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Multiple Season Reductions in Herbicide, Downy Brome (*Bromus tectorum*), and Irrigation in Corn

Randall S. Currie, Norman L. Klocke, Holly N. Davis, and Lawrent L. Buschman*

This research explored the use of downy brome (BROTE) as a cover crop in irrigated corn. Although BROTE is a difficult weed to control, it could not be maintained as a cover crop in no-till irrigated corn for more than one season. A 10-fold reduction in BROTE occurred in the second year of corn. By the fourth year, only one BROTE plant could be found at the two locations. Because BROTE did not persist across years, soil coverage decreased 5 to 18% in the later location-years. At one location, normal herbicide rates decreased Johnsongrass biomass more than 22-fold both years it was applied. Increasing herbicide input decreased Palmer amaranth density more than 3-fold, but only in a single location-year. In three of six location-years, level of herbicide input had no significant effect on evapotranspiration (ET). Increased BROTE biomass decreased ET 0.033 to 0.083 cm/d during the first season at both locations. Increased irrigation increased corn yield by 240 to 1,900 kg/ha in five of six location-year combinations. Half rates of in-season herbicides reduced yield only in one of six location-years. High BROTE density reduced ET but did not translate into increased crop yield. In three of six location-year combinations, high BROTE density decreased yield by 300 to 1,000 kg/ha. In a single location-year, increased surface residues provided by BROTE increased yield by 560 kg/ha. Increased irrigation inputs decreased water use efficiency (WUE) by 6.3 kg/ha-cm in a single location-year and increased WUE by 10.8 to 121.6 kg/ha-cm in four of six location-years. Increased herbicide inputs increased WUE by 10.3 kg/ha-cm in one location-year. BROTE density had no significant effect on WUE at location 1. At location 2 in the first 2 yr, WUE was increased 9.4 to 22.2 kg/ha-cm.
Nomenclature: Downy brome, *Bromus tectorum* L. BROTE; Johnsongrass, *Sorghum halepense* (L.) Pers.; Palmer amaranth, *Amaranthus palmeri* S. Wats. AMAPA; corn, *Zea mays* L.
Key words: Integrated weed management, reduced herbicide rates.

A wheat (*Triticum aestivum* L.) cover crop can improve irrigated corn grain yield, ET, WUE, and weed control (Currie and Klocke 2005). Although a wheat cover crop can reduce weed biomass three-fold, this effect is masked by herbicide inputs that can provide a 15-fold reduction (Currie and Klocke 2005). When wheat grain prices are high, using wheat as a cover crop is perceived to be prohibitively expensive. Additionally, wheat must be established at a time of year when labor and time inputs come at a premium. There has been a great deal of work describing many complex strategies to eliminate weedy winter annual grasses. Many studies have been performed to determine optimal rates and application timing of glyphosate for removal of winter annuals (Lins et al. 2007; Monnig and Bradley 2007; Monnig et al. 2007). Furthermore, winter annual grasses have proven more difficult to manage under no-till conditions (Ball et al. 2008; Stone et al. 2006). Therefore, we hypothesized that using a naturally occurring self-seeding population of the winter annual grass downy brome (BROTE) as a cover crop in no-till corn could reduce inputs of capital and labor.

Although there is speculation on how crop residues and weeds affect how crops compete for water (Gallagher et al. 2003; Teasdale and Mohler 1993), there is very little rigorous work on actual measurement of this phenomenon. Norris (1996) measured the effect of weeds on irrigation water use efficiency (IWUE) and the incremental return for each additional unit of irrigation, and made a forceful argument for its further study. WUE is the increase in total yield accrued from the comprehensive water balance of soil water, irrigation, rainfall, and leaching losses. Although some studies of the interaction of WUE and weed and crop growth have been done (Field and Ayisi 1992; Lenssen 2008; Massinga et al. 2003), this interaction is still not well understood. Available data on the effects of weeds on WUE have been used by extension professionals to help producers and researchers measure and conceptualize weed crop water competition (Boerboom 2008). The complex effect of long-term–no-till on surface residues has been exhaustively reviewed (Kladivko 2001). Further, these changes in residues affect the number and diversity of a broad range of organisms (Kladivko 2001). Increasing residues under both till and no-till systems reduced emergence of redroot-pigweed (*Amaranthus retroflexus* L.) (Buhler et al. 1996). This effect was often more pronounced in the no-till system. It also has been shown that even after tillage and cover crop practices are discontinued, the effect of the history of their use can be measured (Davis et al. 2009). Davis et al. (2009) evaluated the effect of tillage levels, cover crops, and herbicide rates on 20 arthropod genera and showed that the past history of herbicide use affected weed seed–consuming arthropod species 18 mo after these practices were discontinued. However, the effect on the interaction of irrigation, presence of cover crops, changing surface residue conditions, and herbicide rates is poorly understood.

Therefore, our objectives were to (1) determine whether BROTE could be maintained as a cover crop in continuous no-till irrigated corn; (2) measure the effect of reduced herbicide rates during the cropping season and increased BROTE residue on weed control, WUE, and yield in

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subsequent corn crops; (3) determine whether in-season herbicide inputs could be reduced in the presence of a BROTE cover crop; and (4) measure the history of multiple season reductions in herbicide rates, irrigation, and cover crop presence on soil surface cover and weed control.

Materials and Methods

A split-plot experiment was established in four blocks with irrigation as the main plot and a random factorial arrangement of subplots that consisted of two densities of BROTE and two rates of in-season herbicide. Main plots were 37 by 30 m with 18 by 15-m subplots. Two locations designated as 1 and 2 were selected for naturally high BROTE antecedent populations that were induced by continuous conventional tillage wheat production from 1997 to 2001. In the fall of 2002, no wheat crop was planted, and the entire plot area was naturally reseeded to BROTE. In the spring of 2003, a near monoculture of BROTE was present. In March 2004, BROTE levels were established at location 1 by treating two of four subplots with 0.8 kg/ha of glyphosate to remove BROTE. In the first week in May 2004, after BROTE had fully pollinated but before it had fully senesced, the entire plot area was treated with 0.8 kg/ha of glyphosate. Previous experience has suggested that applications of glyphosate fail to provide complete coverage in dense stands of BROTE. This reduced coverage has been observed to produce poor BROTE control that maintains a significant BROTE seed load for the subsequent year. Corn was then planted no-till at 64,000 kernels/ha across the whole plot area. Two rates of preemergence herbicides, isoxaflutole + atrazine + S-metolachlor at 0.06 + 1.7 + 2.2 kg/ha or at half these rates, were applied on each of the two densities of BROTE within the larger main plot immediately after corn planting. Multiple years of replicated work in conventionally tilled corn near this location have shown that the full rate of this tank mixture should provide 90 to 100% control of weeds common to this region (Currie 2000, 2001, 2002). Others have reported confounding effects under no-till systems and in cover crop residues on crop emergence and interception of herbicides by crop residues (Gallagher et al. 2003; Ghadiri et al. 1984). To reduce the confounding interception of herbicide and uneven crop emergence due to cover crop residue (Gallagher et al. 2003), 2.5 cm of irrigation were applied over the entire plot area within several hours of applications of these tank mixes.

Volumetric soil water content was measured biweekly to a depth of 2.4 m in 0.3-m increments by the neutron attenuation method, with locally derived models for this specific soil type (Stone et al. 1955). No further irrigation was applied until the total soil available water was depleted 25 to 40% in the top 1.2 m of the soil profiles in the high-water treatment. The high-water treatment simulated a typical well capacity for this region of 46 L/min-ha to supply a maximum application of 5 cm/wk. The low-water treatment simulated half of the full capacity, which is predicted to be the typical well capacity in 2030 because of declining aquifers across the American Great Plains (Klocke et al. 2007). Corn was harvested when grain moisture dropped below 15.5%. IWUEs were calculated by dividing total corn grain mass by total water applied. WUEs were calculated by dividing total corn grain mass by growing season ET. ET was derived by summing the stored soil moisture in the top 1.8 m used during the growing season, effective rainfall (Table 1), and net irrigation. Drainage was assumed to be negligible.

Table 1. Rainfall during the growing season.

	2004	2005	2006	2007	30-yr average
	cm				
May	1.3	8.7	6.0	2.6	8.61
June	15.0	7.8	5.1	5.7	7.32
July	7.9	11.0	10.7	3.7	6.58
August	12.9	4.6	6.7	6.3	6.50
September	8.9	1.9	3.0	6.5	3.18
Total	46.1	34.1	31.5	24.8	32.18

Although previous experience near these locations suggested that Palmer amaranth will be the predominant weed when full or reduced herbicide treatments are used, an unexpected infestation of Johnsongrass was present at location 1 in 2004. Past experience has shown that there is no utility in measuring effects of uncontrolled Johnsongrass. Therefore, at all other location-years, nicosulfuron was applied 6 weeks after planting (WAP) at 0.034 kg/ha or at half this rate, to the high- and low-input–in-season herbicide plots, respectively. Although past experience suggested that a full rate of nicosulfuron would not control Palmer amaranth, half rates were included for comparison and to improve the possibility that some weeds were present to measure. Further, nicosulfuron was selected to control Johnsongrass to minimize the interaction of the preemergence and postemergence treatments for broadleaf control. Although others have shown effective broadleaf control with reduced rates of the acetolactate synthase (ALS) inhibitory herbicide nicosulfuron (Gallagher et al. 2003), putative ALS-resistant Palmer amaranth, the predominant broadleaf weed problem at these locations, was first indicated in replicated trials more than a decade before in fields adjacent to these locations (Currie 1996). In concurrent tests in plot areas adjacent to these locations, ALS-type herbicides failed to provide effective control of Palmer amaranth (Thompson et al. 2008). The same set of treatments was imposed on the same plots at location 1 in 2005 and 2006.

The experiment was repeated in 2005 at location 2. Location 2 was allowed to naturally reseed to BROTE during 2004 and was kept free of summer annual weeds by applications of 0.8 kg/ha of glyphosate as needed. The experiment was repeated at location 2 in 2006 and 2007.

Weed Measurements. Prior to corn planting, all above-ground BROTE biomass was removed from 0.6-m^2 quadrats and oven dried at 60 C for 48 h. Prior to corn harvest, the number of weeds/ha for each species was determined by counting the number of weed species found in the entire area between two rows the full length of the plot, or 13.7 m^2. Biomass samples were harvested from the same 13.7-m^2 area at the time of counts and oven dried as described for BROTE samples.

Line Transect Method for Residue Measurement. In the spring of 2005 at the first location, the decline in BROTE population was so great it was clear that a nondestructive method of residue measurement was needed. The line transect method was used for this purpose (Laflen et al. 1981). These methods do not quantify the types of residue. Therefore, this method was adapted and modified to not only measure soil cover but also attempt to describe its composition.

Corn residue, BROTE residue, detritus, or bare soil was recorded at 30-cm intervals along an 18-m transect. Transects were taken at random angles to produce threes subsamples per plot. Percentages of the four cover types of residue were calculated from these counts.

Statistical Analyses. Plots were arranged in a split-block design, with irrigation level as the main plot, and BROTE density and herbicide rate as subplots in a randomized complete block design with four replicates. All data were subjected to ANOVA using PROC ANOVA.[1] Means were separated with Fisher's Protected LSD ($P < 0.05$ or 0.10).

Results and Discussion

BROTE Residue. Beginning BROTE populations were robust in the first year and did not differ between locations, producing 6,900 ± 860 kg/ha (95% CI) of residue in the high-density BROTE plots. In the low-density BROTE plots, residue was too low to measure with a destructive sample. By the second year, BROTE residue declined to 1,500 ± 622 kg/ha (95% CI). By the third year, the BROTE population was less than 0.36 ± 0.28 (95% CI) plants/m^2 at location 1 and 0.32 ± 0.32 (95% CI) plants/m^2 at location 2, which was too low and too variable to harvest a destructive sample to determine weight. No BROTE was observed in any plots in the spring or fall of the fourth cropping year of the study at location 1. A single plant was found in the spring of 2008 at location 2. We speculate that an extra year of BROTE monoculture at location 2 produced a larger soil seed bank than at location 1. However, it is also possible that this single plant was a result of dispersal from another location. Clearly our hypothesis was flawed as to the ability of BROTE to maintain a sufficient seed bank after late applications of glyphosate. It appeared that only a single application of glyphosate in May over a 3-yr period was needed to eliminate most of the BROTE. This was in contrast to results from previous research (Anderson et al. 2007; Daugovish et al. 1999; Lins et al. 2007; Stone et al. 2006). Others have been unable to eliminate BROTE under these conditions, but when BROTE was desired, it could not be maintained in our study. This disparity could be due to a moister environment or BROTE biotypes. None of the previous studies were conducted under irrigation. BROTE is not common in the southeastern United States (Thill et al. 1984). Perhaps the environmental conditions produced by irrigation at this location mimic moist environments where BROTE is not adapted. Further, no-till systems are more conducive to *Bromus* spp. seedling recruitment (Dao 1987), which may have depleted the BROTE soil seed bank. Other researchers have also shown regional genetic diversity of *Bromus* spp. populations that may have led to this difference (Kao et al. 2008). Further study is needed to define the genetic and environmental interactions of BROTE dormancy.

BROTE Residue Coverage. By the time the third corn crop was planted, total growing season BROTE coverage was less than 1% at location 1 and less than 6% at location 2 (Table 2). BROTE residue was not influenced by level of irrigation, herbicide input, or initial BROTE density. Level of in-season herbicide applied to kill summer annual weeds had no effect on BROTE residue in any location-year. March glyphosate treatment reduced BROTE residue more than 10-fold in the second year at both locations. In the third season, BROTE levels were so low in all plots that differences could not be measured.

Corn Residue Coverage. At location 1, level of irrigation did not affect the percentage of the soil surface covered by corn stover. However, at location 2, added irrigation increased corn residue from 29 to 36% in 2006 ($P = 0.10$) and 43 to 53% in 2007 ($P = 0.05$). Level of in-season herbicide use did not affect the percentage of the soil surface covered by corn residue. The high-density BROTE treatment had less corn residue than the low-density BROTE treatment (4.6%) in only one of four location-years, 2005.

Detritus Coverage. Level of irrigation did not affect the percentage of the soil surface covered by detritus in the second year. However, by the third year, increased irrigation decreased detritus cover 5 to 8.3% ($P = 0.10$ and 0.05, respectively). Perhaps more frequent irrigations caused more cumulative detritus decomposition over the 3-yr period.

Bare Soil Present. Irrigation did not influence ($P = 0.10$) the percentage of the soil surface that was bare at any location-year. Higher levels of in-season herbicide use increased ($P = 0.10$) the percentage of the soil surface that was not covered with residue (5.3%) in only the third year of location 2. Application of glyphosate in March to the low-density BROTE plots increased the percentage of bare soil 5 to 18% in all location-years measured.

Johnsongrass Control. Interactions in Johnsongrass control were found in all location-years with all factors, but no three-way interactions were found. Therefore, each location-year is presented separately. In the first year, when BROTE was present as a cover crop, BROTE reduced the number of Johnsongrass stems/ha two-fold (Table 3). At the second location, addition of nicosulfuron at full or half rates produced a level of control that masked any effects of a BROTE cover crop. In the second year, no factor affected Johnsongrass stem number. In the third year at location 1, the high herbicide treatment produced a 12-fold reduction in Johnsongrass stem number. At location 2, high irrigation elevated Johnsongrass density and biomass in the third year (Table 2). At location 1, which had the presumed higher Johnsongrass infestation, a 12-fold reduction in Johnsongrass biomass was measured at the high herbicide use rate in both years it was applied.

High BROTE density reduced Johnsongrass only at location 1 in the first season when it was present at levels sufficient to act as a cover crop and no nicosulfuron was applied. Irrigation did not affect Johnsongrass biomass at location 1. However, in 2 of 3 yr, irrigation increased Johnsongrass biomass 2- to 50-fold at location 2. High

Table 2. Effect of irrigation, herbicide rate, and initial downy brome (BROTE) level on percent of soil surface covered with crop residue.

	Location 1						Location 2					
	Irrigation		Herbicide		BROTE		Irrigation		Herbicide		BROTE	
Input level	2005	2006	2005	2006	2005	2006	2006	2007	2006	2007	2006	2007
	%											
BROTE residue												
High	15	1	14	0	27	1	7	4	8	2	16	6
Low	15	0	15	1	3	0	9	4	8	6	0	2
LSD (0.05)	NS	NS	NS	NS	7	NS	NS	NS	NS	NS	5	NS
Corn residue												
High	11	39	12	36	9	38	36	53	32	48	32	50
Low	11	37	10	40	13	38	29	43	33	49	32	47
LSD (0.05)	NS	NS	NS	NS	2	NS	6[a]	7	NS	NS	NS	NS
Detritus												
High	48	27	50	31	48	31	15	11	14	14	15	20
Low	50	32	48	27	50	27	13	19	15	15	14	10
LSD (0.05)	NS	5[a]	NS	NS	NS	NS	NS	7	NS	NS	NS	7
Bare soil												
High	27	34	24	33	16	30	48	32	46	36	37	25
Low	24	31	27	32	34	35	43	34	45	30	54	41
LSD (0.05)	NS	NS	NS	NS	6	3[a]	NS	NS	NS	5[a]	12	5

[a] Only statistically significant at P = 0.1.

herbicide rate decreased Johnsongrass biomass more than 22-fold at location 1 in both years measured. However, Johnsongrass biomass was unaffected by herbicide rate at location 2. Johnsongrass was not treated at location 1 in 2004, but nicosulfuron was applied in all 3 yr at location 2. Further, location 2 had one more year of uncontrolled BROTE as well as an additional summer with no annual weed seed production prior to study initiation. This suggests that beginning weed pressure should be carefully and accurately measured in future studies of reduced herbicide rates. The lowest rates of nicosulfuron masked the effects of irrigation and BROTE on Johnsongrass. If the set point population had been higher, these factors may have produced some measurable influence.

Palmer Amaranth Control. Interactions in Palmer amaranth control were found in all location-years with all factors, but no three-way interactions were found. Therefore, each location-year is presented separately. In the initial year, when BROTE was present as a cover crop, no significant effect could be measured on Palmer amaranth density at either location.

Irrigation level produced no significant changes in Palmer amaranth density in five of six location-years. In a single location year, increasing irrigation level depressed the number of Palmer amaranth more than 3-fold (Table 4). High irrigation level increased Palmer amaranth biomass 1.5- to 3-fold in three of five location-years measured. Increased levels of in-season herbicide use did not significantly affect Palmer amaranth density in five of six location-years. In the third year at location 2, increasing in-season herbicide input decreased Palmer amaranth density more than 3-fold. At location 1 in 2005, high BROTE treatment increased BROTE residue, which increased Palmer amaranth density. This trend was also observed when a wheat cover crop was killed with herbicide

Table 3. Effect of levels of irrigation, in-season herbicide use, and level of downy brome (BROTE) on Johnsongrass.

	Location 1									Location 2								
	Irrigation			Herbicide			BROTE			Irrigation			Herbicide			BROTE		
Input level	2004	2005	2006	2004	2005	2006	2004	2005	2006	2005	2006	2007	2005	2006	2007	2005	2006	2007
Density																		
	1,000 stems/ha																	
High	3.5	0.6	10.8	4.7	0.4	1.6	3.7	1.6	11.6	0.4	11.3	4.4	0.5	1.6	1.2	0.8	2.4	1.5
Low	9.0	1.7	10.8	7.8	1.9	19.9	8.8	0.7	10.0	1.2	1.3	0.5	1.0	11.0	3.7	0.7	10.2	3.4
LSD (0.05)	5.2	NS	NS	NS	NS	13.6	4.3[a]	NS	NS	NS	NS	2.8	NS	NS	NS	NS	NS	NS
Biomass																		
	kg/ha																	
High	na[b]	40	89	na	7	7	na	75	75	37	66	51	25	1	16	16	14	26
Low	na	118	62	na	151	145	na	83	76	14	9	1	26	73	36	38	61	26
LSD (0.05)	na	NS	NS	na	108	120	na	NS	NS	21	NS	26	NS	NS	NS	18[a]	NS	NS

[a] Only statistically significant at P = 0.1.

[b] na = not applicable.

Table 4. Effect of levels of irrigation, in-season herbicide use, and downy brome (BROTE) on Palmer amaranth.

	Location 1									Location 2								
	Irrigation			Herbicide			BROTE			Irrigation			Herbicide			BROTE		
Input level	2004	2005	2006	2004	2005	2006	2004	2005	2006	2005	2006	2007	2005	2006	2007	2005	2006	2007
Density																		
	1,000 plants/ha																	
High	29.8	147.3	97.9	40.0	151.0	106.2	36.9	164.8	96.8	50.4	127.2	4.2	57.6	109.2	4.6	45.9	99.8	9.1
Low	44.2	119.5	130.2	34.0	115.8	121.8	37.1	102.0	131.3	47.3	105.4	14.6	40.1	123.5	14.3	51.8	132.9	9.7
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	50.5	3.2[a]	NS	NS	9.7	NS	NS	9.7	NS	NS	NS
Biomass																		
	kg/ha																	
High	na[b]	4,540	1,900	na	3,200	1,400	na	4,400	1,300	2,600	1,600	60	1,400	1,200	30	1,600	1,400	90
Low	na	2,900	1,200	na	4,200	1,700	na	3,000	1,800	800	1,200	90	2,000	1,600	120	1,800	1,400	60
LSD (0.05)	na	1,610[a]	600[a]	na	NS	NS	na	NS	NS	900	NS	NS	NS	NS	80	NS	NS	NS

[a] Only statistically significant at P = 0.1.

[b] na = not applicable.

application at corn planting (Currie and Klocke 2005). Palmer amaranth biomass was never affected by initial BROTE density in year 1. As with Johnsongrass control, no consistent advantage or disadvantage could be established for efforts to control BROTE prior to planting the corn crop, and beginning weed pressure may have influenced the effects of reduced rates of in-season herbicide use. In a related study, Palmer amaranth overwhelmed the effects of cover crop and reduced herbicide use (Currie and Klocke 2005).

Evapotranspiration. There was a significant interaction of levels of irrigation, in-season herbicide use, and BROTE control in all six location-year combinations. However, there was no significant three-way interaction of these factors with any one location-year. Therefore, data are presented averaged over these factors for each location-year (Table 5). In the initial year, when BROTE was present as a cover crop, irrigation elevated ET, and presence of BROTE cover crop reduced ET at both locations. At location 1, the high herbicide input reduced ET, but only at the 10% significance level. ET was 0.046 to 0.012 cm/d greater in all location-years with high irrigation (Table 4). Such increases have been measured with a broad range of cultural practices (Klocke et al. 2008).

Although increased levels of in-season herbicide inputs decreased ET at location 1 in the first year, when BROTE was present as a cover crop, high herbicide increased ET in the second year at location 2 with less BROTE cover. In all other location-years, level of in-season herbicide input had no significant effect on ET.

High BROTE density decreased ET 0.033 to 0.083 cm/d; however, this occurred only in the first season at both locations, when BROTE was present at levels to function as a cover crop. Decreased ET rates may have been due to the higher amounts of BROTE residue suppressing soil water evaporation. In the third year at location 2, ET was not affected by the initial high level of BROTE residue present in the first year. However, at location 1, these cumulative effects over a 3-yr period increased ET 0.025 cm/d. This was due to the decrease in total BROTE density with successive crops of no-till corn and the concomitant reduction in surface residue. As seen with Johnsongrass control, no consistent advantage or disadvantage could be established for increased inputs over a 3-yr period for BROTE control in the subsequent corn crop.

Corn Grain Yield. As with ET, there was a significant interaction of levels of irrigation, in-season herbicide use, and BROTE control among the six location-years. However, there was no significant three-way interaction of these factors in any one location-year. Therefore, data are presented averaged over these factors for each location-year.

In the initial year, when BROTE was present as a cover crop, irrigation elevated yield 240 to 1,200 kg/ha (Table 6). Unlike a wheat cover crop, which elevated yield in eight of nine location-years, BROTE cover reduced yield at one of the two locations.

Table 5. Effect of irrigation levels, in-season herbicide rate, and initial downy brome (BROTE) density on evapotranspiration during the growing season.

	Location 1									Location 2								
	Irrigation			Herbicide			BROTE			Irrigation			Herbicide			BROTE		
Input level	2004	2005	2006	2004	2005	2006	2004	2005	2006	2005	2006	2007	2005	2006	2007	2005	2006	2007
	cm/d																	
High	0.58	0.60	0.54	0.55	0.57	0.49	0.52	0.56	0.50	0.56	0.56	0.43	0.53	0.51	0.40	0.49	0.50	0.40
Low	0.53	0.55	0.44	0.58	0.58	0.49	0.59	0.59	0.48	0.50	0.43	0.38	0.53	0.48	0.41	0.57	0.49	0.41
LSD (0.05)	0.03	0.02	0.02	0.02[a]	NS	NS	0.03	0.02	0.02	0.02	0.03	0.03	NS	0.03	NS	0.02	NS	NS

[a] Only statistically significant at P = 0.l.

Table 6. Effect of levels of irrigation, in-season herbicide use, and downy brome (BROTE) on corn grain yield.

	Location 1									Location 2								
	Irrigation			Herbicide			BROTE			Irrigation			Herbicide			BROTE		
Input level	2004	2005	2006	2004	2005	2006	2004	2005	2006	2005	2006	2007	2005	2006	2007	2005	2006	2007
	kg/ha																	
High	5,800	5,300	8,500	5,700	5,500	6,400	5,300	5,100	6,300	6,700	10,700	7,000	6,100	7,000	6,200	6,200	7,100	5,500
Low	5,500	5,200	3,900	5,600	5,000	5,900	6,000	5,400	6,000	5,500	3,100	5,100	6,100	6,700	5,900	6,000	6,600	6,500
LSD (0.05)	200[a]	NS	800	NS	300	NS	300	200[a]	NS	500	500	600	NS	NS	NS	NS	500	600

[a] Only statistically significant at $P = 0.1$.

Increased irrigation increased corn yield 240 to 1,900 kg/ha in five of six location-years (Table 5). Irrigation increased yield at location 1 in 2005, but this increase was not significant, possibly because of hail injury on July 4 (Currie and Klocke 2008). Level of in-season herbicide inputs increased crop yield in all location-years but was significant only in the second year at the second location.

Although high BROTE density or the history of high BROTE reduced ET, this did not translate into increased crop yield. In three of six location-year combinations, high BROTE density decreased yield 300 to 1,000 kg/ha. In one location-year, increased surface residues provided by BROTE increased yield 558 kg/ha. In two of six location-years, no significant yield results could be measured. Results indicated that increased efforts to control BROTE prior to planting may not translate into increased corn yield.

Irrigation Water Use Efficiency. As with ET, there was a significant interaction of irrigation amounts, herbicide, and BROTE control among the six location-years. No complex three-way interactions of these factors were measured for IWUE in five of six location-years.

Increased irrigation decreased IWUE 95 to 110 kg/ha-cm (Table 7) in the initial year, when BROTE was present as a cover crop. In the second year, IWUE also decreased at location 1 but increased at location 2. This increase in irrigation produced a complex three-way interaction at location 2 in the third year. In the second year at both locations, high in-season herbicide use increased IWUE. In the initial year, when BROTE was present as a cover crop, despite reductions in ET, it depressed IWUE at location 1 and did not affect IWUE at location 2. No effect of past efforts to control BROTE was seen at location 1 in the third season. However, a significant three-way interaction of factors was seen at location 2 in the third year.

At the only location-year where a three-way interaction occurred (location 2 in 2007), no significant effect on IWUE was measured if any one of the inputs was at the normal level. However, IWUE was reduced by the cumulative effects of three seasons of reduced in-season herbicide use and irrigation amounts, and the increase in the historical level of inputs for BROTE control (Table 8).

Water Use Efficiency. WUE had significant interactions among levels of irrigation, in-season herbicide use, and BROTE control for six location-years. However, there was no significant three-way interaction of these factors with any one location-year. Therefore, data are presented averaged over these factors for each location-year.

In the initial year, when BROTE was present as a cover crop, WUE was unaffected by irrigation at location 1 and increased at location 2. In the second year, WUE was decreased by high irrigation at location 1 and increased at location 2. In the third year, after residue had declined, high irrigation increased WUE at both locations.

Table 7. Effect of levels of irrigation, in-season herbicide use, and downy brome (BROTE) on water use efficiency (WUE) or applied water only (IWUE).

	Location 1									Location 2								
	Irrigation			Herbicide			BROTE			Irrigation			Herbicide			BROTE		
Input level	2004	2005	2006	2004	2005	2006	2004	2005	2006	2005	2006	2007	2005	2006	2007	2005	2006	2007
IWUE																		
	kg/ha-cm																	
High	252.0	207.7	278.0	308.0	285.1	300.0	284.5	267.8	297.0	264.6	348.4	sig int[b]	315.0	310.4	sig int	315.0	314.0	sig int
Low	362.0	341.0	304.0	306.0	263.6	282.0	329.6	280.9	285.0	360.3	242.2	sig int	310.0	281.7	sig int	310.0	286.0	sig int
LSD (0.05)	16.0	13.6	NS	NS	13.6	NS	16.1	11.2[a]	NS	27.3	28.2		NS	28.2	NS	NS		
WUE																		
	kg/ha-cm																	
High	100.0	87.9	158.3	104.0	96.2	128.0	100.0	92.0	123.0	121.7	192.6	161.9	118.1	132.0	153.0	127.4	136.5	136.4
Low	103.0	94.2	87.7	99.0	85.9	118.0	103.0	91.0	123.0	110.9	71.0	133.0	114.4	131.0	142.0	105.2	127.1	158.5
LSD (0.05)	NS	6.1	16.0	NS	6.1	NS	NS	NS	NS	9.0[a]	9.8	14.6	NS	NS	NS	10.9	8.1[a]	14.6

[a] Only statistically significant at $P = 0.1$.

[b] Three-way interaction significant at $P = 0.05$.

Table 8. Effect of levels of irrigation, in-season herbicide use, and initial downy brome (BROTE) density on irrigation water use efficiency in 2007.

	Herbicide high		Herbicide low	
	BROTE residue level			
Irrigation	High	Low	High	Low
	kg/ha-cm			
High	538	584	522	565
Low	642	741	499	785
LSD (0.10)	232			
LSD (0.05)	280			

In-season herbicide use did not affect WUE in the initial year, when BROTE was present as a cover crop. In the second year, it increased WUE at location 1 and had no effect at location 2. In the third year, when residue had declined, WUE was unaffected by high herbicide treatment at both locations.

BROTE or past history of BROTE control over a 3-yr period had no effect on WUE at location 1. At location 2, BROTE elevated WUE in the initial year, when present as a cover crop, and in the second year as well. In the third year, past history of BROTE control reduced residue and depressed WUE.

Regardless of treatment, BROTE was not present after a 3-yr period in no-till irrigated corn. Therefore, it could not be maintained as a cover crop. Further, unlike a wheat cover crop, BROTE reduced corn yield as often as it increased it. In many studies, BROTE populations were dramatically reduced with 2- to 4-yr crop rotations, but eradication could not be achieved (Daugovish et al. 1999). Beginning BROTE populations of one plant/m^2 survived two cycles of a 4-yr rotation (Daugovish et al. 1999). Results with shorter rotation intervals are similar (Anderson et al. 2007; Stone et al. 2006). However, BROTE populations declined more quickly under the moister, warmer conditions in this study.

Low rates of herbicide preformed as well as high rates in most years. However, when low rates were ineffective, the high rate produced a several-fold improvement in weed control.

Although BROTE was not present in levels high enough to act as a cover in the second and third year of the study, the history of BROTE control had a measurable effect, perhaps because of the reduced soil surface cover in all subsequent years. This decline in total residue cover and its effect on WUE in the high irrigation treatments was most pronounced in the third year at both locations.

Although BROTE affected weed densities, its effect was small and inconsistent. The threat of yield losses from the BROTE far outweighed any value it had as a cover crop. As others have reported, the effects of changes in residue produced by cover crops and reduced herbicide rates can be measured in subsequent years after these practices have been discontinued.

Sources of Materials

[1] SAS software, version 9.1, 2003, SAS Institute, Inc., 100 SAS Campus Drive, Cary, NC 27513.

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