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Residual Weeds of Processing Sweet Corn in the North Central Region

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Knowledge of weed community structure in vegetable crops of the north central region (NCR) is poor. To characterize weed species composition present at harvest (hereafter called residual weeds) in processing sweet corn, 175 fields were surveyed in Illinois, Minnesota, and Wisconsin from 2005 to 2007. Weed density was enumerated by species in thirty 1-m^2 quadrats placed randomly along a 300- to 500-m loop through the field, and additional species observed outside quadrats were also recorded. Based on weed community composition, population density, and mean plant size, overall weed interference level was rated. A total of 56 residual weed species were observed and no single species dominated the community of NCR processing sweet corn. Several of the most abundant species, such as common lambsquarters and velvetleaf, have been problems for many years, while other species, like wild-proso millet, have become problematic in only the last 20 yr. Compared to a survey of weeds in sweet corn more than 40 yr ago, greater use of herbicides is associated with reductions in weed density by approximately an order of magnitude; however, 57% of fields appeared to suffer yield loss due to weeds. Sweet corn harvest in the NCR ranges from July into early October. Earlier harvests were characterized by some of the highest weed densities, while late-emerging weeds such as eastern black nightshade occurred in fields harvested after August. Fall panicum, giant foxtail, wild-proso millet, common lambsquarters, and velvetleaf were the most abundant species across the NCR, yet each state had some unique dominant weeds.

Nomenclature: Common lambsquarters, *Chenopodium album* L. CHEAL; eastern black nightshade, *Solanum ptychantum* Dunal. SOLPT; fall panicum, *Panicum dichotomiflorum* Michx. PANDI; giant foxtail, *Setaria faberi* Herrm. SETFA; velvetleaf, *Abutilon theophrasti* Medic. ABUTH; wild-proso millet, *Panicum miliaceum* L. PANMI; sweet corn, *Zea mays* L.

Key words: Density, frequency, interference, occurrence, relative abundance, vegetable, weed communities, uniformity, weed survey.

A fundamental component of management and research of weed species is knowledge of weed community structure. Plant species composition and abundance at a single point in time reflect outcomes from a suite of dynamic forces including soil and climate characteristics, management practices, and species interactions (Harper 1977). Knowledge of weed community structure is critical to planning effective weed management systems (Dewey and Anderson 2004) and directing future research (Thomas and Dale 1991; Van Acker et al. 2000; Webster and Coble 1997). Because of the influence of weed management on individual species fitness, weed surveys have been used to compare management practices (Frick and Thomas 1992; Van Acker et al. 2000) and assess changes in weed community structure over time (Frick and Thomas 1992; Webster and Coble 1997).

Surveys have provided knowledge of weeds in agronomic cropping systems of the NCR. Recent mail surveys in Indiana found that farmers perceived giant ragweed (*Ambrosia trifida* L.), Canada thistle [*Cirsium arvense* (L.) Scop.], common lambsquarters, common cocklebur (*Xanthium strumarium* L.), and velvetleaf, to be the most important weed species in field corn (*Zea mays* L.) and soybean (*Glycine max* L.) (Gibson et al. 2005, 2006). Creech and Johnson (2006) found that winter annual weed hosts of soybean cyst nematode (*Heterodera glycines* Ichinohe) occurred in 93% of field corn and soybean fields. Frick and Thomas (1992) reported the six most abundant weeds in field crops of southwestern Ontario had been problematic for over 60 yr. Survey of weeds in vegetable cropping systems of the NCR are rare; however, Alex (1964) reported dominant weeds of sweet corn and tomato (*Solanum lycopersicum* L.) in Ontario at a time when few fields were treated with herbicides, and most were interrow cultivated several times. Hillger et al. (2006) identified relationships among tomato management systems and weed species in Indiana. A more recent characterization of weed community structure of NCR vegetable cropping systems that includes sweet corn is lacking.

Sweet corn, one of the most popular vegetable crops in North America, is grown for processing and fresh markets. The majority of sweet corn acreage in the United States is grown for processing, and Illinois, Minnesota, and Wisconsin account for 98% of processing acreage within the North-central United States (Anonymous 2006). Sweet corn is differentiated from field corn by genes that determine kernel characteristics and traits relevant to weed management, such as emergence rate (Azanza et al. 1996; Hassell et al. 2003), canopy growth (Treat and Tracy 1994; Williams et al. 2008a), and tolerance to some herbicides (O'Sullivan et al. 2002; Robinson et al. 1994). Processing sweet corn is planted and harvested over a wide range of dates to extend market availability, and few herbicide-resistant hybrids are available.

Individual weed plants observed late in the season, hereafter called residual weeds, either survived management tactics or emerged after tactics were applied. Weed emergence patterns vary among species and influence species composition and density. For instance, April-planted fields would likely have

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residual weed communities different from June-planted fields. Sweet corn is a shorter season crop; thus, residual weeds have limited time for growth, and their fecundity status at the time of crop harvest is unknown. Furthermore, dominant residual weed species may vary within the NCR, given the influence of soil, climate, and crop rotation on weed community structure (Thomas and Dale 1991; Van Acker et al. 2000). Information on residual weed communities of sweet corn would identify specific limitations to current weed management systems and help establish priorities for future research.

The goal of this research was to provide a contemporary assessment of residual weed communities in sweet corn and identify the most serious shortfalls in existing weed management systems. The specific objective was to characterize weed composition of species persisting in sweet corn grown for processing based on (1) the NCR as a whole, and (2) general subdivisions within the region, namely time of harvest and geographic location.

Materials and Methods

One hundred seventy-five individual fields, grown under contract for processed sweet corn, were surveyed across major processing sweet corn production areas within Illinois, Minnesota, and Wisconsin from 2005 to 2007 (Figure 1). In order to locate sweet corn fields over a range of harvest times (July through early October), collaborators in the vegetable processing industry provided weekly lists of fields scheduled for harvest from which a random sample was drawn. Fields in Illinois were surveyed in 2005 and 2006, fields in Minnesota were surveyed in 2006 and 2007, and fields in Wisconsin were surveyed in 2006. Number of fields sampled per state/year ranged from 29 to 52.

Survey Protocol. Fields were surveyed following the methodology of Thomas (1985) with some modification. Fields were generally surveyed 5 or fewer days before harvest; however, 2% of fields were harvested immediately before surveys were conducted. Weed species and density were enumerated within thirty 1-m^2 quadrats, the functional minimum area required to represent a majority of weed species richness in tilled fields (Mulugeta et al. 2001). Quadrats were placed randomly along a 300- to 500-m loop through the field, accounting for field shape and avoiding 20 m near the field margin, with greater distance between quadrats as field size increased. Species that were not observed in quadrats but were observed elsewhere in the field were also recorded. Differentiation of species of the Amaranthacea family involved considerable uncertainty; therefore, species were grouped into a single class. Using the criteria of filled and hard seed, species that produced any mature seed by the time of sweet corn harvest were recorded. Based on weed community structure, plant size distribution, expert opinion, and perceived loss of ear mass, each field was scored for overall weed interference level. One of four outcomes were used, including 1 = no interference and yield loss unlikely; 2 = possible interference and possible yield loss of ≤ 5%; 3 = interference and potential yield loss > 5 and ≤ 20%; and 4 = severe interference and potential yield loss > 20%. Fields harvested prior to the survey were not scored for weed interference level.

State	Counties
Illinois	Bureau, Dekalb, LaSalle, Lee, Mason, Ogle, Tazwell, Whiteside
Minnesota	Blue Earth, Brown, Dakota, Nicollet, Sibley, Watonwan
Wisconsin	Adams, Portage, Rock, Walworth, Waushara

Figure 1. Counties surveyed (shaded) for weeds in processing sweet corn near the time of harvest in Illinois, Minnesota, and Wisconsin in 2005 to 2007.

Data Analysis. Individual species data were summarized for the NCR using several quantitative measures (McCully et al. 1991; Thomas 1985). Unadjusted frequency was the percentage of all fields infested by a species based on within-quadrat observations. Adjusted frequency was the percentage of fields infested by a species either within a quadrat or elsewhere within the field. Uniformity, expressed as a percentage, in all fields was obtained by dividing the number of quadrats in which the species was observed by the total number of quadrats. Uniformity in occurrence fields was similar with the exception that the divisor only included quadrats from those fields in which the species was observed. Density of all fields was the number of plants/m^2 of each species averaged over all fields. Density of occurrence fields

Table 1. Residual weeds observed near harvest of 175 processing sweet corn fields surveyed in Illinois, Minnesota, and Wisconsin in 2005 to 2007.

						Frequency^{b}		Uniformity^{c}		Density^{d}			
Rank	Common name	Latin Name	Code	Life cycle^{a}	State	unadjusted	adjusted	all fields	occurrence fields	all fields	occurrence fields	Fecundity status^{e}	Relative abundance^{f}
						%	%	%	%	no./m^{2}	no./m^{2}	%	
1	fall panicum	*Panicum dichotomiflorum* Michx.	PANDI	A	IL,MN,WI	27	33	6.7	29	1.53	10.19	35	45
2	giant foxtail	*Setaria faberi* Herrm.	SETFA	A	IL,MN,WI	46	47	11	25	0.54	1.13	60	37
3	wild-proso millet	*Panicum miliaceum* L.	PANMI	A	IL,MN,WI	35	48	10	26	0.88	2.04	56	37
4	common lambsquarters	*Chenopodium album* L.	CHEAL	A	IL,MN,WI	45	53	10	23	0.46	0.94	37	33
5	velvetleaf	*Abutilon theophrasti* Medik.	ABUTH	A	IL,MN,WI	47	50	12	24	0.27	0.53	48	23
6	pigweed species	*Amaranthus spp.*	AMSSP^{g}	A	IL,MN,WI	33	42	5.7	22	0.13	0.46	35	16
7	eastern black nightshade	*Solanum ptychanthum* Dunal	SOLPT	A	IL,WI	15	21	4	23	0.55	2.94	18	12
8	shepherd's-purse	*Capsella bursa-pastoris* (L.) Medik.	CAPBP	A	WI	6.9	7.6	3.6	52	0.46	6.74	9.1	11
9	green foxtail	*Setaria viridis* (L.) Beauv.	SETVI	A	IL	25	26	4.8	19	0.28	1.11	51	11
10	Canada thistle	*Cirsium arvense* (L.) Scop.	CIRAR	P	IL,MN,WI	15	27	2.4	14	0.06	0.4	10	10
11	giant ragweed	*Ambrosia trifida* L.	AMBTR	A	IL,MN,WI	8.9	14	2.2	20	0.05	0.49	19	7.7
12	large crabgrass	*Digitaria sanguinalis* (L.) Scop.	DIGSA	A	IL,WI	11	13	2.5	18	0.23	1.31	33	6.2
13	common purslane	*Portulaca oleracea* L.	POROL	A	IL,MN,WI	12	12	1.5	14	0.19	1.8	15	5.8
14	ivyleaf morningglory	*Ipomoea hederacea* Jacq.	IPOHE	A	IL	12	13	3.6	28	0.08	0.65	45	5.5
15	dandelion	*Taraxacum officinale* G.H. Weber ex Wiggers	TAROF	P	IL,WI	18	15	2.2	12	0.05	0.24	0	5.3
16	wheat	*Triticum aestivum* L.	TRIAE	A	IL	3.5	4.1	2.1	61	0.16	4.56	0	4
17	yellow foxtail	*Setaria pumila* (Poir.) Roemer & J.A. Schultes	SETLU	A	IL,MN,WI	8.8	17	1.2	17	0.07	0.5	8.9	3.4
18	prickly sida	*Sida spinosa* L.	SIDSP	A	IL	8	18	1.2	15	0.04	0.48	36	2.6
19	woolly cupgrass	*Eriochloa villosa* (Thunb.) Kunth	ERBVI	A	IL,MN,WI	7.3	9.2	0.8	9.7	0.04	0.49	54	2.6
20	horsenettle	*Solanum carolinense* L.	SOLCA	P	IL	7	15	0.7	9.9	0.02	0.28	33	1.8
21	common ragweed	*Ambrosia artemisiifolia* L.	AMBEL	A	IL,MN,WI	3.5	6	0.6	16	0.01	0.32	31	1.4
22	carpetweed	*Mollugo verticillata* L.	MOLVE	A	IL	3.8	2.7	0.6	16	0.02	0.51	0	1.4
23	barnyardgrass	*Echinochloa crus-galli* (L.) Beauv.	ECHCG	A	IL,MN,WI	5.2	9.8	0.4	8	0.02	0.27	56	1.3
24	venice mallow	*Hibiscus trionum* L.	HIBTR	A	IL	5.1	5.7	0.4	6	0.01	0.1	17	1.2
25	tall morningglory	*Ipomoea purpurea* (L.) Roth	PHBPU	A	IL	5.1	5.3	0.3	6.1	<0.01	0.08	45	1
26	common cocklebur	*Xanthium strumarium* L.	XANST	A	IL,MN,WI	5	17	0.2	4.1	<0.01	0.05	9.3	0.9
27	common milkweed	*Asclepias syriaca* L.	ASCSY	P	IL,MN,WI	3	7.3	0.1	4.8	<0.01	0.11	15	0.9
28	yellow nutsedge	*Cyperus esculentus* L.	CYPES	P	IL	3.1	3.5	0.3	9.7	0.02	0.55	0	0.9
29	prickly lettuce	*Lactuca serriola* L.	LACSE	A	IL,WI	2.7	6.1	0.4	18	0.01	0.44	17	0.8
30	longleaf groundcherry	*Physalis longifolia* Nutt. var. *longifolia*	PHYLF	P	IL	4.1	8.6	0.2	4.3	<0.01	0.1	4.2	0.8
31	hemp dogbane	*Apocynum cannabinum* L.	APCCA	P	IL	3.1	4.5	0.3	7.1	0.01	0.19	0	0.8
32	soybean	*Glycine max* (L.) Merr.	GLMA4	A	IL,WI	2.7	4.1	0.3	11	<0.01	0.11	0	0.7
33	white campion	*Silene latifolia* Poir.	MELAL	P	WI	2.1	2.1	0.3	13	<0.01	0.18	0	0.7
34	ladysthumb	*Polygonum persicaria* L.	POLPE	A	WI	2.1	2.8	0.2	11	0.01	0.31	25	0.7
35	crownvetch	*Coronilla varia* L.	CZRVA	P	IL	1.9	2.3	0.2	11	0.01	0.37	0	0.6
36	spotted spurge	*Chamaesyce maculata* (L.) Small	EPHMA	A	IL	1.2	1.2	0.3	28	0.01	0.66	0	0.6
37	horseweed	*Conyza canadensis* (L.) Cronq.	ERICA	A	IL,MN,WI	1.1	4.2	0.1	10	<0.01	0.1	50	0.5
38	honeyvine milkweed	*Ampelamus albidus* (Nutt.) Britt.	AMPAL	P	IL	1.9	4.3	0.2	8	<0.01	0.21	25	0.5
39	field bindweed	*Convolvulus arvensis* L.	CONAR	P	IL	2.3	3.5	0.1	5	<0.01	0.1	22	0.5
40	cabbage	*Brassica oleracea* L.	BRAOL	A	IL	1.2	1.8	0.3	23	<0.01	0.42	0	0.4
41	common pokeweed	*Phytolacca americana* L.	PHTAM	P	IL	1.5	2.3	0.2	10	<0.01	0.16	0	0.4
42	hairy nightshade	*Solanum physalifolium* Rusby	SOLSA	A	WI	1.4	1.4	0.1	6.7	<0.01	0.2	0	0.4
43	Pennsylvania smartweed	*Polygonum pensylvanicum* L.	POLPY	A	IL,WI	1.3	3.6	0.1	6.7	<0.01	0.37	33	0.4
44	quackgrass	*Elymus repens* (L.) Gould	AGRRE	P	IL,MN,WI	1.3	1.9	0.1	6.7	<0.01	0.22	33	0.3
45	common chickweed	*Stellaria media* (L.) Vill.	STEME	A	IL,WI	0.7	3	0.1	13	<0.01	0.53	0	0.3
46	field corn	*Zea mays* L.	ZEAMX	A	IL	0.6	1.4	0.1	23	<0.01	0.73	50	0.2
47	shattercane	*Sorghum bicolor* (L.) Moench ssp. *arundinaceum* (Desv.) de Wet & Harlan	SOBIA	A	IL,WI	1.2	4.9	0.1	4.4	<0.01	0.09	64	0.2

Table 1. Continued.

Rank	Common name	Latin Name	Code	Life cycle[a]	State	Frequency[b] unadjusted	Frequency[b] adjusted	Uniformity[c] all fields	Uniformity[c] occurrence fields	Density[d] all fields	Density[d] occurrence fields	Fecundity status[e]	Relative abundance[f]
48	swamp smartweed	*Polygonum amphibium* L. var. *emersum* Michx.	POLCC	P	IL	0.7	0.6	0	6.7	<0.01	0.07	0	0.2
49	hedge bindweed	*Calystegia sepium* (L.) R. Br.	CAGSE	P	IL	0.8	1.4	0.1	6.7	<0.01	0.13	0	0.2
50	pitted morningglory	*Ipomoea lacunosa* L.	IPOLA	A	IL	0.8	0.8	0.1	6.7	<0.01	0.13	0	0.2
51	curly dock	*Rumex crispus* L.	RUMCR	P	IL, WI	0.8	6.5	0	3.3	<0.01	0.07	0	0.1
52	toothed spurge	*Euphorbia dentata* Michx.	EPHDE	A	IL	0.6	1.8	0	6.7	<0.01	0.07	67	0.1
53	snap bean	*Phaseolus vulgaris* L.	PHAVU	A	IL	0.6	0.6	0	3.3	<0.01	0.03	0	0.1
54	downy brome	*Bromus tectorum* L.	BROTE	A	IL	0.4	0.4	0	10	<0.01	0.27	0	0.1
55	longspine sandbur	*Cenchrus longispinus* (Hack.) Fern.	CCHPA	A	IL	0.4	0.4	0	3.3	<0.01	0.03	0	0.1
56	common burdock	*Arctium minus* Bernh.	ARFMI	B	IL	0	0.6	0	0	<0.01	<0.01	0	<0.1

[a] Abbreviations: A = annual, B = biennial, P = perennial.

[b] Frequency was the percentage of fields with a species present based on within-quadrat observations (unadjusted) or regardless of quadrats (adjusted).

[c] Uniformity was determined by dividing the number of quadrats in which the species was observed by the total number of quadrats of all surveyed fields (all fields) or total number of quadrats of fields where the species was observed (occurrence fields), both expressed as a percentage.

[d] Density was the number of plants per square meter in all fields, or fields where the species was observed (occurrence fields).

[e] Fecundity status was determined by dividing the number of fields where viable seed of each species was observed by the number of fields with the species, expressed as a percentage.

[f] Relative abundance ranks the contribution of individual species in the overall weed community based on equal importance of unadjusted frequency, uniformity in all fields, and density in all fields. The total value for relative abundance of all species is 300.

[g] AMSSP designates the *Amaranthus* complex.

was similar with the exception that means were only calculated from fields in which the species was observed. The values for unadjusted frequency, uniformity in all fields, and density in all fields were combined into a single index called relative abundance (Thomas 1985). Relative abundance was used to rank the contribution of individual species in the community, and frequency, uniformity, and density were assumed to have equal importance in estimating abundance of a species. Relative abundance has no units; however, the total value for the relative abundance of all species is 300. Also, fecundity status of each species was determined by dividing the number of fields where viable seed of the species was observed by the number of fields with the species, expressed as a percentage.

In order to characterize residual weed communities of sweet corn in greater detail, field data were sorted by general subdivisions that potentially influenced weed composition; namely, time of harvest and geographical location. Time of harvest was defined as the month in which survey fields were harvested and included July, August, and September. Since only four fields were harvested in October, and all were harvested within the first week, data from these fields were pooled with data from fields harvested in September. Geographic location was defined as the state in which fields resided. Based on relative abundance described above, the three most abundant weed species of each month or state were determined. In addition, diagnostic tests of residuals indicated total weed density, percentage of weed-free quadrats, and weed interference ratings complied with ANOVA assumptions of homoscedasticity and normality; therefore, data were not transformed. ANOVA for a completely randomized design was conducted on the aforementioned variables for both harvest criteria. Means of each month or state were compared using protected, Bonferroni multiple comparisons (Neter et al. 1996).

To characterize individual weed species observed at harvest times and geographic locations, scatter plots were constructed using all field uniformity and occurrence density values for each species (Van Acker et al. 2000). For purposes of discussion, each scatter plot was divided into four quadrants by a vertical grid line at an occurrence density of 0.5 plants/m^2 and a horizontal grid line at 5% all field uniformity. Species in the upper right quadrant were relatively abundant and uniform, and were considered the dominant residual weed species. Species in the upper left quadrant were relatively uniform at low population densities, and were considered the subdominant residual weeds. Species in the lower right quadrant were relatively abundant in only some fields, and were considered locally abundant. Species in the lower left quadrant occurred infrequently at low densities, and were not considered problematic weeds at the time of sampling. The goal of a survey is to sample a representative portion of a greater weed community (Dewey and Anderson 2004); further subdivisions of these data would have weakened our ability to meet our objective of characterizing residual weed communities of the NCR.

Results and Discussion

North Central Region Composite. A total of 56 residual weed species were observed, and 28 species had an adjusted frequency greater than 5% in surveyed fields (Table 1). Thirty-nine annual species, 16 perennial species, and 1 biennial species were observed. Five species were volunteer crops, including wheat (*Triticum aestivum* L.), soybean, cabbage (*Brassica oleracea* L.), field corn, and snap bean (*Phaseolus vulgaris* L.). Most volunteer crops were infrequently observed (e.g., relative abundance ≤ 0.7 of 300) except volunteer wheat. Volunteer wheat was the most uniform species in occurrence fields (61%); however, plants were seedlings from a preceding wheat crop and appeared to pose no threat to sweet corn growth or yield.

No single species dominated the residual weed community in processing sweet corn of the NCR. Fall panicum, the top-ranked weed based on a relative abundance of 45, was followed closely by giant foxtail, wild-proso millet, common lambsquarters, and velvetleaf with relative abundance of 37, 37, 33, and 23, respectively (Table 1). These five species, present in all three states, were among the most frequently observed and uniformly distributed within all fields. Fall panicum ranked first because population density was the highest, as evidenced by an all-field density of 1.53 plants/m^2.

While some of these top five species have been agricultural weeds for many years, others are relative newcomers in the NCR. The first reports in southwestern Ontario of lambsquarters, velvetleaf, fall panicum, and giant foxtail as "common problem weeds" were in 1928, 1964, 1979, and 1992, respectively (Frick and Thomas 1992). Though not observed in 1988 through 1989 surveys by Frick and Thomas (1992), wild-proso millet began spreading within the NCR during the 1980s (Khan et al. 1996). In contrast, wild buckwheat (*Polygonum convolvulus* L.) was among the most problematic weeds of tomato and sweet corn in Ontario in the early 1960s (Alex 1964), yet was not observed in our surveys and was rarely observed in Ontario vegetable production in recent years (D. Robinson, personal communication).

Changes in weed management in sweet corn over the years could significantly influence residual weed communities. In the early 1960s, Alex (1964) reported one-half of sweet corn fields were treated with either a preemergence banded application of simazine or atrazine, or a postemergence application of 2,4-D or atrazine. All fields received one or more interrow cultivations. Today a greater number of preemergence and postemergence herbicides are available for use in processing sweet corn, although atrazine continues to be the most widely used herbicide and less than one-half of surveyed fields are interrow cultivated (M. Williams, unpublished data). As a result, the frequency and density of individual weed species has been reduced over the last 4 decades. Among the five most abundant weeds in the 1960s (Alex 1964) and today (Table 1), average adjusted frequency has declined from 72 to 46% and average all-field density has declined from approximately 4 to 0.7 plants/m^2.

Despite historical gains in weed control efficacy, residual weeds continue to compromise processing sweet corn yield. Fifty-seven percent of fields were scored to have some level of interference that could result in yield loss, with 25% of fields scored for greater than 5% yield loss (data not shown). These values are reasonable considering observed densities and recent publications on sweet corn losses due to weeds. Using functional relationships of weed density and yield loss (Williams and Masiunas 2006; Williams et al. 2008a), average predicted sweet corn yield loss from occurrence densities of wild-proso millet (2.04 plants/m^2) and giant ragweed (0.49 plants/m^2) was 5 and 37%, respectively. Further research might identify relationships between weed management tactics applied, residual weed communities, and the level of interference within these fields.

Species with high relative abundance and fecundity status would presumably continue to persist in processing sweet corn production fields because they produce at least some viable seed in this relatively short-season crop. Based on the percentage of occurrence fields with viable seed, the most fecund species were giant foxtail (60%), barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] (56%), wild-proso millet (56%), woolly cupgrass [*Eriochloa villosa* (Thunb.) Kunth] (54%), and green foxtail [*Setaria viridis* (L.) Beauv.] (51%) (Table 1). Despite a low frequency in these surveys, the relatively high fecundity status of shattercane [*Sorghum bicolor* (L.) Moench] (64%) and toothed spurge (*Euphorbia dentata* Michx.) (67%) would be a beneficial trait for these species to become more predominant in fields with sweet corn. The most abundant species successfully produced viable seed in 35% or more of occurrence fields (Table 1).

Residual Weed Species by Month of Harvest. Composition of residual weed species varied by month of sweet corn harvest. Fields harvested in July were characterized by some of the highest total weed densities (11 plants/m^2) with fall panicum, wild-proso millet, and giant foxtail accounting for a combined 47% (141 of 300) of the cumulative relative abundance of all species (Table 2). Common purslane (*Portulaca oleracea* L.) was locally abundant, whereas common lambsquarters, ivyleaf morningglory (*Ipomoea hederacea* Jacq.), and velvetleaf were subdominant residual weeds (Figure 2a).

Fields harvested in August were characterized by a mean weed interference score of 2.1, which exceeded weed interference scores of fields harvested in September (Table 2). Similar to fields harvested in July, giant foxtail and wild-proso millet were dominant residual weeds of fields harvested in August; however, velvetleaf was the most abundant residual weed. Common lambsquarters, green foxtail, and pigweed species (primarily *Amaranthus retroflexus* L. and *Amaranthus rudis* Sauer) were the more uniformly distributed species at low densities (Figure 2b).

Eastern black nightshade was the most abundant species observed in fields harvested in September, followed by fall panicum and common lambsquarters (Table 2). Subdominant residual weeds included velvetleaf, giant foxtail, wild-proso millet, ivyleaf morningglory, pigweed species, wheat, and shepherd's-purse [*Capsella bursa-pastoris* (L.) Medik.] (Figure 2c).

Species of the genus *Panicum*, namely fall panicum or wild-proso millet, consistently dominated residual weed communities throughout the growing season. Both species have some natural tolerance to many of the herbicides used in sweet corn, including atrazine. Wild-proso millet seed dispersal by harvest machinery has long been a concern among sweet corn growers (Anonymous 2003), and this species has been the subject of

Table 2. Characteristics of weed communities observed in processing sweet corn, at harvest, in Illinois, Minnesota, and Wisconsin in 2005 to 2007.

Subdivision		No. fields	Total weed density	Weed-free quadrats	Mean weed interference[a]	Three most abundant species	Relative abundance[b]
			no./m^2	%			
By month	July	36	11.0 a[c]	40 a[c]	1.8 ab[c]	PANDI	60
						PANMI	48
						SETFA	33
	August	86	4.6 b	40 a	2.1 a	ABUTH	39
						PANMI	36
						SETFA	33
	September	53	6.4 ab	33 a	1.5 b	SOLPT	45
						PANDI	39
						CHEAL	24
By state	Illinois	86	7.7 a	29 b	2.2 a	ABUTH	33
						SETVI	27
						SETFA	27
	Minnesota	60	4.4 a	57 a	1.6 b	PANDI	84
						SETFA	54
						CHEAL	48
	Wisconsin	29	7.1 a	28 b	1.2 b	PANMI	60
						CAPBP	57
						CHEAL	39

[a] Based on a scale where 1 = no interference and yield loss unlikely; 2 = possible interference and possible yield loss of $\leq 5\%$; 3 = interference and potential yield loss > 5 and $\leq 20\%$; and 4 = severe interference and potential yield loss $> 20\%$. By month, number of fields was 36, 83, and 52 in July, August, and September, respectively. By state, number of fields was 85, 60, and 26 in Illinois, Minnesota, and Wisconsin, respectively.

[b] Relative abundance ranks the contribution of individual species in the overall weed community based on equal importance of unadjusted frequency, uniformity in all fields, and density in all fields. The total value for relative abundance of all species is 300.

[c] For each harvest subdivision, means followed by the same lower-case letter were not significantly different at $P < 0.05$ as determined by a protected Bonferroni multiple comparison test.

considerable weed control research (Harvey and McNevin 1990; Kleppe and Harvey 1991; Shenk et al. 1990; Williams and Harvey 2000).

Fields harvested later in the season were planted later, and several mechanisms may account for changes in weed community composition throughout the season. First, delayed planting has been associated with lower weed population density (Buhler and Gunsolus 1996; Gower et al. 2002), presumably the result of depleted seedbanks or induced dormancy, and may have contributed to observed differences. Total weed density declined in fields harvested from July to August, and weed density in September-harvested fields was similar to fields harvested in August (Table 2). Secondly, lower weed interference scores of September-harvested fields compared to August-harvested fields is consistent with previous research on planting date influences on crop growth and competitive ability. The greater ability of June-planted sweet corn to tolerate weed interference, relative to a May planting, corresponded to lower weed biomass and more robust crop growth (Williams 2006; Williams and Lindquist 2007). Thirdly, weed emergence patterns vary among species. Eastern black nightshade was not a dominant weed observed in fields harvested in July and August, but by September, it was the most abundant species. This observation is consistent with a delayed peak in eastern black nightshade emergence reported by Ogg and Dawson (1984).

Residual Weed Species by State. Despite a relatively high number of species observed in processing sweet corn in the NCR, only 17 weeds occurred in all three states surveyed and included fall panicum, giant foxtail, wild-proso millet, common lambsquarters, velvetleaf, pigweed species, Canada thistle, giant ragweed, common purslane, yellow foxtail [*Setaria glauca* (L.) Beauv.], woolly cupgrass, common ragweed (*Ambrosia artemisiifolia* L.), barnyardgrass, common cocklebur, common milkweed (*Asclepias syriaca* L.), horseweed [*Conyza canadensis* (L.) Cronq.], and quackgrass [*Elytrigia repens* (L.) Nevski] (Table 1). A greater number of species observed in Illinois may be in part a result of more fields being surveyed in the state. While some of the most abundant species were common to Illinois, Minnesota, and Wisconsin, the fact that several species were not observed in all states suggests that relatively unique weed management problems exist among production areas.

The most abundant residual weed species in Illinois were velvetleaf, green foxtail, and giant foxtail, accounting for 29% (87 of 300) of the cumulative relative abundance (Table 2). Other dominant residual weeds were fall panicum, wild-proso millet, and eastern black nightshade (Figure 2d). Subdominant weeds included ivyleaf morningglory and common lambsquarters. Residual weeds in Illinois were also scored 2.2 for level of weed interference, higher than any other state (Table 2).

Compared to Illinois, fewer problematic weed species were observed in Minnesota (Table 1). The three most abundant species—fall panicum, giant foxtail, and common lambsquarters—accounted for 62% (186 of 300) of the cumulative relative abundance (Table 2). Fields in Minnesota had approximately twice as many weed-free quadrats compared to Illinois or Wisconsin despite a similar total weed density, suggesting greater weed patchiness in Minnesota fields. The only additional problematic weed was wild-proso millet (Figure 2e).

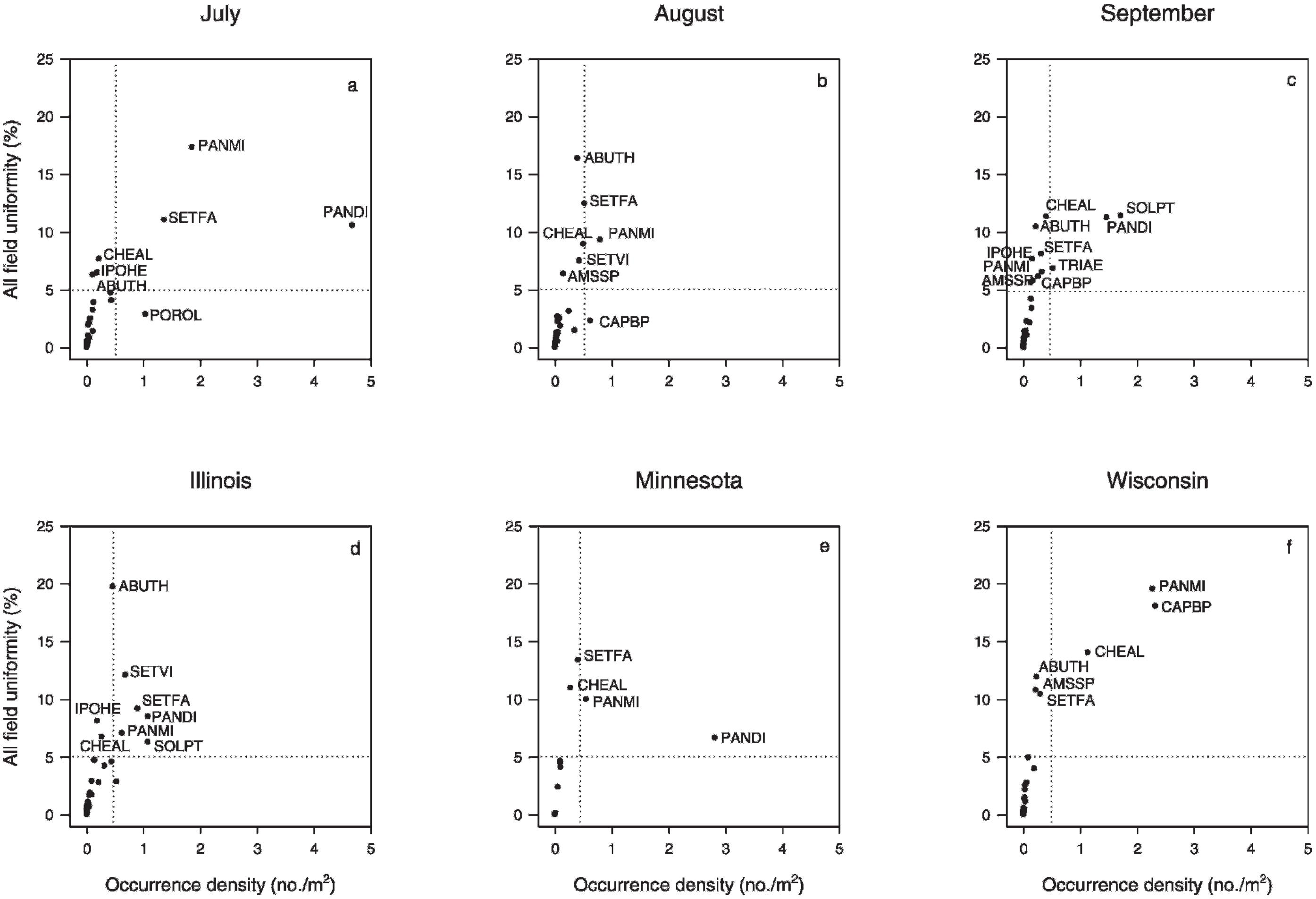

Figure 2. Uniformity (% of all surveyed quadrats) and density (plants/m^2 in occurrence fields) at sweet corn harvest in (a) July, (b) August, and (c) September; and in (d) Illinois, (e) Minnesota, and (f) Wisconsin. Bayer codes for species are given in Table 1.

Dominant residual weeds of Wisconsin included wild-proso millet, shepherd's-purse, and common lambsquarters, and subdominant residual weeds included velvetleaf, pigweed species, and giant foxtail (Figure 2f). Fields in Wisconsin had a similar total weed density and percentage of quadrats that were weed-free as fields in Illinois, but had a lower mean weed interference score of 1.2 (Table 2). Apparently there were aspects of the weed community, beyond density and patchiness, that resulted in Wisconsin fields hosting a weed community less threatening than fields in Illinois. For instance, the most abundant species in Illinois, velvetleaf, is more competitive than wild-proso millet (Mortensen et al. 2002), the most abundant species in Wisconsin.

While changes in weed management over the last 40 yr appear to have altered the residual weed community of processing sweet corn, a majority of fields continue to suffer crop yield loss due to weed interference. Residual weeds with high relative abundance and fecundity status are identified as species that are not being adequately controlled by weed management systems in the NCR. These survey data may be useful in directing research towards improving weed management systems, such as generating data in support of registration of herbicides that control dominant and subdominant species. In addition, the survey data provides a context for the appropriateness of recent research in sweet corn. For instance, recent research on managing wild-proso millet with competitive hybrids is pertinent (Williams et al. 2008a, 2008b) given that registered sweet corn herbicides do not provide consistent season-long wild-proso millet control, and wild-proso millet was one of the most abundant weeds in the crop. Finally, differences in the residual weed community across time of harvest and geographic location indicate the challenges of relying on a limited set of weed management tactics. Further improvements in weed management systems will require recognition of these unique aspects of processing sweet corn production.

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