

Fumigant Alternatives for Methyl Bromide Prior to Turfgrass Establishment¹

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Abstract: Potassium azide (PA) (112 kg/ha), oxadiazon + 1,3-dichloropropene (1,3-D) (168 kg/ha + 140 L/ha), dazomet (392 kg/ha), dazomet + chloropicrin (392 + 168 kg/ha), dazomet + 1,3-D (392 kg/ha + 140 L/ha), iodomethane (IM) (336 kg/ha), metam-sodium (MS) (748 L/ha), MS + chloropicrin (748 L/ha + 168 kg/ha), and MS + 1,3-D (748 + 140 L/ha) were evaluated at Jay and Arcadia, FL, in 1998 and 1999 as alternatives to methyl bromide (MeBr) fumigation for the management of common turfgrass weeds. Potassium azide was as effective as MeBr in controlling 'Coastal' bermudagrass, yellow and purple nutsedges, alexandergrass, broadleaf signalgrass, tall and sharp-pod morningglories, and various winter annual broadleaf weeds, but it failed to provide acceptable control of redroot pigweed. 1,3-Dichloropropene + oxadiazon did not control yellow nutsedge, purple nutsedge, or Coastal bermudagrass. Similarly, this combination treatment failed to control carpetweed but did provide 83% control of the winter annual weed species, 71% control of alexandergrass and broadleaf signalgrass, and $\geq 80\%$ control of tall morningglory, sharp-pod morningglory, and redroot pigweed. Dazomet + combination treatments provided control of Coastal bermudagrass at Jay; however, control of common bermudagrass, alexandergrass, and broadleaf signalgrass was not acceptable at Arcadia. Sedge species control with dazomet + combinations was poor ($< 63\%$) at both sites. Iodomethane, a treatment not yet registered by the U.S. Environmental Protection Agency (EPA), controlled weedy grass species, sedge species, and broadleaf weeds present at the two locations under different environmental conditions. Metam-sodium alone and MS + chloropicrin, tarped and untarped, and MS + 1,3-D provided acceptable weed control; however, MS + chloropicrin covered with a plastic tarp for 48 h was the best MS treatment. Metam-sodium + chloropicrin, with plastic tarp, controlled weedy grass and broadleaf species equal to MeBr; however, unacceptable sedge species control at Jay and Arcadia was 56 and 79%, respectively. Metam-sodium applied alone failed to control redroot pigweed; however, MS + combinations provided control. These studies confirm that no EPA-registered fumigant alternative to MeBr, applied alone or in combination for preplant turf soil fumigation, exists. Consequently, until such time that an effective alternative is identified, turf managers will be forced to forego fumigation, or they will have to choose a less-effective alternative and accept the consequences of contamination.

Nomenclature: Chloropicrin (trichloronitromethane); dazomet; 1,3-dichloropropene; iodomethane; metam-sodium; methyl bromide; oxadiazon; potassium azide; alexandergrass, *Brachiaria plantaginea* (Link) A.S. Hitchc. #³ BRAPL; bermudagrass, *Cynodon dactylon* (L.) Pers. # CYNDA; broadleaf signalgrass, *Brachiaria platyphylla* (Griseb.) Nash # BRAPP; carpetweed, *Mollugo verticillata* L. # MOLVE; purple nutsedge, *Cyperus rotundus* # CYPRO; redroot pigweed, *Amaranthus retroflexus* L. # AMARE; sharp-pod morningglory, *Ipomoea cordatotriloba* Dennstedt # IPOTC; tall morningglory, *Ipomoea purpurea* L. # IPOPU; yellow nutsedge, *Cyperus esculentus* L. # CYPES.

Additional index words: Fumigation, sod, turf.

Abbreviations: 1,3-D, 1,3-dichloropropene; EPA, Environmental Protection Agency; IM, iodomethane; MeBr, methyl bromide; MITC, methyl isothiocyanate; MS, metam-sodium; PA, potassium azide; WAT, weeks after treatment.

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³ Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

INTRODUCTION

Methyl bromide (MeBr) has been the predominant broad-spectrum soil fumigant for controlling pests in several agricultural commodities for many years. First reported as a soil fumigant in 1940, MeBr is now used as a preplant soil fumigant for more than 100 crops, including turfgrass, as well as in postharvest treatment (e.g., citrus) and as a plant quarantine treatment (Noling 1996). Target pest problems include weeds, diseases, and plant-parasitic nematodes.

Renovation of putting greens at Greensboro (NC) Country Club is an early documented use of MeBr (Edwards and Barnes 1958). It has remained the most widely used soil fumigant in the turf industry, including golf courses, sports fields, and sod farms. Methyl bromide fumigation is primarily used to eliminate weeds and to ensure the genetic purity of turfgrasses. This is especially important during the reconstruction and regrassing of existing turf sites, where off-type contamination from vegetative mutations or other previously planted cultivars can occur, and legal action over contaminated sod is an issue. Some states even require the use of a soil fumigant for turfgrasses to be sold as certified sod (Anonymous 1999).

However, MeBr has been targeted for registration cancellation because of environmental concerns. With this cancellation, turfgrass managers will lose an effective, inexpensive, broad-spectrum soil fumigant. Without adequate fumigation, turfgrass managers may be forced to forego planting improved turfgrasses because of concerns over contamination.

Much research on MeBr alternatives has been conducted on commodities such as tomato (*Lycopersicon esculentum* Mill.), pepper (*Capsicum frutescens* L.), and strawberry (*Fragaria* spp.), where diseases and nematodes are the primary MeBr targets (Duniway et al. 1999; Noling and Gilreath 2000). These pests are less important during turf preplant fumigation because turf is grown as a perennial crop, and nematodes and diseases can be expected to reinfest a fumigated area regardless of preplant treatment. Weeds, such as common bermudagrass, off-type hybrid bermudagrass (*Cynodon dactylon* × *C. transvaalensis* Burt-Davy) contaminants, and sedge species, are the pest problems that necessitate fumigation prior to turfgrass establishment. These weeds cannot be effectively controlled with nonselective herbicides prior to sprigging or by selective herbicides during turf establishment (Boyd 1991). Imazapyr at 1.1 kg ae/ha eradicated common bermudagrass, but warm-season turfgrass species could not be planted safely until

the next growing season (Griffin et al. 1994). Furthermore, their study was conducted on a Dothan sandy loam soil, and the authors cautioned against extrapolating their results to other soils and climates. In this same study, multiple applications of glyphosate at 2.2 kg ae/ha failed to eradicate common bermudagrass.

Potential MeBr fumigant replacements include 1,3-dichloropropene (1,3-D), chloropicrin (trichloronitromethane), metam-sodium (MS), dazomet, iodomethane (IM), and potassium azide (PA). 1,3-Dichloropropene was developed in 1943, and was the first effective and inexpensive nematicide for general field use (Noling 1996). 1,3-Dichloropropene provides excellent control of nematodes and some soilborne insects; however, little activity against weeds is obtained at use rates of ≤ 140 L/ha (Noling and Becker 1994). 1,3-Dichloropropene is frequently used in combination with other fumigants, such as chloropicrin and MS, that provide some control of pathogens and weeds. Although 1,3-D at high rates (> 234 L/ha) has been suggested for weed control, replicated research has not validated this observation (T. Weiss, Dow AgroSciences, personal communication).

Chloropicrin has proven to be an effective fungicide; however, it does not have the herbicidal properties of MeBr (Csinos et al. 1997, 2000). For this reason, chloropicrin is used extensively in combination with MeBr, and more recently in combination with 1,3-D.

Metam-sodium is a water-soluble, preplant soil fumigant that has been used in the turf industry to control soil fungi, nematodes, soil insects, and weeds. Because MS must decompose to the biologically active compound methyl isothiocyanate (MITC), inconsistent pest control can occur (Carpenter 1997), especially under soil temperature and moisture extremes. Similarly, MS is soluble and may diffuse out of the soil too quickly, resulting in inadequate accumulation of the active biocide.

Dazomet is a microgranular product that reacts with soil moisture to produce the same biocidal agent (MITC) as MS. Consequently, dazomet responds to environmental factors in the same manner as MS. Furthermore, dazomet's physical characteristics (ultra-fine powder) impose application limitations (e.g., extremely corrosive, vulnerable to drift, equipment must be sealed to limit spillage). Fumigation specifications for dazomet limit its usage because the product label states that at a soil temperature of 10 C (10-cm depth), 22 to 27 d are required for effective fumigation, and for temperatures above 18 C, 10 to 12 d are required (Anonymous 2001). A novel soil-blending process has been developed, where dazomet is incorporated into golf-putting green sand-peat

mix (Anonymous 1995); however, efficacy has not been substantiated in replicated research.

Iodomethane (IM) has biocidal properties analogous to MeBr (Zhang et al. 1997), yet is considered ozone safe because the ozone depletion potential of IM is estimated to be below the level of concern (Albritton and Watson 1992; Ohr et al. 1996). Limited research has demonstrated that IM is equal to or better than MeBr for the control of weeds, nematodes, and soilborne plant pathogenic fungi (Ohr et al. 1996; Zhang et al. 1997). In particular, IM was 1.5 times more effective than MeBr in controlling purple nutsedge (Zhang et al. 1997).

Hill et al. (1953) reported that sodium azide was potentially useful as a herbicide for tobacco (*Nicotina tabacum* L.) plant beds, providing for the eradication of bermudagrass. Danielson (1965, 1973) found that PA successfully killed vegetative propagules of Dutch Iris (*Iris lollandica* Hoog) and mugwort (*Artemisia vulgaris* L.). A U.S. Patent was granted in 1968 for the utilization of PA either alone or in combination with other chemical compounds to kill, deactivate, or regulate the growth of organisms, e.g., plants, fungi, and soil microorganisms.⁴ Potassium azide has not been evaluated in turfgrass systems.

Currently, MeBr alternatives for use in turf preplant soil fumigation have not been identified. Our objective was to compare in replicated studies IM, MS, 1,3-D, chloropicrin, dazomet, and oxadiazon, applied alone or in combination, to determine their effectiveness relative to MeBr fumigation for the management of common turfgrass weeds.

MATERIALS AND METHODS

Experiments were conducted in 1998 and 1999 at two locations in Florida, the West Florida Research and Education Center near Jay, FL, and a commercial sod farm near Arcadia, FL. The soil type at Jay was an Orangeburg sandy loam (fine-loamy, kaolinitic, thermic Typic Kandiudults) with pH 5.5 and 1% organic matter. The soil type at Arcadia was an EauGallie sand (sandy, siliceous, hyperthermic Alfic Alaquods) with a pH 5.0 and 8% organic matter.

Jay. Two weeks prior to fumigation, the total plot area was sprayed with glyphosate (4.2 kg ae/ha) to kill the existing annual weed species and to provide some initial suppression of existing purple nutsedge, Coastal bermudagrass, and 'Pensacola' bahiagrass (*Paspalum notatum* Flugge). The plot area was harrowed and rototilled

several times to prepare the soil for fumigation treatments. Treatments are listed in Table 1. Treatments were applied over a 3-d period starting from July 28, 1998, using the various kinds of application equipment described later. Iodomethane was applied on September 9, 1998. Plots measured 9.1 by 19.8 m and were arranged in a completely randomized block design with four replications. On September 15, 1998, the plots were rototilled, harrowed, and hand sprigged with 'Tifdwarf' bermudagrass at 40 m³/ha. Sprigs were broadcast over the soil surface and inserted into the soil with a double-row coultter (10-cm spacing) sprig planter. Irrigation was applied to encourage turf establishment.

Arcadia. Prior to fumigation, the plot area was sprayed with glyphosate (4.2 kg ae/ha) to kill the existing annual weed species and to provide some initial suppression of existing purple nutsedge, yellow nutsedge, globe sedge (*Cyperus globulosus* Aublet # CYPGL), alexandergrass, broadleaf signalgrass, and common bermudagrass. The plots were then moldboard plowed and cultivated to prepare the soil for fumigation treatments. All treatments listed in Table 1 were applied over a 3-d period, starting from August 25, 1998, with the application equipment described later. Tifdwarf bermudagrass was sprigged, as described earlier, on October 29, 1998 at 40 m³/ha. Plots measured 9.1 by 15.2 m, and treatments were arranged in a completely randomized block design with four replications.

Fumigant Application. Treatment rates are listed in Table 1. Methyl bromide, IM, and chloropicrin were shank injected to a depth of 20 cm with shanks spaced 30 cm apart, using a 10.8-m Hendrix and Dail⁵ fumigation rig. 1,3-Dichloropropene was placed in the soil at a depth of 25 cm, using an 8.7-m Hendrix and Dail broadcast rig with five 46-cm sweeps with three fumigant outlets per sweep, with a cultipacker fitted behind the rig for soil sealing. Dazomet was applied through a Gandy⁶ applicator mounted on a tractor-powered 7.6-m Ferguson TilRovator⁷ fitted with L-shaped tines that incorporated the material to a depth of 5 cm. A Hendrix and Dail power-driven roller attached to the tilrovator smoothed the soil surface to provide a soil seal. Three irrigation cycles, each delivering 1.3 cm of water, were applied 6 to 10 h apart to activate the dazomet.

Potassium azide was dissolved in water and sprayed

⁵ Hendrix and Dail, Inc., 1101 Industrial Boulevard, Greenville, NC 27834.

⁶ Gandy Co., 528 Gandrud Road, Owatonna, MN 55060-0528.

⁷ Ferguson Manufacturing Co., P.O. Box 1098, Suffolk, VA 23439.

⁴ United States Patent 3,376,126.

Table 1. Rates and formulations of fumigants.

Treatment	Rate product/ha	Formulation	Application method ^a	Tarped ^b
Methyl bromide + chloropicrin	549 + 11 kg/ha	98% MeBr + 2% chloropicrin	Shank injected	Yes
Potassium azide	112 kg/ha	98 G	Surface spray fb rototill	Yes
1,3-dichloropropene + oxadiazon	140 L/ha + 168 kg/ha	98% + 2 G	Shank injected + surface broadcast	Yes
Dazomet	392 kg/ha	99 G	Surface broadcast fb rototill fb soil seal	No
Dazomet + chloropicrin	392 + 168 kg/ha	99 G + 99%	Surface broadcast fb rototill fb soil seal + shank injected	No
Dazomet + 1,3-dichloropropene	392 kg/ha + 140 L/ha	99 G + 98%	Surface broadcast fb rototill fb soil seal + shank injected	No
Iodomethane	336 kg/ha	100%	Shank injected	Yes
Metam-sodium	748 L/ha	42%	Surface spray fb rototill fb soil seal	No
Metam-sodium + chloropicrin	748 L/ha + 168 kg/ha	42 + 99%	Surface spray fb rototill fb soil seal shank injected	No
Metam-sodium + chloropicrin tarped	748 L/ha + 168 kg/ha	42 + 99%	Surface spray fb rototill + shank injected	Yes
Metam-sodium + 1,3-dichloropropene	748 + 140 L/ha	42 + 98%	Surface spray fb rototill + shank injected	No
Untreated control				

^a Abbreviation: fb, followed by.^b Tarped = covered with a plastic tarpaulin for 48 h after fumigant application.

Table 2. Effect of fumigants on the control of sedge (*Cyperus*) species.^a

Treatment	Rate product/ha	Jay, FL		Arcadia, FL		
		6 WAT ^b	44 WAT	3 WAT	5 WAT	15 WAT
Methyl bromide + chloropicrin	549 + 11 kg/ha	100	89	100	96	83
Potassium azide	112 kg/ha	75	73	100	97	79
1,3-dichloropropene + oxadiazon	140 L/ha + 168 kg/ha	0	86	0	0	74
Dazomet	392 kg/ha	80	57	78	56	58
Dazomet + chloropicrin	392 + 168 kg/ha	81	63	81	74	48
Dazomet + 1,3-dichloropropene	392 kg/ha + 140 L/ha	51	31	76	70	41
Iodomethane	336 kg/ha	—	84	100	96	81
Metam-sodium	748 L/ha	43	26	71	74	73
Metam-sodium + chloropicrin	748 L/ha + 168 kg/ha	55	38	72	66	76
Metam-sodium + chloropicrin tarped	748 L/ha + 168 kg/ha	64	56	100	97	79
Metam-sodium + 1,3-dichloropropene	748 + 140 L/ha	69	50	87	76	70
Untreated control		0	0	0	0	0
LSD (0.05)		25	24	17	13	23

^a Sedge species including purple nutsedge at Jay, FL, and yellow nutsedge, purple nutsedge, and globe sedge at Arcadia, FL.

^b Abbreviation: WAT, weeks after treatment.

on the soil surface, using three TF-VS10⁸ nozzles calibrated to deliver 468 L/ha, and immediately incorporated to a depth of 15 cm with a tractor-powered 6.5-m Ferguson TilRovator fitted with L-shaped tines. Metam-sodium was applied using the same equipment, but calibrated to deliver 748 L/ha. For the chloropicrin coapplication with MS, shanks mounted on 30-cm centers placed the chloropicrin directly below the rototilled soil to a depth of 23 cm. Oxadiazon 2G was applied at 3.4 kg ai/ha, using a walk-behind broadcast fertilizer spreader, after 1,3-D application.

Plots treated with MeBr, PA, and one-third of each plot treated with the coapplication of MS–chloropicrin were covered with 0.025-mm high-barrier polyethylene clear plastic tarp, immediately after fumigant application. The plastic tarp remained on the plots for a minimum of 48 h, was then sliced, allowed to vent for 48 h, and removed.

Data Collection and Analysis. Weed control data were collected by visually estimating the level of weed control relative to the nontreated control (0 to 100%), at 6 and 44 wk after treatment (WAT) at Jay, and 3, 5, and 15 WAT at Arcadia. An additional rating to assess the control of winter annual broadleaf weeds at Jay was made at 32 WAT. Weeds (and densities) present at Jay included blackberry (*Rubus* spp. # RUBZZ) (2/m²), Carolina geranium (*Geranium carolinianum* L. # GERCA) (5/m²), carpetweed (5/m²), Coastal bermudagrass (10/m²), cutleaf eveningprimrose (*Oenothera laciniata* Hill # OEO-LA) (4/m²), cutleaf groundcherry (*Physalis angulata* L.

PHYAN) (4/m²), Florida pusley (*Richardia scabra* L. # RCHSC) (6/m²), prostrate spurge (*Chamaesyce humistrata* Engelm. Small # EPHMA) (7/m²), purple nutsedge (20/m²), and wandering cudweed (*Gnaphalium pennsylvanicum* Willd. # GNAPE) (5/m²). Weeds (and densities) present at Arcadia were alexandergrass (5/m²), broadleaf signalgrass (5/m²), common bermudagrass (8 to 10/m²), globe sedge (10/m²), purple nutsedge and yellow nutsedge (20/m²), tall morningglory and sharppod morningglory (5/m²), and redroot pigweed (5/m²). Tif-dwarf bermudagrass coverage (0 to 100%) at Arcadia was evaluated 15 WAT. Data were subjected to ANOVA, and significant differences among treatment means were determined using Fisher's LSD test at $P \leq 0.05$.

RESULTS AND DISCUSSION

Jay. Methyl bromide. The test standard, MeBr, provided complete control of the existing purple nutsedge 6 WAT. By 44 WAT, however, some reinfestation occurred in MeBr-treated plots resulting in 89% control (Table 2). Excellent (100%) control of Coastal bermudagrass with MeBr was also observed with no loss of control 44 WAT (Table 3). Similar results were obtained with carpetweed control (Table 4). By 32 WAT, MeBr provided an average 80% control of winter annual species, including Carolina geranium, cutleaf eveningprimrose, and wandering cudweed (Table 4).

Potassium azide. Potassium azide compared well with MeBr. At 6 WAT, PA provided 100% control of the existing Coastal bermudagrass (Table 3); however, by 44 WAT, reinfestation from latent weed propagules resulted in control decreasing to 90%. Although not significantly

⁸ TeeJet TF-VS10 Spraying Systems Co., North Avenue, Wheaton, IL 60189.

Table 3. Effect of fumigants on the control of weedy grass^a species.

Treatment	Rate product/ha	Jay, FL		Arcadia, FL		
		6 WAT ^b	44 WAT	3 WAT	5 WAT	15 WAT
Methyl bromide + chloropicrin	549 + 11 kg/ha	100	98	100	98	74
Potassium azide	112 kg/ha	100	90	100	96	78
1,3-dichloropropene + oxadiazon	140 L/ha + 168 kg/ha	0	53	13	0	71
Dazomet	392 kg/ha	98	93	83	45	44
Dazomet + chloropicrin	392 + 168 kg/ha	96	93	91	70	38
Dazomet + 1,3-dichloropropene	392 kg/ha + 140 L/ha	100	95	90	70	54
Iodomethane	336 kg/ha	—	98	100	99	80
Metam-sodium	748 L/ha	98	88	87	69	65
Metam-sodium + chloropicrin	748 L/ha + 168 kg/ha	100	89	92	66	69
Metam-sodium + chloropicrin tarped	748 L/ha + 168 kg/ha	100	94	100	99	70
Metam-sodium + 1,3-dichloropropene	748 + 140 L/ha	96	94	95	71	59
Untreated control		0	0	0	0	0
LSD (0.05)		35	13	13	17	27

^a Grass species include Coastal bermudagrass at Jay, FL, and alexandergrass, broadleaf signalgrass, and common bermudagrass at Arcadia, FL.

^b Abbreviation: WAT, weeks after treatment.

($P \leq 0.05$) different from MeBr, PA provided only 75% control of purple nutsedge at 6 WAT and 73% control at 44 WAT (Table 2). The control of winter annual broadleaf weeds was as effective (92%) with PA as with MeBr (Table 4).

1,3-Dichloropropene + oxadiazon. Oxadiazon, a herbicide applied preemergence for annual grass and broadleaf weed management, provided no control of purple nutsedge or Coastal bermudagrass. The data indicate a significant level of purple nutsedge control 44 WAT; however, this can be attributed more to competition from weeds not controlled by oxadiazon than to purple nut-

sedge control with this herbicide (Table 2). Similarly, this combination treatment failed to control carpetweed but did provide 83% control of the aforementioned winter annual weed species (Table 4).

Dazomet + combinations. At 6 WAT, dazomet alone and in combination with chloropicrin provided 80% control of purple nutsedge, whereas the dazomet + 1,3-D combination controlled only 51% of purple nutsedge (Table 2). Although dazomet + combinations performed well initially, by 44 WAT, purple nutsedge control diminished to 31% for dazomet + 1,3-D, 57% for dazomet alone, and 63% for the dazomet + chloropicrin combination

Table 4. Effect of fumigants on broadleaf weeds.

Treatment	Rate product/ha	Jay, FL		Arcadia, FL			
		Carpetweed 6 WAT ^a	Winter annuals ^b 32 WAT	<i>Ipomoea</i> spp. ^c 3 WAT	<i>Ipomoea</i> spp. 5 WAT	<i>Ipomoea</i> spp. 15 WAT	Redroot pigweed ^d 15 WAT
Methyl bromide + chloropicrin	549 + 11 kg/ha	98	75	100	84	68	73
Potassium azide	112 kg/ha	100	92	100	90	80	54
1,3-dichloropropene + oxadiazon	140 L/ha + 168 kg/ha	0	83	10	10	83	80
Dazomet	392 kg/ha	89	83	93	50	60	70
Dazomet + chloropicrin	392 + 168 kg/ha	96	77	95	71	76	75
Dazomet + 1,3-dichloropropene	392 kg/ha + 140 L/ha	86	82	80	81	68	75
Iodomethane	336 kg/ha	—	84	100	92	25	55
Metam-sodium	748 L/ha	93	86	92	78	55	7
Metam-sodium + chloropicrin	748 L/ha + 168 kg/ha	93	88	92	74	43	100
Metam-sodium + chloropicrin tarped	748 L/ha + 168 kg/ha	98	87	100	91	53	100
Metam-sodium + 1,3-dichloropropene	748 + 140 L/ha	89	88	92	92	68	100
Untreated control		0	0	0	0	0	0
LSD (0.05)		9	11	14	23	35	48

^a Abbreviation: WAT, weeks after treatment.

^b Winter annual species include Carolina geranium, cutleaf eveningprimrose, and wandering cudweed.

^c *Ipomoea* spp. include tall morningglory and sharppod morningglory.

^d LSD ($P = 0.10$) for redroot pigweed only.

(Table 2). All dazomet combinations provided 96 to 100% control of Coastal bermudagrass at 6 WAT, equaling that of MeBr (Table 3). By 44 WAT, control diminished only slightly (3 to 5%). Control of carpetweed with dazomet + chloropicrin was similar to MeBr (96%), but dazomet and the dazomet + 1,3-D combination provided 9 and 13% less control than that provided by MeBr, respectively (Table 3). The efficacy of dazomet + combinations against winter annual weeds was similar to that of MeBr.

Iodomethane. Iodomethane controlled purple nutsedge, Coastal bermudagrass, and the winter annual broadleaf weeds (Tables 1–3). Control equaled that of MeBr on all rating dates.

Metam-sodium + combinations. Metam-sodium alone and in combination treatments failed to provide acceptable control of purple nutsedge, ranging from 43 to 69% at 6 WAT and diminishing to 26 to 56% at 44 WAT (Table 2). The addition of chloropicrin increased the level of control over MS alone by 12% on both rating dates. A plastic tarp covering the plots treated with MS + chloropicrin provided an additional 9 and 18% control over untarped plots at 6 and 44 WAT, respectively. The addition of 1,3-D to the MS treatment provided a 26 and 24% increase in the control of purple nutsedge over that of MS alone at 6 and 44 WAT, respectively (Table 2). Control of Coastal bermudagrass and broadleaf weed species, including carpetweed and winter annual weeds, with MS and the various combinations was equal to that provided by MeBr (Tables 3 and 4).

At 6 WAT, complete control of Florida pusley, prostrate spurge, blackberry, and cutleaf groundcherry was obtained with all the fumigants, including MeBr; however, these broadleaf weeds were not controlled by the combination of oxadiazon and 1,3-D (data not shown).

Arcadia. Rate of Tifdwarf bermudagrass coverage 15 WAT indicated no differences among the fumigation treatments (data not shown).

Methyl bromide. Methyl bromide provided 100% control of purple nutsedge, yellow nutsedge, and globe sedge 3 WAT, with a decrease to 83% 15 WAT (Table 2) because of reinfestation from latent weed propagules. Control of the weedy grass species, which included common bermudagrass, alexandergrass, and broadleaf signalgrass, was similar to the control of the aforementioned sedges (Table 3). Methyl bromide also provided control of tall morningglory and sharppod morningglory at 3 WAT; however, by 15 WAT, control was reduced to only 68% (Table 3).

Potassium azide. Potassium azide performed equal to or better than MeBr in controlling purple nutsedge, yellow nutsedge, and globe sedge (Table 2), weedy grass species (Table 3), and both morningglory species (Table 4). However, PA failed to provide acceptable control of redroot pigweed (Table 4).

Oxadiazon + 1,3-D. This combination treatment failed to provide control of sedges and common bermudagrass at Arcadia. This preemergence herbicide did provide 71% control of alexandergrass and broadleaf signalgrass 15 WAT (Table 3). Similarly, acceptable preemergence control ($\geq 80\%$) of tall morningglory, sharppod morningglory, and redroot pigweed was also observed at 15 WAT (Table 4).

Dazomet + combinations. Although dazomet performed well initially against alexandergrass, broadleaf signalgrass, and common bermudagrass, weeds rapidly reinfested, resulting in only short-term control (Table 3). This was especially true at Arcadia where weed pressure was extreme. The combination of dazomet + chloropicrin provided initial control of the weedy grass species, equaling that of MeBr. However, by 15 WAT, control had decreased to 38% for this combination treatment (Table 2). Control of purple nutsedge, yellow nutsedge, and globe sedge was less than that provided by MeBr for all dazomet + combination treatments. Similar to our findings, Csinos et al. (1997) reported that dazomet failed to provide adequate control of yellow nutsedge, which is generally recognized as less difficult to control than purple nutsedge.

Iodomethane. Iodomethane provided excellent control of the three sedge species and common bermudagrass, equaling that of MeBr throughout the duration of the Arcadia study (Tables 2 and 3). Similarly, 13 WAT the control of tall morningglory and sharppod morningglory equaled that of MeBr (data not shown), but by 15 WAT, the control diminished to 25%, well below that of MeBr (Table 4). Furthermore, IM did not control redroot pigweed; these results are different from those reported by Zhang et al. (1997). They found that redroot pigweed was the weed species most sensitive to IM.

Metam-sodium + combinations. Metam-sodium + combinations tended to provide better control at Arcadia than at Jay. Metam-sodium + chloropicrin covered with a plastic tarp was as effective as MeBr, providing 100% control of sedges, common bermudagrass, alexandergrass, and broadleaf signalgrass 3 WAT (Tables 2 and 3). Metam-sodium applied alone failed to provide comparable control of sedge and weedy grass species. Sim-

ilar results have been observed with other pest species in different cropping systems (Csinos et al. 1997; Dickson et al. 1999). At 3 WAT, MS + chloropicrin (without a tarp) or 1,3-D provided grass control comparable with MeBr; however, by 5 WAT, control diminished to a level below that of MeBr (Table 3). Control of broadleaf weeds with MS + combinations equaled that of MeBr for up to 5 WAT (Table 4). Complete control of redroot pigweed was achieved only when MS was applied in combination with other fumigants (Table 4).

We concluded that the EPA registered fumigants, dazomet, MS, and 1,3-D, and the various combinations of these fumigants and 1,3-D + oxadiazon herbicide were not effective replacements for MeBr as a preplant soil fumigant. Iodomethane was the most effective fumigant studied, and controlled weedy grass species, sedge species, and broadleaf weeds present at the two locations under different environmental conditions (temperature, moisture, soil type). Zhang et al. (1998) demonstrated that IM performance was more consistent across all soil textures than that of MeBr. Furthermore, they showed that IM was much more effective than MeBr at low temperatures, which suggests a much wider application area and better fumigation results when injected deeper into the soil because the soil temperature decreases with increasing depth. Although this material proved efficacious, IM will probably not be available prior to the complete MeBr ban because of the time required for EPA registration of IM.

Potassium azide shows promise as a preplant soil fumigant; however, at present, this material is not registered by the EPA. Potassium azide was as effective as MeBr in controlling Coastal bermudagrass, yellow nutsedge, purple nutsedge, alexandergrass, broadleaf signalgrass, tall morningglory, sharppod morningglory, and various winter annual broadleaf weeds, but failed to provide acceptable control of redroot pigweed.

Although the analysis suggests that dazomet + combination treatments provided control of Coastal bermudagrass at Jay, acceptable control of common bermudagrass, alexandergrass, and broadleaf signalgrass was not achieved at Arcadia. Similarly, control of sedge species with dazomet + combinations was poor (< 63%) at both sites. Additionally, inconsistent control of the weeds evaluated in this study was observed. Because dazomet requires thorough mixing with the soil, failure to incorporate this material uniformly will result in unacceptable control. Control was reduced by equipment tire compaction of soil and rototiller overlap between successive passes (data not shown).

Metam-sodium + combinations with all other fumigants provided some control of the weeds evaluated. Metam-sodium + chloropicrin tarped provided the best results of the MS treatments evaluated. This tarped coapplication gave control of weedy grass and broadleaf species equal to that provided by MeBr. Previous research indicated that the addition of the polyethylene film enhanced control achieved with MS alone and in combination with 1,3-D or chloropicrin for several pests of tobacco and pepper (Csinos et al. 1997).

Control of sedge species with MS + chloropicrin (tarped) at Jay was less than acceptable, whereas much better control was achieved at Arcadia (56 vs. 79%). This may be because of the differences in soil texture. Sporadic failure, similar to that observed with dazomet, was also seen with these materials. In addition, the personal protective equipment requirements (coveralls over long-sleeved shirt and long pants, face-sealing goggles, and chemical-resistant headgear) for MS application are impractical for use in extremely hot climates, such as in South Florida, thus limiting widespread acceptance of this system (Anonymous 1998). Furthermore, the costs associated with this treatment (slower application speeds, multiple applicators, transportation costs) are expected to exceed that of MeBr by two to three times, making this alternative economically unacceptable.

Results obtained from these studies confirm that no EPA-registered fumigant alternative to MeBr, applied alone or in combination for preplant turf soil fumigation, exists. Consequently, until such time that an effective alternative is identified, turf managers will be forced to forego fumigation, or they will have to choose a less-effective alternative and accept the consequences of contamination.

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