

1 **YIELD AND STABLE ISOTOPE CHANGES IN CORN (*ZEA MAYS*) GRAIN**  
2 **DUE TO WEED AND WATER STRESS**

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10 **ABSTRACT**

11  
12 Understanding and developing tools to assess the mechanisms and magnitude of weed  
13 competition and interference with crops are needed in order to make biologically and  
14 environmentally sound decisions about weed management. Corn (*Zea mays*) was grown  
15 in weed-free or weedy conditions and supplemental water was applied to some treatments  
16 in order to evaluate the magnitude of changes in yield and stable isotope (<sup>15</sup>N and <sup>13</sup>C)  
17 discrimination due to water and weeds. This study was conducted at two eastern South  
18 Dakota locations, Beresford in southeast SD and Brookings in east central SD. Corn  
19 yields in weedy plots were reduced compared to yields in weed-free plots within a water  
20 treatment. Corn receiving supplemental water in weedy plots, in some cases, had yields  
21 similar to yields in weed-free/natural rainfall areas. Isotope discrimination indicated that  
22 yield losses due to competition between corn and weeds for N accounted for between 70  
23 to 99% of the weed-induced losses.

24  
25 **Keywords:** <sup>13</sup>C discrimination, <sup>15</sup>N discrimination, yield losses, weed competition.  
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29 **INTRODUCTION**

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31 In landscapes containing relatively few weeds and rolling topography, water may be  
32 the most limiting factor in summit/backslope areas due to low infiltration or relatively  
33 high amounts of runoff, or both. However in toeslope positions, water may not be as  
34 limiting a factor to crop growth because more water is available due to runoff/runin from  
35 higher elevations or from the upward movement of water by capillary flow from seeps or  
36 underground water sources. If water limits growth, additional nutrients will not be useful  
37 to the crop to eliminate environmental stress (Clay et al., 2001a).

38 Weeds interfere with crop growth and reduce crop yield by competing for light, water,  
39 and nutrients. Because of differences in water and nutrient availability across the  
40 landscape, weeds have the potential to reduce yields more at some landscape positions  
41 than others. The impact of interactions among landscape position, weed, nutrients and  
42 crop growth and yield is not well understood. However, understanding and developing  
43 tools to assess the mechanism(s) of competition and interference across fields are  
44 important to improve management decisions.  
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1 One of the diagnostic tools to estimate water stress is determining the  $^{13}\text{C}$   
2 discrimination level in plant tissue and grain (Smeltekop et al., 2002). In plants with the  
3 C-3 photosynthesis pathway, soybean for example, RUBISCO preferentially fixes  $^{12}\text{CO}_2$   
4 over  $^{13}\text{CO}_2$ . Under water stress, the stomata close and relatively more  $^{13}\text{CO}_2$  is fixed  
5 during photosynthesis.  $^{13}\text{C}$  discrimination ( $\Delta$ ) in C-3 plants can range from 21‰ in non-  
6 water stressed plants to 16‰ in water stressed plants. Plants with the C-4 photosynthetic  
7 process, corn for example, have similar reactions to water stress. However, instead of  
8 decreasing  $\Delta$  with water stress as observed in C-3 plants,  $\Delta$  increases with water stress in  
9 C-4 plants. Clay et al. (2001) reported that  $\Delta$  in corn can range from 2.5‰ in nonwater  
10 stressed plants to 4‰ in severely water stressed plants.  $^{13}\text{C}$  discrimination can be  
11 influenced by any factors that influence photosynthesis efficiency. For example, N stress  
12 has the opposite effect on  $\Delta$  than water stress (Clay et al., 2001). Therefore, plant and  
13 grain analysis of stable isotopes can be a useful tool because the plant integrates these  
14 stress factors throughout the life cycle of the plant.

15 The use of  $^{13}\text{C}$  as an indicator of water stress may be complicated if N stress is  
16 involved in yield loss reduction. Total percentage yield loss (TYL) has been defined as a  
17 function of both water and N stress (Clay et al., 2001b). The equations,

$$18 \quad \text{TYL} = X + Y \quad (1)$$

19 and

$$20 \quad \delta\Delta = X * (\delta\Delta_{\text{water stress}}) + Y * (\delta\Delta_{\text{N stress}}) \quad (2)$$

21 where X was the percentage yield loss due to water stress, Y was the percentage yield  
22 loss due to N stress,  $\delta\Delta$  was the change in  $\Delta$  due to adding weeds,  $\delta\Delta_{\text{water stress}}$  was the  
23 change in  $\Delta$  for each percentage of yield lost to water stress, and  $\delta\Delta_{\text{N stress}}$  was the change  
24 in  $\Delta$  for each percentage of yield lost due to N stress.

25 Clay et al. (2001) estimated that for corn each 1% in yield loss due to water stress  
26 results in an increase of  $\delta\Delta_{\text{water stress}}$  by 0.0117‰. The change in  $\delta\Delta_{\text{N stress}}$  for each 1%  
27 yield loss due to N stress in corn has been calculated to be -0.007‰ (Clay et al., 2002).  
28 The change in signs from a positive change in  $\Delta$  for water stress to a negative change in  $\Delta$   
29 for N stress indicates that plants grown under N stress use less water due to decreases in  
30 total biomass production.

31 Another diagnostic tool is the analysis of the amount of  $^{15}\text{N}$  in plant biomass, grain, or  
32 both. Fertilizer N and N mineralized from soil organic matter have different  $^{15}\text{N}$  numbers.  
33  $^{15}\text{N}$  values in fertilizer typically range from -2 to 0‰ (Spalding et al., 1982) whereas, soil  
34 mineralized N typically has  $^{15}\text{N}$  values ranging between 4 and 9‰ (Heaton, 1986). If  
35 plant or grain analysis indicates relatively higher numbers the source of N would be from  
36 N mineralized from soil organic matter rather than fertilizer applied.

37 The objective of this study was to evaluate the magnitude of changes in yield and  
38 stable isotope ( $^{15}\text{N}$  and  $^{13}\text{C}$ ) discrimination due to water and weeds.

## 39 40 MATERIALS AND METHODS

41  
42 Research was conducted in field studies at two eastern South Dakota sites, Beresford  
43 in southeastern South Dakota and Brookings in east central South Dakota in 2000 and  
44 2001. Yield goals at Beresford and Brookings were 9,490 and 7,500 kg ha<sup>-1</sup>, respectively.  
45 These yield goals are equivalent to 137 (Beresford) and 109 (Brookings) g grain plant<sup>-1</sup>,  
46 based on a population of 69,000 plants ha<sup>-1</sup>. At Beresford, the corn variety had a 112-d

1 Table 1. Weed and corn biomass, corn yield, and  $^{13}\text{C}$  discrimination, % N, and  $^{15}\text{N}$   
 2 amounts in grain at Beresford, SD. Nitrogen sufficiency in grain has been  
 3 calculated to be about 2.7% N/g grain (Stichler and McFarland, 2001).

Year	Treatment		Weed biomass g/m <sup>2</sup>	Corn Stover g/plant	Grain				
	Weeds	Water			Yield	Yield loss <sup>a</sup>	$^{13}\text{C}$ discrimination	Total N	$^{15}\text{N}$
						%	‰	%	‰
2000	No	No	-	73	112		3.15	2.436	0.21
	Yes	No	728	52	95	15.1	2.97	2.039	0.81
p value				0.05	0.08		<0.01	<0.01	0.35
	No	Yes	-	99	158		3.04	2.362	-0.49
	Yes	Yes	1001	62	114	27.9	2.98	2.107	1.49
p value				<0.01	<0.01		0.27	0.05	<0.01
2001	No	No	-	188	155		2.91	1.767	1.02
	Yes	No	1334	101	71	54.2	2.68	1.537	1.54
p value				<0.01	<0.01		<0.01	<0.01	0.91
	No	Yes	-	206	137		2.94	1.681	1.51
	Yes	Yes	1486	116	95	30.6	2.82	1.743	0.05
p value				<0.01	<0.01		0.61	0.73	<0.01

4  
 5 <sup>a</sup> Yield loss due to weeds is calculated within a water treatment  
 6

7 maturity, whereas at Brookings, the corn variety had a 95-d maturity rating. The factorial  
 8 treatments were two rates of weed (weed-free and weedy) and water (natural rainfall and  
 9 rainfall plus supplemental water). Each plot was replicated four times and each plot  
 10 contained three plants.  
 11

## 12 RESULTS AND DISCUSSION

13  
 14  
 15 Growing degree days (GDD) (base 10 C) at Beresford were 1629 and 1640 for the  
 16 2000 and 2001 growing season (April through September), respectively. Brookings GDD  
 17 totals were 1405 and 1515 for 2000 and 2001, respectively. Rainfall amounts from April  
 18 through September at Beresford were about 35.6 and 39.9 cm in 2000 and 2001 growing  
 19 seasons, respectively. Rainfall amounts from April through September at Brookings were  
 20 slightly higher and were 39.4 and 42.4 cm for 2000 and 2001, respectively.

21 At Beresford in 2000, weeds reduced corn stover biomass production by 28% in areas  
 22 receiving only natural rainfall (Table 1). In areas that received supplemental water, weeds  
 23 reduced corn stover biomass by 37% compared to weed-free watered plants. The yield  
 24 goal was only met in the weed-free supplemental water treatment. Yield loss due to  
 25 weeds were 15.1% in natural rainfall areas and 27.9% in supplemental rainfall areas. In  
 26 2001, a slightly warmer and wetter season, weed biomass was 60% greater than in 2000.

1 Table 2. Weed and corn biomass, yield, and  $^{13}\text{C}$  discrimination, % N, and  $^{15}\text{N}$  amounts  
 2 in grain at Brookings, SD. Nitrogen sufficiency in grain has been calculated to  
 3 be 2.7% N/g grain (Stichler and McFarland, 2001).

Year	Treatment		Weed biomass g/m <sup>2</sup>	Corn biomass g/plant	Grain			Total N %	$^{15}\text{N}$ ‰
	Weeds	Water			Yield loss <sup>a</sup> %	$^{13}\text{C}$ discrimination ‰			
2000	no	no	-	98	152		3.17	1.443	3.25
	yes	no	783	58	69	54.6	3.03	1.197	2.01
p value				<0.01	<0.01		0.35	0.05	0.21
	no	yes	-	115	156		3.26	1.484	3.46
	yes	yes	934	87	113	27.5	3.05	1.332	3.05
p value				<0.01	<0.01		<0.01	<0.01	<0.01
2001	no	no	-	96	141		3.00	1.226	2.79
	yes	no	1136	42	52	63.1	2.84	1.261	2.29
p value				<0.01	<0.01		0.05	0.34	0.28
	no	yes	-	123	164		3.16	1.540	3.73
	yes	yes	1144	65	79	51.8	2.96	1.299	2.54
p value				<0.01	<0.01		0.02	<0.01	<0.01

4 <sup>a</sup> Yield loss due to weeds is calculated within a water treatment

5  
 6 Although corn stover biomass weights and yields in 2001 were greater in almost all  
 7 treatments compared to these parameters in 2000, yield losses in weedy areas receiving  
 8 either natural and supplemental water were increased compared with yield losses in 2000  
 9 and ranged from 30.6 (supplemental water) to 54.2% (natural rainfall).

10 Yield reductions due to weeds at Brookings were greater than 50% in both years, total  
 11 N in grain was below 2.7%, a sufficiency level for corn grain N based on calculations  
 12 derived from Stichler and McFarland (2001) and Martin et al. (1976). Generally, weed  
 13 competition reduced total grain N. These data indicate that corn was under N stress. The  
 14 increase in  $^{15}\text{N}$  concentration in the natural and supplemental rainfall treatments in 2000  
 15 and the natural rainfall treatment in 2001 suggests that weeds reduced the amount of N in  
 16 the plant that was derived N fertilizer since  $^{15}\text{N}$  values in fertilizer typically range from  
 17 -2 to 0‰, whereas, soil mineralized N typically has  $^{15}\text{N}$  values ranging between 4 and  
 18 9‰ (Spalding et al., 1982; Heaton, 1986).

19 At Brookings, the yield goal of 109 g grain plant<sup>-1</sup> in all the weed-free plots both years  
 20 and yields were similar to the amount harvested at Beresford (Table 2). Adding water did  
 21 not increase yields in weed-free plots in 2000 but increased yield by 15% in 2001. Weed  
 22 biomass was similar to Beresford and was greater in 2001 than in 2000.

23 Yield losses due to weeds at Brookings were greater than 50% in weed/natural rainfall  
 24 treatments in both years and weed/supplemental water treatment in 2001. Based on yield

1 goals and the amount of N in grain, N stress was severe. Unlike Beresford the <sup>15</sup>N values  
 2 suggest that soil-N was a major source of N to plants in all treatments.

3 Yield loss at both sites was attributed to weed competition for both water and N and  
 4 was not attributed to competition for light because corn was taller than the weeds starting  
 5 relatively early in the growing season (V-3 to V-4 growth stage). Total yield loss was  
 6 divided into loss due to water and loss due to N based on  $\Delta$  values of grain and equations  
 7 1 and 2 (Table 3). Yield losses due to N stress at all sites accounted for over 70% of the  
 8 total yield loss. While additional water generally increased yield in weedy treatments, the  
 9 amount of yield lost to water stress was similar to or greater than when no water was  
 10 added. This may have been due to where the water resource was obtained. For example,  
 11 nonwatered corn may have had deeper roots and drawn water from areas not accessible to  
 12 weeds whereas corn in watered plots may have had a much shallower root system  
 13 allowing weeds and corn to be in direct competition for surface water. Cultural  
 14 management of corn, such as row spacing (Forcella et al. 1992; Anderson 2000) and N  
 15 application (Nieto and Staniforth 1961; Tollenaar et al. 1994), also influences the amount  
 16 of yield lost due to weeds. Additional studies need to be conducted in areas where  
 17 nutrients are not a limiting factor and across landscapes to better define these complex  
 18 interactions.

19  
 20 Table 3. Total yield loss in weedy plots when compared within a similar water treatment  
 21 and divided into yield loss due to N stress and due to water stress based on  $\delta\Delta$   
 22 compared to the weed-free treatment. The equation  $\delta\Delta = X * (\delta\Delta_{\text{water stress}}) + Y$   
 23  $* (\delta\Delta_{\text{N stress}})$  where, X was the percentage yield loss due to water stress, Y is the  
 24 percentage yield loss due to N stress,  $\delta\Delta$  is the change in  $\Delta$  due to adding weeds,  
 25  $\delta\Delta_{\text{water stress}}$  is the change in  $\Delta$  for each percentage of yield lost to water stress,  
 26 and  $\delta\Delta_{\text{N stress}}$  is the change in  $\Delta$  for each percentage of yield lost due to N stress  
 27 was used. Values used for changes in  $\Delta$  due to water stress were estimated at  
 28 0.0117‰ per 1% change in yield and values of  $\Delta$  due to N stress were estimated  
 29 at -0.007‰ per 1% change in yield.  
 30

Year	Site	Treatment	Change in $\Delta$ due to weeds	Total yield loss due to weeds	Yield loss due to	
					N stress	water stress
					(%)	
2000	Beresford	No water	-0.18	15.1	13.2	1.9
		Water	-0.06	27.9	20.6	7.3
	Brookings	No water	-0.14	54.6	41.6	13.0
		Water	-0.19	27.5	27.3	0.2
2001	Beresford	No water	-0.23	54.2	46.1	8.1
		Water	-0.07	30.6	22.9	7.8
	Brookings	No Water	-0.13	63.1	46.3	16.8
		Water	-0.15	51.8	40.4	11.4

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3 **ACKNOWLEDGMENTS**

4 Partial support provided by USDA-CSREES-NRI.

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