seeds ha^{-1} on May 2, 1996, and May 5, 1997, in a row spacing of 0.76 m. Starter fertilizer (15–37–37 kg ha^{-1} N–P–K) was applied at planting, and 110 kg N ha^{-1} was incorporated as a side-dress with the second interrow cultivation in both years. For control of nontarget weeds, nicosulfuron was applied POST at a rate of 0.035 kg ai ha^{-1} with nonionic surfactant and liquid N, and 2,4-D was applied POST at a rate of 0.56 kg ai ha^{-1}. Both herbicides were applied on June 13, 1996, and June 1, 1997. To prevent herbicide injury, selected foxtail plants were covered individually for the duration of herbicide application and for a short time thereafter to allow herbicides to dissipate. For supplemental weed management, plots were cultivated on June 20 and July 9, 1996, and June 11 and 26, 1997. Interrow cultivation did not injure selected cohort plants. In RT, ridges were built on July 3 and June 26, in 1996 and 1997, respectively.

Soybean plots were seeded with 'Pioneer 9091' seed at the rate of 300,000 seeds ha^{-1} on May 3, 1996 and May 5, 1997, in rows spaced 0.76 m apart. Starter fertilizer (15–37–37 kg ha^{-1} N–P–K) was applied at planting. For weed control, sethoxydim was applied POST at a rate of 0.34 kg ai ha^{-1} with nonionic surfactant on June 12, 1996 and June 1, 1997. Selected foxtail plants were covered to prevent herbicide injury as indicated above. For supplemental weed management, plots were cultivated on June 20 and July 9, 1996 and June 11 and 26, 1997. Interrow cultivation did not injure selected cohort plants. In RT, ridges were built on July 9 and June 26, in 1996 and 1997, respectively.

Daily precipitation and daily maximum and minimum temperature for May to September were recorded, and the number of growing degree-days (GDD), base 10 C, were calculated from air temperature (Table 1). Total amount of precipitation received was similar between years but varied in its distribution. GDD also were similar between years.

Selection of Foxtail Cohorts

Three cohorts each for green foxtail and yellow foxtail were selected within each corn and soybean plot. Rings made from plastic pipe (4 cm diameter) were placed around foxtail seedlings, along with a small stake that designated a plant number, to facilitate identification of cohort plants. Cohort 1 seedlings emerged 5 d before crop emergence, Cohort 2 seedlings emerged within the same period as crop emergence, and Cohort 3 seedlings emerged 7 d after crop emergence. A weed-free period of 7 d was maintained between periods of cohort emergence. For example, once Cohort 1 plants had been selected, the entire plot was hand-weeded to remove all other existing foxtail seedlings. The plots were kept weed-free until crops began to emerge. Subsequent foxtail emergence comprised Cohort 2 seedlings.

Upon identifying Cohort 2 seedlings, the plots were kept weed-free for 7 d, and the subsequent flush of emerging seedlings was used to select Cohort 3 plants. Cohort plants were spaced at least 1 m apart to minimize intraspecific competition but to maximize the effect of crop competition on foxtails.

Initial emergence of green foxtail and yellow foxtail was on May 16, 1996 and May 17, 1997. Corn and soybean emerged on May 20, 1996 and May 22, 1997. Foxtail Cohorts 1, 2, and 3 were established on May 22, 30, and June 10, respectively in 1996, and on May 27, and June 3 and 10, respectively in 1997.

Each cohort initially consisted of 40 seedlings that were within the crop row from which 10 seedlings each of green foxtail and yellow foxtail were randomly selected. Selected foxtail plants were monitored for production of tillers, panicles, and seeds. Interrow cultivation did not injure or dislodge selected plants except for a few instances in RT where building of ridges resulted in some plants being covered with soil that was removed quickly by hand.

Tiller, Panicle, and Seed Production

Foxtail tiller and panicle production were determined periodically by counting the number of primary tillers and the number of panicles produced by individual green foxtail and yellow foxtail plants within cohorts. Determination of the number of primary tillers per plant started when all three cohorts were established and the first few primary tillers had been initiated and ceased shortly after plants began to senesce. Total number of panicles produced by individual plants within cohorts was determined at time of seed collection.

Foxtail seed production was determined by collecting all seeds produced by individual plants within each cohort. Seed collection was accomplished by inserting each panicle into a porous mesh bag and collecting all bagged panicles before crop harvest. To prevent seed loss, the mesh bags were tied securely to the stem at the base of each panicle. Panicles were bagged weekly beginning 7 d after the first panicles were observed. A 7-d interval allowed for panicles to emerge fully, pollinate, and set seeds, but was not long enough for seeds to mature and disperse. To prevent possible lodging due to the additional weight of mesh bags, individual foxtail tillers with bagged heads were loosely tied to slender wooden stakes that were placed next to each plant.

Seeds were collected immediately before corn and soybean harvest. Panicles were measured for size, stripped of seeds, and seeds aggregated within plants so that fecundity per plant could be calculated. The combined sample was air-cleaned to remove chaff, immature seeds, etc. Cleaned samples were weighed, and the number of seeds per plant was estimated from the weight of a 100-seed subsample of each foxtail species. The 100-seed weights of each cohort of either foxtail species did not vary significantly, therefore, an average 100-seed weight of the cohorts was used.

Statistical analysis

At the end of the growing season, the data for total number of primary tillers per plant, panicles per plant, average panicle size, and total seed production per plant were subjected to analysis of variance[1] to test for main treatment effects and interactions. Means were separated using Fisher's protected LSD test at the 5% level of significance. Linear regression analysis was performed to describe the relationship between number of primary tillers per plant and number of panicles per plant and between number of panicles per plant and number of seeds per plant. Differences between tillage systems were determined by pairwise comparisons of the regression coefficients using the Student's *t* test. Significant main treatment effects and interactions are presented and discussed.

TABLE 2. Influence of year, tillage system, crop, and cohort on the average number of green and yellow foxtail primary tillers per plant and panicles per plant at the end of the growing season in 1996 and 1997, at Morris, MN.

	Green foxtail		Yellow foxtail	
Treatment	Primary tillers	Panicles	Primary tillers	Panicles
	No. plants^{-1}			
Year				
1996	2.4	4.5	3.8	7.4
1997	1.8	4.3	2.4	3.7
LSD (0.05)	0.5	NS[a]	0.6	1.1
Tillage System				
Moldboard Plow	2.3	5.6	4.6	9.0
Chisel Plow	1.7	3.2	2.4	4.5
Ridge Till	1.6	3.1	2.0	3.4
Spring Disk	1.6	2.9	4.2	7.0
No Till	3.1	6.9	2.1	3.7
LSD (0.05)	0.9	1.8	1.1	1.9
Crop				
Corn	1.9	4.1	2.3	3.8
Soybean	2.4	4.8	4.1	7.6
LSD (0.05)	NS	NS	0.6	1.1
Cohort				
1	3.2	6.2	4.9	8.3
2	2.3	4.8	2.9	5.3
3	0.9	2.4	1.4	3.0
LSD (0.05)	0.6	1.3	0.8	1.4

[a] Abbreviation: NS, not significant.

Results and Discussion

Number of Primary Tillers and Panicles at end of Growing Season

Average number of green foxtail primary tillers per plant was higher in 1996 (2.4) than in 1997 (1.8), and more primary tillers were produced by plants in NT (3.1) than in the other tillage systems ($\bar{x}$ = 1.8) (Table 2). Average number of primary tillers per green foxtail plant was similar among crops ($\bar{x}$ = 2.2) and was generally higher with Cohort 1 plants (3.2) compared with Cohort 2 (2.3) and Cohort 3 (0.9). The average number of green foxtail panicles per plant was similar between years ($\bar{x}$ = 4.4) and generally followed the pattern that was observed with tiller numbers, where it was higher in NT (6.9) and in MP (5.6) and was relatively low in the other tillage systems ($\bar{x}$ = 3.1). Panicle number was similar among crops ($\bar{x}$ = 4.5) and was highest with Cohort 1 plants (6.2) compared with Cohort 2 (4.8) and Cohort 3 (2.4) plants.

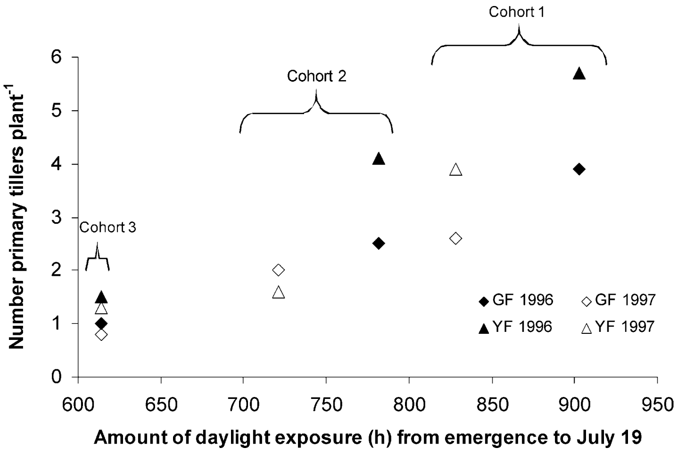

FIGURE 1. Average number of primary tillers per plant for Cohorts 1, 2, and 3 green foxtail (GF) and yellow foxtail (YF) plants produced in relation to cumulative time of exposure to daylight from emergence time (cohort) to July 19 (both years), when maximum number of tillers was reached.

Average number of yellow foxtail primary tillers per plant was higher in 1996 (3.8) than in 1997 (2.4), was highest in MP and SD ($\bar{x}$ = 4.4) than in the other tillage systems ($\bar{x}$ = 2.2), was higher in soybean (4.1) than in corn (2.3), and was higher with Cohort 1 plants (4.9) than with Cohort 2 (2.9) and Cohort 3 (1.4) plants (Table 2). The average number of yellow foxtail panicles per plant followed the trend observed with the number of primary tillers per plant. Yellow foxtail produced more panicles per plant in 1996 (7.4) than in 1997 (3.7), in MP and SD ($\bar{x}$ = 8) than in the other tillage systems ($\bar{x}$ = 3.9), in soybean (7.6) than in corn (3.8), and with Cohort 1 plants (8.3) than with Cohort 2 (5.3) and Cohort 3 (3.0) plants.

Maximum number of primary tillers of green foxtail and yellow foxtail appeared to occur around July 19, regardless of year, tillage system, crop, or cohort (data not shown). Maximum day length of 15.47 h was reached on June 21, and by July 19, it had declined to 15.02 h. Long days promote tiller production in yellow foxtail and giant foxtail, whereas they inhibit production of panicles (Santelmann et al. 1963; Steel et al. 1983). Panicles were observed initially at the time when maximum tiller number was reached and, subsequently, until harvest. In addition to sensitivity to day length, stress due to competition for resources between foxtail plants and crops was probably another reason why tiller production ceased in favor of panicle production. For example, as the level of shading increased, the number of tillers produced by green, yellow, and giant foxtail decreased (Bubar and Morrison 1984; Knake 1972).

Time of cohort emergence and rainfall distribution may help explain some of the differences in primary tiller production that were observed between years. In 1996, Cohorts 1 and 2 green foxtail and yellow foxtail plants were established on earlier dates compared with similar cohorts in 1997. Consequently, Cohorts 1 and 2 in 1996 had 75 and 61 h, respectively, of additional cumulative exposure to daylight between time of emergence and July 19, compared with similar cohorts in 1997 (Figure 1). As shown in Figure 1, a near-linear relationship may exist between daylight exposure time and tiller production. Additionally in 1996, 43% of the total precipitation was received in May and June (Table 1), which probably benefited early season primary tiller production by both foxtail species. In contrast, May and June 1997 had 26% of the total precipitation and, due to competition with crops, the lower amount of precipitation was probably insufficient for the abundant primary tiller production apparent in 1996. Precipitation received in July and August 1997 (63% of the total precipitation) did not restore tiller production to levels similar to 1996. Cohort 3 green foxtail and yellow foxtail seedlings were established on June 10 in both years.

Tiller development by grass weeds is dependent upon the ability of the weed to occupy space and proximity to neighboring plants. In the absence of crop competition, both foxtail species produced many primary tillers, which gave rise to numerous panicles per plant. Number of primary tillers and panicles per plant declined drastically when both foxtails grew in competition with crops. For example, in the absence of a competing crop, green foxtail cohorts averaged 39 primary tillers and 54 panicles per plant (data not shown). In the presence of a competing crop, however, green foxtail cohorts averaged only 2.1 primary tillers and 4.5 panicles per plant.

Number of primary tillers per plant was closely correlated to the number of panicles per plant. This linear relationship was consistent for green foxtail and yellow foxtail plants across tillage systems and crops, with r^2 values for best-fit equations ranging from 0.56 to 0.87 in corn and from 0.72 to 0.95 in soybean (Figure 2). The linear functions indicated that each additional primary tiller per plant would yield 0.98 to 1.92 green foxtail panicles per plant in corn and 1.08 and 2.25 panicles per plant in soybean.

Pairwise comparisons of regression coefficients of the tillage systems indicated that NT corn was significantly different from all other tillage systems, except MP (Table 3). Likewise, in soybean, the comparison of regression coefficients for green foxtail indicated that the MP and NT tillage systems were similar, and both were different from CP, RT, and SD. With yellow foxtail, there was no difference among tillage systems in corn, whereas in soybean, the analysis of regression coefficients indicated that there was wide variation among tillage systems and no consistent trend was detected (Table 3)

Panicle Size at End of Growing Season

Size of green foxtail panicles did not follow any distinct pattern in either year. Size of green foxtail panicles ranged from 4.2 cm in SD to 5.9 cm in MP in 1996, and 3.6 cm in SD to 5.7 cm in NT in 1997 (Table 4). In 1996, green foxtail panicles were similar in size when grown in corn and soybean, but were larger when grown in soybean in 1997. Similarly, the size of green foxtail panicles was similar among cohorts in 1996 but was greatest with Cohorts 1 and 2 in 1997.

Yellow foxtail panicles were generally larger in SD and NT in 1996, and in MP in 1997, whereas they were consistently smaller in RT both years when compared with the other tillage systems (Table 4). Long-term RT is known to limit crop growth through decreased potassium availability (Rehm et al. 1994), and the same may happen with yellow foxtail. In 1996, yellow foxtail panicle size was larger in corn than in soybean, whereas in 1997, panicles were larger in soybean than in corn. Among cohorts, yellow foxtail panicle size was greatest with Cohorts 1 and 2 in 1996, and with

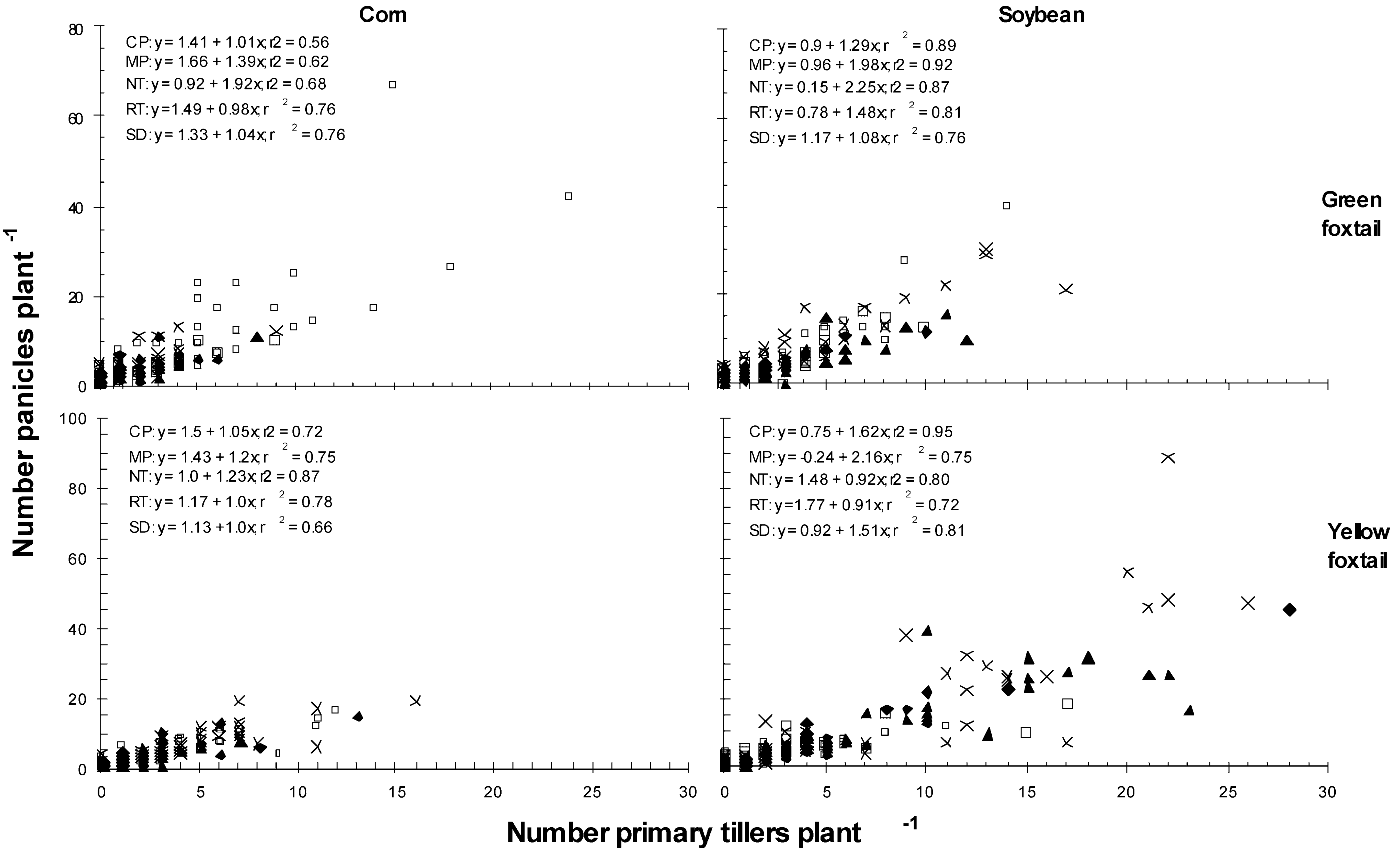

FIGURE 2. Relationship between the number of primary tillers per plant and the number of panicles per plant for green foxtail and yellow foxtail, as influenced by tillage system [CP, chisel plow (◆); MP, moldboard plow (×); NT, no till (□); RT, ridge till (◇); and SD, spring disk (▲)] and crop (corn and soybean). Equations represent best-fit linear regressions for each foxtail species within tillage systems and crops, and r^2 values indicate goodness of fit.

Cohort 1 in 1997. There were no differences in panicle size among yellow foxtail cohorts that grew in the absence of a competing crop (data not shown).

Understanding the dynamics of foxtail panicle size has important implications for estimation of seed production. For example, Forcella et al. (2000) found that the relationship between panicle size and seed production by green foxtail and yellow foxtail can be consistent across crops (corn and soybean) and herbicide treatments, although plants that survived herbicide treatments produced smaller panicles than untreated plants. Similar positive correlations between inflorescence size and seed production have been reported for barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] (Norris 1992).

TABLE 3. Significance of *t* values from paired *t* tests that compared the regression coefficients of the tillage systems. Regression equations that describe the relationship between the number of panicles per plant and the number of seeds per plant in green foxtail and yellow foxtail are presented in Figure 2.

Tillage system comparison[a]	Green foxtail		Yellow foxtail	
	Corn	Soybean	Corn	Soybean
MP vs. CP	NS[b]	*[c]	NS	*
MP vs. RT	NS	*	NS	*
MP vs. RT	NS	*	NS	*
MP vs. NT	NS	NS	NS	*
CP vs. RT	NS	NS	NS	*
CP vs. SD	NS	NS	NS	NS
CP vs. NT	*	*	NS	*
RT vs. SD	NS	NS	NS	*
RT vs. NT	*	*	NS	NS
SD vs. NT	*	*	NS	*

[a] Tillage systems: CP, chisel plow; MP, moldboard plow; NT, no till; RT, ridge till; SD, spring disk.

[b] NS, not significant at P ≤ 0.05.

[c] *, significant at P ≤ 0.05.

Seed Production

In corn, green foxtail seed production per plant did not vary greatly among cohorts or among MP, CP, RT, and SD tillage systems in 1996 ($\bar{x}$ = 1,611) or 1997 ($\bar{x}$ = 375) (Figure 3). Green foxtail plants in NT corn, however, produced more seeds per plant in 1996 (2,734) and 1997 (6,973) compared with the other tillage systems, with little difference among cohorts. In contrast, green foxtail seed production per plant in soybean was highly variable among cohorts and tillage systems in 1997 (3,400 ± 991) (Figure 4). In 1996, green foxtail seed production per plant in soybean was lowest in NT (444) compared with the other tillage systems ($\bar{x}$ = 2,775). Why green foxtail was more prolific in NT corn compared with other tillage systems is not clear. Several researchers have reported that reductions in tillage favor green foxtail (Anderson et al. 1998; Buhler and Mester 1991; Spandl et al. 1998), whereas others have found the opposite effect (O'Donovan and McAndrew 2000; Ominski and Entz 2001). Possibly, the frequently observed de-

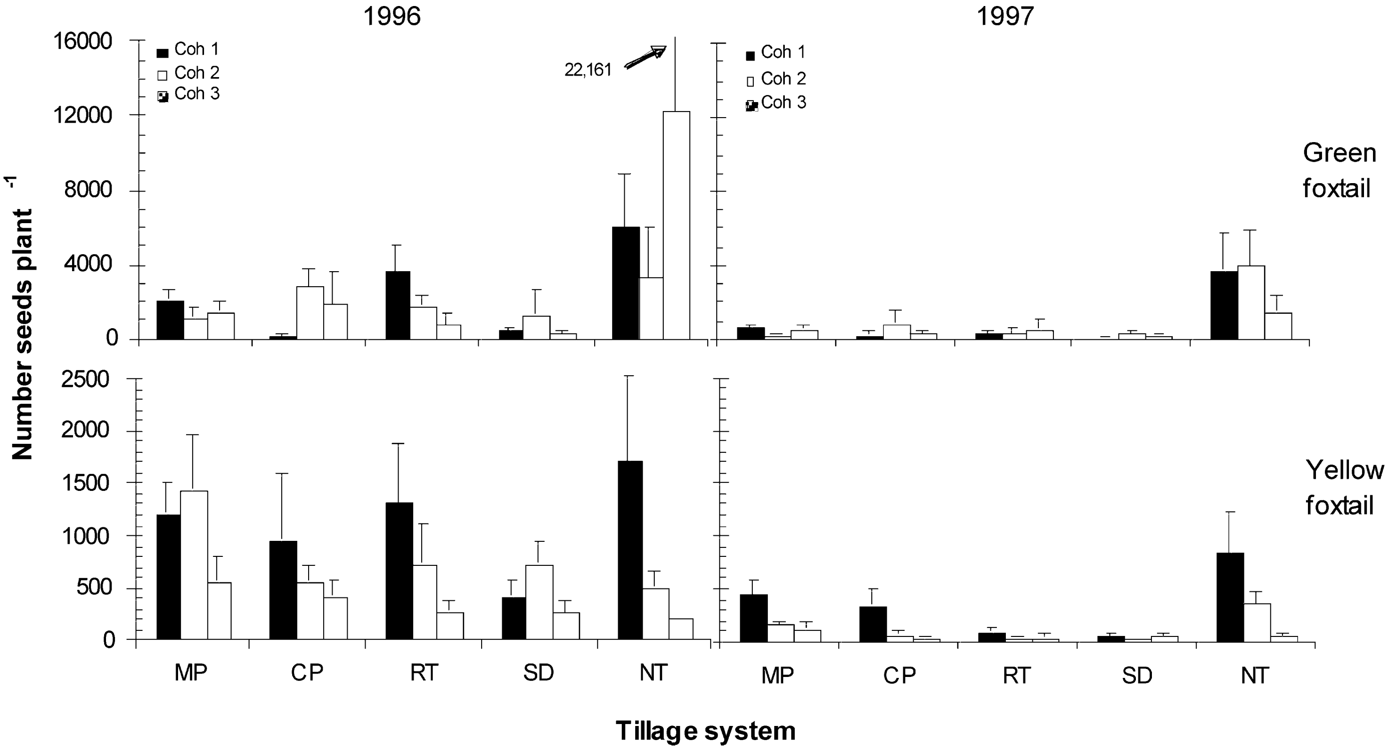

Figure 3. Effect of tillage system (MP, moldboard plow; FC, fall chisel; RT, ridge till; SD, spring disk; ZT, zero till) on number of seeds produced by individual green foxtail and yellow foxtail cohort plants in corn in 1996 and 1997. Error bars represent the standard error of the mean.

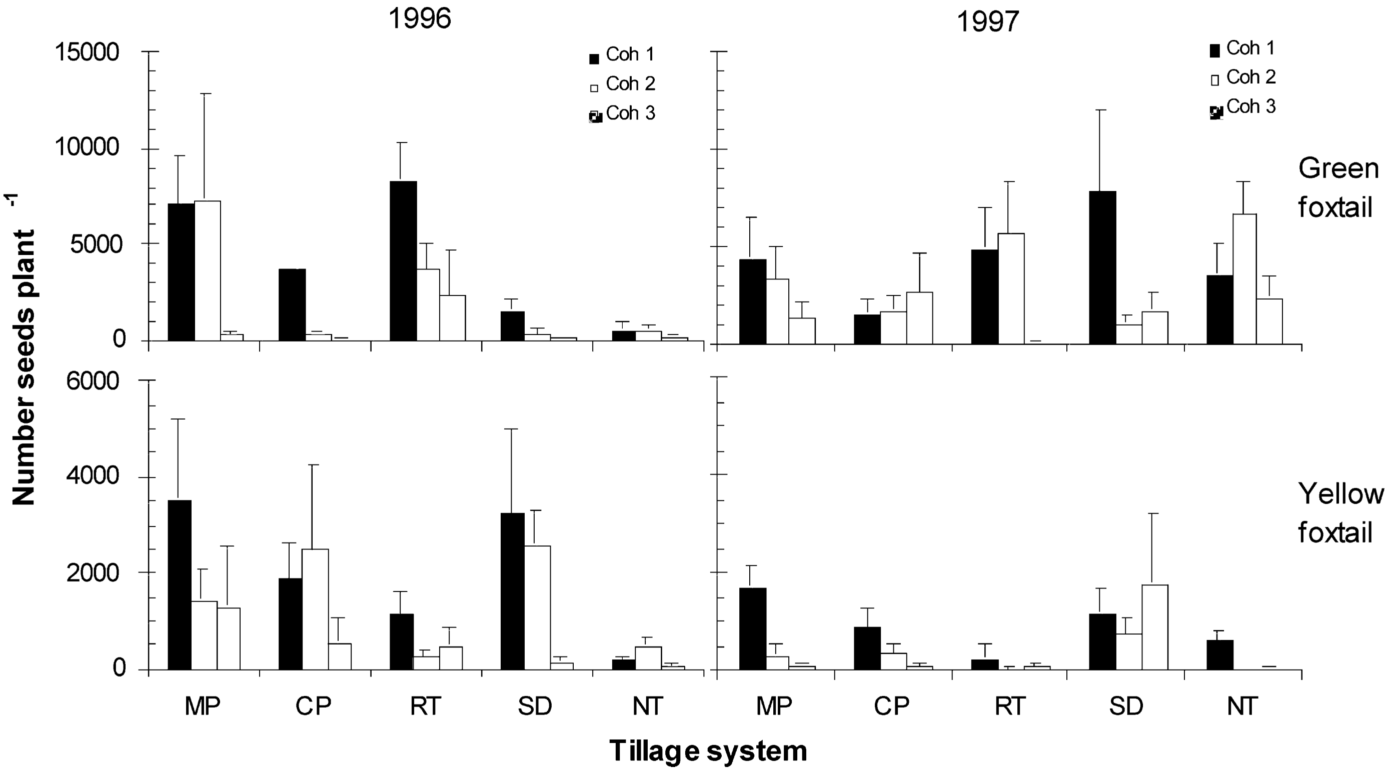

Figure 4. Effect of tillage system (MP, moldboard plow; FC, fall chisel; RT, ridge till; SD, spring disk; ZT, zero till) on number of seeds produced by individual green foxtail and yellow foxtail cohort plants in soybean in 1996 and 1997. Error bars represent the standard error of the mean.

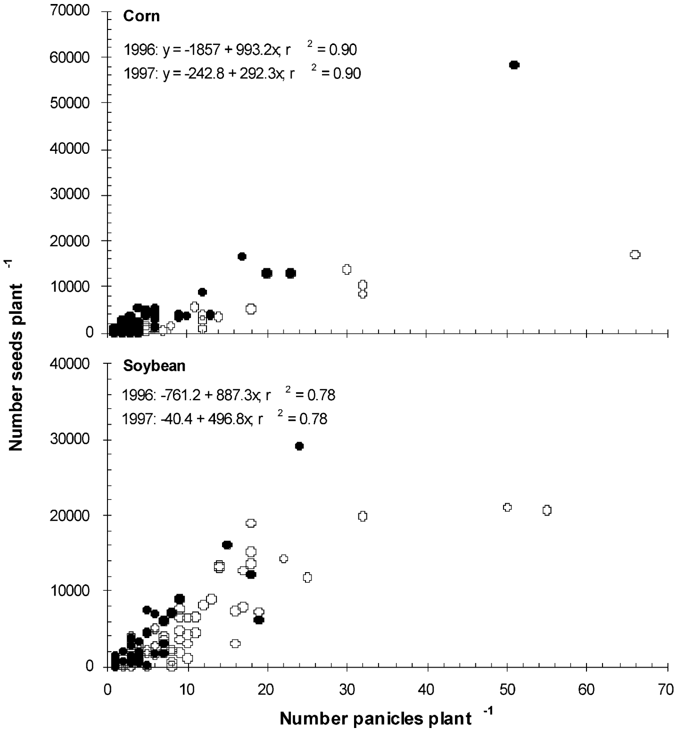

Figure 5. Relationship between number of panicles per plant and number of seeds per plant for green foxtail in corn and soybean in 1996 (●) and 1997 (○). Equations represent best-fit linear regressions across tillage systems and crops, and r^2 values indicate goodness of fit.

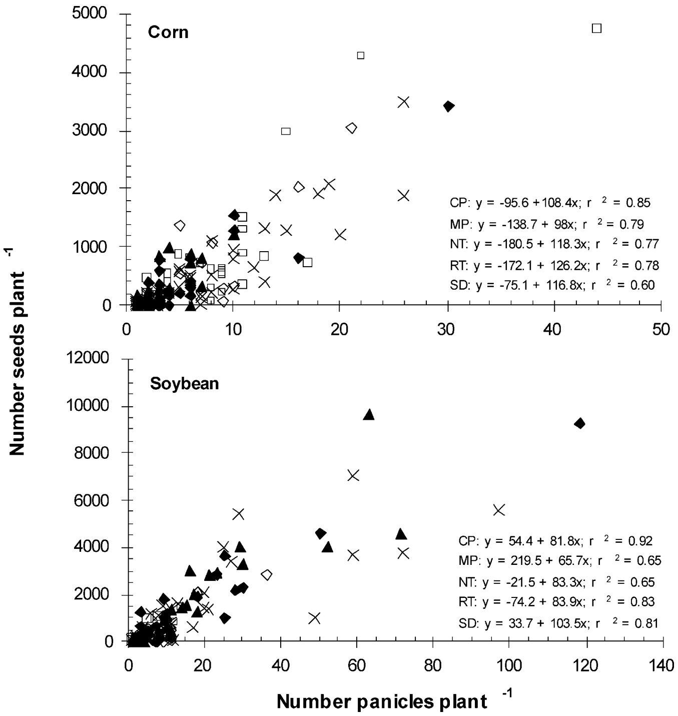

Figure 6. Relationship between the number of panicles per plant and the number of seeds per plant for yellow foxtail in corn and soybean as influenced by tillage system [CP, chisel plow (◆); MP, moldboard plow (×); NT, no till (□); RT, ridge till (◇); and SD, spring disk (▲)]. Equations represent best-fit linear regressions for each foxtail species across tillage systems and crops, and r^2 values indicate goodness of fit.

crease of crop growth in clay-rich soils under NT management may have promoted growth and fecundity of green foxtail.

Yellow foxtail seed production per plant in 1996 averaged 792 in corn and 1,331 in soybean, and 1,545, 1,170, and 434 for Cohorts 1, 2, and 3, respectively. In corn, yellow foxtail seed production per plant in 1997 followed a similar pattern as green foxtail seed production in corn but with only a slight increase in seed output in NT (Figure 3). Likewise, in 1997, yellow foxtail seed production per plant in soybean was highly variable among tillage systems.

A relationship between seed number per plant and the number of panicles per plant, which differed significantly across crops and years, was evident for green foxtail (Figure 5). The linear relationships indicated that in 1996, green foxtail produced 701 more seeds per panicle in corn (r^2 = 0.90) than in analogous green foxtail plants in 1997. Similarly, in soybean, each green foxtail panicle produced 391 more seeds in 1996 than in 1997 (r^2 = 0.78).

Yellow foxtail seed number per plant was related to number of panicles per plant, a relationship that was significant across crops and tillage systems (Figure 6). In corn, the linear relationship indicated that each additional yellow foxtail panicle produced 98 to 126 seeds (r^2 = 0.60 to 0.85); whereas in soybean, each additional panicle produced 66 to 104 seeds (r^2 = 0.65 to 0.92). Pairwise comparisons of tillage system regression coefficients, using the Student's *t* test, indicated that tillage systems were highly variable, with no consistent trend (data not shown).

Seed production estimates of weeds that escape control are important features for choosing alternative weed management approaches. For example, they are part of the overall decision-support system available in WeedSOFT (Anonymous 2003). However, obtaining reliable estimates of seed production requires that the variability in factors that control such production be understood.

The importance of weed seed production per plant was first outlined by Stevens (1932, 1957), where he reported that yellow foxtail could produce a maximum of 6,420 seeds per plant. Apparently, this yellow foxtail plant was of average size and grew where competition was low (Stevens 1957). Later, other researchers showed how plant density, location, and photoperiod influenced vegetative and reproductive output of foxtails (Santelmann et al. 1963). These authors reported a maximum of more than 8,000 seeds plant^{-1} was produced by yellow foxtail growing in noncompetitive conditions. Our study shows that without competition, maximum yellow foxtail seed production varied annually, from 8,000 seeds plant^{-1} in 1996 to 44,000 seeds plant^{-1} in 1997. Undoubtedly, the abundance of moisture in midseason 1997 (Table 1) had a positive impact on seed production. Whereas these studies were conducted on foxtails growing in the absence of competing crops, other studies have shown that the size of foxtail panicles is closely related to seed production at the population level and to crop environments (Forcella et al. 2000).

Several questions remain unanswered regarding the productivity of individual plants under competitive situations. Our research shows that the time of foxtail seedling emergence (cohort) can result in differences in tiller and panicle production early in the growing season that may not relate to differences in seed production per plant. For example, Cohort 1 foxtail plants produced more primary tillers and

TABLE 4. Influence of tillage system, crop, and cohort on average size of green foxtail and yellow foxtail panicles at the end of the growing season in 1996 and 1997, at Morris, MN.

	Green foxtail		Yellow foxtail	
Treatment	1996	1997	1996	1997
	mm			
Tillage system				
Moldboard plow	5.9	4.3	5.2	5.6
Chisel plow	5.5	4.4	5.2	4.1
Ridge till	5.4	4.8	5.1	3.7
Spring disk	4.2	3.6	5.7	4.6
No till	5.5	5.7	5.5	5.0
LSD (0.05)	0.4	0.3	0.3	0.2
Crop				
Corn	5.3	3.8	5.8	4.3
Soybean	5.4	5.4	4.9	5.0
LSD (0.05)	NS[a]	0.5	0.3	0.3
Cohort				
1	5.8	4.8	5.6	5.3
2	5.6	4.9	5.8	4.3
3	4.6	4.0	4.6	3.9
LSD (0.05)	NS	0.8	0.5	0.4

[a] Abbreviation: NS, not significant.

TABLE 5. Significance of *t* values from paired *t* tests that compared the regression coefficients of the tillage systems. Regression equations that describe the relationship between the number of panicles per plant and the number of seeds per plant in yellow foxtail are presented in Figure 6.

Tillage system comparisons[a]	Corn	Soybean
MP vs. CP	*[b]	*
MP vs. RT	*	*
MP vs. RT	*	*
MP vs. NT	*	*
CP vs. RT	*	NS[c]
CP vs. SD	*	*
CP vs. NT	*	NS
RT vs. SD	*	*
RT vs. NT	*	NS
SD vs. NT	NS	*

[a] Tillage systems: CP, chisel plow; MP, moldboard plow; NT, no till; RT, ridge till; SD, spring disk.

[b] *, significant at $P \leq 0.05$.

[c] NS, not significant at $P \leq 0.05$.

panicles per plant than later cohorts (Table 2), but that did not consistently result in more seeds per plant at seasons' end (Figures 3 and 4). Presumably, tillers and panicles "set the stage" for seed production, but other factors, such as weather, can influence production greatly.

Forcella et al. (2000) reported that foxtail seed production was higher in corn than soybean, primarily, because of higher foxtail plant and panicle density in corn. However, in the present study, where densities were held constant, foxtail panicle and seed production per plant were generally higher in soybean compared with corn, within all tillage systems (Figures 2 and 3). Mature foxtails grew above the soybean canopy, whereas in corn they did not, and shading by this latter crop almost certainly lowered foxtail seed production. Whatever the case, this variation in foxtail seed production needs to be studied further, so that fecundity of weeds growing within crop environments can be predicted with greater reliability.

Tillage system affected green foxtail and yellow foxtail vegetative and reproductive growth, and effects were inconsistent, especially with yellow foxtail. For example, yellow foxtail seed production in corn produced of 792 (± 109) seeds plant^{-1}, averaged among cohorts and tillage systems in 1996, whereas in 1997 yellow foxtail seed production among cohorts averaged 548 (± 186) seeds plant^{-1} in NT and 129 (± 35) seeds plant^{-1} among CP, MP, RT, and SD tillage systems (Figure 3). In 1996, yellow foxtail panicles were slightly larger than similar plants in 1997 (Table 4), but this fact does not give insight into the disparity in seed production. Kegode et al. (2003) reported that late sowing can reduce the size of foxtail panicles, but this was not consistent for yellow foxtail over a 2-yr period. Yellow foxtail plants that emerged late had longer panicles in 1996 (16%) than in 1997, when they were 28% shorter. The variability in yellow foxtail vegetative growth and fecundity in our study (Tables 2–5; Figures 3 and 4) illustrates that more reliable predictions of seeds production for this species will require further investigation of the variation due to tillage system.

Green foxtail, on the other hand, responded uniformly between 1996 and 1997 with a 10 to 34% reduction in panicle length when crop sowing was delayed (Kegode et al. 2003). In our study, the absence of significant interactions with tillage system, the consistently higher number of primary tillers and panicles per plant in NT and MP compared with other tillage systems (Table 2), and consistently higher seed production in NT corn compared with other tillage systems (Figure 3) show that relatively reliable estimates for seed production were obtained for this species. However, the variability in number of seeds per plant due to year and crop, particularly soybean (Figure 4), suggests that more work is needed to address the variability due to crop competition to make such estimates more accurate.

Sources of Materials

[1] SAS statistical software, Statistical Analysis Systems, SAS Institute, Inc. 100 SAS Campus Dr., Cary, NC 27513-2414.

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