Herbicide Effects on Bermudagrass Lawn Recovery and Crabgrass Control during Spring Root Decline in the North-South Transition Zone

Lloyd M. Callahan¹

Department of Ornamental Horticulture and Landscape Design, The University of Tennessee, Knoxville, TN 37901

Joe W. High, Jr.²

Middle Tennessee Agricultural Experiment Station, The University of Tennessee, Spring Hill, TN 37174

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Abstract. A bermudagrass [*Cynodon dactylon* (L) Pers. × *C. transvaalensis* Burt-Davy 'Tifgreen'] lawn in the transition zone (about lat. 35°N) was treated in late March for 3 years with a high and a low level each of benefin, bensulide, DCPA, oxadiazon, and siduron. Objectives were to determine if relationships exist between field environment and dates of preemergence herbicide applications for large crabgrass (*Digitaria sanguinalis* L. Scop.) control, the spring root decline (SRD) phenomenon, and herbicide phytotoxicity to the bermudagrass. Herbicide treatments in late March generally controlled large crabgrass, reduced total weed competition, and appeared to aid bermudagrass spring growth following winter dormancy. Herbicide injury to 'Tifgreen' bermudagrass roots during SRD does occur under practical field conditions and was more severe when bermudagrass spring green-up occurred closer to the herbicide treatment date, as in 1982. Bermudagrass stand density was significantly reduced with the high level of siduron in 1980 and 1981, and with both levels of oxadiazon and siduron in 1982. Bensulide and oxadiazon, at both levels, gave 92% to 100% crabgrass control during all three treatment years. The high levels of benefin and DCPA in 1980, both levels of benefin and the high level of DCPA in 1981, and both levels of DCPA and the high level of benefin in 1982 gave crabgrass control in excess of 95%. Chemical names used: N-butyl-N-ethyl-2,6-dinitro-4-(trifluoromethyl)-benzenamine (benefin), O,O-bis(1-methylethyl)-S-[2-[(phenylsulfonyl)-amino]ethyl] phosphorodithioate (bensulide), dimethyl 2,3,5,6-tetra-chloro-1,4-benzenedicarboxylate (DCPA), 3-[2,4-dichloro-5-(1-methylethoxy)phenyl]-5-(1,1-dimethylethyl)-1,3,4-oxadiazol-2-(3H)-one (oxadiazon), N-(2-methylcyclohexyl)-N'-phenylurea (siduron).

Large crabgrass continues to be a serious weed in the transition zone (about lat. 35°N). Information is available from northern regions and from the deep southern part of the United States, where temperatures are more consistent, on herbicides giving effective crabgrass control. Sharply fluctuating temperatures, distinctive of the transition zone, make it difficult for either cool- or warm-season turfgrass to grow and compete optimally with crabgrass.

Warm-season turfgrasses in particular have difficulty recover-

ing during the spring green-up period in the transition zone. Part of the problem can be attributed to spring root die-back or spring root decline (SRD) (Beard, 1986; DiPaola and Beard, 1980; DiPaola et al., 1982; Sifers et al., 1985). With the advent of spring green-up, roots of warm-season turfgrasses (i.e., 'Tifgreen' bermudagrass) may rapidly senesce and die. New root initiation occurs ≈1 day thereafter from crowns and from nodes of lateral stems. New roots reach 30 cm in about 20 days. During spring root growth, warm-season turfgrasses become especially susceptible to root-inhibiting preemergence herbicides commonly applied for annual grass control, causing herbicidal root pruning, often followed by loss of turfgrass stand (Callahan, 1976).

According to Beard (1986), a canopy temperature higher than 28°C after shoot green-up is required to induce SRD. Beard also states that the SRD phenomenon is triggered when the soil tem-

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¹Professor, Turfgrass Management.

²Superintendent of the Middle Tennessee Agr. Expt. Sta., Spring Hill.

perature at a 10-cm depth rises to 18°C. Sifers et al (1985), reporting on 8 years of SRD observations in warm-season grasses, states that the winters of 1980 and 1981 at College Station, Texas, were mild and 1982 was very cold. Spring green-up of the warm-season grasses was late during 1980 and 1981, but early in 1982. Spring root growth was very slow in 1980, slow in 1981, and normal in 1982. SRD did not occur in 1980 or 1981, but did in 1982.

Breuminger and Schmidt (1981) applied benefin, DCPA, and oxadiazon to sod-plugs of three bermudagrasses. Postdormant bermudagrass root growth was inhibited when new roots came into contact with the herbicide residues from an application before dormancy. However, the most severe root reduction occurred from herbicide applications immediately before dormancy break.

In other herbicide phytotoxicity studies in bermudagrass, 'Tifgreen' appeared intermediate in root inhibition response to five herbicides (Coats and Ward, 1972). DCPA appeared least inhibitory to roots and bensulide was more inhibitory than benefin and DCPA. Bingham (1967) reported that bensulide, DCPA, and siduron reduced initiation of roots on stolons and prevented elongation of roots in 'Tifgreen' bermudagrass. Other researchers found that selected preemergence herbicides significantly delayed spring dormancy break of bermudagrass and delayed spring growth (Freeman et al., 1975). DCPA delayed growth 3 to 4 weeks and benefin 2 to 3 weeks after untreated plots began growth.

Bensulide and DCPA gave excellent control of large crabgrass when applied to bermudagrass from February to April in the transition zone and high elevations of the upper south (Callahan, 1983; Johnson, 1976a, 1976b, 1982; King and Miller, 1982). Treatments applied in April and May gave poor control (Johnson, 1976a; King and Miller, 1982). Bensulide and DCPA resulted in delayed green-up of bermudagrass (Johnson, 1978a, 1983). Both herbicides browned leaves, and DCPA caused moderate to severe root injury in a 'Tifgreen' bermudagrass green (Callahan, 1976). Both herbicides slightly thinned common bermudagrass in the transition zone (Callahan, 1976), but no effect was observed at southern locations (Johnson, 1976a, 1976b, 1982, 1983).

Benfen treatments in bermudagrass gave good to excellent control of large crabgrass when applied during late March at 3.4 kg·ha⁻¹ or higher (Callahan, 1983; Johnson, 1976a). Two annual applications of at least 3.4 kg·ha⁻¹ in upper south locations, not the transition zone, were required for good control of crabgrass (Johnson, 1978a, 1982). Treatments made at higher elevation sites gave better control of crabgrass than at lower elevations (Johnson, 1978a). Injury to bermudagrass cultivars ranged from slight turf thinning in common (Callahan, 1983), 'Tifgreen' (Callahan, 1976), and 'Tifdwarf' [*C. dactylon* (L.) Pers. × *C. transvaalensis* Burt-Davy] (Johnson, 1983); to delayed green-up of 'Tifgreen', 'Tifdwarf', and 'Tifway' [*C. dactylon* (L.) Pers. × *C. transvaalensis* Burt-Davy] (Johnson, 1978b, 1983); to no observed effects in common bermudagrass (Johnson, 1976a, 1976b, 1978a, 1982; King and Miller, 1982). Degree of injury often reflected regional location, elevation, and growing conditions.

Studies with oxadiazon in the southern United States have generally reported excellent long-season crabgrass control at both low and high elevations (Johnson, 1976a, 1976b, 1982; King and Miller, 1982). Although no injury to common bermudagrass was noted (Johnson, 1976a, 1976b, 1982; King and Miller, 1982), reduced green-up, quality, and stand density were re-

ported for 'Tifgreen', 'Tifdwarf', and 'Tifway' (Johnson, 1978b, 1985). Root growth was reduced in 'Tifgreen' (Johnson, 1980) and severe stand reduction occurred in 'Tifdwarf' (Johnson, 1983).

A high level of siduron gave only moderate large crabgrass control in common bermudagrass in the transition zone (Callahan, 1983). Severe leaf burn and moderate thinning of the common bermudagrass occurred (Callahan, 1983). Siduron caused severe stand loss of 'Tifgreen' under golf green conditions (Callahan, 1976). Phytotoxicity studies resulted in an exclusion statement for bermudagrass on the siduron label.

We determined whether practical relationships exist between dates of preemergence herbicide applications for crabgrass control, the spring root decline phenomenon, herbicide phytotoxicity to bermudagrass, and weather patterns under field conditions.

Materials and Methods

Six herbicides, at two levels each, were applied to an established 'Tifgreen' bermudagrass lawn at the Middle Tennessee Agricultural Experiment Station, Spring Hill, in late Mar. 1980, 1981, and 1982. The test site was maintained on a Maury silt loam (Typic Paleudalf fine, mixed, mesic) soil that had a pH of 6.4 and high levels of available phosphorus (72 kg·ha⁻¹) and potassium (246 kg·ha⁻¹). Soils in this region are naturally high in phosphorus and give no measurable plant response to P treatment. The test site was divided into three sub-test areas adjacent to each other.

Maintenance fertilizer was applied about 1 Apr., 15 May, 1 July, and 1 Sept. of each year, except in crabgrass-seeded strips. Nitrogen, as ammonium nitrate, was applied at 49 kg·ha⁻¹ on each date. Potash, as muriate of potash, was applied at 59 kg·ha⁻¹ in April and September. Plots were mowed weekly at a 3.8-cm cutting height and clippings dropped. Irrigation was applied to water in herbicides on the date of application and thereafter only during July and August as needed, except for 50 mm of irrigation applied during June 1982. No fungicides, insecticides, or additional herbicides were applied.

Large crabgrass was seeded into 1.8-m-wide strips across each plot with a 0.9-m-wide gravity flow spreader at 245 kg·ha⁻¹ on 29 Oct. 1979, 4 Nov. 1980, and 2 Nov. 1981. Just before seeding, plots were vertically grooved with a dethatching machine and vacuumed. Uniform stands of crabgrass developed each spring in untreated check plots and in border strips.

Each year, herbicide treatments were made in a separate sub-test area with no repeat treatments made in a previously treated area. Treatment dates were 24 Mar. 1980, 24 Mar. 1981, and 22 Mar. 1982. Herbicide formulations [granular (G) or wettable powder (W)] and levels of active ingredients applied in each sub-test area were: benefin (2.5 G) at 2.2 and 4.5 kg·ha⁻¹, bensulide (12.5 G) and DCPA (5 G) at 11.2 and 22.4 kg·ha⁻¹, oxadiazon (2 G) at 4.5 and 9.0 kg·ha⁻¹, and siduron (50 W) at 13.4 and 26.9 kg·ha⁻¹. The low quantities were those indicated as low on the label, except for oxadiazon, in which the high label level was used as the lower treatment level. This level was selected for oxadiazon to gain more information on phytotoxicity induced in bermudagrass by the high level.

Granular herbicides were applied with a 0.9-m-wide gravity flow spreader and wettable powder herbicides were applied with a gauged hand-pump compression sprayer delivering 406 liter·ha⁻¹. Treatments were irrigated into the turf with 25 mm of water immediately after the last herbicide was applied.

Arrangement of the field plots was in a randomized complete block design with three replications. Each replication consisted

of all the herbicides at two levels each plus an untreated plot. The treated portion of each plot measured 0.9×6 m with a 0.3-m border between plots and a 1.2-m border between replications.

Each year, sod-plugs were cut and examined in untreated plots, and at random throughout the sub-test area just, before herbicide applications. Bermudagrass plugs, 10 cm in diameter and 7.5 cm deep, were cut with a mechanical sod plugger. Bermudagrass crowns and nodes of rhizomes and stolons were observed to determine persistence, occurrence, and condition of roots. After examination, the sod-plugs were returned to their respective holes and firmed into place. Sod-plugs were cut in each treated plot between 8 and 14 days after herbicides were applied. Observations determined root growth progress and noted herbicide phytotoxicity to roots as root initials came into contact with the herbicide in the soil surface zone. Old live winter roots appeared tan or light-brown and suberized and had whitish-tan root tips with white root hairs. Senescing winter roots were decaying dark-brown to black with collapsed tissue (SRD). New spring roots were clean and white. A live root exhibiting herbicide phytotoxicity appeared white or whitish-tan, with the root tip appearing dark-brown to black and shrunken.

Temperature and rainfall data were determined with the aid of a climatological station immediately adjacent to the test site (Environmental Data and Information Service, 1980-82).

Assessments of bermudagrass stand density in each plot were made throughout spring at monthly intervals following herbicide treatments. Values were based on 0 to 100, where 0 = no bermudagrass and 100 = complete coverage. Foliage coloration of the bermudagrass was recorded for each herbicide treatment as needed. Turfgrass injury was recorded as yellow or brown foliage and used to aid interpretation of results. Crabgrass control was assessed 13 to 14 weeks after herbicide application as density in each plot and converted to percent control based on density in untreated plots. Values reflect effective weed control before chemical dissipation appeared significant. Plot composition as percent grass, total weeds, or bare ground were recorded on the same dates. Reported bermudagrass stand densities generally reflect peak turf stand loss. Results were subjected to analysis of variance and mean separation with the Waller-Duncan K-ratio *t* test at the 0.05 level of probability.

Results and Discussion

Rainfall was plentiful (Environmental Data and Information Service, 1980-82), i.e., either normal or above for this location (see Tables 1, 3, and 4). Winter and spring temperatures for these three years generally were warm. Well-defined SRD (Beard, 1986; DiPaola et al., 1980, 1982; Sifers et al., 1985) occurs with a cold winter followed by a normal or early spring green-up, resulting in total rapid root decline in 1 to 2 days after shoot green-up with new root initials occurring 1 day later.

Temperature patterns at the plots in 1980 were close to normal, which was generally a mild winter and spring (Table 1). Turfgrass shoot canopy temperatures did not exceed 28C until 23, 24, and 25 Apr. (Table 2). The soil at the 10-cm depth reached 18C on 8 Mar., and ranged between 18 and 27C during 28 days in April. These soil temperatures induced shoot green-up beginning 6 Apr. 1980.

Temperature patterns in 1981 were slightly milder than 1980 (Table 3). The shoot canopy did not exceed 28C until 11 Apr.; for 6 days between 11 and 29 Apr. the canopy ranged between 28 and 29C (Table 2). The soil at the 10-cm depth reached 22C

Table 1. Temperatures of turfgrass sod canopy and soil depth at 10 cm and rainfall totals at the Spring Hill Agr. Expt. Sta., Jan.-June 1980.*

Month	Rainfall (mm)	No. days canopy temp. (°C) was above			No. days soil temp. (°C) at 10-cm depth was above		
		21	28	32	18	21	28
Jan.	10						
Feb.	15						
Mar.	25						
Apr.	35						
May	45						
June	55						

*Environmental Data and Information Service (1980-82).

*March, rainfall includes 25 mm of irrigation applied 24 Mar. to water-in herbicides.

Table 2. Chronology of events for 1980, 1981, and 1982.

Event	1980	1981	1982
Canopy temp. exceeds 28C	23-25 Apr.	11-29 Apr. (6 days)	18-20 Mar.
10-cm soil temp. exceeds 18C	8 Mar. + 28 days in April	31 Mar. + all of April	16-26 Mar.
Herbicide applied	24 Mar.	24 Mar.	22 Mar.
Shoot greenup (new leaves)	6 Apr.	2 Apr.	18 Mar.
Partial SRD	8 Apr.	4 Apr.	20-22 Mar.
New root initials (estimated)	10 Apr.	6-7 Apr.	23-25 Mar.
Days from herbicide treatment to new roots	18	14-15	1-3
Crabgrass date of germination	22 Apr.	18 Apr.	11 Apr.
Peak crabgrass germination	Late May	Mid-May	Early May

Table 3. Temperatures of turfgrass sod canopy and soil depth at 10 cm and rainfall totals at the Spring Hill Agr. Expt. Sta., Jan.-June 1981.*

Month	Rainfall (mm)	No. days canopy temp. (°C) was above			No. days soil temp. (°C) at 10-cm depth was above		
		21	28	32	18	21	28
Jan.	10						
Feb.	15						
Mar.	25						
Apr.	35						
May	45						
June	55						

*Environmental Data and Information Service (1980-82).

*March rainfall includes 25 mm of irrigation applied 24 Mar. to water-in herbicides.

on 31 Mar. and, over the next 30 days, ranged between 19 and 28C. Shoot green-up began on 2 Apr.

The warmest of the three years was 1982 (Table 4). Canopy temperatures exceeded 28C on 18, 19, and 20 Mar. (Table 2). The soil at the 10-cm depth was 18 to 22C on 8 days between 16 and 26 Mar., and exceeded 28C on 9 days between 1 and 29 Apr. Shoot green-up began early on 18 Mar.

Table 4. Temperatures of turfgrass sod canopy and soil depth at 10 cm and rainfall totals at the Spring Hill Agr. Expt. Sta., Jan.-June 1982.^z

Month	Rainfall (mm)	No. days canopy temp. (°C) was above			No. days soil temp. (°C) at 10 cm depth was above		
		21	28	32	18	21	28
January	140	0	0	0	0	0	0
February	110	3	0	0	0	0	0
March	120 ^y	9	3	0	8	3	0
April	100	10	1	0	12	3	0
May	90	30	20	1	31	29	20
June	70 ^x	30	15	5	30	30	26

^xEnvironmental Data and Information Service (1980-82).

^yMarch rainfall includes 25 mm of irrigation applied 22 Mar. to water-in herbicides.

^zJune rainfall includes 50 mm of irrigation.

A chronology of herbicide treatment dates, bermudagrass green-up, SRD occurrence, and new root initiation for the three test years is given in Table 2. In 1980, roots were checked on 24 Mar. when all appeared alive and were suberized and tan or whitish-tan. No new root initials were observed. On 8 Apr. roots were in a state of partial SRD, with no new white spring root initials showing. We estimated new root initials to have started 10 Apr. There were $\approx$ 18 days elapsed from the herbicide treatment date to new root initials. Observations 17 Apr. revealed partial root stunting (pruning) and root tip rotting as a result of root initials coming into contact with the herbicide in the soil surface. Heavy rains occurred during Mar. 1980 (Table 1). The highest bermudagrass stand density, or lowest herbicide phytotoxicity to the bermudagrass, for the three test years was recorded during 1980 (Table 5).

Sod-plug examinations on 24 Mar. 1981 revealed roots that appeared alive, were suberized, tan or whitish-tan, and with live root tips. No new root initials were observed. On 7 Apr., many new roots were beginning from crowns and from stolon and rhizome nodes. However, some live winter roots persisted.

We estimated that partial SRD occurred 4 Apr. and new roots began 6 Apr. There were $\approx$ 14 days from herbicide treatments to new root initials. Observations on 13 Apr. showed partial root pruning. Bermudagrass stand densities recorded during 1981 generally were not as high as in 1980 (Table 5).

In 1982 herbicides were applied 4 days after leaf budbreak. A warm March was followed by a cool April. Sod-plugs checked on 22 Mar. showed a mix of residual live winter roots, but no new spring roots. On 30 Mar., many new roots were developing but were severely stunted and partially rotted. Thus, we estimated that new root growth began between 1 and 3 days following herbicide applications.

In 1982, new spring roots were exposed to herbicides applied only 1 to 3 days earlier (Table 5). No rain fell during this period, but 25 mm of irrigation was applied immediately following herbicide applications on 22 Mar. to water-in the herbicides; thus, they remained concentrated in the soil surface zone. The most severe herbicide-induced root pruning, or rotting and stunting of root initials, as they came into contact with the herbicides in the soil surface occurred in 1982, the same year that the most severe reduction in bermudagrass stand densities occurred. None of the herbicides significantly aided in increasing density of bermudagrass by eliminating crabgrass competition during 1982. Bermudagrass stand densities following both levels of benefin, bensulide, and DCPA were not significantly different than in untreated plots (Table 5). Stand densities significantly lower than in untreated plots resulted with both levels of oxadiazon and siduron.

The highest bermudagrass stand densities occurred in 1980 (Table 5). About 18 days elapsed between herbicide treatments and new spring root formation. Rainfall on 24 Mar., and during the following 18 days, totaled 115 mm. This amount would be expected to have some diluting effect on the herbicides, thus reducing the concentration of the chemicals in the soil surface. Bermudagrass stand densities following treatment with both levels of bensulide, DCPA, and oxadiazon were significantly higher than in control plots (Table 5). This increase in stand densities appeared to be aided by herbicides eliminating crabgrass competition and some herbicide residue dilution by rainfall. The

Table 5. Plot composition (%) of 'Tifgreen' bermudagrass, total weeds, and bare ground following herbicide treatments in late Mar. 1980-82.^{z,y}

		Plot composition*								
		1980			1981			1982		
Herbicide	Quantity (kg·ha ⁻¹)	Bermudagrass	Total weeds	Bare ground	Bermudagrass	Total weeds	Bare ground	Bermudagrass	Total weeds	Bare ground
Percent										
DCPA	11.2	73 a	20	7	68 ab	25	7	47 a	38	15
	22.4	69 ab	17	14	58 bc	25	17	42 a	40	18
Oxadiazon	4.5	73 a	15	12	73 a	23	4	28 bc	51	21
	9.0	69 ab	17	14	63 abc	18	19	22 c	45	33
Bensulide	11.2	72 a	18	10	57 c	22	21	42 a	39	19
	22.4	70 ab	15	15	55 c	25	20	37 ab	40	23
Benefin	2.2	61 bc	32	7	68 ab	18	14	43 a	40	17
	4.5	54 c	22	24	60 bc	15	25	42 a	30	28
Siduron	13.4	55 c	21	24	42 d	38	20	10 d	42	48
	26.9	30 d	24	46	18 e	37	45	4 d	31	65
None (control)		54 c	41	5	40 d	44	6	47 a	49	4

^xHerbicides applied in independent plots on 24 Mar. 1980, 24 Mar. 1981, and 22 Mar. 1982.

^yValues are means of three replications. Means within columns followed by a common letter are not significant at the 5% level of probability based on the Waller-Duncan K-ratio *t* test.

^zPlot composition consists of 'Tifgreen' bermudagrass, total weeds (including crabgrass), and bare ground and are the means, respectively, for 23 June 1980, 29 June 1981, and 21 June 1982.

high level of siduron remained significantly phytotoxic to the bermudagrass.

Crabgrass germination in the middle Tennessee region of the transition zone can be expected to occur anytime during April and peak in May (Table 2), thus necessitating preemergence herbicide treatments during late March.

Results of these studies indicate improved weed control with preemergence herbicides when the chemical persistence time between herbicide treatment and crabgrass germination is relatively short. The shortest herbicide persistence time to crabgrass germination was 20 days, which occurred during 1982. Only 40 mm of water from rainfall and irrigation occurred during this period, which should have favored a high active concentration of herbicide in the soil surface. The most effective overall crabgrass control, as determined by the effectiveness of briefly persisting herbicides, occurred during 1982 (Table 6). The least effective overall crabgrass control occurred during 1980, with 29 days between herbicide treatments and crabgrass germination. Rainfall and irrigation water totaling 210 mm during this period may have contributed to reduced crabgrass control due to increased herbicide breakdown and dissipation. Crabgrass control during 1981 was, intermediate, following 25 days of herbicide effectiveness against crabgrass germination; 170 mm of rainfall and irrigation wetted the plots during this period.

The most effective crabgrass control was achieved with both levels of bensulide and oxadiazon, giving 92% to 100% control during all three treatment years (Table 6). The high levels of benefin and DCPA in 1980, both levels of benefin and the high level of DCPA in 1981, and both levels of DCPA and the high level of benefin in 1982 gave 96% to 100% crabgrass control. Siduron gave poor crabgrass control during 1980 and 1981, and gave only 89% control with the high level during the shortest interval (20 days) between herbicide application and crabgrass

germination during 1982. Siduron generally exhibits a short residue period (Callahan 1983).

These investigations indicate that herbicide injury to 'Tifgreen' bermudagrass roots during SRD does occur under practical field conditions. Root injury was greater with a shorter herbicide residue period between the date of chemical treatment and the date of new root development, as occurred in 1982. Herbicide treatments in late March gave excellent crabgrass control, generally reduced total weed competition, and appeared to aid bermudagrass spring growth following winter dormancy, especially under conditions that existed in 1980.

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Table 6. Large crabgrass control (%) in a 'Tifgreen' bermudagrass lawn following herbicide treatments in late Mar. 1980, 1981, and 1982.^{1,2}

Herbicide	Quantity (kg·ha ⁻¹)	Crabgrass control ³		
		1980	1981	1982
		Percent		
DCPA	11.2	83 b	76 b	96 a
	22.4	100 a	100 a	100 a
Oxadiazon	4.5	100 a	100 a	100 a
	9.0	100 a	100 a	100 a
Bensulide	11.2	92 ab	100 a	100 a
	22.4	100 a	100 a	100 a
Benefin	2.2	84 b	100 a	89 b
	4.5	100 a	100 a	98 a
Siduron	13.4	49 d	34 d	51 d
	26.9	67 c	60 c	89 b

¹Herbicides applied in independent plots on 24 Mar. 1980, 24 Mar. 1981, and 22 Mar. 1982.

²Values are means of three replications. Means within columns followed by a common letter are not significant at the 5% level of probability based on the Waller-Duncan K-ratio *t* test.

³Values reported are for 23 June 1980, 29 June 1981, and 21 June 1982.