Control of Annual Weedy Grasses in a Bentgrass Green with Treatment Programs of Tri-calcium Arsenate

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Abstract. A creeping bentgrass (*Agrostis palustris* Huds. 'Pennncross') green was treated with flowable tri-calcium arsenate (Ca-Ars) in increment levels of 17 or 34 kg-ha⁻¹ in 12 multiple treatment date programs. Treatments were made over 4 years to determine effectiveness of initial applications and accumulated residues in controlling annual bluegrass (*Poa annua* var. *annua* L.) and large crabgrass (*Digitaria sanguinalis* L. Scop.) and to evaluate the phytotoxicity to the bentgrass. Multiple treatments of Ca-Ars at increments of 17 or 34 kg-ha⁻¹ effectively controlled annual bluegrass and large crabgrass when cumulative application amounts totaled at least 136 kg-ha⁻¹. Excellent control of annual bluegrass was achieved by timing treatments and soil residue buildup totals to coincide with the major germination and regrowth period of late winter to early spring. Optimum timing included treatments during the fall and spring. This treatment sequence also gave excellent control of crabgrass. Sustained control of both weeds was achieved when continued low level follow-up applications totaled >136 kg-ha⁻¹. Pennncross bentgrass appeared tolerant of Ca-Ars treatments totaling as high as 272 kg-ha⁻¹. Arsenic apparently influenced thatch accumulation by killing earthworms.

Turfgrass managers and researchers have been using pre-emergence herbicides to control annual bluegrass and crabgrass for several decades. Many chemicals have been effective in controlling crabgrass (Callahan, 1986; Hall et al., 1974; Jag-schitz, 1972; Juska, 1961; Murray et al., 1983). However, chemical controls for annual bluegrass have been only partially successful (Carrow and Rieke, 1977; Daniel, 1955; Freeborg and Daniel, 1972; Kerr, 1969). One of the more successful herbicides for annual bluegrass control has been calcium arsenate (Ca-Ars), but incorrect timing of a single application often resulted in poor success (Carrow and Rieke, 1977; Daniel, 1955; Freeborg and Daniel, 1972; Kerr, 1969). Arsenical have been used as herbicides since the 1920s (Ross and Lembi, 1985) and were in use on >2000 golf courses to control annual bluegrass before 1972 (Freeborg and Daniel, 1972).

Although arsenic can be an effective herbicide for the control of annual bluegrass and crabgrass, it also has the potential to be phytotoxic to turfgrasses (Callahan, 1972, 1976; Carrow et al., 1975; Cole and Turgeon, 1978; Ross and Lembi, 1985; Turgeon et al., 1974). The chances for phytotoxicity are great when arsenic is applied as an annual preemergence treatment at a single very high rate. Thus, determining proper rates, timing, and frequency of treatments becomes a very important factor in safety to the turfgrass (Daniel, 1955; Kerr, 1969).

Reports vary on the influence of P on herbicidal activity of arsenic and the phytotoxicity of arsenic to turfgrasses. According to Ross and Lembi (1985), arsenic, like P, is tightly bound in soil and resists leaching by water. Elemental arsenic does not break down, so there is potential for accumulation of residues in soil if used repeatedly. Woolson et al. (1973) reported the

amount of P in the soil solution appeared to govern the uptake of arsenic by corn (*Zea mays* L.) plants. When solution P was high, arsenic was apparently less toxic. However, Carrow et al. (1975) found that increased arsenic levels decreased growth of turfgrasses regardless of P levels in soil. Phosphorus had little or no effect on arsenic toxicity exhibited by turfgrass growth even under very high P (4 kg P/100 m²).

Early recommendations advocated that, to increase arsenic uptake for effective annual weed grass control, soil pH should be maintained between 6.0 and 7.8 and P should be reduced so it would not compete with arsenic uptake (Kerr, 1969). However, Juska (1961) reported increased phytotoxicity to turfgrasses and 100% control of annual bluegrass with Ca-Ars at 582 kg-ha⁻¹ in a high P and K loam soil with a pH of 5.5. According to Hall et al. (1974), Ca-Ars at 209 kg-ha⁻¹ significantly reduced turfgrass root numbers and controlled crabgrass when applied to a soil high in P, medium in K, and with a pH of 6.0.

Arsenic can affect turfgrass quality by influencing thatch accumulation. Turgeon et al. (1974) found thatch to increase in a 'Merion' Kentucky bluegrass (*Poa pratensis* L.) lawn following 8 years of annual Ca-Ars treatments at 683 kg-ha⁻¹. They attributed thatch buildup to elimination of earthworms (*Lumbricus terrestris* Linn.) since Ca-Ars functions also as an insecticide. In a subsequent study, Turgeon et al. (1975) showed significant thatch increases in a 'Kenblue' Kentucky bluegrass lawn following four annual applications of Ca-Ars at 439 kg-ha⁻¹. Again, thatch accumulation was associated with a complete lack of earthworms. When the test area was examined for microbial abundance and activity, amount of undecomposed plant material was greatest in arsenic-treated plots in which microbial activity was most severely affected (Cole and Turgeon, 1978). These results suggest that increased residue accumulation was the direct consequence of a reduction in soil microorganisms, earthworms, and insects.

Calcium-arsenate has the characteristics to be an excellent herbicide for selective control of annual bluegrass and crabgrass in turfgrasses generally sensitive to herbicides. This study was

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conducted to determine the effectiveness of coordinated timing and frequency of very low treatment levels of Ca-Ars in gradually removing annual bluegrass and large crabgrass in a 'Penn-cross' bentgrass green. An important aspect of the study included determining the safety of the various accumulated soil residue levels of Ca-Ars to the bentgrass.

Materials and Methods

These investigations were conducted on a PURR-WICK green (Daniel, 1970), 14×20 m in size, newly constructed in 1984 to confine arsenic treatments. The top 20 cm of the root zone over plastic was off-site mixed and consisted of 94.5% medium fraction sand, 2.1% silt, 1.0% clay, and 2.4% organic matter (OM) by weight. The bottom 10 cm of the root zone was 100% medium fraction sand. A laboratory physical analysis of the root zone mixture showed 34% noncapillary and 16% capillary pores. Bulk density was $1.43 \text{ g}\cdot\text{cm}^{-3}$ and infiltration and percolation rate was $21 \text{ cm}\cdot\text{hr}^{-1}$.

Seedbed preparation consisted of thoroughly mixing dolomitic limestone, ammonium nitrate, super phosphate, and sulfate of potash into the top 15 cm of the root zone. An initial soil test indicated a pH of 5.2, 38 kg P/ha, and 235 kg K/ha. A soil test at the conclusion of the study during Fall 1988 showed a pH of 6.4, P at $19 \text{ kg}\cdot\text{ha}^{-1}$, and K at $46 \text{ kg}\cdot\text{ha}^{-1}$. The green was fumigated with methyl bromide at $974 \text{ kg}\cdot\text{ha}^{-1}$ in August and seeded with thiadiazole-treated 'Penn-cross' bentgrass seed 7 Sept. 1984. Bentgrass annual maintenance fertilization totaled 294N-0P-164K $\text{kg}\cdot\text{ha}^{-1}$. Nitrogen applications were divided equally between March, April, May, September, October, and November. Potash applications were divided equally between March, April, September, and October. The green was mowed five times per week at a 4.5-mm cutting height with clippings caught and removed. Irrigation was from one to three times per week, as needed, to prevent wilting, supplying 25 mm of water each time. Fungicides were applied as needed to control parasitic diseases. The test area was lightly dethatched with a vertical mower and lightly topdressed with medium fraction sand in April and October of each year for thatch control. No core aeration was performed.

Plot sizes were 1.2×4.2 m arranged in a randomized complete-block design with three replications per treatment and four untreated plots per replication. Harvested and cleaned seed of annual bluegrass and large crabgrass were seeded with a gravity spreader into respective 1.2-m-wide strips across each plot. Just before weed seeding, strips were vertically mowed with a dethatching machine and then vacuumed. Annual bluegrass was seeded at $244 \text{ kg}\cdot\text{ha}^{-1}$ $\approx$ 1 Feb. and again 15 Aug. and large crabgrass was seeded at $488 \text{ kg}\cdot\text{ha}^{-1}$ $\approx$ 1 Feb. Very high seedings of $488 \text{ kg}\cdot\text{ha}^{-1}$ were used for crabgrass for initial and annual reseeds as compared to annual bluegrass seedings of $244 \text{ kg}\cdot\text{ha}^{-1}$. Previous research using $244 \text{ kg}\cdot\text{ha}^{-1}$ of crabgrass in very high porosity greens indicated a need to increase the seeding amount considerably to assure a higher percent of annual germination in order to achieve more accurate weed control results (Callahan, 1986). The high seeding rates were necessary to sustain the sequential type of results required in this study.

Seeding of weed grasses began 1 Feb. 1985 and continued annually to 1 Feb. 1988. Because of the competitive nature of bentgrass and the need to maintain continuous infestations of the target weedy grasses, the weed grass strips received no maintenance fertilizations. Annual reseeding of a fresh supply of annual bluegrass and crabgrass posed a severe test on the effectiveness of the Ca-Ars treatment programs unlike normal

infestations under natural golf green conditions. However, re-seeding was necessary to test the effectiveness of the widely spaced multiple treatment date programs and the effectiveness of soil residues of arsenic in controlling the weeds.

All arsenic treatments were tri-calcium arsenate, 26% flowable, and were applied with a gauged, pressurized, hand-held sprayer delivering $406 \text{ liter}\cdot\text{ha}^{-1}$. We used Ca-Ars at either 17 or $34 \text{ kg}\cdot\text{ha}^{-1}$, depending upon which treatment program was being applied. The entire green was irrigated with 25 mm of water immediately following the last Ca-Ars application for each date. All Ca-Ars treatments were applied on about the 15th of each month in each of the respective programs. Calcium-arsenate treatment programs by year are shown in Table 1.

A single Ca-Ars treatment (programs 11 and 12) was made 1 Oct. 1984, on bentgrass seedlings when they were $\approx$ 2 weeks old. Intended follow-up treatments were omitted due to extensive kill of the seedlings and the need for reseedling. The first series of treatment programs began 15 Mar. 1985 and ended 15 Nov. 1986. After completion of the first series of programs and data evaluation, a follow-up series of programs was started 15 Mar. 1987 and ended 15 May 1988. Treatment programs consisted of applications of Ca-Ars at 17 and/or $34 \text{ kg}\cdot\text{ha}^{-1}$ applied in variable combinations in March, April, May, September, October, and November.

Visual assessments of bentgrass stand density in each plot were based on percent sod cover and reflect the portion of the plot not seeded to weed grasses. Foliage coloration of bentgrass was recorded weekly and included leaf blade reaction to arsenic as yellowing or browning, which was used to aid interpretation of results. Annual bluegrass and crabgrass control was assessed by visual density of each in their respective plots and converted to percent control relative to percentages of these weeds in untreated control plots. Calcium-arsenate treatments were considered effective when they resulted in weedy grass control $\geq 90\%$. Data were collected weekly throughout the year and subjected to analysis of variance consistent with a randomized complete-block design and completed via PROC GLM in SAS (Sas Institute, Cary, N.C.). Means were partitioned using least significant differences with alpha-risk set at 0.05.

Thatch measurements were taken annually in the fall by measuring the thickness of the thatch layer in four randomly collected profile plugs $1.6 \times 8 \times 3$ cm (width/length/depth) from each plot. Earthworm activity following water saturations of plots was observed during Fall 1987 and Spring and Summer 1988. In Oct. 1988, four 10-cm-dia. $\times$ 18-cm-deep soil cores were examined in all plots for earthworms.

Results and Discussion

Annual bluegrass control. Calcium-arsenate totals and treatment concentrations during 1985 were insufficient to produce desired annual bluegrass control of $\geq 90\%$.

By the end of Spring 1986, program 8 was giving 100% control with an accumulated Ca-Ars total of $170 \text{ kg}\cdot\text{ha}^{-1}$ (Tables 1 and 2). However, no follow-up treatments were made during Fall 1986 and program 8 dropped to 73% control. Program 7 gave 93% control by June 1986 with an accumulated Ca-Ars total of $136 \text{ kg}\cdot\text{ha}^{-1}$. However, with no fall follow-up treatments, program 7 dropped to 61% control. The only other effective program in 1986 was program 15, which gave 90% control with an accumulated Ca-Ars total of $136 \text{ kg}\cdot\text{ha}^{-1}$. Results for 1986 indicate that when Ca-Ars accumulated totals were inadequate due to lack of follow-up treatments, and allow-

Table 1. Tri-calcium arsenate treatment programs and sequences in a 'Penncross' bentgrass green from 1984 to 1988.

Program no. ^z	Applications of Ca-Ars (kg·ha ⁻¹) in years indicated	
	1984, 1985, and 1986	1987 and 1988
1	34 kg Sept. + 17 kg Oct. & Nov. 1985	
2	34 kg Sept., Oct. & Nov. 1985	17 kg Sept., Oct. & Nov. 1987
3	34 kg Mar. + 17 kg Apr. & May 1985	
4	34 kg Mar., Apr., & May 1985	17 kg Mar., Apr., & May 1987
6	34 kg Mar. + 17 kg Apr., May + 34 kg Sept. + 17 kg Oct. & Nov. 1985	17 kg Mar., Apr., & May + 17 kg Sept., Oct., & Nov. 1987
7	34 kg Sept. + 17 kg Oct. & Nov. 1985 + 34 kg Mar. + 17 kg Apr. & May 1986	
8	34 kg Sept. + 17 kg Oct. & Nov. 1985 + 34 kg Mar., Apr., & May 1986	17 kg Sept., Oct., & Nov. 1987 + 17 kg Mar., Apr., & May 1988
11	34 kg Oct. 1984	34 kg Mar. + 17 kg Apr. & May + 34 kg Sept. + 17 kg Oct. & Nov. 1987
12	34 kg Oct. 1984	34 kg Mar., Apr., & May + 34 kg Sept., Oct., & Nov. 1987
13	17 kg Sept. & Nov. 1985 + 17 kg Mar. & Sept. 1986	17 kg Mar. & Apr. + 17 kg Sept. & Oct. 1987
14	17 kg Sept., Oct. & Nov. 1985 + 17 kg Mar., Apr., & Sept. 1986	17 kg Mar. & Apr. + 17 kg Sept., Oct., & Nov. 1987
15	17 kg Sept., Oct., & Nov. 1985 + 17 kg Mar. & Apr. 1986 + 17 kg Sept., Oct., & Nov. 1986	17 kg Mar., Apr., & May + 17 kg Sept., Oct., & Nov. 1987

^zPrograms 5, 9, 10, and 16 were untreated controls.

Table 2. Annual bluegrass control with treatment programs of tricalcium arsenate compared to untreated controls in a 'Penncross' bentgrass green from 1985 to 1988.^z

Program no. ^y	Tri-calcium arsenate totals by year (kg·ha ⁻¹)		Annual bluegrass control following seasonal treatments (%) ^x					
			1985		1986		1987	
			22	5	21	5	24	3
			Nov.	June	Nov.	June	Nov.	June
1		68	69	46	6	0	0	0
2		102	79	68	12	0	58	23
3		68	6	0	0	0	0	0
4		102	29	33	6	61	31	14
6		136	71	73	21	100	100	100
7		68 68	70	93	61	53	21	4
8		68 102 51	64	100	73	61	100	100
11	34		0	0	0	71	97	100
12	34		0	0	0	95	100	100
13		34 34 68	26	60	30	77	85	97
14		51 51 85	39	81	70	100	100	100
15		51 85 102	30	81	90	100	100	100
LSD (0.05) ^w			7.9	3.9	4.9	2.9	7.2	3.6

^zAnnual bluegrass was seeded annually in early February and late August from 1985 to 1988.

^yPlots 5, 9, 10, and 16 were untreated controls.

^xTable 1 gives expanded treatment dates and rates within years.

^wData are means of three replications and were partitioned using LSD with alpha-risk set at 0.05.

ing several months for dissipation, control of annual bluegrass was gradually or drastically reduced.

With the combination of new Ca-Ars applications and soil residue accumulations during 1987, effectiveness of the treatment programs improved substantially (Tables 1 and 2). Annual bluegrass control was 100% by 5 June 1987 with programs 6, 14, and 15, and 95% with program 12. Calcium-arsenate totals by 5 June were 187, 136, 187, and 136 kg·ha⁻¹, respectively, for programs 6, 14, 15, and 12. By 24 Nov. 1987, annual bluegrass control was 100% with programs 6, 8, 12, 14, and

15, and 97% with program 11. Totals of Ca-Ars by 24 Nov. were 238, 221, 238, 187, 238, and 170 kg·ha⁻¹, respectively, for programs 6, 8, 12, 14, 15, and 11. With the substantial increases in Ca-Ars totals during Fall 1987, selected programs considerably increased in effectiveness of annual bluegrass control.

Program 8 treatments were the only applications made during 1988 and were applied only during the spring (Tables 1 and 2). Annual bluegrass control with other programs was the result of soil residue 'carryover from treatments made during previous

years. Annual bluegrass control was 100% during 1988 with programs 6, 8, 11, 12, 14, and 15, and 97% with program 13. By 3 June 1988, Ca-Ars totals for program 8 had increased to 272 kg·ha⁻¹. Calcium-arsenate for programs 6, 11, 12, 14, and 15 remained at the levels they had reached in Nov. 1987. Program 13 gave only 85% control by 24 Nov. 1987 with a Ca-Ars total of 136 kg·ha⁻¹. However, control effectiveness of program 13 reached 97% by Spring 1988 with no additional Ca-Ars treatments due to sufficient soil residues being present during this late-winter germination and regrowth period for annual bluegrass.

In summary, the low treatment levels of either 17 or 34 kg·ha⁻¹ proved effective in gradually removing annual bluegrass from the bentgrass when treatment totals reached at least 136 kg·ha⁻¹. Annual bluegrass control was sustained with continued follow-up treatments totaling >136 kg·ha⁻¹. Control appeared to be most effective when treatments were applied during fall (September, October, and November) followed by spring treatments (March, April, and May). The most effective programs, which reached 100% control of annual bluegrass, were 6, 8, 11, 12, 13, 14, and 15. Programs giving sustained control for the longest period were 6, 8, 14, and 15.

Large crabgrass control. In Spring 1985, programs 3, 4, and 6 gave 100% control of crabgrass with Ca-Ars totals of 68 or 102 kg·ha⁻¹ applied in Mar., Apr., and May 1985 (Tables 1 and 3). By Spring 1986, crabgrass control was 96% to 100% with programs 2, 4, 7, 8, and 15. Calcium-arsenate totals increased to 102, 102, 136, 170, and 85 kg·ha⁻¹, respectively, for programs 2, 4, 7, 8, and 15.

On 12 June 1987, crabgrass control ranged from 90% to 99% for programs 6, 11, 12, 13, 14, and 15 (Tables 1 and 3). Calcium-arsenate soil residue carryover and renewal treatments should have been sufficient to give 100% control. By 12 June 1987, the test area had already received three heavy crabgrass seedlings. Apparently, dissipation and tie-up of arsenic in soil, combined with the heavy supply of crabgrass seed, diminished the effectiveness of Ca-Ars in controlling crabgrass.

By 22 June 1988, high soil arsenic residues, combined with

current treatments, were sufficient to overcome the heavy crabgrass seed reserve, and 90% to 100% control was achieved with programs 8, 12, and 15 (Tables 1 and 3). Calcium-arsenate totals by this time had reached 272, 238, and 238 kg·ha⁻¹, respectively, for programs 8, 12, and 15. By 14 Oct. 1988, only program 8 was able to sustain effective control of crabgrass with the ultra-high soil residues of 272 kg·ha⁻¹.

Arsenic effects on bentgrass. A single Ca-Ars treatment of 34 kg·ha⁻¹ was made 1 Oct. 1984 in two plots (programs 11 and 12) on 2-week-old 'Penncross' bentgrass seedlings (Table 1). The intention was to follow-up with two separate multiple treatment programs on the seedlings. However, the 34 kg·ha⁻¹ treatments killed 98% and 95% of the bentgrass, respectively, in plots 11 and 12 (Tables 1 and 4), necessitating reseeding. Four reseeds were made in late Oct. and mid-Nov. 1984 and in mid-Feb. and mid-Mar. 1985. Seedling stand density on 12 June 1985² reached 95% and 99%, respectively, in plots 11 and 12 (Table 4).

'Penncross' bentgrass in the test area had reached an average density of 89%, omitting plots 11 and 12, by 8 Oct. 1984 (Table 4). By 12 June 1985, bentgrass average density reached 99%, omitting plots 11 and 12. Formal Ca-Ars treatment programs began 15 Mar. 1985 (Table 1). A few hours after almost every Ca-Ars application, throughout the period of this study, bentgrass foliage exhibited discoloration ranging from a faint to a prominent yellowing that lasted from 2 to 5 weeks. The only time during the entire test period that bentgrass showed any foliage browning was within a 2-week period following the 15 Mar. and 15 Apr. 1985 programs 3, 4, and 6 treatments (Tables 1 and 4). Bentgrass was in a juvenile stage of growth during this period and apparently was mildly vulnerable to arsenic phytotoxicity. Bentgrass stand densities during 1985 that were significantly lower than that of the controls resulted with programs 1 and 11 with densities of 92% and 95%, respectively (Table 4).

Bentgrass stand densities during 1986 that were significantly lower than controls occurred with programs 1 and 8, with densities from 94% to 96% (Tables 1 and 4).

Table 3. Large crabgrass control with treatment programs of tricalcium arsenate compared to untreated controls in a bentgrass green from 1985 to 1988.²

Program no. ^y	Tri-calcium arsenate totals by year (kg·ha ⁻¹)					Crabgrass control following seasonal treatments* (%)						
						1985	1986		1987		1988	
	1984	1985	1986	1987	1988	27 June	19 June	17 Oct.	12 June	29 Sept.	22 June	14 Oct.
1		68				0	49	23	0	0	0	0
2		102		51		0	98	79	11	20	18	2
3		68				100	62	62	0	0	0	0
4		102		51		100	96	81	89	48	42	20
6		136		102		100	89	77	95	94	71	65
7		68	68			0	100	100	77	35	24	9
8		68	102	51	51	0	100	100	84	89	100	100
11	34			136		6	0	0	91	95	82	75
12	34			204		6	0	0	96	100	90	84
13		34	34	68		0	38	70	90	95	57	43
14		51	51	85		0	85	82	93	97	64	56
15		51	85	102		0	100	100	99	100	93	83
LSD (0.05) ^w						4.1	7.2	4.6	10.8	10.5	11.0	9.9

²Large crabgrass was seeded annually in early February from 1985 to 1988.

³Plots 5, 9, 10, and 16 were untreated controls.

^{*}Table 1 gives expanded treatment dates and rates within years.

^wData are means of three replications and were partitioned using LSD with alpha-risk set at 0.05.

Table 4. Stand density of a 'Pennncross' bentgrass green following treatment programs of tri-calcium arsenate from 1985 to 1988 and compared to untreated controls.^z

Program no.	Ca-Ars totals 1984-88 (kg·ha ⁻¹)	Bentgrass stand density following seasonal treatments (%) ^y				
		1984	1985		1986	
		8 Oct.	12 June	20 Nov.	12 June	26 Nov.
1	68	88	100	92	94	96
2	153	91	100	98	98	97
3	68	91	96	98	96	99
4	153	91	96	100	98	99
6	238	87	99	100	97	99
7	136	90	100	97	97	99
8	272	89	100	97	97	96
11	170	2	95	100	97	98
12	238	5	99	100	97	97
13	136	93	100	98	96	98
14	187	89	100	99	96	98
15	238	87	100	97	96	97
Control		88	99	99	97	99
LSD (0.05) ^w		5.6	4.3	3.4	2.3	2.7

^yBentgrass was seeded 7 Sept. 1984 and germinated 14 Sept. 1984.

^zBentgrass stand density percentages reflect the portion of the plot not seeded to weeds.

^xCheck or untreated plot reflects four controls per replication (plots 5, 9, 10, and 16). None of the differences were significant in 1987 or 1988.

^wData are means of three replications and were partitioned using LSD with alpha-risk set at 0.05.

Bentgrass stand densities for all Ca-Ars programs during 1987 and 1988 ranged from 93% to 99%, with none of the differences being significant. Calcium-arsenate totals for the leading weed control programs by 1987 and 1988 had reached levels of 238 kg·ha⁻¹ for programs 6, 12, and 15, and 272 kg·ha⁻¹ for program 8. In general, mature 'Pennncross' bentgrass maintained under golf-green conditions appeared tolerant of Ca-Ars when treatments were applied at increments of 17 or 34 kg·ha⁻¹ in multi-date treatment programs.

Arsenic influence on thatch accumulation. Significant levels of thatch accumulation began developing during 1986 with programs 6 through 15 (Table 5). Significant thatch increases above untreated controls during 1987 occurred with programs 2, 4, 5, 8, 11, 12, 13, 14, and 15 with thatch thicknesses from 5.9 to 7.2 mm. Program 8, with a thick thatch buildup (7.2 mm), contributed to mild mower scalping in all plot replications during Aug. 1987. By Oct. 1988 all Ca-Ars program treatments were completed. The highest thatch buildup (8.7 and 8.0 mm) occurred with programs 8 and 12, respectively (Table 5). Program 8 totaled 272 kg Ca-Ars/ha⁻¹ and program 12 totaled 238 kg·ha⁻¹.

No earthworms were found in any of the Ca-Ars program treatment plots (Table 5). Control plots contained 54/m². As indicated by Turgeon et al. (1974), Ca-Ars can function as an insecticide and is toxic to earthworms. Based on the buildup of thatch and absence of earthworm activity in Ca-Ars program plots, arsenic clearly influences thatch accumulation.

Phosphorus and pH influence on arsenic. An initial soil test for P showed 38 kg·ha⁻¹, which was high. Following 5 years of maintenance fertilization omitting P and 4 years of Ca-Ars treatments, a soil test in Fall 1988 showed 19 kg P/ha, which was low. Due to the very high porosity of the green and lack of P fertilization, the considerable decrease in soil P was ex-

Table 5. Thatch thickness in a 'Pennncross' bentgrass green following treatment programs of tri-calcium arsenate from 1985 to 1988.^z

Program no.	Ca-Ars totals 1984-88 (kg·ha ⁻¹)	Mean thatch measurements in October of each year (mm)			
		1985	1986	1987	1988
1	68	10.7	4.5	5.1	5.7
2	153	10.7	5.0	6.1	6.0
3	68	11.0	4.4	5.3	5.7
4	153	10.7	5.1	6.0	5.7
6	238	10.3	6.3	6.1	6.0
7	136	11.0	5.3	5.3	5.7
8	272	10.0	6.8	7.2	8.7
11	170	10.7	5.3	6.7	5.3
12	238	10.3	5.5	6.7	8.0
13	136	10.0	5.6	5.9	7.3
14	187	10.3	5.3	6.3	6.0
15	238	10.3	6.3	6.8	7.0
Control ^y		10.7	4.5	5.0	4.7
LSD (0.05) ^x		NS	0.68	0.63	0.94

^yThe green was vertically mowed and sand topdressed September and October of each year beginning just after thatch measurements were made.

^xCheck or untreated plot reflects four controls per replication (plots 5, 9, 10, and 16).

^zData are means of three replications and were partitioned using LSD with alpha-risk set at 0.05.

petted. Judging by the responses of annual bluegrass, crabgrass, and bentgrass in our study (Tables 2, 3, and 4), the initial high soil P level did not diminish the effect of arsenic toxicity, just as was shown by Carrow et al. (1975). Other researchers used very high single arsenic levels, ranging from 209 to 683 kg·ha⁻¹ (Hall et al., 1974; Juska, 1961; Turgeon et al., 1974, 1975). In this study, very low increment levels of 17 or 34 kg·ha⁻¹ were used with gradual accumulations over 4 years totaling a maximum of 272 kg·ha⁻¹.

The initial soil pH in this study was 5.2 but elevated to 6.4 by the end of the study. There were no clear indications that pH had any influence on arsenic toxicity, as suggested by Kerr (1969), since 100% control of annual bluegrass and crabgrass occurred during the beginning and end of this study (Tables 2 and 3).

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