EFFICACY OF ORIENTAL MUSTARD (*Brassica juncea* L. Czern.) SEED MEAL FOR WEED AND DISEASE CONTROL IN TURF

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CHAPTER 1

Literature Review

Introduction

Oriental mustard (*Brassica juncea* L. Czern.), one of the yellow seeded cultivars is sometimes referred to as brown or Indian mustard, brown seeded cultivars. All are members of the Brassicaceae family. Other members of Brassicaceae family include several types of mustards such as yellow mustard (*Sinapis alba* L), sometimes referred to as white mustard (*Brassica hirta* Moench); black mustard (*Brassica nigra* L.); cabbages (*Brassica* spp.); rapeseed (*Brassica napus* L.), and turnips (*Brassica rapa* L.) (Kimber and McGregor 1995). The center of origin for oriental mustard is uncertain; however, suggested sites of origin are the Middle East, Central Asia, and China (Kimber and McGregor 1995; Pua and Douglas 2004). Oriental mustard is used primarily for the production of table mustards, spices, and an oilseed crop (Kimber and McGregor 1995). Oriental mustard is produced worldwide, but it is grown primarily in Canada, China, India, Australia, United States, and various parts of Europe (Kimber and McGregor 1995).

Oriental mustard plants produce seed pods containing up to twenty seeds that are one to two mm in diameter. Seeds are light brown to yellow in color and are harvested before the seeds are mature (Kimber and McGregor 1995). Once harvested, the seeds are pressed and oils collected. The remaining seed hulls and kernels are ground into meal

(Kimber and McGregor 1995; Sang et al. 1984). Many varieties of mustards are now being evaluated for use as biodiesel (Kimber and McGregor 1995).

Seed meals from many mustards species have been found to contain biofumigant characteristics. Mustard seed meals and/or mustard green manures contain secondary plant compounds known as glucosinolates (GSL). GSLs are found throughout plant tissues and are converted by the enzyme myrosinase into isothiocyanates (ITC), oxazolidinethiones, nitriles, and thiocynates (Kirkegaard and Sarwar 1998; Brown and Morra 1995; and Vaughn et al. 2006). Kirkegarrd and Sarwar (1998) also stated that approximately twenty unique GSLs are found normally in *Brassica* species, with GSL concentrations varying between species and also within different plant tissues. Cold pressed mustard seed meal contains GSLs which, when in the presence of water, are converted to active hydrolysis products by the enzyme myrosinase (Kirkegaard and Sarwar 1998; Brown et al. 1991). The strong taste one experiences from consuming mustard comes from the hydrolysis of GSLs to ITC's (Kimber and McGregor 1995). The main glucosinolate found in *B. juncea* is predominately 2-propenyl (allyl) GSL (sinigrin) (Kimber and McGregor 1995; Peter 2004). The highly volatile hydrolysis product produced from sinigrin is allyl isothiocyanate (AITC) (Kimber and McGregor 1995; Peter 2004).

Fumigation with Mustard Seed Meals

Biofumigation with mustard seed meals has been shown to suppress and/or kill many weed species, nematodes, and soil borne pathogens (Melander et al. 2004). Pests such as the masked chafer beetle (*Cyclocephala spp*.) larvae exhibited complete mortality when (*Brassica juncea* L.) tissue was amended in the soil with the larvae (Noble et al. 2002). Other studies have also demonstrated suppression of black vine weevil (*Otiorhynchus sulcatus* F.) larvae (Borek et al. 1998) and wire worms (Elberson et al. 1996) with *B. napus*.

According to Melander et al. (2004), weed suppression depends upon weed species and the *Brassica* cultivar used to generate mustard seed meal. GSLs from seed meals have been shown to suppress seedling emergence depending up on the concentration, mustard variety, and the products hydrolyzed from GSLs (Vaughn et al. 2006). Isothiocyanates released from different mustard species incorporated into the soil have been shown to suppress weeds like Texas panicum (*Panicum texanum*), large crabgrass (*Digitaria sanguinalis* (L.) Scop.), and sicklepod (*Senna obtusifolia* L.) (Norsworthy and Meehan 2005).

Previous greenhouse studies have demonstrated that *Brassica* residues containing ITCs reduced germination rates and the size of emerged weed seedlings (Al-Khatib et al. 1997; Boydston and Hang 1995; Krishnan et al. 1998). Other studies conducted by Norsworthy et al. (2006) also found that shoot biomass and densities of purple nutsedge (*Cyperus rotundus* L.) and yellow nutsedge (*C. esculentus* L.) were reduced by five different ITCs when applied to the soil.

Although weed suppression has been shown using *Brassica* green manures and seed meals, Melander et al. (2004), observed more effective weed suppression with mustard seed meals than with green manures. In Washington, delayed pigweed seed germination was observed when seeds were placed into nylon sacks, buried at 2.5 or 10.5 cm depths, and overseeded with white mustard and a variety of other cover crops

(Suszkiw and Boydston 2004). In other experiments, white mustard residues reduced prickly lettuce (*Lactuca serriola* L.) and common chickweed (*Stellaria media* L. Vill.) germination 55 to 80% and the viability of root-knot nematode (*Meloidogyne javanica*) was decreased 70 to 80% compared to the control (Suszkiw and Boydston 2004). A study done by Haramoto and Gallandt (2005) showed that *Brassica* cover crops reduced seedling emergence from 23 to 34% for sixteen different weed and crop species.

Suppression of pests such as insects and weeds are not the only targets affected by *Brassica* cover crops and seed meals. Plant-parasitic nematodes are other pests that can largely affect vineyard and citrus fruits, but can also affect other agronomic crops, vegetables, and ornamental and turfgrass crops. A study conducted by Rahman and Somers (2005), found the most effective suppression of root-knot nematode in soil treated with *B. juncea* 'Nemfix' mustard green manures from 8,164 to 10,432 kg of dry matter/ha and mustard seed meal at 1,814 kg/ha. Other studies have shown reductions in sting nematode (*Belonolaimus longicaudatus* Rau) by 92 and 99.5% in irrigated and nonirrigated pots, respectively using an extract of *B. juncea* 'Pacific Gold' seed meal (Cox et al. 2006).

Soil Fumigants

The horticulture industry has shown a greater interest in biofumigation with the recent ban of the soil fumigants methyl bromide and ethylene dibromide (Kirkegaard and Sarwar 1998). Methyl bromide is an odorless, colorless toxic gas that was phased out of production by the Environmental Protection Agency due to ozone depletion (USEPA 2006). Chloropicrin (tear gas) is often added to methyl bromide (10 to 15%) to create a stronger fumigant, but mainly to warn humans of the presence of methyl bromide (Elliott and Jardin 2001). Chloropicrin is also combined with many other gaseous fumigants used to sterilize soil and kill seed, fungi, and insects.

Another fumigant, 1, 3 dichloropropene (1, 3-D), trade name Telone® II[1], is a fumigant that has been used mainly in nursery, orchard and vegetable production systems (Anonymous 2006 T). A study showed that when 1, 3-D plus chloropicrin was applied at >468 L/ha either by shank, by using equipment that will incorporate the chemical into the soil, or by using drip irrigation (targets the base of the plants), control of plant –parasitic nematodes was similar to methyl bromide during the first year of vineyard production (Schneider et al. 2006). However, areas treated with methyl bromide resulted in greater amounts of vine growth. Trenholm et al. (2005) observed higher quality bermudagrass (*Cynodon dactylon* x *C. transvaalensis* Burtt-Davy) that was more resistant to drought stress when 1, 3-D was used to control sting nematode (*Belonolaimus longicaudatus* Rau.) in infested soils.

Metam sodium, trade name Vapam® HL[2], is another fumigant that was first registered in 1975 (USEPA 2008). When metam sodium is applied to soil, methyl isothiocyanate (MITC) is released (USEPA 2008). MITC is related to isothiocyanate (ITC) (Neal 1999). Metam sodium is used mainly in vegetable and fruit crops, and has had great success because of its low cost, moderate toxicity, and broad spectrum control of many different weeds, fungi, and nematodes. Metam sodium has several advantages over methyl bromide. First, metam sodium is not a restricted use pesticide (Anonymous 2006 Vapam). Second, it can be applied through irrigation systems (Anonymous, 2006

[1] Telone ® II, Dow AgroSciences LLC, 9330 Zionsville Road, Indianapolis, IN 46268.
[2] Vapam® HL, AMVAC chemical corporation, 4100 E. Washington Blvd., Los Angeles, CA 90023.

Vapam). When comparing the cost of metam sodium to methyl bromide, methyl bromide average cost ranges from $1,200 to 1,500 per acre, compared to metam sodium ranging from $750 to $1,000 per acre (USEPA 1997). According to Unruh et al. (2002), metam sodium mixed with chloropicrin or 1, 3-dichloropropene suppressed redroot pigweed up to 93% more than metam sodium alone 15 weeks after treatment (WAT). Dazomet and metam sodium or their combinations with other chemicals resulted in differences in control compared to methyl bromide ranging from 4 to 50% at 6 and 3 WAT in Jay, FL and 5 and 15 WAT in Arcadia, FL. However, potassium azide, which has not been evaluated for turfgrass systems, suppressed weeds as well as methyl bromide and was considered the most effective methyl bromide replacement (Unruh et al. 2002). Even though metam sodium is commonly used as a methyl bromide replacement, many fruit and vegetable production systems find it cost prohibitive (Matthiessen and Kirkegaard 2006).

Dazomet, trade name Basamid®[3], is another fumigant that is used as a methyl bromide replacement (Neal 1999). Like metam sodium, dazomet releases MITC when applied to soils. However, dazomet is a granular formulation whereas metam sodium is a liquid (Neal 1999). Dazomet is used mainly in nurseries containing tree seedlings, but is also used in the turf industry during complete renovations (Park and Landschoot 2003; USEPA 1995). Dazomet is considered an effective fumigant that poses less human health risks, lower cost per acre, and less environmental hazards than methyl bromide (USEPA 1995). In renovation and establishment studies by Park and Landschoot (2003), dazomet applied at 388, 340, 291, and 194 kg/ha controlled annual bluegrass >98 %. The Park and Landschoot (2003) studies also showed that percent control increased when

[3] Basamid®, Certis U.S.A. LLC, 9145 Guilford Road, Suite 175, Columbia, MD 21046.

treatments were covered with plastic sheeting. Dazomet at 388 kg/ha showed no adverse effects when creeping bentgrass was seeded 3 days following application (Park and Landschoot 2003). Methyl bromide is applied on average at 420 kg ai/ha compared to dazomet from 280 to 392 kg ai/ha, but dazomet costs on average $271 to $988 more per hectare (USEPA 1995). Both metam sodium and dazomet can be applied with or without tarping the soil. However, both are more effective when covered by plastic sheeting to hold in the gaseous MITC (Neal 1999). Dazomet should be continuously irrigated after the first day of application; however, excess moisture that leads to waterlogged soil conditions must be avoided. This process of watering in is called soil capping, which seals the surface and prevents the release of MITC into the air (Anonymous 2008 B).

Many professionals in the turfgrass industry use soil fumigants prior to seeding turfgrasses or for renovation of existing turf in golf courses, sod farms, or athletic fields (Park and Landschoot 2003). These soil fumigants are often used to eliminate persistent soil borne pests such as insects and diseases, but also serve to minimize competition of weeds with seeded turfgrasses (McCarty and Miller 2002).

Fungicidal Properties of Mustard Seed Meals

Mustard seed meals and mustard green manures have shown promise for use as an organic fungicide. According to Goodard et al. (2005), Indian mustard (*B. juncea* L. Czerniak) seed meal applied at 0.05 to 10.0 g mustard seed meal residues MR/L inhibited mycelial growth of dollar spot (*Sclerotinia homoeocarpa*) up to 100%. Goodard et al. (2005) further stated during field studies with a Crenshaw creeping bentgrass (*Agrostis stolonifera* L.) putting green that mustard seed meal caused unacceptable turf injury at rates of 0.5 and 1.0 g MR/L. There have been other studies that reported reductions in disease affecting crops other than turfgrasses during the use of mustard seed meal. Lyons and Sams (2003), showed increased tomato yield and decreased southern blight incidence (*Sclerotium rolfsii* Sacc.) when soils were incorporated with a combination of mustard seed meal and mushroom compost. Chung et al. (2002), found that cabbage seeds treated with mustard seed meal combined with peat, showed less Rhizoctonia damping-off (*Rhizoctonia solani* Kühn AG-4) with no detrimental effects on germination. Kirkegaard et al. (1996), during an *in vitro* study demonstrated that *B. juncea* prevented regrowth of five cereal fungal pathogens including: (*Gaeumannomyces graminis* var. *tritici* Sacc.) (*Rhizoctonia solani* Kühn), (*Fusarium graminearum* Schwabe), (*Pythium irregulare* Buisman), and (*Bipolaris sorokiniana* Sacc.). In addition, Cohen et al. (2005) demonstrated that black mustard (*Brassica napus* L.) applied as an organic soil amendment increased the total culturable bacteria and ammonia–oxidizing bacteria that release nitric oxide, preventing Rhizoctonia root rot in apples.

Dollar spot

Dollar spot is a major turfgrass disease found in Missouri, but also throughout the U.S. This disease can affect many different warm and cool season grasses including: annual bluegrass (*Poa annua* L.), bentgrasses (*Agrostis spp*. L.), fescues (*Festuca* spp.), Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne* L.), bermudagrasses (*Cynodon* spp. [L.] Rich), zoysiagrasses (*Zoysia* spp. Willd.), centipedegrass (*Eremochloa ophiuroides* [Munro] Hack.), and St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze.) (Watschke et al. 1995; Turgeon 2005).

Dollar spot can be most prevalent on closely mowed golf course putting greens and fairways (Turgeon 2005). Although, dollar spot not only affects closely mowed turf, it can also affect turf that is maintained at taller heights, whether found on golf courses, sports fields, sod farms, or even home lawns. During the winter months, the resting bodies of dollar spot, known as stromata and dormant mycelium can be found in the crowns and roots of diseased turfgrass plants (Couch 2000 and Turgeon 2005). Dollar spot symptoms can initially appear when air temperatures reach 16 C; disease development is optimal at temperatures from 21 to 27 C (Couch 2000). Peak development of dollar spot on cool season turfgrasses can be seen during late spring and early summer, and then again in late summer into early fall (Couch 2000). Dollar spot symptoms first appear as straw colored spots of blighted turf, with reddish brown borders and margins on turfgrass leaves. These areas later appear as bleached spots or patches in turf (Couch 2000; Turgeon 2005; Emmons 2008 and Watschke et al. 1995). The straw colored spots develop into small patches that are 5 to 7.5 cm in diameter or the size of a silver dollar on closely mowed turf (Turgeon 2005; Couch 2000, and Emmons 2008). On turfgrasses that are maintained at a higher mowing height, dollar spot patches can range from 7.6 to 15.2 cm in diameter (Watschke et al. 1995, and Emmons 2008). If not prevented, dollar spot patches will coalesce and become larger patches in affected turfgrass areas (Emmons 2008).

Dollar spot is favored by warm days and cool nights with heavy dew formation, but periods of high humidity in the turfgrass canopy can also increase fungal growth. (Watschke et al. 1995 and Turgeon 2005). When dollar spot is active and the turf leaves are wet, a white mycelium, that resembles a cobweb, can often be seen in the infected patches (Couch 2000; Turgeon 2005; Emmons 2008 and Watschke et al. 1995). Dollar spot damages turf stressed by low soil moisture, low nitrogen fertility, high humidity, heavy dew, and an excessive thatch (Couch 2000; Turgeon 2005; Emmons 2008 and Watschke et al. 1995). According to Watschke et al. (1995), cultural practices such as applying nitrogen will facilitate re-growth of the turfgrass plant and mask the disease. Couch (2000) also stated that adequate fertility will reduce the occurrence and severity of dollar spot.

According to Vargas (1994), more money is spent on prevention and management of dollar spot on golf courses around the U.S. than any other turfgrass disease. A common synthetic fungicide for suppressing dollar spot is iprodione (Anonymous 2004). A study by Latin (2006) reported that iprodione suppressed dollar spot 14 days after application, but no suppression was evident at 21 days, indicating the need for additional applications. Previous research by Wang et al. (2004), found soil bacterial communities increased during incubation when iprodione was applied at higher temperatures and higher concentrations (Wang et al. 2004).

In the late1960's and early 1970's, the first published findings of dollar spot resistances to benzimidazole fungicides were reported (Cole et al., 1968; Warren et al., 1974). In 1983, dollar spot also developed resistance to dicarboximide fungicides (Detweiler et al. 1983) followed by demthylation inhibitor (DMI) fungicides in the early 1990's (Golembiewski et al. 1995). Some other reports of dollar spot resistance to iprodione, propiconazole, and thiophanate-methyl have been reported on golf courses in Ohio and Tennessee (Goddard et al. 2005; Jo et al. 2006). With overuse of fungicides and an increase in dollar spot resistance occurring throughout the U.S., turf managers are looking for alternative ways to prevent dollar spot occurrences and severity. Dollar spot control with mustard seed meal is unknown. However, it may become an important consideration for management of fungicide resistance.

Mustard seed meal has many soil and crop benefits beyond fumigation and fungicidal properties. In potato cropping systems, mustard green manures created higher soil-water infiltration rates compared to the use of metam sodium (McGuire 2003). According to Balesh et al. (2005), use of mustard seed meal as an organic source of nitrogen increased grain yields. However, yield increases were greater using mustard seed powder compared with a granular formulation. Rahman and Somers (2005) also observed improved soil structure when Indian mustard meal was incorporated into vineyard rows and inter-rows.

Summary and Objectives

Currently, many synthetic fumigants and fungicides are on the market. Oriental mustard seed meal and/or green manure have shown biofumigant and biofungicidal characteristics when used under several crops. Several studies have demonstrated how green manures have improved soil structure, increased microbial communities, and increased soil nitrogen. Currently, there is limited information using oriental mustard seed meal in turf. A better understanding of the efficacy of oriental mustard seed meal and its use as a soil fumigant in controlling weeds commonly found in turf, and as a preventative measure on dollar spot are needed. This may reveal an organic approach as a possible alternative to weed and disease control in turf. Therefore, experiments were conducted comparing the effects of oriental mustard seed meal to dazomet on the germination of different weeds and turfgrasses, by evaluating plant counts, biomass, and heights. Also, comparisons were conducted with mustard seed meal to commonly used fungicides to determine effectiveness for control of dollar spot in the transition zone. The transition zone is a zone that goes through the central part of the U.S. where cool and warm season grasses have difficulty reaching their full growth potential, and require intensive maintenance practices due to the variation of precipitation and climate changes throughout the year. Finally, the last objective of the thesis was to determine plant-back intervals for cool season turfgrasses. This was determined following the use of oriental mustard seed meal as a soil fumigant by evaluating plant counts weekly after application, plant biomass, and plant heights.

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Chapter II

Evaluation of Oriental Mustard (*Brassica juncea* L. Czern.) Seed Meal for Weed Control in Turfgrass

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Abstract. Oriental mustard seed meal (MSM) is a natural soil amendment with herbicidal properties. With the removal of methyl bromide as a soil fumigant for turf renovation, MSM is a potential biofumigant. The objective of this research was to determine the effectiveness of MSM for control of selected weeds as well as inhibitory effects on the establishment of desirable turfgrasses. Greenhouse trials were conducted in 2006 and 2007 and field studies in 2007 and 2008 with MSM amended in soil from 0 to 3,360 kg/ha. A broad range of problem weed species in turf and selected turfgrasses were seeded into amended soil. Soil was either tarped (sealed) with polyethylene bags (greenhouse) or sheets (field study) for 7 days or left untarped. MSM under greenhouse conditions, reduced the density of buckhorn plantain, white clover, and common chickweed by ≥42% at 1,350 kg/ha MSM compared to the untreated control, 28 days after planting (DAP). MSM at 3,360 kg/ha reduced stand counts of tall fescue and perennial ryegrass up to 81% and 77% respectively. MSM suppressed bermudagrass emergence ≤30%, regardless of MSM rate or tarping. Biomass of buckhorn plantain,

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annual bluegrass, common chickweed, white clover, and large crabgrass was reduced from 37 to 99% at 3,360 kg/ha MSM compared to the untreated control. The biomass of tall fescue, perennial ryegrass, and bermudagrass was reduced by 85, 68, and 10%, respectively, at 3,360 kg/ha MSM. In field studies, tarping reduced emergence of all species except annual bluegrass by 54 to 100% compared to the untarped, untreated control in 2007. In 2008, increasing the rate of MSM from 1,120 to 3,360 kg/ha reduced plant emergence by 19 to 79% for all species except bermudagrass. During 2007, annual bluegrass biomass was most sensitive to MSM, with reductions up to 70% at 3,360 kg/ha MSM compared to the untreated control. Tall fescue was the least sensitive to MSM, and biomass increased over all MSM rates, with the highest increase in biomass for 3,360 kg/ha. In 2008, bermudagrass was the least sensitive to MSM. MSM suppresses a number of weeds and turfgrasses, with potential selectivity for bermudagrass.

Nomenclature: Oriental mustard, *Brassica juncea* L. Czern.; dazomet 3,5-dimethyl-1,3,5-thiadiazinane-2-thione; annual bluegrass, *Poa annua* L. POAAN; 'Rembrant' tall fescue, *Festuca arundinacea* Schreb. FESAR; 'Evening Shade' perennial rye, *Lolium perenne* LOLPE; 'Riviera' bermudagrass, *Cynodon dactylon* L. CYNDA; large crabgrass, *Digitaria sanguinalis* L. Scop. DIGSA; buckhorn plantain, *Plantago lanceolata* L. PLALA; white clover, *Trifolium repens* L. TRFRE; and common chickweed, *Stellaria media* L. Vill. STEME.

Key Words: Fumigation, green manures, isothiocyanate, turfgrass.

Introduction

Soil fumigation has been used for more than 65 years to suppress soil borne pests such as nematodes, diseases, insects, and weeds (Pessarakli 2007). Pre-plant fumigation is used in many situations: forestry, agronomic crops, vegetables, ornamentals, and turfgrass establishment and renovation.

There are concerns over the use of soil fumigants, due to the risks for humans and the environment (Noling 1997; Herzstein 1990; Pimentel 2007; USEPA 2008), as well as the high cost. Methyl bromide was long a standard in the turf industry. Edwards and Barnes (1958) reported use of methyl bromide for renovation of golf course putting greens in 1958. Since the early 1990's, methyl bromide has been slowly phased out of production by the U.S. EPA due to ozone depletion (USEPA 2009). The recent ban of soil fumigants such as methyl bromide and ethylene dibromide has sparked interest in the development of alternative fumigants (Kirkegaard and Sarwar, 1998).

One possible source of natural fumigants is plant residues from the Brassicaceae family. Over the past 30 years, plants in the *Brassica* genus have been used as cover crops and incorporated as green manures in vegetable (McGuire 2003) and vineyard production systems (Rahman and Somers 2005; McLeod et al. 1995) to suppress common soil borne pathogens, nematodes, and weeds (Haramoto and Gallandt 2005; Norsworthy and Meehan 2005). Mustard species contain secondary plant compounds known as glucosinolates (GSL). The GSLs are found throughout plant tissues and are converted by the enzyme myrosinase into isothiocyanates (ITC), oxazolidinethiones, nitriles, and thiocynates (Kirkegaard and Sarwar 1998; Brown and Morra 1995; and Vaughn et al. 2006). There are approximately twenty unique GSLs in *Brassica* species, with GSL concentrations varying between species and also within different plant tissues (Kirkegaard and Sarwar 1998). Vaughn et al. (2006) traced differences in emergence to the concentration of GSL. Among all the GSL's, ITC is considered the most active compound for soil borne pest suppression (Brown and Morra 1997). A compound similar to ITC, methyl isothiocyanate (MITC) (Neal, 1999; Matthiessen and Kirkegaard, 2006), is released by synthetic fumigants such as metam sodium and dazomet (USEPA, 2008).

Many varieties of mustards grown for condiments, spices, and primarily as oilseed crops are now being evaluated for use as biofuels due to the high oil content in the seed (Kimber and McGregor 1995). Extraction of oils from seed results in by-products known as seed meal. Recently, seed meals and cover crops from the *Brassica*ceae family such as *B. napus*, B. *juncea*, and *Sinapis alba*, were reported to exhibit biofumigation properties (Kirkegaard et al. 1993; Mazzola et al. 2001; Mazzola et al. 2006; Brown et al. 2006). Studies conducted by Al-Khatib et al. (1997) showed that shepherd's-purse (*Capsella bursa-pastoris* L.), kochia (*Kochia scoparia* L.), and green foxtail (*Setaria viridis* L.) emergence was reduced by 97, 54, and 49% respectively when planted in soil that contained 20 g 'Martigena' white mustard (*Brassica hirta* Moench) shoots per 400 g air dry soil. Boydston and Hang (1995) found that hairy nightshade (*Solanum sarrachoides* Sendtner) emergence was reduced by 56% when planted in white mustard under similar conditions. Although mustard seed meals and cover crops have resulted in suppression of weeds due to their biofumigant properties, phytotoxicity has also been observed toward crops. A study by Rice et al. (2007) showed that lettuce (*Lactuca sativa* L.) emergence was reduced ≥75% when planted 1 to 4 weeks after amending a soil with 3% (w/w) yellow mustard (*S. alba* L.) seed meal. Rice et al. (2007)

also stated that beet (*Beta vulgaris* L.) and lettuce emergence was inhibited by 1 to 3% (w/w) applications of canola (*B. napus* L.), oriental mustard (*B. juncea* L.), and yellow mustard seed meal.

Existing research using MSM for weed suppression has focused on annual cropping systems; little research has focused on turf. Therefore, the objectives of this research were to evaluate the herbicidal effects of oriental mustard seed meal on common weeds and turfgrasses in Missouri.

Materials and Methods

Greenhouse Study. Greenhouse trials were initiated in 2006 and 2007 using polypropylene containers[1] (51 cm by 25 cm) filled with a Menfro silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalfs) collected from the A horizon. The soil had a pH of 6.3, organic matter content of 4.9 %, and a composition of 15% sand, 65% silt, 20% clay. Treatments consisted of dry Oriental mustard seed meal (MSM) (Carl Sams, University of Tennessee) that was surface applied and hand amended into the soil, up to 5 cm in depth. The glucosinolate and nutrient analysis of MSM are described in Appendix Tables A1, A2, and A3. Rates included 0, 1350, 2350, and 3360 kg/ha. Dazomet[2] was applied at 392 kg/ha as a standard (Anonymous, 2008). Eight, 25 cm rows of weeds or turfgrass species were seeded at a depth of 0.5 cm and then lightly covered with the MSM amended soil. The weed species used in these trials included: annual bluegrass (*Poa annua* L.), large crabgrass (*Digitaria sanguinalis* L.), buckhorn plantain (*Plantago lanceolata* L.), white clover (*Trifolium repens* L.), and common chickweed (*Stellaria media* (L.) Vill.). The weed species selected are commonly found in turf in Missouri.

Turfgrass species were represented by: 'Rembrant' tall fescue (*Festuca arundinacea* Schreb.), 'Evening Shade' perennial rye (*Lolium perenne* L.), and 'Riviera' bermudagrass (*Cynodon dactylon* L.), which are common cool and warm season turfgrasses found in Missouri.

After seeding, containers were irrigated lightly to initiate the hydrolyzation of GSL's. This was followed by covering one-half of all polypropylene containers with a clear polyethylene plastic bag for 7 days to trap volatile GSLs. After one week, all polyethylene bags were removed and all treatments were irrigated as needed for 21 additional days. Air temperatures were maintained between 22 and 32 C and no supplemental lighting was used.

Emergence by species was counted weekly, beginning 7 days after planting (DAP) and continuing until 28 DAP. All of the seedling counts were summed to represent cumulative affects of MSM on weed and turfgrass species germination. Biomass of all plants was determined 28 DAP by clipping each species at the soil surface and recording fresh weight.

Trials were designed as a randomized complete block with four replications and repeated. Plant counts and biomass were separated using a Mixed Model Analysis in SAS (SAS 2003). Means were separated using Fisher's Protected LSD at the 5% level of probability. No significant variance was found between each trial and, therefore, data were pooled.

Field Study. Trials were initiated in 2007 and 2008 at the Turfgrass Research Center near Columbia. The experimental area consisted of zoysiagrass (*Zoysia* spp. Willd.), for the past 12 years. The soil was a Mexico silt loam (fine, smectitic, mesic Vertic

Epiaqualfs) with a pH of 5.7, and organic matter content of 2.3 %. Plot size was 3 by 1.5 m. Prior to initiating the study, the area was treated with glyphosate at 2.2 kg ae/ha. Two weeks later, the experimental area was tilled twice with a RotaDarion®[3] to a depth of 12 cm.

Treatments consisted of MSM applied at 0, 1120, 1680, 2240, 2800 and 3360 kg/ha and incorporated into the soil. Dazomet[2] was applied at 392 kg/ha as a standard (Anonymous, 2008). Within each plot, eight, 91-cm rows containing a weed or turfgrass species were planted at a depth of 0.5 cm, and then lightly covered with the MSM amended soil. The weed species used in these trials were large crabgrass, buckhorn plantain, white clover, and annual bluegrass. Turfgrass species were 'Rembrant' tall fescue, 'Evening Shade' perennial rye, and 'Riviera' bermudagrass.

After seeding, small 14 cm deep trenches were dug around each plot. Plots were then irrigated lightly to promote seed germination and activate the production of GSL's. Immediately following watering, half of the experimental area was sealed with a 0.1 mm clear polyethylene plastic sheet for seven days to trap the volatile GSLs. After one week, all polyethylene sheets were removed and the entire trial was irrigated as needed for 35 days.

Emergence by species was counted at 1, 3, and 6 weeks after planting (WAP). At 2 and 6 WAP, plant height was measured by randomly selecting 3 plants of each species per 91 cm row, and measuring from the soil surface to the maximum growth of each sample (data not shown). All plants were harvested at 6 WAP by clipping each species at the soil surface and recording fresh weight. Plant material was then oven dried at 60 C for

72 h before determining dry weight. Weather conditions (rainfall and air temperatures) were monitored throughout the duration of the research trials (Table 2.1, Figure 2.1).

Trials were designed as a randomized complete block with four replications and conducted similarly in 2007 and 2008. Plant counts and biomass were separated based on PROC GLM analysis using SAS (SAS 2003). Prior to analysis, Bartlett's test for equal variance was performed (Little and Hills 1978; SAS 2003). Plant counts were subject to square root transformation only if unequal variances. Transformed means did not affect conclusions; therefore non-transformed means are presented. There was also a treatment by year interaction, so data were separated by year, and means were compared using Fisher's Protected LSD at the 5% probability level.

Results and Discussion

Greenhouse Study. Main effects for MSM on plant emergence rate were significant across all species, while tarping was significant for all species except large crabgrass (Table 2.2). There was an interaction between MSM rate and tarping on common chickweed germination. Common chickweed emergence was strongly impacted by MSM (Table 2.3). Emergence for tarped versus untarped containers was suppressed by 80% compared to 34% at 1,350 kg/ha MSM. This was likely due to trapping volatile GSLs. Increasing the MSM rate to 2,350 kg/ha or higher masked tarping.

Emergence of weed and turf species was reduced as rates of MSM increased, with optimum effects noted at 2,350 kg/ha (Table 2.4). MSM at 1,350 kg/ha reduced seedling emergence of all species except bermudagrass. Buckhorn plantain was the most sensitive to MSM, with plant counts reduced 82% at 1,350 kg/ha. A rate of 3,360 kg/ha suppressed buckhorn plantain by 95% compared to the untreated control (Table 2.4). For annual bluegrass, MSM at 1,350 kg/ha reduced emergence by 42%; 2,350 and 3,360 kg/ha resulted in 87% and 82% lower stand counts, respectively. White clover emergence was reduced 55% at the lowest MSM rate, and reduced by 82% at higher rates. Large crabgrass emergence was reduced 50 to 62% across all MSM rates (Table 2.4). Common chickweed emergence was reduced 50% with 1,350 kg/ha MSM, but 83 to 90% at MSM rates up to 3,360 kg/ha. In comparison to MSM, dazomet resulted in 100% suppression of all weed and turf species. Tall fescue emergence was reduced > 40% at the lowest MSM rate, with higher rates reducing plant counts up to 81% compared to the untreated control (Table 2.4). Perennial ryegrass emergence was reduced 41% at 1,350 kg/ha MSM, but increased to 77% at 3,360 kg/ha MSM. Bermudagrass was least sensitive to MSM, with seedling emergence reduced 29% at 2,350 kg/ha MSM. However, the rate of 3,360 kg/ha only reduced emergence by 17%, similar to emergence in the untreated control.

For all turfgrass and weed species, plant biomass was impacted by the rate of MSM (Table 2.5). However, the impact of tarping was only noted on five of the eight species, and the interaction of MSM rate and tarping was only significant for annual bluegrass.

Annual bluegrass biomass was strongly reduced by higher rates of MSM (Table 2.6). Biomass for tarped versus untarped containers was reduced by 60% compared to an increase of 17% at 1,350 kg/ha. Higher MSM rates for tarped versus untarped treatments reduced biomass > 97% and > 51%, respectively (Table 2.6)

Plant biomass of weed and turfgrass seedlings was reduced with increasing rates of MSM. Buckhorn plantain was among the most sensitive species. The biomass for buckhorn plantain was reduced by 87% at 1,350 kg/ha MSM with reductions of 74 and 97% at rates of 2,350 and 3,360 kg/ha MSM, respectively, compared to the untreated control (Table 2.7). For annual bluegrass, MSM treatments of 1,350 kg/ha reduced biomass by 23%, but higher MSM rates of 2,350 and 3,360 kg/ha resulted in 86 and 76% reductions, respectively. White clover biomass was reduced 61% at the lowest MSM rate and by 76 and 89%, respectively at 2,350 and 3,360 kg/ha. Large crabgrass biomass was reduced only 37% at the highest rate of MSM. Common chickweed biomass was reduced by 52% with 1,350 kg/ha, but up to 95% at 3,360 kg/ha. Tall fescue, perennial ryegrass, and bermudagrass biomass was reduced by 85, 68, and 10%, respectively at the 3,360 kg/ha MSM rate compared to the untreated control (Table 2.7). Perennial ryegrass and tall fescue biomass were significantly reduced at even the lowest MSM rate.

Tarping improved the effectiveness of MSM by up to 50% for emergence data (Table 2.8), and 57% for biomass data (Table 2.9) compared to the untreated control. Tarping bermudagrass did not reduce plant emergence or biomass compared to untarped plants. A slight increase in germination for the tarped bermudagrass is presumably due to increasing heat units while the treatments were covered. Sandlin (2006) reported that optimal germination temperatures ranged from 25 to 40 C for different seeded bermudagrasses, which is dependant on cultivars. Sandlin (2006) further observed that maximum germination for 'Riviera' bermudagrass was seen at a day/night temperature regime of 35/25 C. Emergence of large crabgrass was low (four plants) (Table 2.8), which may not have been a representative sample to assess the impact of MSM.

Field Study. Overall emergence of weed and turfgrass species at 6 WAP was strongly impacted by tarping, but the rate of MSM was not a major factor (Tables 2.10 and 2.11). In 2007, tarping reduced emergence of all species except annual bluegrass by 54 to 100%, compared to the untarped, untreated control. This was likely the result of very high air temperatures beneath the polyethylene sheets, ultimately reducing seed viability of most species. In 2008, mean emergence of weeds and turfgrasses was overall lower for tarped versus untarped treatments, indicating the process of tarping was not the only variable affecting plant emergence (Table 2.11). In untarped treatments for both 2007 and 2008, there was little or no influence of increasing rates of MSM, except at the highest MSM rate for buckhorn plantain and large crabgrass in 2007 and white clover in 2008. This suggests that GSL activity was quickly lost from the untarped soil, resulting in poor suppression of seedling emergence. In 2008, increasing the rate of MSM from 1,120 to 3,360 kg/ha reduced plant emergence from 19 to 79% for all species except bermudagrass (Table 2.11). Bermudagrass emergence was not influenced by MSM. In both years, dazomet completely suppressed emergence of all species (Tables 2.10 and 2.11).

The effectiveness of tarping suggests that the influence of MSM should be examined with covered treatments; therefore plant biomass from only tarped treatments will be presented (Tables 2.12 and 2.13). Similar to weed and turfgrass emergence, results varied with biomass over all species tested, with differences each year (Tables 2.12 and 2.13). During 2007, annual bluegrass biomass was most sensitive to MSM, with reductions from 34 and 70% at 2,800 and 3,360 kg/ha MSM compared to the untreated control (Table 2.12). Slight biomass reductions were also observed with buckhorn plantain, bermudagrass, and large crabgrass, although plant biomass was not statistically different, compared to the untreated control. Tall fescue was the least sensitive to MSM, and biomass increased for over all MSM rates, with the highest increase in biomass for 3,360 kg/ha. In 2008, plant biomass for buckhorn plantain and large crabgrass was not impacted by MSM rate (Table 2.13). White clover biomass was reduced by 66% for the highest MSM rates during 2008 (Table 2.13). Perennial ryegrass biomass was reduced the greatest at 2,800 kg/ha (71%).

MSM selectively suppresses the emergence of several weed species. Emergence for turfgrasses was inconsistent for both years. Bermudagrass showed an increase in plant densities for untarped treatments during 2007, while tall fescue and perennial ryegrass was less influenced by untarping. Differences in both years are presumably due to differences in rainfall amounts during June to August (Table 2.1), but differences also were noted in air temperature (Figure 2.1). Studies by Rice et al. (2007) stated that early season weed control with *B. juncea* meal is possible, but sequential applications are necessary for adequate control of weeds that emerge later in the season due to additional nitrogen from the seed meal. Similar results were seen in our studies where weed control was inconsistent from year to year for most weed and some turfgrass species. Differences in environmental conditions could have played a role in the efficacy of MSM as a soil fumigant, despite an increase in MSM rates. Results from the greenhouse and field study indicate that tarping is necessary to control certain weed and turfgrass species when applying MSM as a soil fumigant. Studies by Vaughn et al. (2005) demonstrated that tarping field pennycress (*Thlaspi arvense* L.) seed meal at ≥5,000 kg/ha reduced weed biomasses > 58% compared to the tarped untreated control. Seed meal from mustard suppressed emergence and growth of a broad number of weed species important in turf. Although plant emergence and biomass was similar among species, differences were evident between species for both the greenhouse and field study. Rice et al. (2007) reported that oriental mustard decreased biomass of common chickweed up to 99%. Suszkiw and Boydston (2004) found that seed meal of brown mustard reduced common chickweed emergence up to 65%. Results in this paper also show common chickweed growth and emergence are sensitive to mustard residues. Rice et al. (2007) demonstrated differential affects of oriental mustard on biomass production of redroot pigweed (*Amaranthus retroflexus* L.) (72 to 93%) and common lambsquarters (*Chenopodium album* L.) (87 to 99%). Al-Khatib et al. (1997) and Krishnan et al. (1998) reported variation in species response with MSM residues. Although mustard seed meal impacted all weed species considered in this study, buckhorn plantain and common chickweed were most sensitive in the greenhouse study, with white clover most sensitive in the 2008 field study.

Seed size could be a factor in the affect of MSM on weed and turfgrass species. Results with the larger seeded turfgrasses, other than bermudagrass, resulted in slightly lower percent reductions in plant counts and biomass compared to the majority of smaller seeded weed species. A study conducted by Boydston et al. (2007) found similar results using white mustard seed meal, with smaller seeded annual weeds suppressed the most by rates of 2,240 kg/ha or higher. Mustard seed meal resulted in measurable reductions in plant emergence and biomass, and responses were more evident as rates increased in the greenhouse, although results varied in the field study. Boydston et al. (2007) found that 1,120 kg/ha white mustard meal was ineffective on weed growth in potatoes. However, rates from 2,240 to 4,480 kg/ha reduced seedling emergence of a broad range of broadleaf and grass weeds. From our results, tarped treatments of 3,360 kg/ha suppressed weed emergence from 25 to 80% with the 1,350 kg/ha rate. A higher rate of mustard seed meal is necessary to impact the broad range of weed species encountered in turf. The utility of mustard seed meal would be selective weed control in areas renovated for turf. Tall fescue and perennial ryegrass responded similarly to MSM as did the weed species examined. However, bermudagrass emergence and growth were not reduced consistently by MSM, suggesting MSM maybe used selectively in bermudagrass.

The importance of soil fumigants to control weeds is very important in turfgrass renovation. Soil fumigants are tarped following application to improve their effectiveness. Results from this study also demonstrate the utility of tarping following MSM application. Tarping reduced the release of volatile ITCs from oxidized MSM, likely allowing diffusion into respiring seeds in the treated soils. Hoagland et al. (2008) also found similar results with tarping, showing reductions in biomass of broadleaf and grass species after applications of *S. alba* meal at 8,533 kg/ha, compared to the untreated control. Additional studies on the time necessary before turfgrass species can be seeded into MSM treated areas (termed plant-back) should be done. Rice et al. (2007) found that lettuce sown in 3% *S. alba* treated soils was negatively impacted if planted within 4 weeks following MSM application.

MSM shows promise as an organic soil fumigant in turfgrass renovated areas. Optimum activity can only be realized if treated soils are tarped following MSM application and rates exceed 2,350 kg/ha. Some consideration for the use of MSM in renovated bermudagrass (seeded) should be given.

Sources of Materials

[1] Polypropylene containers: F1020 Flat, Hummert International, 4500 Earth City Expy, Earth City, MO 63045.

[2] Dazomet: Basamid® Granular Soil Fumigant, Certis USA, L.L.C 1945 Guilford Road, Suite 175, Columbia, MD 21046.

[3] RotaDarion® soil renovator, Greer Bros. Inc., 6290 Lardon Rd. NE, Salem, OR 97305.

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Table 2.1. Average rainfall (cm) from May to August at the University of Missouri Turfgrass Research farm during 2007 and 2008.

Year	May	June	July	August
	Average rainfall (cm)			
2007	9.5	9.9	5.0	2.4
2008	18.4	13.0	24.6	7.3

Table 2.2. ANOVA description for plant counts (28 DAP) following exposure to oriental mustard seed meal (MSM) in the greenhouse. MSM rates ranged from 0 to 3,360 kg/ha with treatments either tarped or untarped. Statistical analyses were combined over two greenhouse experiments.

	2006						2007	
Plant Species	FESAR[a]	LOLPE	PLALA	POAAN	STEME	TRFRE	CYNDA	DIGSA
	Pr > F							
Rate	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cover	0.0011	0.0109	0.0042	<0.0001	0.0012	0.0051	0.0235	NS
Rate*Cover	NS[b]	NS	NS	NS	0.0347	NS	NS	NS

[a] Abbreviations: CYNDA, 'Riviera' bermudagrass; DIGSA, large crabgrass; FESAR, 'Rembrandt' tall fescue; LOLPE, 'Evening Shade' perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; STEME, common chickweed; TRFRE, white clover.
[b] NS indicates that means within the column for each weed species are not significantly different using Fisher's Protected LSD at P = 0.05.

Table 2.3. Mean plant counts of common chickweed in the greenhouse 28 days after planting (DAP) following exposure to mustard seed meal (MSM) and dazomet during 2006.

Treatment	Rate (kg/ha)	Tarped	Untarped
		——Plant Counts [b]——	
Untreated	-	24 aA[c]	36 aB
MSM[a]	1,350	5 bA	24 bB
MSM	2,350	4 bA	5 cA
MSM	3,360	0 bA	4 cA
Dazomet	392	0 bA	0 cA
Treatment*Cover (LSD 0.05)		9	

[a]Abbreviations: MSM, oriental mustard seed meal.
[b] Plant counts were collected from 25 cm rows.
[c] Means within each column followed by the same lower case letter are not significantly different using Fisher's Protected LSD test at P = 0.05. Means within each row followed by the same capital letter are significantly different using Fisher's Protected LSD at P = 0.05.

Table 2.4. Mean cumulative plant counts of tarped treatments in the greenhouse 28 days after planting (DAP) following exposure to mustard seed meal (MSM) during 2006 and 2007.

Treatment	Rate	2006						2007	
	(kg/ha)	FESAR[a]	LOLPE	PLALA	POAAN	STEME	TRFRE	CYNDA	DIGSA
		Plant Counts/row[b]							
Untreated	-	37 a[c]	39 a	38 a	68 a	30 a	59 a	24 ab	8 a
MSM	1,350	21 b	23 b	7 b	40 b	15 b	27 b	26 a	4 b
MSM	2,350	9 c	13 c	7 b	9 c	5 c	11 c	17 c	4 b
MSM	3,360	7 c	9 c	2 bc	12 c	3 c	11 c	20 bc	3 c
Dazomet	392	0 d	0 d	0 c	0 d	0 d	0 c	0 d	0 d

[a] Abbreviations: CYNDA, 'Riviera' bermudagrass; DIGSA, large crabgrass; FESAR, 'Rembrandt' tall fescue; LOLPE, Evening Shade' perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; STEME, common chickweed; TRFRE, white clover; MSM, oriental mustard seed meal.
[b] Plant counts were collected by counting each 25 cm row for each weed and turfgrass species.
[c] Means within each column followed by the same letter are not significantly different using Fisher's Protected LSD at P = 0.05.

Table 2.5. ANOVA description for plant biomass 28 days after planting (DAP) following exposure to oriental mustard seed meal (MSM) (rates 0 to 3,360 kg/ha) for tarped and untarped plants. Statistical analyses were combined over two experiments in greenhouse.

	2006						2007	
Plant Species	FESAR[a]	LOLPE	PLALA	POAAN	STEME	TRFRE	CYNDA	DIGSA
	Pr > F							
Rate	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0087
Cover	0.0136	0.0045	0.0216	0.0011	NS[b]	NS	NS	0.0253
Rate*Cover	NS	NS	NS	0.0336	NS	NS	NS	NS

[a] Abbreviations: CYNDA, 'Riviera' bermudagrass; DIGSA, large crabgrass; FESAR, 'Rembrandt' tall fescue; LOLPE, 'Evening Shade' perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; STEME, common chickweed; TRFRE, white clover.

[b] NS indicates that means within the column for each weed species are not significantly different using Fisher's Protected LSD at P = 0.05.

Table 2.6. Plant biomass of annual bluegrass in the greenhouse 28 days after planting (DAP) following exposure to mustard seed meal (MSM) and dazomet during 2006.

Treatment	Rate (kg/ha)	Tarped	Untarped
		Plant Biomass[b]	
Untreated	-	0.77 a A[c]	0.76 a A
MSM[a]	1,350	0.31 bc B	0.89 a A
MSM	2,350	0.03 cd A	0.22 bcd A
MSM	3,360	0.005 d B	0.38 b A
Dazomet	392	0 b	0 d
Treatment*Cover LSD $_{0.05}$		0.3	

[a]Abbreviations: MSM, oriental mustard seed meal.
[b] Plant biomass was collected by cutting each 25 cm row at the soil surface and a weight was recorded.
[c] Means within each column followed by the same lower case letter are not significantly different using Fisher's Protected LSD at P = 0.05; - Means within each row followed by the same capital letter are significantly different using Fisher's Protected LSD at P = 0.05.

Table 2.7. Mean plant biomass of tarped treatments in the greenhouse 28 days after planting (DAP) following exposure to mustard seed meal (MSM) during 2006 and 2007.

Treatment	Rate	2006						2007	
	(kg/ha)	FESAR[a]	LOLPE	PLALA	POAAN	STEME	TRFRE	CYNDA	DIGSA
		Plant Biomass[b]							
Untreated	-	1.3 a[c]	1.32 a	3.75 a	0.77 a	1.52 a	1.75 a	0.44 ab	5.08 a
MSM	1,350	0.94 b	1.15 a	0.51 b	0.60 a	0.73 b	0.69 b	0.58 a	5.00 a
MSM	2,350	0.27 c	0.58 b	1.01 b	0.12 b	0.16 c	0.43 bc	0.34 b	4.99 a
MSM	3,360	0.20 c	0.43 b	0.12 b	0.19 b	0.09 c	0.20 c	0.40 b	3.24 a
Dazomet	392	0 c	0 c	0 b	0 b	0 c	0 c	0 c	0 b

[a] Abbreviations: CYNDA, 'Riviera' bermudagrass; DIGSA, large crabgrass; FESAR, 'Rembrandt' tall fescue; LOLPE, Evening Shade' perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; STEME, common chickweed; TRFRE, white clover; MSM, oriental mustard seed meal.

[b] Plant biomass for each weed and turfgrass species was collected by cutting each 25 cm row at soil level and a weight was recorded.

[c] Means within each column followed by the same letter are not significantly different using Fisher's Protected LSD at P = 0.05.

Table 2.8. Mean plant counts, averaged over all treatments, for tarped and untarped treatments of weed and turfgrass species four weeks following exposure to mustard seed meal (MSM). Studies were conducted in a greenhouse during 2006 and 2007.

	2006						2007	
Treatment	FESAR[a]	LOLPE	PLALA	POAAN	STEME	TRFRE	CYNDA	DIGSA
	Plant Counts/row[c]							
Tarped	12 b[b]	14 a	7 b	20 b	7 b	15 b	19 a	4a
Untarped	17 a	19 b	13 a	31 a	14 a	28 a	15 b	4a

[a] Abbreviations: CYNDA, 'Riviera' bermudagrass; DIGSA, large crabgrass; FESAR, 'Rembrandt' tall fescue; LOLPE ,'Evening Shade' perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; STEME, common chickweed; TRFRE, white clover; MSM, oriental mustard seed meal.
[b] Within each column, means followed by the same letter are not significantly different using Fisher's Protected LSD at $P = 0.05$.
[c] Plant counts were collected by counting each 25 cm row for each weed and turfgrass species.

Table 2.9. Mean plant biomass averaged over all treatments, for tarped and untarped treatments of weed and turfgrass species four weeks following exposure to mustard seed meal (MSM). Studies were conducted in a greenhouse during 2006 and 2007.

	2006						2007	
Treatment	FESAR[a]	LOLPE	PLALA	POAAN	STEME	TRFRE	CYNDA	DIGSA
	Plant Biomass[c]							
Tarped	0.42 b[b]	0.50 b	0.69 b	0.22 b	NS[d]	NS	NS	2.49 b
Untarped	0.68 a	0.89 a	1.45 a	0.45 a	NS	NS	NS	4.84 a

[a] Abbreviations: CYNDA, 'Riviera' bermudagrass; DIGSA, large crabgrass; FESAR, 'Rembrandt' tall fescue; LOLPE ,'Evening Shade' perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; STEME, common chickweed; TRFRE, white clover; MSM, oriental mustard seed meal.
[b] Within each column, means followed by the same letter are not significantly different using Fisher's Protected LSD test at P = 0.05.
[c] Plants biomass for each weed and turfgrass species was collected by cutting each 25 cm row at soil level and a weight was recorded.
[d] NS indicates that means within the column for each weed species are not significantly different using Fisher's Protected LSD at P = 0.05.

Table 2.10. Mean emergence of weed and turfgrass species in response to tarped and untarped treatments at various rates of mustard seed meal (MSM). Data were collected 6 weeks after planting (WAP) from a 2007 field study in Columbia, MO.

Treatment	Rate (kg/ha)	Taped/ Untarped	Species						
			FESAR[a]	LOLPE	TREFE	POAAN	PLALA	CYNDA	DIGSA
			Counts/ 91 cm row [c]						
Untreated	-	Tarped	0 d[b]	0 d	0.2 c	20.0 ab	4.0 d	2.5 bcd	1.2 c
MSM	1,120	Tarped	0.7 d	0.5 d	0.5 c	17.7 abc	4.2 d	2.5 bcd	1.5 c
MSM	1,680	Tarped	0 d	0 d	1.7 c	7.5 cde	1.2 d	2.0 cd	1.2 c
MSM	2,240	Tarped	0.5 d	0 d	0.2 c	5.2 de	0 d	3.7 abcd	0 c
MSM	2,800	Tarped	0 d	0 d	0 c	9.7 bcde	0 d	2.0 cd	2.5 cb
MSM	3,360	Tarped	0 d	0 d	0.5 c	1.2 e	0 d	3.2 bcd	4.2 b
Dazomet	392	Tarped	0 d	0 d	0 c	0 e	0 d	0 d	0 c
Untreated	-	Untarped	35.7 bc	37 bc	118.2 a	18 ab	49.2 ab	3.7 abcd	9.2 a
MSM	1,120	Untarped	35.5 bc	52.7 a	107.7 ab	20.5 ab	53.7 a	7.7 a	7.5 a
MSM	1,680	Untarped	37.2 b	43.2 ab	104 ab	20 ab	35.5 c	6.7 abc	7.7 a
MSM	2,240	Untarped	48.2 a	48.2 ab	120 a	22.5 a	40.7 bc	9 a	7 a
MSM	2,800	Untarped	29.2 c	28.5 c	85 b	20 ab	42.2 abc	8 ab	9.5 a
MSM	3,360	Untarped	41.5 ab	41.5 ab	117 a	12.2 abcd	34.7 c	4.7 abcd	4.2 b
Dazomet	392	Untarped	0 d	0 d	0 c	0 e	0 c	0 d	0.5 c
LSD (0.05)			7.5	11.5	25.9	10.9	12.8	5.7	2.7

[a] Abbreviations: CYNDA, common bermudagrass; DIGSA, large crabgrass; FESAR, tall fescue; LOLPE, perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; TRFRE, white clover; MSM, oriental mustard seed meal.
[b] Within each column, means followed by the same letter are not significantly different using Fisher's Protected LSD at P= 0.05.
[c] Plant counts were collected by counting each 91cm row for each weed and turfgrass species.

Table 2.11. Mean emergence of weed and turfgrass species in response to tarped and untarped treatments at various rates of mustard seed meal (MSM). Data were collected 6 weeks after planting (WAP) from a 2008 field study in Columbia, MO.

Treatment	Rate (kg/ha)	Taped/ Untarped	Species						
			FESAR[a]	LOLPE	TREFE	POAAN	PLALA	CYNDA	DIGSA
			Counts/ 91 cm row [c]						
Untreated	-	Tarped	22 abc[b]	23 bcd	7.5 cd	5.7 ab	27.5 a	25.7 a	24 ab
MSM	1,120	Tarped	9.7 bcd	11.7 de	4.7 cd	4 ab	5.7 cdef	9 cd	20.2 bcd
MSM	1,680	Tarped	9.7 cd	8.5 de	1.5 d	7.7 a	5 cdef	9.7 bc	17 bcd
MSM	2,240	Tarped	13.7 bcd	14.5 cde	0.7 d	5.7 ab	0.7 ef	9.2 cd	18 bcd
MSM	2,800	Tarped	4.5 de	7.5 de	4.5 cd	1.7 ab	3.2 def	7.7 de	10.2 d
MSM	3,360	Tarped	3.5 de	9.5 de	1 d	1.5 ab	3.2 def	9.7 bcd	11 dc
Dazomet	392	Tarped	0 e	0 e	0 d	0 b	0 f	0 e	0 e
Untreated	-	Untarped	30.2 a	44 a	38.7 a	5 ab	12.7 abcd	16 bc	32.2 ab
MSM	1,120	Untarped	29.5 a	20.5 bcd	26.7 ab	8.7 a	11.2 abcd	8.2 cd	18.2 bcd
MSM	1,680	Untarped	26 a	29.7 abc	32.5 a	8 a	26.5 a	13 bcd	22.7 abc
MSM	2,240	Untarped	27.7 a	34.5 ab	23.5 ab	7 a	20.7 ab	17.7 ab	24 ab
MSM	2,800	Untarped	26 a	20.2 bcd	23 ab	4.5 ab	10.2 bcde	10.7 bcd	38.5 a
MSM	3,360	Untarped	25.7 ab	34.2 ab	15.5 bc	4.2 ab	17.2 abc	14.7 bcd	31.5 ab
Dazomet	392	Untarped	0 e	0 e	0 d	0 b	0 f	0 e	0 e
LSD (0.05)			14.4	17.9	14.8	7.4	12.6	8.1	15.0

[a] Abbreviations: CYNDA, common bermudagrass; DIGSA, large crabgrass; FESAR, tall fescue; LOLPE, perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; TRFRE, white clover; MSM, oriental mustard seed meal.
[b] Within each column, means followed by the same letter are not significantly different using Fisher's Protected LSD at P = 0.05.
[c] Plant counts were collected by counting each 91 cm row for each weed and turfgrass species.

Table 2.12. Weed and turfgrass biomass as a percent of the untreated for tarped treatments. Data were collected 6 weeks after planting (WAP) from a 2007 field study.

Treatment	Rate (kg/ha)	Species						
		FESAR[a]	LOLPE	TREFE	POAAN	PLALA	CYNDA	DIGSA
		Biomass (% of control)[c]						
Untreated	-	100 de[b]	100 ab	100 ab	100 a	100 ab	100 ab	100 a
MSM	1,120	153 bcd	222 a	82 ab	99.5 a	128 a	165 a	94 ab
MSM	1,680	208 abc	146 ab	74 ab	54 abc	95 ab	109 ab	103 a
MSM	2,240	251 ab	247 a	130 a	100.5 a	105 ab	210 a	137 a
MSM	2,800	129 dc	221 a	58 bc	66 ab	105 ab	114 ab	126 a
MSM	3,360	300 a	271 a	113 ab	30 bc	80 b	90 ab	82 ab
Dazomet	392	0 e	0 b	0 c	0 c	0 c	0 b	23 b
LSD (0.05)		107	214	62	64	40	130	78

[a] Abbreviations: CYNDA, common bermudagrass; DIGSA, large crabgrass; FESAR, tall fescue; LOLPE, perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; TRFRE, white clover; MSM, oriental mustard seed meal.
[b] Within each column, means followed by the same letter are not significantly different using Fisher's Protected LSD at P = 0.05.
[c] Plant biomass for each turfgrass and weed species was collected by cutting each 91 cm row and then drying at

Table 2.13. Weed and turfgrass biomass as a percent of the untreated for tarped treatments. Data were collected 6 weeks after planting (WAP) from a 2008 field study.

Treatment	Rate (kg/ha)	Species						
		FESAR[a]	LOLPE	TREFE	POAAN	PLALA	CYNDA	DIGSA
		Biomass (% of control)[c]						
Untreated	-	100 a[b]	100 a	100 a	100 a	100 b	100 ab	100 ab
MSM	1,120	64 ab	75 ab	100 a	101 a	48 b	103 ab	59 b
MSM	1,680	63 ab	56 abc	60 ab	102 a	280 a	58 ab	101 ab
MSM	2,240	97 a	71 ab	53 ab	109 a	47 b	217 a	155 a
MSM	2,800	62 ab	29 bc	38 ab	47 a	34 b	51 ab	101 ab
MSM	3,360	54 ab	73 ab	34 ab	75 a	71 b	118 ab	93 ab
Dazomet	392	0 b	0 c	0 b	0 a	0 b	0 b	0 c
LSD (0.05)		71	68	93	NS	167	173	86

[a] Abbreviations: CYNDA, common bermudagrass; DIGSA, large crabgrass; FESAR, tall fescue; LOLPE, perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; TRFRE, white clover; MSM, oriental mustard seed meal.
[b] Within each column, means followed by the same letter are not significantly different using Fisher's Protected LSD at P = 0.05.
[c] Plant biomass for each turfgrass and weed species was collected by recording the dry weight each 91 cm row.

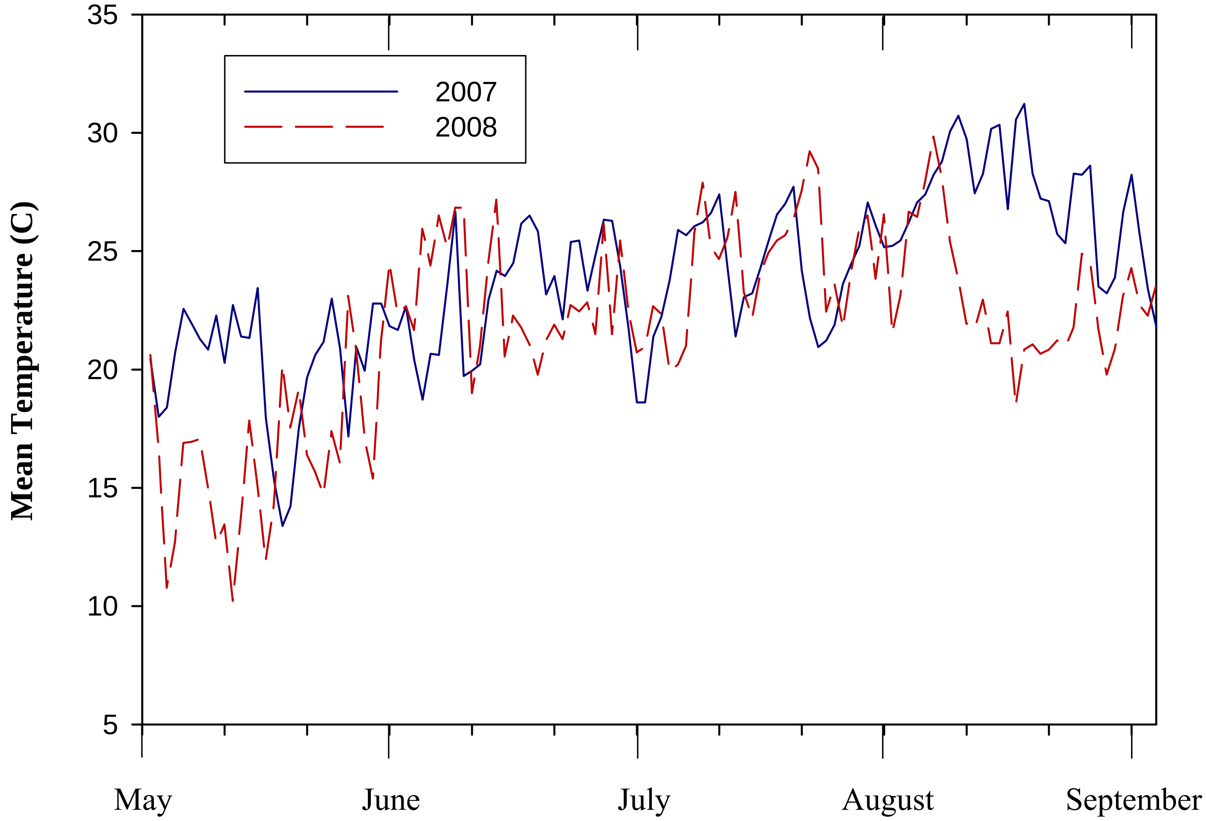

Figure 2.1. Daily mean temperatures from May through September for Columbia, MO in 2007 and 2008.

Chapter III

Use of oriental mustard (*Brassica juncea* L. Czern.) for dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett) control in the transition zone

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Abstract. Dollar spot (*Sclerotina homoeocarpa* F.T. Bennett), is a major turfgrass disease found throughout the United States. Intensive fungicide use has resulted in resistance to numerous fungicides. Natural alternatives are necessary for development of an integrated disease management program. Oriental mustard (*Brassica juncea* L. Czern.) seed meal (MSM) was evaluated for control of dollar spot in a creeping bentgrass (*Agrostis stolonifera* L.) golf green during 2007 and 2008. Field experiments consisted of surface applied MSM at 0, 56, 168, 280, 560, 840, 1120, and 1680 kg/ha. All treatments were compared to iprodione at 3.1 kg ai/ha. Treatments were re-applied to identical areas at 14 day intervals. Dollar spot counts, turf color and quality were recorded weekly for 16 weeks. In 2007, dollar spot counts varied among MSM treatments with higher rates resulting in lower dollar spot counts, although this wasn't consistent over time. In 2008, MSM rates of 1,120 and 1,680 kg/ha resulted in the most effective suppression of dollar spot (50 to 74%) from 6 to 16 weeks after initial

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application (WAIA). Iprodione resulted in the most consistent control of dollar spot densities during 2007; in 2008, rates of MSM > 840 kg/ha resulted in 21 to 68% higher dollar spot suppression than iprodione. Creeping bentgrass color and quality was initially lower 1 WAIA for both years following sequential applications of MSM. Both creeping bentgrass color and quality increased 6 WAIA as rates of MSM increased when compared to the untreated control. Collectively, results indicate that rates of surface applied MSM ≥ 840 kg/ha to creeping bentgrass have the potential to suppress dollar spot with sequential applications; however, rates of MSM > 840kg/ha is likely to cause unacceptable turfgrass injury following initial application. MSM application rates/intervals need to be further studied.

Nomenclature: Oriental mustard meal, *Brassica juncea* L. Czern.; 'Penncross' creeping bentgrass (*Agrostis palustris* Huds.); Dollar spot (Sclerotina homeocarpa F.T. Bennett).

Key Words: biofungicide, green manures, isothiocyanate.

Introduction

Dollar spot is a major disease of turfgrass (Turgeon 2005). Many different warm and cool season grasses are susceptible to dollar spot including: annual bluegrass (*Poa annua* L.), bentgrasses (*Agrostis* spp. L.), fescues (*Festuca* spp.), Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne* L.), bermudagrasses (*Cynodon* spp. [L.] Rich), zoysiagrasses (*Zoysia* spp. Willd.), centipedegrass (*Eremochloa ophiuroides* [Munro] Hack.), and St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze.) (Watschke et al. 1995; Turgeon 2005). Dollar spot symptoms first appear as straw colored areas on the margin of turfgrass leaves, with the edge of the spots outlined in red/brown coloration. Progressive symptoms appear as bleached spots or patches in the turf (Couch 2000; Turgeon 2005; Emmons 2008 and Watschke et al. 1995). Turf stressed by low soil moisture, low nitrogen fertility, high humidity, heavy dew, and an excessive thatch are more sensitive to the onset of dollar spot (Couch 2000; Turgeon 2005; Emmons 2008 and Watschke et al. 1995). Peak development of dollar spot on cool season turfgrasses can be observed during late spring to early summer and then again in late summer to early fall (Couch 2000).

There are many management practices that turf managers can utilize to suppress or prevent the incidence of dollar spot. Reducing the duration of leaf wetness prevents initial infestation by stromata and mycelial growth. Techniques include: poling, dragging, mowing, or syringing during the early morning (Watschke et al. 1995; Couch 2000). Other practices include minimizing drought stress, removal of excess thatch, and core aerating (Couch 2000; Fermanian et al. 1997; Watschke et al. 1995). According to Watschke et al. (1995), cultural practices such as the application of nitrogen will facilitate re-growth of turfgrass plants, masking the disease. Couch (2000) also stated that adequate fertility will reduce the occurrence and severity of dollar spot.

According to Vargas (1994), more money is spent on prevention and management of dollar spot on golf courses in the U.S. than any other turfgrass disease. Besides cultural practices, fungicides are used to suppress the severity of dollar spot. A common fungicide for suppressing dollar spot is iprodione (Anonymous, 2004). Iprodione is a member of the dicarboximide group of fungicides, which are considered surface active materials (Emmons 2008; Vargas 1994). However, foliar applied iprodione is known to exhibit limited systemic activity (Couch 2000; Corwin et al. 2007; Danneberger and

Vargas 1982). According to Latin, (2006) suppresstion of dollar spot was observed 14 days after application (DAA) of iprodione, but no activity was evident at 21 DAA.

Overdependence on fungicide use has resulted in the selection of resistant *S. homeocarpa* biotypes. In the 1960's, dollar spot resistance to benzimidazole fungicides was reported (Cole et al., 1968; Warren et al., 1974). In 1983, a dollar spot biotype was identified with resistance to dicarboximide fungicides (Detweiler et al., 1983); resistance to demthylation inhibitors (DMI) was confirmed in the early 1990's in Michigan (Golembiewski et al., 1995). Since then, other reports of dollar spot resistance to iprodione, propiconazole, and thiophanate-methyl have been reported on golf courses in Ohio and Tennessee (Goddard et al. 2005; Jo et al., 2006).

Plant materials derived from mustard (*Brassica* and *Sinapis*) species may provide a natural means to suppress diseases and reduce the selection pressure for fungicide resistance. Seed meals contain glucosinolates (GSL), which in the presence of water are hydrolyzed into secondary compounds termed isothiocyanates (ITCs), thiocyanates, nitriles, and oxazolidinethiones (Brown and Morra 1995; Vaughn et al. 2006; Brown et al. 1991). ITCs are considered highly active on soil borne fungal pathogens (Brown and Morra 1997; Kirkegaard et al. 1996). According to Goddard et al. (2005), oriental mustard (*B. juncea* L. Czern.) seed meal from 0.05 to 10 g/L inhibited mycelial growth of dollar spot fungus in a petri dish assay up to 100%. However, MSM resulted in unacceptable turf injury when applied to 'Crenshaw' creeping bentgrass (*Agrostis stolonifera* L.) at rates as low as 0.5 g/L (Goddard et al. 2005). Lyons and Sams (2003) found soil incorporated residues of mustard seed meal and mushroom compost decreased southern blight incidence (*Sclerotium rolfsii* Sacc.) in tomato. The prevalence of

Rhizoctonia damping-off (*Rhizoctonia solani* Kühn AG-4) was reduced on cabbage (*Brassica oleracea* L.) seedlings by mustard seed meal, with no detrimental effects on cabbage germination (Chung et al. 2002). Applications of black mustard (*Brassica napus* L.*)* around apple trees prevented Rhizoctonia root rot in apples (Cohen et al. 2005).

Sustainable management of dollar spot in turf should consider the integration of mustard seed meals. The objective of this research was to evaluate the effects of repeated surface applications of oriental mustard seed meal on the suppression of dollar spot in creeping bentgrass and determine the response of turf tissue.

MATERIALS AND METHODS

Field experiments were initiated on May 18 in 2007 and May 5 in 2008 on a 'Penncross' creeping bentgrass (*Agrostis palustris* Huds.) putting green (with a history of dollar spot infestation) at the Turfgrass Research Center near Columbia, MO. The soil was a USGA root zone mix, which followed USGA specifications (Hummel 1993). The pH was 6.2 and organic matter content was 0.5 %. The golf green was mowed 5 days a week to a height of 9 mm; no fertilizer was applied to the experimental area for the duration of the experiment. Individual plots measured 91.4 cm^2. Rainfall and air temperatures during the course of the study were recorded (Table 3.1 and Figure 3.1).

Treatments consisted of surface applied dry oriental mustard seed meal (Carl Sams, University of Tennessee) at 56, 168, 280, 560, 840, 1120, and 1680 kg/ha. The glucosinolate and nutrient analysis of MSM are described in Appendix Tables A1, A2, and A3. MSM was applied to each plot using shaker bottles to ensure a uniform application. An untreated control was also included. Once MSM was applied, approximately 1.0 cm of water was applied to the entire golf green, initiating the release of the breakdown products including ITC. Following watering, iprodione[1] at 3.1 kg ai/ha was applied as a standard treatment. Iprodione was applied to the assigned plots using a CO_2-pressurized backpack sprayer equipped with flat fan nozzles[2] and calibrated at 275 kPa to deliver 561 L/ha. All treatments were applied every two weeks to the same initial plots with a total of 3 applications. Irrigation was also applied as needed throughout the remainder of the study.

The density of dollar spot was recorded weekly up to 16 WAIA. Creeping bentgrass injury was evaluated at 3, 7, and 14 DAA on a scale of 0 to 100%, with 0 indicating no injury and 100% indicating turf death. The lack of observable injury resulted in these data not being shown. Both color and quality of creeping bentgrass was evaluated weekly up to 15 WAIA. Evaluations were based upon the national turfgrass evaluation program (NTEP) scale of 1 to 9 with 1 indicating straw color or plant death, and 9 indicating the highest green color or an ideal quality putting green. A rating of 6.0 or above is considered acceptable turf for both color and quality (NTEP 2003). Trials were designed as a randomized complete block with four replications and repeated. All data were subject to ANOVA using PROC Mixed analysis in SAS (SAS 2003). A square root transformation of dollar spot counts did not affect conclusions; therefore non-transformed means are presented. There was also a treatment by year interaction, so data were separated by year, and means were compared using Fisher's Protected LSD at P = 0.05.

Results and Discussion

Dollar spot was evident at the initiation of trials in both years, but overall severity was lower in 2007 (Figure 3.2A) compared to 2008 (Figure 3.2B). In 2007, differences in dollar spot counts between treatments were generally noted when densities exceeded 8 counts per $0.83m^2$ (Figure 3.2 A). Under those conditions, higher MSM rates resulted in lower dollar spot densities, but this was not consistent at each evaluation time. In 2008, differences in dollar spot density between treatments were noted 5 weeks after initiating the trial, when densities exceeded 20 per 0.83 m^2 (Figure 3.2B). Optimum MSM rates included 1,120 and 1,680 kg/ha which resulted in the most suppression of dollar spot (50 to 74%) from 6 to 16 weeks after initial application (WAIA). Iprodione resulted in the most consistent control of dollar spot densities during 2007. In 2008, rates of MSM > 840 kg/ha resulted in 21 to 68% greater dollar spot suppression compared to iprodione, when dollar spot densities exceeded 50 per $0.83m^2$ in the untreated check (7 to 13 WAIA). The lack of residual activity by iprodione is the result of factors such as rainfall, possible photodecomposition, and emergence of new foliage that is not protected (Vargas 1994). During this time period, temperatures ranged from 15 to 23 C which is ideal for dollar spot activity (Figure 3.1). Dollar spot counts were much higher for 2008 compared to 2007, presumably due to differences in daytime temperatures during the same time period. Rainfall during 2008 was also greater compared to 2007, especially during May and August (Table 3.1).

Creeping Bentgrass Color. Creeping bentgrass color never reached an acceptable level (6) in 2007, with a level of 7 observed in 2008 (Figure 3.3A and B). In both years, overall turf color during the course of the experiment improved with increasing rates of

MSM. During 2007, creeping bentgrass color varied widely between WAIA, corresponding to the timing of MSM application (0, 2, and 4 weeks after initial application) (Figure 3.3A). Reductions in turfgrass color were presumably due to turfgrass injury from MSM; chlorosis of the turfgrass leaves was observed. Overall turfgrass color was lowest (below 3.5) for treatments of MSM >840 kg/ha at 1 and 3 WAIA (1 week following the first and second applications). Color values below 6 are considered unacceptable (NTEP 2003). Differences in turfgrass color were generally noted from 1 to 6 WAIA of MSM. By 7 WAIA, turf grass color remained consistent, with optimum color observed for 1,120 and 1,680 kg/ha of MSM. In 2008, variation in turf color between MSM application dates were not evident (Figure 3.3B). Initial color values at 1 WAIA were the lowest, ranging from 3.0 to 5.5, and reached an optimum at 9 WAIA (5.5 to 7.5). From 6 WAIA through the remainder of the study, MSM rates at 1,680 kg/ha resulted in the highest turf color.

Creeping Bentgrass Quality. Turfgrass quality was relatively consistent between years, ranging from 1.5 to 5.5 in 2007, and 2.5 to 6.0 in 2008 (Figure 3.4A and B). These levels are not acceptable compared to NTEP standards (NTEP 2003). During 2007, turfgrass quality for all MSM treatments was lower than the untreated control until 6 WAIA (Figure 3.4A), likely reflecting injury induced by MSM. Quality varied between WAIA during the initial weeks of the experiment, corresponding to the timing of MSM application (0, 2, 4 WAIA) (Figure 3.3A). Although there was inconsistency across MSM rates, MSM was comparable to iprodione for affects in turf quality. In 2008, creeping bentgrass quality was initially lower at higher rates of MSM, with quality clearly greater at higher MSM rates from 9 to 15 WAIA (Figure 3.4B). Turfgrass quality following treatment with iprodione was among the highest treatments for 1 to 6 WAIA, but among the lowest treatments from 10 to 15 WAIA.

Despite differences in the incidence of dollar spot between years (Figure 3.2), the impact on creeping bentgrass color (Figure 3.3) and quality (Figure 3.4) were relatively consistent across MSM rates. Improvement in creeping bentgrass color and quality with higher MSM rates may be related to greater availability of soil nitrogen (Appendix Table A.3). Gale et al. (2006) documented that seed meals from members of the Brassicaceae family contain from 5 to 6% nitrogen. A study by Synder et al. (2009) stated that *B. napus*, *B. juncea*, and *Sinapis alba* seed meals at 909 and 1,818 kg/ha increased plant available N. According to Watschke et al. (1995), application of nitrogen will facilitate turfgrass growth masking dollar spot symptoms. Couch (2000) also stated that adequate fertility will reduce the occurrence and severity of dollar spot.

Environmental factors such as rainfall (Table 3.1) influenced the incidence of dollar spot and corresponding turf color and quality. Higher rainfall during June to August for 2008 versus 2007 decreased dollar spot counts, increased overall turf color, and slightly impacted turf quality for rates > 840 kg/ha after 6 WAIA. In order for MSM to provide its fullest efficacy when surface applied to turf, additional irrigation might need to be implemented, along with applying during cooler temperatures, and with lower MSM rates to prevent prolonged turfgrass injury and to increase effectiveness.

MSM influences the response of creeping bentgrass. Studies by Goddard et al. (2005) reported Crenshaw creeping bentgrass injury was unacceptable at rates of 0.5 and 1.0 g/L. A study by Tompkins et al. (2004), found that mustard seed meal applied at 1250, 5000, and 10,000 kg/ha increased turfgrass color. Tompkins et al. 2004 further stated that the overall impact on turf color with MSM was negligible, overall turfgrass cover was impacted. Our results demonstrated that MSM influenced creeping bentgrass color and quality initially at higher MSM rates, but these differences were ameliorated later in the season.

Although MSM is not commercially available in the U.S., commercial soil amendment products from other countries are used by turfgrass managers. Products such as FumaFert®, produced in Australia, is used as an amendment for turf and is composed of 66.6% mustard seed meal (*B. juncea*), and 33.3% cold pressed Neem Kernal (*Azadirachia indica*) (Anonymous, 2009). Oriental mustard seed meal used in these studies consisted of a very fine meal (similar to corn meal). This may make surface application in large scale turf situations not feasible for uniform coverage. The uniform release of ITCs depends upon a consistent form of MSM.

Collectively, suppression of dollar spot in creeping bentgrass with MSM shows promise. MSM appears to injure creeping bentgrass following initial application, but results in healthier turf later in the season. Suppression of dollar spot and the impact on turf color and quality were comparable for MSM and labeled use rates of iprodione.

Sources of Materials

[1] Iprodione: 26GT® fungicide, Bayer Environmental Sciences, 2 T.W. Alexander Drive Research Triangle PK, NC 27709.

[2] TeeJet® XR8004VS spray nozzles, Spraying Systems Co., P.O. Box 7900 Wheaton, IL 60189-7900.

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Table 3.1. Total rainfall (cm) from May to August in Columbia, MO during 2007 and 2008.

Year	May	June	July	August
	Total rainfall (cm)			
2007	9.5	9.9	5.0	2.4
2008	18.4	13.0	24.6	7.3

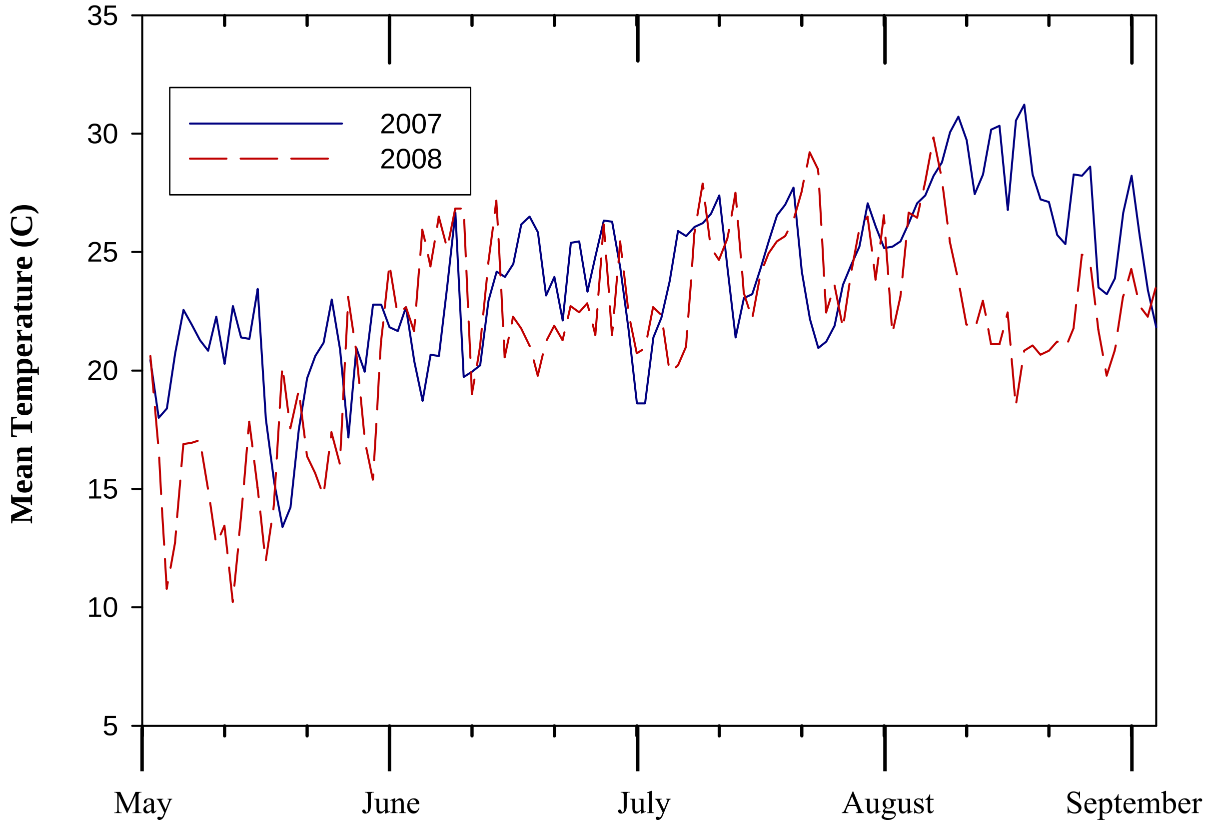
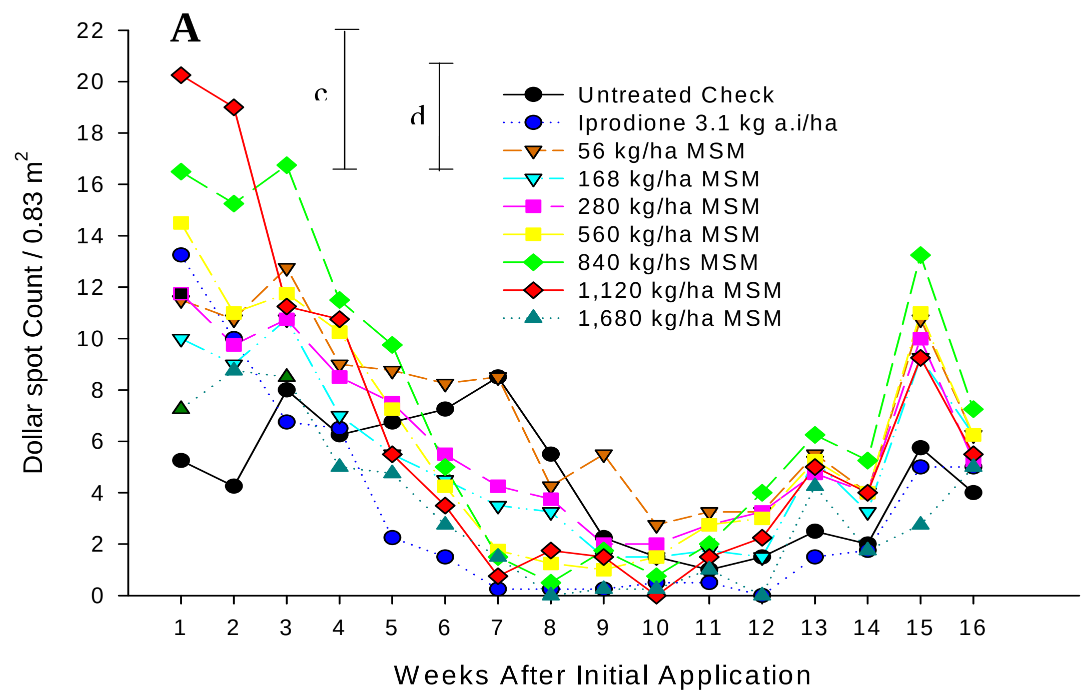


Figure 3.1. Daily mean air temperature from May through September for Columbia, MO in 2007 and 2008.



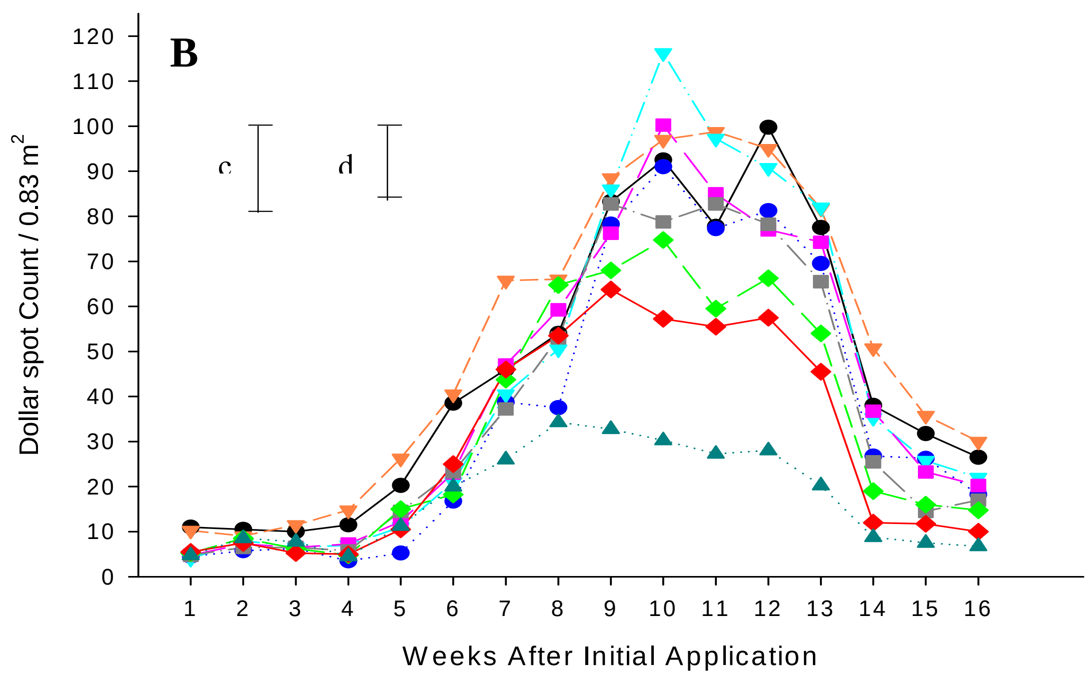
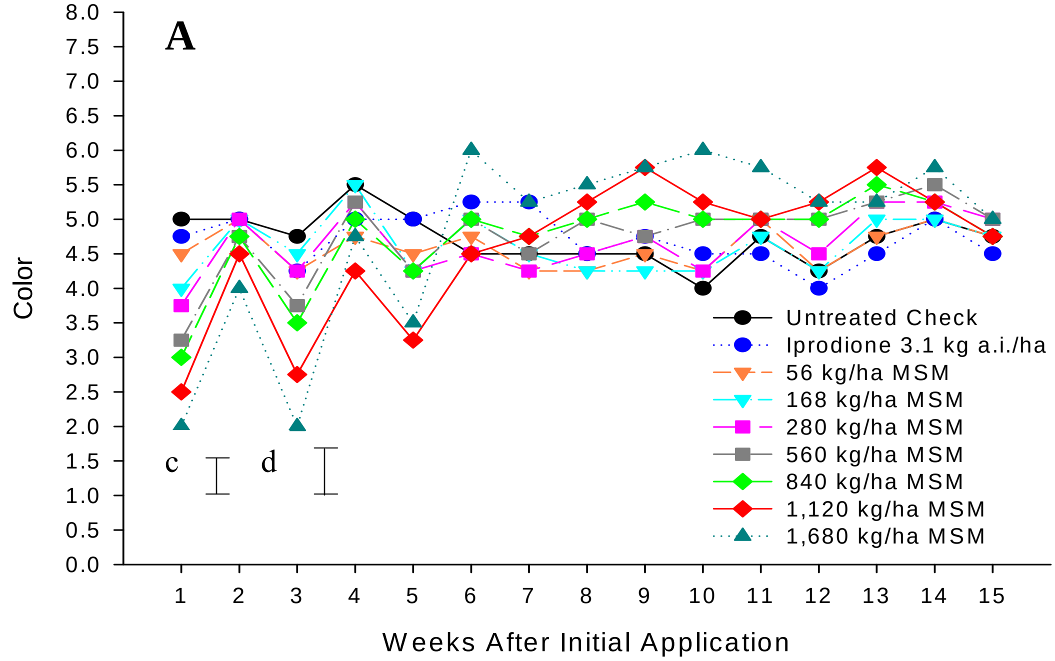


Figure 3.2. Mean dollar spot counts/ 0.83 m^2 during 2007 (A) and 2008 (B). For comparisons between treatments each week, means within the bar (c) are not significantly different based on Fishers Protected LSD at (P = 0.05); LSD = 5.9 for 2007 and 19.0 for 2008. For comparisons within a treatment across weeks, means within the bar (d) are not significantly different based on Fishers Protected LSD at (P = 0.05); LSD = 4.9 for 2007 and 17.1 for 2008. The dates of application of treatments were week 0, 2, and 4.



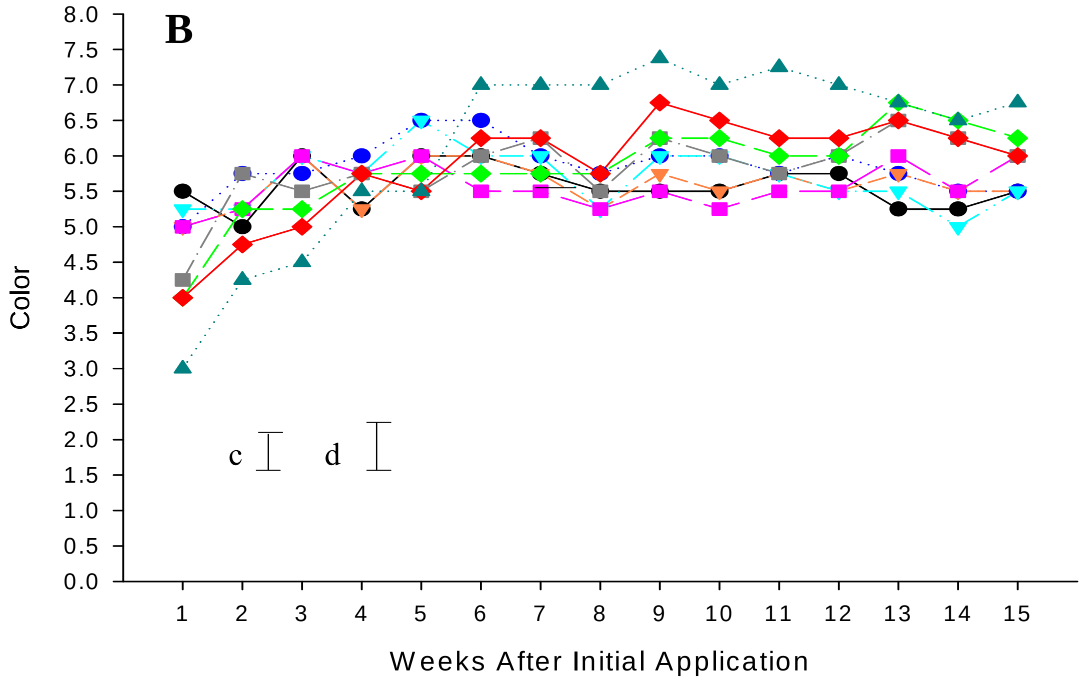
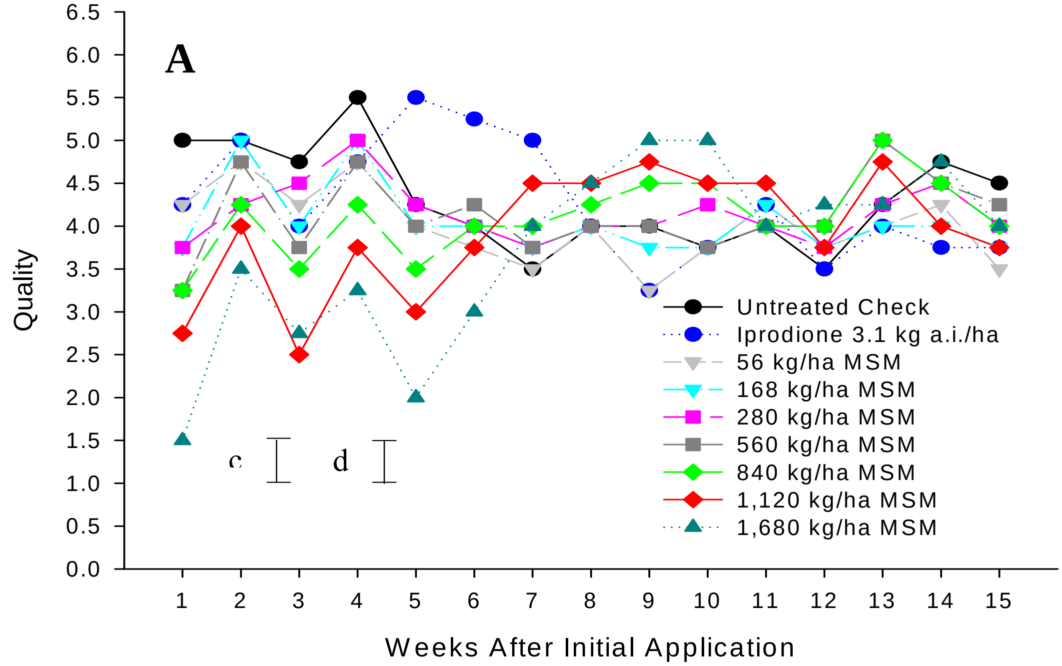


Figure 3.3. Mean turfgrass color during 2007 (A) and 2008 (B). For comparisons between treatments for each week, means within the bar (c) are not significantly different based on Fishers Protected LSD at (P = 0.05); LSD =0.5 for 2007 and 0.7 for 2008. For comparisons within a treatment across weeks, means within the bar (d) are not significantly different based on Fishers Protected LSD at (P = 0.05); LSD =0.6 for 2007 and 0.7 for 2008. The dates of application of treatments were week 0, 2, and 4.



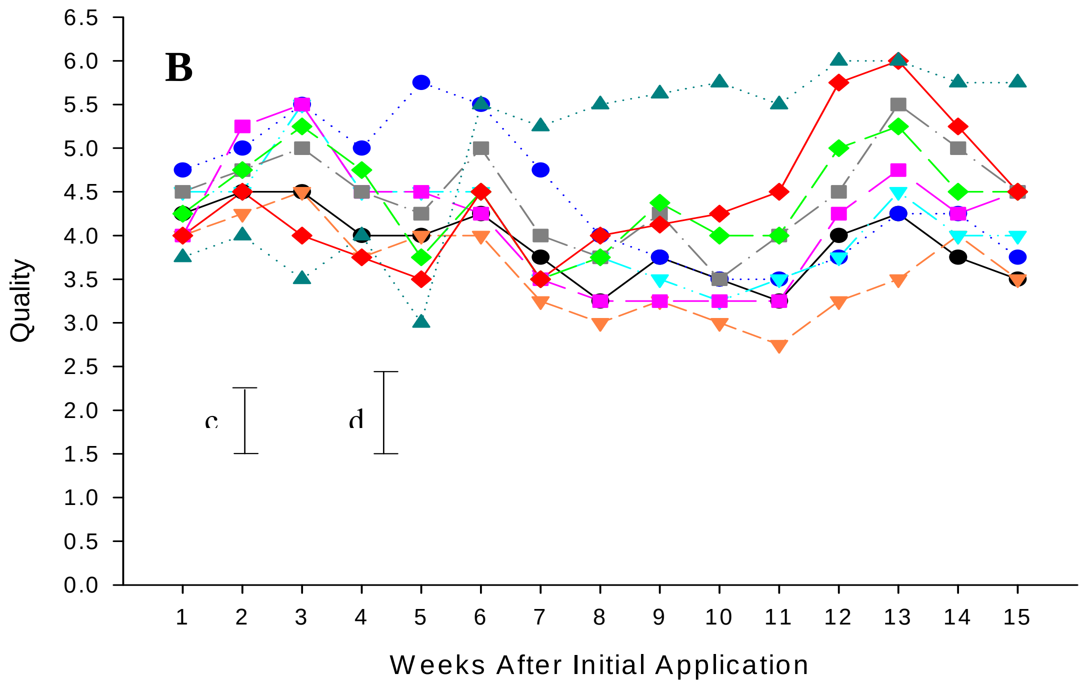


Figure 3.4. Mean turfgrass quality during 2007 (A) and 2008 (B). For comparisons between treatments each week, means within the bar (c) are not significantly different based on Fishers Protected LSD at (P = 0.05); (LSD = 0.05) for 2007 and 0.7 for 2008. For comparisons within a treatment across weeks, means within the bar (d) are not significantly different based on Fishers Protected LSD at (P = 0.05); LSD =0.6 for 2007 and 0.9 for 2008. The dates of application of treatments were week 0, 2, and 4.

Chapter IV

Residual activity of oriental mustard (*Brassica juncea* L. Czern.) on turfgrass species

Daniel T. Earlywine, Reid J. Smeda, Travis C. Teuton, and Carl E. Sams [6]

Abstract. Oriental mustard (*Brassica juncea* L. Czern.) seed meal (MSM) has shown potential as a natural soil fumigant in turf for controlling weeds, but the extent of activity following application is poorly described. The objective of this research was to determine the plant-back interval for cool season turfgrasses after application of MSM. Field trials were conducted during 2007 and 2008 with treatments consisting of 3,360 kg/ha MSM amended into soil and covered with polyethylene at 28, 21, 14, and 7 days before seeding cool season turfgrass species. In addition, a 0 days before seeding treatment was included where MSM application was followed by seeding and covered for 7 days. Turfgrass species included: 'Rembrant' tall fescue (*Festuca arundinacea* Schreb.), 'Evening Shade' perennial rye (*Lolium perenne* L.), 'Crenshaw' creeping bentgrass (*Agrostis stolonifera* L.), and 'Thermal Blue' Kentucky bluegrass (*Poa pratensis* L.). Cumulative emergence was recorded 1 to 6 weeks after planting (WAP) and plant biomass was collected at 6 WAP. During both years, reductions in creeping bentgrass emergence when planted within 7 days before planting (DBP) resulted in reductions from 22 to 100%, with Kentucky bluegrass emergence reduced by 99% during

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2008. Tall fescue, perennial ryegrass, and Kentucky bluegrass emergence was reduced from 58 to 75%, 46 to 75%, and 42 to 51%, respectively when grasses were planted at the time of MSM application. Creeping bentgrass and tall fescue biomass was reduced from 95 to 99.9% and 74 to 94% at the MSM 0 DBP application compared to the untreated control for both years. Perennial ryegrass in 2007 and 2008 was reduced 82 and 88%, respectively, at the 0 DBP treatment. Results from this study indicate MSM suppresses early growth of selective turfgrass species if planted the day of MSM application. Tall fescue and perennial ryegrass were the least sensitive to MSM application after 7 DBP treatments, indicating no phytotoxic affects on seeding turfgrasses following MSM application were present. MSM overall stimulated turfgrass growth by 6 WAP over all MSM treatments compared to the untreated control, except Kentucky bluegrass.

Nomenclature: Oriental mustard meal, (*Brassica juncea* L. Czern.); annual bluegrass, (*Poa annua* L.) POAAN; 'Rembrant' tall fescue (*Festuca arundinacea* Schreb.) FESAR; 'Evening Shade' perennial rye (*Lolium perenne* L.) LOLPE; 'Crenshaw'creeping bentgrass (*Agrostis stolonifera* L.) AGSST; and 'Thermal Blue' Kentucky bluegrass (*Poa pratensis* L.) POAPR.

Key Words: Fumigation, isothiocyanate, natural products.

Introduction

Fumigants are important for suppressing soil borne pests in turf. During renovation, fumigants eliminate the incidence of important pathogens and nematodes (Pessaraki 2007; McCarty and Miller 2002) that reduce stands of re-seeded turfgrasses. Fumigants also reduce weed populations ensuring minimal competition for emerging turf seedlings. In many situations, soil fumigants are used during turf renovation and establishment as a method to kill existing or unwanted turf, but are also used to provide extended weed control after turfgrasses are seeded, sprigged, or sodded (Pessaraki 2007; McCarty and Miller 2002).

Until recently, methyl bromide was widely used for fumigation in turf (USEPA 2009). Effective synthetic materials are being considered as alternatives (Unruh et al. 2002), but many synthetic compounds pose risks to applicators and the environment (Noling 1997; Herzstein 1990; Pimentel 2007; USEPA 2008). The desire for sustainable, environmentally friendly practices has led to the discovery of natural compounds, so called biofumigants.

Select *Brassica* and *Sinapis* species in the Brassicaceae family have been used as cover crops for more than 30 years to reduce soil borne pests in vegetable crops and vineyards. A study conducted by Mayton et al. (1996) reported macerated leaf tissue from *B. juncea* 'Cutlass' reduced radial growth of a fungus that causes potato dry rot (*Fusarium sambucinum* Fuckel) by >50%, compared to an untreated control. Larkin et al. (2006) reported leaf tissue from *B. juncea* reduced the incidence of *Rhizoctonia solani* Kühn, *Phytophthora erythroseptica* Pethybr., *Pythium ultimum* Trow, *Sclerotinia sclerotiorum* Lib., and *F. sambucinum* Fuckel by 80 to 100%. Rahman and Somers (2005), determined that root-knot nematode (*Meloidogyne javanica*) suppression with *B. juncea* mustard green manures was optimal with 8,164 to 10,432 kg of dry matter/ha and mustard seed meal at 1,814 kg/ha.

Brassica tissues also exhibit activity on a broad range of plant species. Haramoto and Gallandt (2005) determined that canola (*Brassica napus* L.), and yellow mustard

(*Sinapis alba* L.) residues suppressed the emergence of sixteen weed and crop species from 23 to 34%. Boydston and Hang (1995) found green foxtail (*Setaria viridis* (L.) Beauv.) and hairy nightshade (*Solanum sarrachoides* Sendtner) biomass was reduced by 70 and 83%, respectively, following incorporation of leaf tissue from white mustard (*Brassica hirta* Moench).

More recently, seed meals from *Brassica* and *Sinapis* species, which are by-products of the growing biofuels industry, also were reported to exhibit herbicidal activity (Boydston et al. 2007; Boydston et al. 2008; Rice et al. 2007). Kirkegaard et al. (1996) reported that 'Dollarbird' wheat (*Triticum aestivum* L.) germination was delayed by 6 days and shoot growth was reduced by 50% when wheat seed was planted into banded strips of *B. juncea* seed meal (500 kg/ha). A rate of 1,000 kg/ha prevented all wheat emergence. Other studies by Rice et al. (2007) showed that beet (*Beta vulgaris* L.) and lettuce (*Lactuca sativa* L.) emergence was inhibited by 4,191 to 12,575 kg/ha applications of canola (*B. napus* L.), oriental mustard (*B. juncea* L.), and yellow mustard (*S. alba* L.) seed meal, when plants were sown 28 days after MSM incorporation. Rice et al. (2007) further stated that *B. juncea* at 12,575 kg/ha reduced emergence of lettuce and beet up to 58% more than the other seed meal treatments.

The basis for biofumigant activity of *Brassica* species is the degradation of glucosinolates (GSL) from plant tissue, and subsequent release of numerous isothiocyanates (ITCs). GSL's are detected in leaves, stems, roots, and seeds (Sang et al. 1984), with the highest GSL concentrations found in the mustard seed itself (Borek and Morra, 2005). The duration of activity of GSL hydrolysis products in the environment is often short. According to Borek et al. (1995), the half-life of allyl isothiocyanate (AITC), hydrolyzed from the GSL sinigrin found in *B. juncea* (Kimber and McGregor, 1995; Borek et al. 1994), can range from 20 to 60 h.

An important consideration for the use of fumigants in turfgrass renovation is the time interval between application and safe establishment of the turfgrass (Pessaraki 2007). This is referred to as the plant-back interval. These planting intervals are crucial for turf managers to provide optimal conditions for germination of newly seeded turfgrasses during renovation. Plant-back intervals are also important because they allow turf managers to predict when seeded turfgrasses should be established prior to a sporting event (athletic fields), or for timing production on sod farms.

Few studies have documented detrimental affects of mustard seed meals on turfgrass species following application. The objective of this research was to determine optimal plant-back intervals for seeding different cool season turfgrasses following incorporation of MSM.

Materials and Methods

Trials were established in 2007 and 2008 at the University of Missouri Turfgrass Research Center near Columbia. The experimental area consisted of bermudagrass (*Cynodon* spp. [L.] Rich) for the past 4 years. The soil was a Mexico silt loam (fine, smectitic, mesic Vertic Epiaqualfs) with a pH of 5.7, and organic matter content of 2.3%. An area of 9.1 square meters was treated with glyphosate[1] at 2.2 kg ae/ha on August 1 in 2007 and August 8 in 2008. Fourteen days later, the experimental area was tilled twice with a RotaDarion®[2] to a depth of 12 cm.

At various times (28, 21, 14, 7 days) prior to seeding turfgrasses in individual plot areas (1.8 by 1.2 m), dry oriental mustard seed meal (Carl Sams, University of Tennessee) was applied at 3,360 kg/ha and incorporated into soil using a rototiller. In addition, a 0 days before seeding treatment was included where MSM application was followed by seeding and covered for 7 days. The glucosinolate and nutrient analysis of MSM are described in Appendix Tables A1, A2, and A3. An untreated control was also included. Following treatment, 14 cm trenches were dug around each plot and irrigated with 0.9 cm of water to initiate release of GSL's. Immediately following watering, each plot was sealed with 0.1 mm clear polyethylene. Seven days later, the polyethylene was removed and additional treatments initiated. This cycle was repeated four times.

Prior to initiating the last treatment (0 days before seeding), the experimental area was tilled to a depth of 14 cm and raked smooth. MSM was incorporated into the soil in the designated treatment before application of water. Four turfgrass species were each seeded to a depth of 0.5 cm in rows 91 cm long in each plot of all treatments. Each seeded turfgrass species is commonly grown in Missouri: 'Rembrant' tall fescue (*Festuca arundinacea* Schreb.); 'Evening Shade' perennial rye (*Lolium perenne* L.); 'Crenshaw' creeping bentgrass (*Agrostis stolonifera* L.); and 'Thermal Blue' Kentucky bluegrass (*Poa pratensis* L.). The 0 day treatment was then sealed with polyethylene for the next seven days.

All plots were watered as needed for the following 3 weeks to maintain adequate soil moisture for seedling emergence. Weekly cumulative emergence by species was recorded up to 6 weeks after planting (WAP). All emerged seedlings were harvested at 6 WAP by clipping plants at the soil surface and recording fresh weight. Dry weights were recorded after placing tissue in a drying oven at 60 C for 72 h. Weather conditions (rainfall and air temperatures) were monitored throughout the duration of the research trials (Table 4.1, Figure 4.1).

Trials were designed as a randomized complete block with four replications and repeated. Plant counts and biomass were separated based upon a PROC MIXED analysis using SAS (SAS 2003). Prior to analysis, Bartlett's test for equal variance was performed (Little and Hills 1978; SAS 2003). Plant counts were subjected to square root transformation, but results were not impacted. Therefore non-transformed means are presented. All means were separated using Fisher's Protected LSD at P = 0.05.

Results and Discussion

The treatment by year interaction was significant; therefore data were evaluated for each year. Main effects of treatment and time were significant over all turfgrass species tested during 2007 and 2008 (Table 4.2). There was an interaction between treatment and time for creeping bentgrass emergence in 2007 and 2008, and for Kentucky bluegrass in 2008 (Table 4.2).

Emergence of creeping bentgrass was affected by the time of MSM incorporation prior to grass seeding, but results varied between years (Tables 4.3 and 4.4). Creeping bentgrass counts at 1 WAP in 2007 and 2008 did not follow a pattern related to MSM applications at different DBP. In both years, application of MSM within 7 DBP resulted in a 22 to 100% reduction in creeping bentgrass emergence compared to the untreated control (Tables 4.3 and 4.4). Creeping bentgrass continued to emerge over the 6 week period for all MSM treatments, as well as the untreated control. In 2007, little emergence of creeping bentgrass was measured over the 6 week period for the 0 DBP treatment, with emergence at 6 WAP reduced by 96% (Table 4.3). In 2008, emergence for the 0 DBP treatment occurred by 3 WAP and continued up to 6 WAP, with cumulative emergence reduced by 40% compared to the untreated control (Table 4.4).

Emergence of Kentucky bluegrass was also affected by the time of MSM incorporation prior to grass seeding in 2008 (Table 4.5), but was not significant during 2007 (data not shown). At 1 WAP, Kentucky bluegrass emergence within 7 DBP was reduced 99% compared to the untreated control with little effect by MSM for earlier applications. Cumulative emergence of Kentucky bluegrass at 6 WAP was reduced by 42%; emergence continued over time where MSM did not reduce initial emergence.

Inhibitory effects of MSM on cumulative emergence varied between turfgrass species for both years (Table 4.6). At 6 WAP in both years, emergence of tall fescue, perennial ryegrass, and Kentucky bluegrass was only impacted when seeding occurred at the time of MSM application. Compared to the untreated control, reductions over both years for tall fescue, perennial ryegrass, and Kentucky bluegrass ranged from 58 to 75%, 46 to 75% and 42 to 51%, respectively. The efficacy of MSM was overall greater in 2007 compared to 2008.

Results with turfgrass biomass were similar to seedling emergence counts for all species. Significant differences were measured among all species tested except Kentucky bluegrass, where no differences were evident in either year (Table 4.7). For both creeping bentgrass and tall fescue, plant biomass was only reduced for the 0 DBP treatment compared to the untreated control in both years (Table 4.8). For perennial ryegrass, plant biomass per row was similar between years for the 0 DBP treatment and reduced by 82 to 89%. It was noted that plant biomass for the untreated control was consistently lower compared to the biomass for the MSM applications from 28 to 7 DBP.

Results from this field study indicate increases in plant biomass could be due to the increase in plant available N after application of MSM (Appendix Table A.3). Current studies by Gale et al. (2006) have stated that the N content for Brassicaceae seed meals can range from 5 to 6 % by weight. A recent study by Synder et al. (2009) reported only slight increases in carrot yields using Brassicaceae seed meals (BSM), they also stated other crops with higher N requirements may benefit from using BSMs as a soil amendment. Synder et al. (2009) further reported short term increases in microbial N content after applications of different BSMs including: *B. juncea*, *B. napus*, and *S. alba* at 909 and 1,818 kg/ha. Synder et al. (2009) claimed that N immobilization was short-lived; organic N was mineralized later in the growing season.

Results from this study indicate that MSM consistently suppressed a number of turfgrass species. However, the suppressive activity of MSM was restricted primarily to within 7 days of planting turfgrass. The suppressive activity could be due to the application of MSM and seeding turfgrass at the same time, in addition to tarping for 7 days. For MSM treatments, emergence of creeping bentgrass in both years (Tables 4.3 and 4.4) and Kentucky bluegrass in 2008 (Table 4.5) where reduced less than 60% by 1 WAP; plant emergence continued over the next 5 weeks. This indicates that MSM activity is short lived. However, where initial suppression of emergence (1 WAP) was > 90%, plant emergence was less likely to occur through time. According to Gimsing and Kirkegaard (2009), GSLs and their breakdown products are short-lived in the soil and affected by soil factors such as soil texture, soil moisture, and temperature. A study conducted by Petersen et al. (2001), reported that 2-phenylethyl ITCs disappearance was enhanced by increasing soil moisture and soil temperature. The short life of isothiocyanates in the soil can vary from 1 to 5 days (Brown and Morra 1997). Other studies have stated the half life of the primary hydrolysis product in *B. juncea*, known as allyl isothiocyanate (AITC), can range from 20 to 60 h (Borek et al. 1995).

Results varied between years for some turfgrass species, presumably due to differences in environmental conditions. Temperatures during the middle of September to the middle of October during 2008 were generally cooler compared to the same period in 2007 (Fig. 4.1). Also, rainfall amounts for August and September were significantly higher during 2008 compared to 2007 with 4.9 and 25.4 cm more rain, respectively. As stated above, a number of soil factors such as soil texture, organic matter, moisture content, and temperature could play a vital role in the degradation of isothiocyanates in the soil, influencing the overall efficacy toward certain soil borne pests (Gimsing and Kirkegaard 2009). Price et al. (2005) stated soil microbes are involved in the degradation of isothiocyanate concentrations in the soil, with up to 3 -fold higher concentrations of 2-propenyl ITC remaining in autoclaved soil compared to non- autoclaved soil.

MSM efficacy towards select turfgrass species varied between years, although some species not impacted showed an increased plant biomass. For both years, tall fescue and perennial ryegrass biomass was higher than the untreated control after MSM incorporation 7 DBP. Increases in biomass are presumably due to N availability of MSM (Appendix Table A.3). Studies by Borek and Morra (2005) stated that mineralized *S. alba* seed meal could be a significant nitrogen source (5 to 6%). Rice et al. (2007) also reported an increase in biomass of red root pigweed in *B. juncea* amended plots;

presumably due to N mineralization by micro-organisms in the soil. This indicates that turfgasses such as tall fescue and perennial ryegrass when sown from 7 to 21 days following MSM application could benefit from MSM as an organic nitrogen source for establishment.

In summary, results from this study indicate that select cool-season turfgrass species vary in sensitivity to MSM when planted 7 days following application. Tall fescue and perennial ryegrass were least sensitive to the incorporation of MSM at 7 DBP, indicating a short plant-back interval. The overall half-life of MSM is short lived, and results indicate that a plant back interval at 7 or more days should be warranted following MSM applications. If MSM treatments reduced emergence for turfgrass species was < 60% initially, emergence continued through time. If turfgrass emergence was > 90% initially, very little increase in emergence followed. Stimulatory growth effects for selected turfgrasses was observed following MSM treatments from 7 to 28 DBP, presumably due to increases in mineralized organic N in the soil.

Sources of Materials

[1] Glyphosate: Roundup Pro®, Monsanto Company, St. Louis, MO 63167.

[2] RotaDarion® soil renovator, Greer Bros. Inc., 6290 Lardon Rd. NE, Salem, OR 97305.

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Table 4.1. Total rainfall (cm) in Columbia, MO from August to October in 2007 and 2008.

Year	August	September	October
	Total rainfall (cm)		
2007	2.4	3.7	6.9
2008	7.3	29.1	4.1

Table 4.2. ANOVA description for turfgrass seedling counts as affected by incorporation of oriental mustard seed meal (MSM) over treatments (28 to 0 days before planting) and time after planting (1 to 6 weeks) during 2007 and 2008.

	2007				2008			
	AGSST[a]	FESAR	LOLPE	POAPR	AGSST	FESAR	LOLPE	POAPR
	Pr > F							
Treatment	<0.0001	0.0015	<0.0001	<0.0001	0.0007	<0.0001	<0.0001	<0.0001
Time	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Treatment*Time	0.0093	NS[b]	NS	NS	0.0007	NS	NS	0.0046

[a] Abbreviations: AGSST, 'Crenshaw' creeping bentgrass (*Agrostis stolonifera* L.) ; FESAR, 'Rembrandt' tall fescue; LOLPE, 'Evening Shade' perennial ryegrass; POAPR, 'Thermal Blue' Kentucky bluegrass.
[b] NS indicates that means within the column for each weed species are not significantly different using Fisher's Protected LSD at P = 0.05.

Table 4.3. Mean cumulative seedling emergence of creeping bentgrass in response to incorporation of oriental mustard seed meal (MSM) in 2007.

	WAP[a]					
Application Timing	1	2	3	4	5	6
	Plant counts/row[b]					
Untreated	17.2 b B[c]	27.7 ab A	28 ab A	30.7 a A	33.7 a A	33.7 a A
MSM (28 DBP[a])	9.2 bc D	19.2 bc C	22 b BC	27.5 ab AB	28.5 ab A	28.5 ab A
MSM (21 DBP)	17 b C	23.5 bc B	26.5 ab AB	31 a A	31 ab A	31 ab A
MSM (14 DBP)	29.0 a A	33.5 a A	34.2 a A	33.5 a A	33.5 a A	33.7 a A
MSM (7 DBP)	2.7 c B	17.2 c A	20.7 b A	21.2 b A	22.7 b A	22.7 b A
MSM (0 DBP)	0 c A	0 d A	1.5 c A	1.5 c A	1.5 c A	1.5 c A

[a]Abbreviations: WAP, weeks after planting; DBP, days before planting.
[b] Plants counts were collected by counting each 91cm row.
[c] Means within each column followed by the same lower case letter are not significantly different using Fisher's Protected LSD test at P = 0.05, LSD = 9.3; Means within each row followed by the same capital letter are not significantly different using Fisher's Protected LSD test at P = 0.05, LSD = 6.2.

Table 4.4. Mean cumulative seedling emergence of creeping bentgrass in response to incorporation of oriental mustard seed meal (MSM) in 2008.

	WAP[a]					
Application Timing	1	2	3	4	5	6
	Plant counts/row[b]					
Untreated	30 a C[c]	32 a BC	34.7 a ABC	37.5 ab AB	37.7 ab AB	39.6 ab A
MSM (28 DBP[a])	7.5 c C	19 abc B	22.7 ab AB	25.7 bc A	28 bc A	28 bc A
MSM (21 DBP)	10.2 bc C	18.2 bc B	23.7 ab AB	24.7 bc A	24.2 bc AB	26.7 bc A
MSM (14 DBP)	5 c E	11.2 cd D	16.5 bc CD	21.7 c BC	26 bc B	32.7 bc A
MSM (7 DBP)	23.5 ab D	28.5 ab D	35 a C	40 a BC	43.7 a AB	46.7 a A
MSM (0 DBP)	0 c C	0 d C	4.5 c C	17.2 c B	22.2 c AB	24 c A

[a] Abbreviations: WAP, weeks after planting; DBP, days before planting.
[b] Plants counts were collected by counting each 91cm row.
[c] Means within each column followed by the same lower case letter are not significantly different using Fisher's Protected LSD test at P = 0.05, LSD = 13.8; Means within each row followed by the same capital letter are not significantly different using Fisher's Protected LSD test at P = 0.05, LSD = 6.1.

Table 4.5. Mean cumulative seedling emergence of Kentucky bluegrass in response to incorporation of oriental mustard seed meal (MSM) during 2008.

	WAP[a]					
Application Timing	1	2	3	4	5	6
	Plant counts/row[b]					
Untreated	15 a C[c]	39.7 ab B	44.5 ab AB	46.7 a AB	49.7 a A	52.5 a A
MSM (28 DBP[a])	7.5 ab C	38.5 ab B	44.2 ab AB	46.2 a AB	49 a A	48.5 ab A
MSM (21 DBP)	15 a C	42.5 a B	49.2 a AB	50.7 a AB	51 a AB	53 a A
MSM (14 DBP)	1 b C	40.7 a B	49.2 a AB	48.5 a AB	49.7 a AB	50.5 ab A
MSM (7 DBP)	11 a C	28.5 b B	37 b AB	41 a A	40 a A	40.7 bc A
MSM (0 DBP)	0.2 b C	0.2 c C	19.2 c B	29 b A	32.2 b A	30.5 c A

[a]Abbreviations: WAP, weeks after planting, DBP, days before planting.
[b] Plants counts were collected by counting each 91cm row.
[c] Means within each column followed by the same lower case letter are not significantly different using Fisher's Protected LSD test at P = 0.05, LSD = 11.7; Means within each row followed by the same capital letter are significantly different using Fisher's Protected LSD test at P = 0.05, LSD = 9.5.

Table 4.6. Mean plant emergence following application of oriental mustard seed meal (MSM) at different time intervals before seeding. Plant counts were cumulative over six weeks for trials in 2007 and 2008 near Columbia, MO.

	2007			2008		
Application Timing	FESAR[a]	LOLPE	POAPR	FESAR	LOLPE	POAPR
	Plant counts/row[b]					
Untreated	30 a[c]	36.7 a	25.5 a	40.5 a	40.5 ab	52.5 a
MSM (28 DBP[d])	32 a	34.5 a	8.5 d	36.7 a	40.7 ab	48.5 ab
MSM (21 DBP)	29.2 a	37.5 a	14 bcd	42.7 a	42.2 ab	53 a
MSM (14 DBP)	30.7 a	39 a	19.2 abc	40.2 a	35.2 b	50.5 ab
MSM (7 DBP)	27.2 a	41 a	21.7 ab	42.5 a	46 a	40.7 bc
MSM (0 DBP)	7.5 b	9.2 b	12.5 cd	17 b	22 c	30.5 c
LSD P= 0.05	7.9	7.3	12.5	8.0	9.2	11.7

[a] Abbreviations: FESAR, 'Rembrandt' tall fescue; LOLPE, 'Evening Shade' perennial ryegrass; POAPR, 'Thermal Blue' Kentucky bluegrass.
[b] Plants counts were collected by counting each 91 cm row for each weed species.
[c] Means within each column followed by the same letter are not significantly different using Fisher's Protected LSD at P = 0.05.
[d] DBP, days before planting.

Table 4.7. ANOVA description for turfgrass seedling biomass as affected by incorporation of oriental mustard seed meal (MSM) 6 weeks after planting (WAP) over treatments (28 to 0 days before planting) during 2007 and 2008.

	2007				2008			
Plant Species	AGSST[a]	FESAR	LOLPE	POAPR	AGSST	FESAR	LOLPE	POAPR
	Pr > F							
Treatment	0.0013	<0.0001	0.0016	NS[b]	NS	0.0004	0.0199	NS

[a] Abbreviations: AGSST, ‘Crenshaw’ creeping bentgrass (*Agrostis stolonifera* L.) ; FESAR, ‘Rembrandt’ tall fescue; LOLPE, ‘Evening Shade’ perennial ryegrass; POAPR, ‘Thermal Blue’ Kentucky bluegrass.
[b] NS indicates that means within the column for each weed species are not significantly different using Fisher’s Protected LSD at P = 0.05.

Table 4.8. Mean plant biomass in response to applications of oriental mustard seed meal (MSM) at various times before planting turfgrass species. Biomass was estimated at 6 weeks after planting (WAP) for field trials in 2007and 2008.

	2007				2008			
Application Timing	AGSST[a]	FESAR	LOLPE	POAPR	AGSST	FESAR	LOLPE	POAPR
	Plant biomass/row[b]							
Untreated	0.86 b[c]	1.89 b	3.30 b	0.50 abc	2.11 a	1.54 c	3.46 ab	1.62
MSM (28 DBP[f])	1.95 a	4.41 a	7.13 a	0.27 abc	1.11 b	2.13 bc	3.02 abc	1.36
MSM (21 DBP)	1.90 a	4.09 a	6.69 a	0.44 abc	0.86 bc	3.14 a	5.28 a	1.79
MSM (14 DBP)	2.01 a	3.93 a	6.54 a	0.12 bc	0.71 bc	1.90 c	2.10 bc	1.11
MSM (7 DBP)	0.82 b	3.92 a	6.83 a	0.63 a	2.40 a	2.94 ab	5.17 a	1.41
MSM (0 DBP)	0.001 c	0.13 c	0.36 b	0.09 c	0.12 c	0.41 d	0.61 c	0.49
LSD P= 0.05	0.9	1.1	3.1	0.5[d]	0.9[d]	0.9	2.7	NS[e]

[a] Abbreviations: AGSST, 'Crenshaw' creeping bentgrass; FESAR, 'Rembrandt' tall fescue; LOLPE, 'Evening Shade' perennial ryegrass; POAPR, 'Thermal Blue' Kentucky bluegrass.
[b] Plants biomass for each turfgrass species was collected by cutting each 91 cm row at soil level, dried for 72 hours at 60 C and a weight was recorded.
[c] Means within each column followed by the same lower case letter are not significantly different using Fisher's Protected LSD test at P = 0.05.
[d] Means within the column followed by the same lower case letter are not significantly different using Fisher's Unprotected LSD at P = 0.05.
[e] NS indicates that means within the column for each weed species are not significantly different using Fisher's Protected LSD at P = 0.05
[f] DBP, days before planting

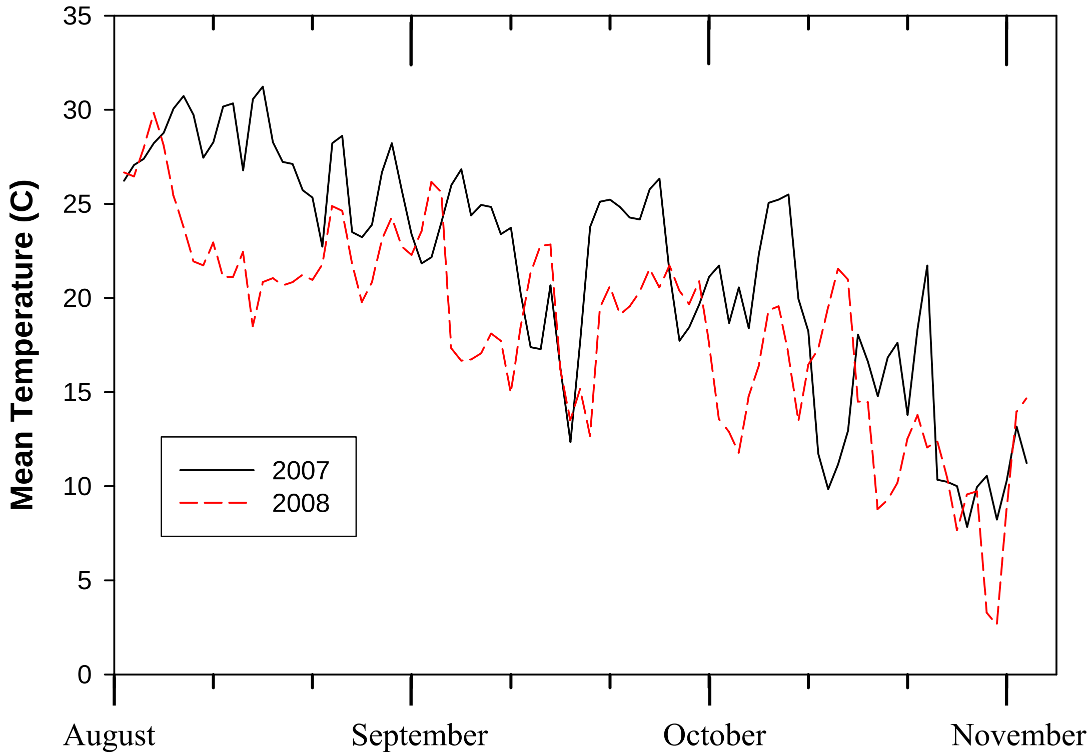


Figure 4.1. Daily mean air temperature from August through November for Columbia, MO during 2007 and 2008.

APPENDIX

Table A.1. Glucosinolate concentrations from oriental mustard (*Brassica juncea* L. Czern.) seed meal used during 2006 through 2007 (greenhouse and field studies).

Glucosinolate R-group		*Brassica juncea*
		——— µmol/g dry weight ———
3-methylsulfinylpropyl	a[a]	0.56
2-propenyl	a	92.95
4-hydroxy-benzyl	b	1.72
3-butenyl	a	0.65
Unknown	d	6.86
4-hydroxy-3-indolylmethyl	c	0.14
3-indolylmethyl	c	0.88
4-methoxy-3-indolylmethyl	c	0.35
2-phenylethyl	b	0.21
1-methoxy-3-indolylmethyl	c	1.46
Aliphatic		**94.17**
Aromatic		**1.93**
Indolyl		**2.83**
Unknown		**6.86**
Total		**105.79**

[a] Glucosinolate R-groups followed by the same letter are considered to be (a) aliphatic, (b) aromatic, (c) indoyl, or (d) unknown glucosinolates. Glucosinolate R-groups were identified by Carl Sams (University of Tennessee), using a high-performance liquid chromatography (HPLC) method.

Table A.2. Glucosinolate concentrations from oriental mustard (*Brassica juncea* L. Czern.) seed meal used during 2008 (field studies).

Glucosinolate R-group		*Brassica juncea*
		——— $\mu mol\ g^{-1}$ dry weight ———
3-methylsulfinylpropyl	a[a]	0.42
2(R)-2-hydroxy-3-butenyl	a	0.10
2(S)-2-hydroxy-3-butenyl	a	0.10
4-methylsulfinylbutyl	a	0.05
2-propenyl	a	80.64
4-hydroxybenzyl	b	3.43
3-butenyl	a	0.66
4-hydroxy-3-indolylmethyl	c	0.64
4-pentenyl	a	0.22
3-indolylmethyl	c	0.25
2-phenylethyl	b	0.33
1-methoxy-3-indolylmethyl	c	0.26
Aliphatic		**82.19**
Aromatic		**3.76**
Indolyl		**1.15**
Total		**87.10**

[a] Glucosinolate R-groups followed by the same letter are considered to be (a) aliphatic, (b) aromatic, or (c) indoyl glucosinolates. Glucosinolate R-groups were identified by Carl Sams (University of Tennessee), using a high-performance liquid chromatography (HPLC) method.

Table A.3. Nutrient content of oriental mustard (*Brassica juncea* L. Czern.) seed meal during 2008 trials.

Element	**Percent Content** [a]
Nitrogen (N)	3.72
Phosphrous (P)	0.83
Potassium (K)	0.57
Calcium (Ca)	0.32
Magnesium (Mg)	0.35

[a] Nutrient anaylsis was conducted by the University of Missouri Soil and Plant Testing Lab

Table A.4. ANOVA table of plant heights, 28 days after planting (DAP) following exposure to oriental mustard seed meal (MSM). Rates ranged from 0 to 3,360 kg/ha for tarped and untarped plants. Statistical analysis were combined over two greenhouse experiments.

Plant Heights	2006						2007	
	FESAR	LOLPE	PLALA	POAAN	STEME	TRFRE	CYNDA	DIGSA
	Pr > F							
Rate	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cover	NS	0.0067	<0.0001	<0.0001	<0.0001	<0.0001	NS	<0.0001
Rate*Cover	0.0013	0.0145	<0.0058	<0.0001	0.0004	<0.0001	NS	<0.0001

[a] Abbreviations: CYNDA, 'Riviera' bermudagrass; DIGSA, large crabgrass; FESAR, 'Rembrandt' tall fescue; LOLPE, 'Evening Shade' perennial ryegrass; PLALA, narrow leaf plantain; POAAN, annual bluegrass; STEME, common chickweed; TRFRE, white clover.
[b] NS indicates that means within the column for each weed species are not significant (P = 0.05).

Table A.5. Mean cumulative plant heights, 28 days after planting (DAP) of tarped and untarped treatments following exposure to oriental mustard seed meal (MSM) during greenhouse experiments in 2006.

Treatment	Rate (kg/ha)	FESAR[a]		LOLPE		PLALA		POAAN		STEME		TRFRE	
		Tarped	Untarped	Tarped	Untarped	Tarped	Untarped	Tarped	Untarped	Tarped	Untarped	Tarped	Untarped
		Plant heights (cm) [b]											
Untreated	-	12.7 a A[c]	10.6 a B	12.2 a A	11.9 a A	6.4 a A	7.2 a A	5.9 a A	5.6 a A	2.7 a A	2.9 a A	3.4 a A	3.5 a A
MSM	1,350	8.4 b B	9.3 b A	9.9 b A	10.2 b A	3.5 b B	5.2 b A	4.7 b A	5.6 a A	1.5 b B	2.6 a A	2.1 b A	2.4 b A
MSM	2,350	4.1 c B	6.1 c A	8.4 b B	10.2 b A	2.3 b B	4.7 b A	2.3 c B	5.5 a A	0.8 c A	1.1 b A	0.7 c B	2.3 b A
MSM	3,360	3.7 c B	5.1 d A	5.5 c B	8.6 c A	0.4 c B	2.7 c A	1.5 c B	5.1 a A	0 d B	1.3 b A	0.3 d B	1.5 c A
Dazomet	392	0 d A	0 e A	0 d A	0 d A	0 c A	0 d A	0 d A	0 b A	0 d A	0 c A	0 d A	0 d A
Treatment*Cover LSD $_{0.05}$		0.9		1.5		1.5		1.1		0.5		0.4	

[a] Abbreviations: CYNDA, 'Riviera' bermudagrass; DIGSA, large crabgrass; FESAR, 'Rembrandt' tall fescue; LOLPE ,'Evening Shade' perennial ryegrass; PLALA, narrow leaf plantain; POAAN, annual bluegrass; STEME, common chickweed; TRFRE, white clover; MSM, oriental mustard seed meal; LSD, least significant difference.
[b] Plant heights were measured by randomly selecting 3 plants within a 25 cm row and measured from soil surface to maximum height of the plant.
[c] Means within each column followed by the same lower case letter are not significantly different using Fisher's Protected Least Significant Difference test at P = 0.05; means within each row within each species followed by the same upper case letter are not significantly different using Fisher's Protected Least Significant Difference test at P =0.05.

Table A.6. Mean cumulative plant heights, 28 days after planting (DAP) of tarped and untarped treatments following exposure to oriental mustard seed meal (MSM) during greenhouse experiments in 2007.

Treatment	Rate (kg/ha)	CYNDA[a]		DIGSA	
		Tarped	Untarped	Tarped	Untarped
		Plant heights (cm) [b]			
Untreated	-	8.6	7.7	26.2 a A[c]	25.1 b A
MSM	1,350	7.8	8.5	13.8 b B	30.5 a A
MSM	2,350	5.8	7.0	13.8 b B	26.8 ab A
MSM	3,360	5.8	7.7	10.2 b B	20.5 c A
Dazomet	392	0	0	0 c A	0 d A
Treatment*Cover LSD $_{0.05}$		NS		4.7	

[a] Abbreviations: CYNDA, 'Riviera' bermudagrass; DIGSA, large crabgrass; MSM, oriental mustard seed meal.
[b] Plant heights were measured by randomly selecting 3 plants within a 25 cm row
[c] Means within each column followed by the same letter are not significantly different using Fisher's Protected Least Significant Difference test at P = 0.05; means within each row within each species followed by the same upper case letter are not significantly different using Fisher's Protected Least Significant Difference test at P = 0.05.

Table A.7. Mean plant heights of weed and turfgrass species in response to tarped treatments at various rates of oriental mustard seed meal (MSM). Data were collected 6 weeks after planting (WAP) during 2007 field studies in Columbia, MO.

Treatment	Rate (kg/ha)	Species							
		DIGSA[a]	CYNDA	LOLPE	POAAN	TRFRE	FESAR	STEME	PLALA
		Heights (cm)[b]							
Untreated	-	4.9 ab[c]	1.5 b	2.3 b	2.3 a	2.5 a	2.1 ab	0.17 a	7.1 b
MSM	1,120	4.2 b	1.5 b	2.8 a	2.4 ab	2.8 a	2.5 ab	0.19 a	8.5 a
MSM	1,680	4.6 a	1.2 b	2.5 ab	2.2 ab	2.6 a	2.5 ab	0.24 a	6.5 bc
MSM	2,240	4.3 b	1.3 b	2.4 ab	2.2 ab	2.8 a	2.6 a	0.25 a	5.9 c
MSM	2,800	4.9 ab	1.5 b	2.8 a	2.1 b	2.6 a	2.1 b	0.07 b	6.5 bc
MSM	3,360	5.8 a	2 a	2.4 ab	1.1 c	2.6 a	2.4 ab	0.03 b	5.6 c
Dazomet	392	0.6 c	0 c	0 c	0 d	0 b	0 c	0 b	0 d
LSD (0.05)		1.3	0.5	0.4	0.4	0.5	0.5	0.09	1.2

[a] Abbreviations: CYNDA, common bermudagrass; DIGSA, large crabgrass; FESAR, tall fescue; LOLPE, perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; TRFRE, white clover; MSM, oriental mustard seed meal.
[b] Plant heights were measured by randomly selecting 3 plants within a 91 cm row and measured from soil surface to maximum height of the plant.
[c] Within each column, means followed by the same letter are not significantly different using Fisher's Protected LSD at P= 0.05.

Table A.8. Mean plant heights of weed and turfgrass species in response to tarped treatments at various rates of oriental mustard seed meal (MSM). Data were collected 6 weeks after planting (WAP) during 2008 field studies in Columbia, MO.

Treatment	Rate (kg/ha)	Species							
		DIGSA[a]	CYNDA	LOLPE	POAAN	TRFRE	FESAR	STEME	PLALA
		Heights (cm)[b]							
Untreated	-	8.3 c[c]	2.8 c	4.9 ab	0.5 c	4.5 a	3.9 ab	0.02 cd	7.2 ab
MSM	1,120	13.1 b	3.5 bc	5.5 a	0.8 ab	3.8 ab	4.2 a	0.11 a	8.1 a
MSM	1,680	13.9 ab	3.9 b	4.9 ab	0.8 a	3.4 b	3.7 ab	0.09 ab	8.3 a
MSM	2,240	15.1 ab	3.5 bc	5.3 a	0.6 bc	3.5 ab	3.7 ab	0.05 bc	6.3 bc
MSM	2,800	12.9 b	2.7 c	4.5 b	0.4 cd	3.8 ab	3.3 b	0.05 bc	4.6 c
MSM	3,360	15.4 a	4.9 a	5 ab	0.3 d	3.9 ab	4.1 ab	0.02 cd	7.3 ab
Dazomet	392	0 d	0 c	0 c	0 e	0 c	0 c	0 d	0 d
LSD (0.05)		2.2	0.9	0.6	0.2	1.1	0.8	0.04	1.7

[a] Abbreviations: CYNDA, common bermudagrass; DIGSA, large crabgrass; FESAR, tall fescue; LOLPE, perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; TRFRE, white clover; MSM, oriental mustard seed meal.
[b] Plant heights were measured by randomly selecting 3 plants within a 91 cm row and measured from soil surface to maximum height of the plant.
[c] Within each column, means followed by the same letter are not significantly different using Fisher’s Protected LSD at P= 0.05.

Table A.9. Mean emergence of weed and turfgrass species in response to tarped and untarped treatments at various rates of oriental mustard seed meal (MSM). Data were collected 1 week after planting (WAP) from a 2007 field study in Columbia, MO.

Treatment	Rate (kg/ha)	Taped/ Untarped	Species						
			FESAR[a]	LOLPE	TREFE	POAAN	PLALA	CYNDA	DIGSA
			Counts/ 91 cm row [d]						
Untreated	-	Tarped	0 d[b]	0 b	0 c	9.7 a	0 d	0 b	0 b
MSM	1,120	Tarped	0 d	0 b	0 c	8.5 a	0 d	0 b	0 b
MSM	1,680	Tarped	0 d	0 b	0 c	0 b	0 d	0 b	0 b
MSM	2,240	Tarped	0 d	0 b	0 c	2.0 b	0 d	0 b	0 b
MSM	2,800	Tarped	0 d	0 b	0 c	2.7 b	0 d	0 b	0 b
MSM	3,360	Tarped	0 d	0 b	0 c	0.2 b	0 d	0 b	0 b
Dazomet	392	Tarped	0 d	0 b	0 c	0 b	0 d	0 b	0 b
Untreated	-	Untarped	24.0 a	30.7 a	98.5 ab	0 b	37.7 ab	1.5 ab	3.7 a
MSM	1,120	Untarped	12.7 abc	29.0 a	106.7 a	0 b	43.7 a	2.5 a	2.2 ab
MSM	1,680	Untarped	20.7 ab	25 a	100.7 ab	0 b	28.7 bc	1.5 ab	3.0 a
MSM	2,240	Untarped	6.5 cd	27.5 a	113.2 a	1.7 b	28.2 bc	0.7 ab	2.5 a
MSM	2,800	Untarped	17.7 abc	20.2 a	78.5 b	0 b	35.7 ab	1 ab	3.7 a
MSM	3,360	Untarped	11.2 bc	17.7 a	109 a	0 b	16.0 c	1 ab	0 b
Dazomet	392	Untarped	0 d	0 b	0 c	0 b	0 d	0 b	0 b
LSD (0.05)			11.5	16.6	23.4	5.3	14.0	1.8[c]	2.7

[a] Abbreviations: CYNDA, common bermudagrass; DIGSA, large crabgrass; FESAR, tall fescue; LOLPE, perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; TRFRE, white clover; MSM, oriental mustard seed meal.
[b] Means within each column, means followed by the same letter are not significantly different using Fisher's Protected LSD test at P= 0.05.
[c] Means within the column followed by the same lower case letter are not significantly different using Fisher's Unprotected LSD at P = 0.05.
[d] Plant counts were collected by counting each 91cm row for weed and turfgrass species.

Table A.10. Mean emergence of weed and turfgrass species in response to tarped and untarped treatments at various rates of oriental mustard seed meal (MSM). Data were collected 3 weeks after planting (WAP) from a 2007 field study in Columbia, MO.

Treatment	Rate (kg/ha)	Taped/ Untarped	Species						
			FESAR[a]	LOLPE	TREFE	POAAN	PLALA	CYNDA	DIGSA
			Counts/ 91 cm row [c]						
Untreated	-	Tarped	0 d[b]	0 d	0 c	20 ab	3.2 c	0 c	0.5 c
MSM	1,120	Tarped	0 d	0 d	0 c	17.7 abc	3.7 c	0.5 c	0.7 cb
MSM	1,680	Tarped	0 d	0 d	0 c	7.2 cde	0 c	0 c	1.0 cb
MSM	2,240	Tarped	0 d	0 d	0 c	3.7 de	0 c	0 c	0 c
MSM	2,800	Tarped	0 d	0 d	0 c	9.7 bcde	0 c	0 c	0 c
MSM	3,360	Tarped	0 d	0 d	0 c	0.5 e	0 c	0 c	3.5 b
Dazomet	392	Tarped	0 d	0 d	0 c	0 e	0 c	0 c	0 c
Untreated	-	Untarped	34 bc	34.2 bc	125 a	13.7 abcd	43.2 ab	3.5 bc	8.5 a
MSM	1,120	Untarped	34.5 bc	49.2 a	107.7 a	20.5 a	50.5 a	6.5 ab	6.7 a
MSM	1,680	Untarped	34.7 bc	39.5 ab	103.5 ab	20 ab	34.0 b	5.0 ab	7.2 a
MSM	2,240	Untarped	47 a	46.5 ab	119.2 a	21.7 a	39.2 ab	8.0 a	6.5 a
MSM	2,800	Untarped	29.5 c	26.2 c	83.2 b	20 ab	38.7 ab	7.7 a	9.0 a
MSM	3,360	Untarped	39.2 b	41.2 ab	117 a	11.5 abcd	32 b	4.5 ab	3.5 b
Dazomet	392	Untarped	0 d	0 d	0 c	0 e	0 c	0 d	0.2 c
LSD (0.05)			7.3	12.4	22.8	10.6	13.5	3.7	2.8

[a] Abbreviations: CYNDA, common bermudagrass; DIGSA, large crabgrass; FESAR, tall fescue; LOLPE, perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; TRFRE, white clover; MSM, oriental mustard seed meal.
[b] Within each column, means followed by the same letter are not significantly different using Fisher's Protected LSD test at P= 0.05.
[c] Plant counts were collected by counting each 91cm row for weed and turfgrass species.

Table A.11. Mean emergence of weed and turfgrass species in response to tarped and untarped treatments at various rates of oriental mustard seed meal (MSM). Data were collected 1 week after planting (WAP) from a 2008 field study in Columbia, MO.

Treatment	Rate (kg/ha)	Taped/ Untarped	Species						
			FESAR[a]	LOLPE	TREFE	POAAN	PLALA	CYNDA	DIGSA
			Counts/ 91 cm row [d]						
Untreated	-	Tarped	0 b[b]	0 b	0 c	0	0 b	0	0 b
MSM	1,120	Tarped	0 b	0 b	0 c	0	0 b	0	0 b
MSM	1,680	Tarped	0 b	0 b	0 c	0	0 b	0	0 b
MSM	2,240	Tarped	0 b	0 b	0 c	0	0 b	0	0 b
MSM	2,800	Tarped	0 b	0 b	0 c	0	0 b	0	0 b
MSM	3,360	Tarped	0 b	0 b	0 c	0	0 b	0	0 b
Dazomet	392	Tarped	0 b	0 b	0 c	0	0 b	0	0 b
Untreated	-	Untarped	5.7 a	12.2 a	36 a	0	5.2 a	0	4.2 a
MSM	1,120	Untarped	0 b	0 b	16.2 b	0	1.7 b	0	0 b
MSM	1,680	Untarped	0 b	1.0 b	14.5 b	0	1.7 ab	0	2 b
MSM	2,240	Untarped	0 b	0 b	14.2 b	0	0.5 b	0	0 b
MSM	2,800	Untarped	0 b	0 b	10.7 b	0	0.2 b	0	0 b
MSM	3,360	Untarped	0 b	0 b	12.5 bc	0	1.5 ab	0	0 b
Dazomet	392	Untarped	0 b	0 b	0 c	0	0 b	0	0 b
LSD (0.05)			3.0	NS[c]	13.5	NS	3.1	NS	2.0

[a] Abbreviations: CYNDA, common bermudagrass; DIGSA, large crabgrass; FESAR, tall fescue; LOLPE, perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; TRFRE, white clover; MSM, oriental mustard seed meal.
[b] Within each column, means followed by the same letter are not significantly different using Fisher's Protected LSD test at P= 0.05.
[c] NS indicates that means within the column for each weed species are not significantly different using Fisher's Protected LSD at P = 0.05.
[d] Plant counts were collected by counting each 91cm row for weed and turfgrass species.

Table A.12. Mean emergence of weed and turfgrass species in response to tarped and untarped treatments at various rates of oriental mustard seed meal (MSM). Data were collected 3 weeks after planting (WAP) from a 2008 field study in Columbia, MO.

Treatment	Rate (kg/ha)	Taped/ Untarped	Species						
			FESAR[a]	LOLPE	TREFE	POAAN	PLALA	CYNDA	DIGSA
			Counts/ 91 cm row [c]						
Untreated	-	Tarped	17.5 ab[b]	22.2 bcd	6.2 de	5.7 ab	24.5 a	11.2 ab	22.2 ab
MSM	1,120	Tarped	7.5 bc	8.7 def	2.7 e	2.7 abc	5.7 cdef	5.7 abc	16 bcd
MSM	1,680	Tarped	6 cd	7.7 def	0.7 e	7.2 a	4.7 cdef	6.2 abc	11.7 bcd
MSM	2,240	Tarped	8 cd	13.5 cdef	0 e	5.0 abc	0 f	3.5 bc	12.5 bcd
MSM	2,800	Tarped	3.2 cd	6.7 def	2 e	0 c	3 ef	5.5 abc	9.7 cd
MSM	3,360	Tarped	2.7 cd	4.2 ef	0.5 e	0.2 bc	3 def	5 abc	6.2 de
Dazomet	392	Tarped	0 d	0 f	0 e	0 c	0 f	0 c	0 e
Untreated	-	Untarped	24.5 a	40 a	37 a	3.2 abc	12.7 abcd	11 ab	25.5 ab
MSM	1,120	Untarped	24 a	16.7 bcde	24.5 abc	7.5 a	9.5 abcde	7.7 abc	13.2 bcd
MSM	1,680	Untarped	22.7 a	28.5 abc	28 ab	6.5 ab	25.2 a	8 ab	20.2 abc
MSM	2,240	Untarped	26 a	30.7 ab	19.7 bc	6.7 abc	18.7 ab	13 a	23 ab
MSM	2,800	Untarped	21.2 a	17.7 bcde	20.2 abc	1.7 abc	10.2 bcde	7.5 abc	34.7 a
MSM	3,360	Untarped	25.2 a	31.5 ab	14.2 cd	2.7 abc	14.7 abc	10.2 ab	26.7 ab
Dazomet	392	Untarped	0 d	0 f	0 e	0 c	0 f	0 c	0 e
LSD (0.05)			14.5	16.7	13.0	7.0	12.2	7.7	14.0

[a] Abbreviations: CYNDA, common bermudagrass; DIGSA, large crabgrass; FESAR, tall fescue; LOLPE, perennial ryegrass; PLALA, buckhorn plantain; POAAN, annual bluegrass; TRFRE, white clover; MSM, oriental mustard seed meal.
[b] Within each column, means followed by the same letter are not significantly different using Fisher's Protected LSD test at P= 0.05.
[c] Plant counts were collected by counting each 91cm row for weed and turfgrass species.

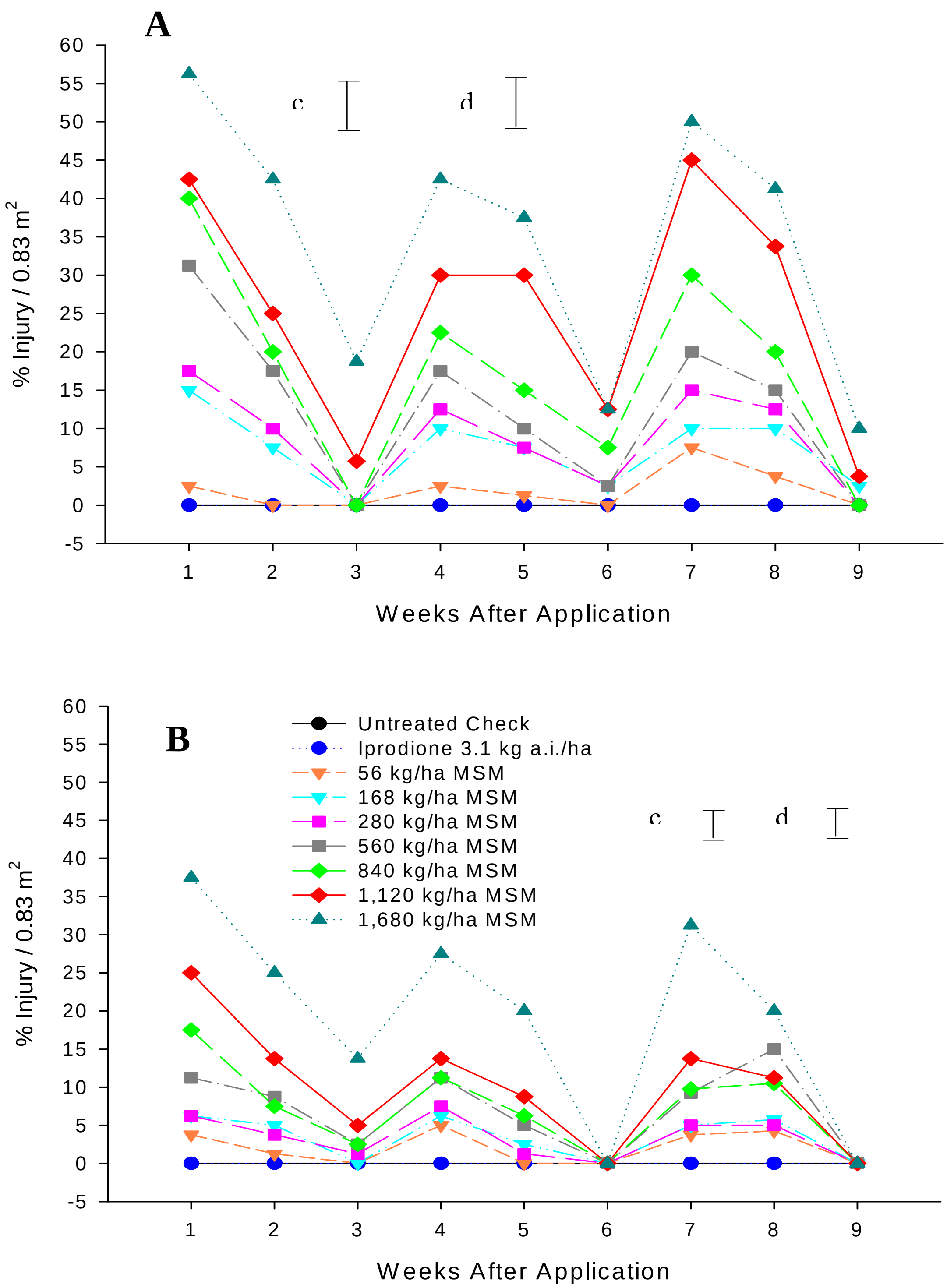
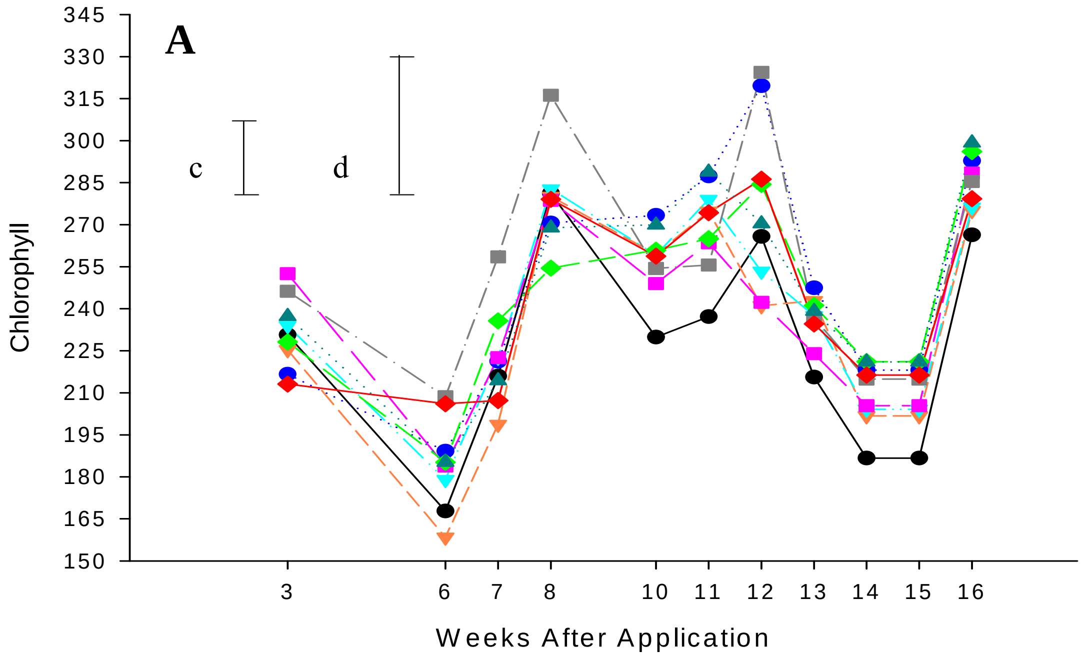


Figure A.1. Mean percent turfgrass injury/ 0.83 m^2 during 2007 (A) and 2008 (B). For comparison between treatments each week, means within the bar (c) are not significantly different based on Fishers Protected LSD at ($P = 0.05$); LSD = 6.4 for 2007 and 3.9 for 2008. For comparisons within a treatment across weeks, means within the bar (d) are not significantly different based on Fishers Protected LSD at ($P = 0.05$); LSD = 5.6 for 2007 and 3.7 for 2008. The dates of application of treatments were week 0, 2, and 4.



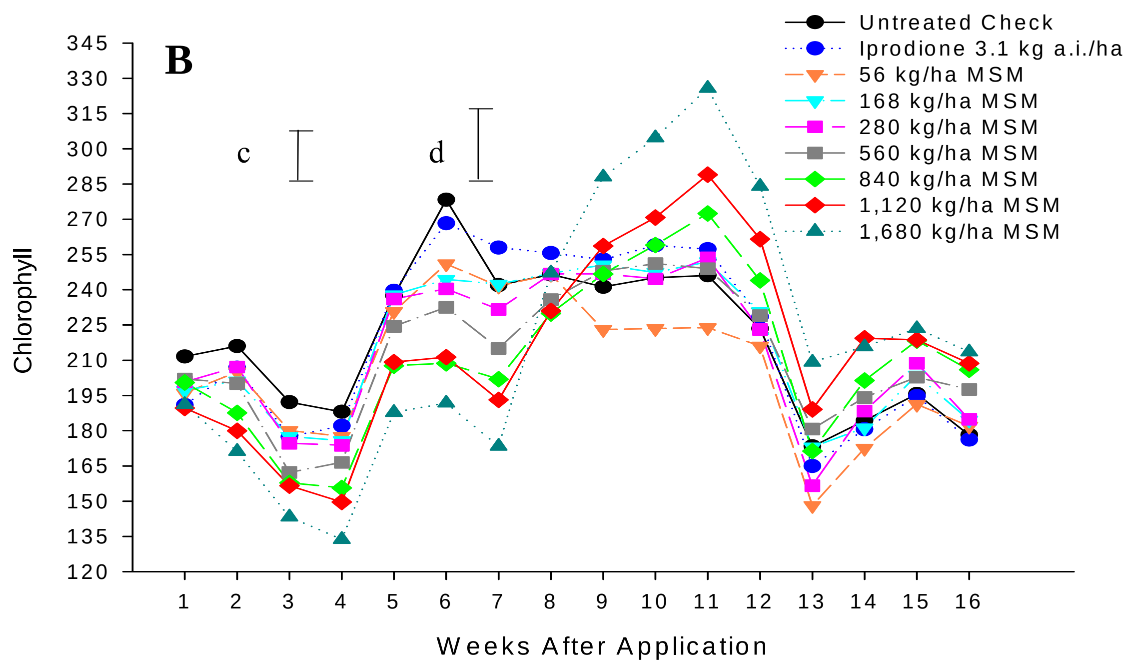


Figure A.2. Mean chlorophyll indices / 0.83 m^2 during 2007 (A) and 2008 (B). For comparisons between treatments each week, within the bar (c) are not significantly different based on Fishers Protected LSD at (P = 0.05); LSD = 26.5 for 2007 and 18.7 for 2008. For comparisons within a treatment across weeks, means within the bar (d) are not significantly different based on Fishers Protected LSD at (P = 0.05); LSD = 48.0 for 2007 and 30.3 for 2008. The dates of application of treatments were week 0, 2, and 4.