GRANULAR FORMS OF SODIUM AND POTASSIUM AZIDE AS A NEMATICIDE

FOR ESTABLISHED TURFGRASSES

Except where reference is made to the work of others, the work described in this dissertation is my own or was done in collaboration with my advisory committee. This dissertation does not include proprietary or classified information.

____
Sheryl McGaha Wells

Certificate of Approval:

Rodrigo Rodriguez-Kabana
Distinguished University Professor
Entomology and Plant Pathology

Robert H. Walker, Chair
Professor
Agronomy and Soils

Elizabeth Guertal
Professor
Agronomy and Soils

David Han
Associate Professor
Agronomy and Soils

George T. Flowers
Dean
Graduate School

GRANULAR FORMS OF SODIUM AND POTASSIUM AZIDE AS A NEMATICIDE FOR ESTABLISHED TURFGRASSES

Sheryl McGaha Wells

A Dissertation

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Doctor of Philosophy

Auburn, Alabama
May 9, 2009

GRANULAR FORMS OF SODIUM AND POTASSIUM AZIDE AS A NEMATICIDE

FOR ESTABLISHED TURFGRASSES

Sheryl McGaha Wells

____
Signature of Author

____
Date of Graduation

DISSERTATION ABSTRACT

GRANULAR FORMS OF SODIUM AND POTASSIUM AZIDE AS A NEMATICIDE FOR ESTABLISHED TURFGRASSES

Sheryl Wells

Doctor of Philosophy, May 9, 2009
(M.S. Georgia College & State University, 2004)
(B.S. Sam Houston State University, 1993)

110 Typed Pages

Directed by Robert H. Walker

There is a need for more user-friendly chemical tools for management of plant parasitic nematodes in both cool-and warm-season turfgrasses. SEP-100 is a stabilized liquid formulation of sodium azide and was extensively researched from 2004 – 2006 as a methyl bromide preplant replacement. Research was initiated to investigate the potential of using reduced rates and granular carriers to improve tolerance in established turfs. Profile® fired ceramic clay and Biodac® cellulose complex, were chosen as the granular carriers. Sodium (NaN_3) and potassium (KN_3) azide were formulated to contain 10% active ingredient by weight.

Research was conducted on a ‘Dominant’ creeping bentgrass [*Agrostis stolonifera* L. (Huds.) Farw.] putting green at Grand National GC, Opelika, AL, and on a mixture of ‘A1 and A4’ at FarmLinks GC, Sylacauga, AL. Little differences were found among

formulations. Tolerance was excellent with 5.6 kg ai/ha rate applied three times at 2-wk intervals. At times, 11.2 to 16.8 rates produced unacceptable injury but bentgrass recovered in 2 to 3-wks. Injury was most pronounced when the granules were applied to wet turf and were not immediately washed into the soil with irrigation. Ring nematode (*Mesocriconema* spp.) control was frequently better with the higher rates, but the 5.6 rate generally provided acceptable control. The 5.6 rate of NaN_3/Profile improved root length density (RLD) 1 of 2 yrs at Opelika while both KN_3 formulations improved RLD at Sylacauga where ring nematode numbers were higher.

Turfgrass tolerance was evaluated for 'Mini-Verde' hybrid bermudagrass (*Cynodon dactylon* x *C. transvaalensis* Burtt-Davy) putting green located at Auburn, AL. Each formulation was applied three times at 22.4 kg ai/ha on a 2 to 3-wk interval. In 2007, RLD was significantly improved over the non-treated with both formulations containing NaN_3 while only the NaN_3/Profile formulation increased RLD in 2008. Visual injury ratings showed only slight injury with all formulation and for both years. Nematode numbers were too low to evaluate efficacy.

Studies were conducted at Kiva Dunes Golf Club located in Gulf Shores, AL on a 'Tifdwarf' bermudagrass putting green with KN_3 impregnated on both carriers. First two applications were at 11.2 kg ai/ha but the final rate was increased to 22.4. Sting (*Belonolaimus* spp.) nematode numbers were reduced to zero in most samplings. Nemacur® and Curfew® were added as comparative treatments in 2008. Nematode infestation was again low but RLD data showed KN_3/Biodac produced the highest RLD which was greater than Nemacur and equivalent to Curfew.

ACKNOWLEDGEMENTS

I am grateful to Dr. Walker for accepting me into the program and helping me get through it. I am appreciative for the opportunity to better myself. I also want to thank Dr. Walker for being generous with conference travel and giving me a research project that was interesting and challenging. Rod (Dr. Rodriguez-Kabana), I would like to thank you for formulating the azide and always offering your help and the help of your staff. Dr. Guertal, you have always given me direction and have always been especially helpful with statistical analysis. Dr. Han, I appreciate you taking the time to serve as a committee member. I appreciate Dr. Lawrence for serving as an outside reader and the suggestions you recommended.

To my mother, sister, extended family, and special friends, I am blessed to have had your love and encouragement during this program. I am especially thankful for my neighbor, Neal Meier, without your help with my pets and house, my life would have been much more difficult.

Finally, I praise God for all of the blessings I have been provided and for strength to persist. I am thankful to have peace and joy in my heart.

Style manual used: Handbook and Style Manual of the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America

Computer software used Microsoft Word XP, Microsoft Excel, Statistix 8, and SAS v.8

TABLE OF CONTENTS

LIST OF TABLES x

LIST OF FIGURES xii

I. LITERATURE REVIEW

Introduction 1
Research Justification 25
General Objectives 26
References

II. CREEPING BENTGRASS RESPONSE TO SODIUM AZIDE AND UREA TREATMENTS

Abstract 35
Introduction 37
Materials and Methods 38
Results 41
Conclusion 42
References

III. SODIUM AND POTASSIUM AZIDE FORMULATIONS FOR RING NEMATODE CONTROL ON A BENTGRASS PUTTING GREEN

Abstract 49
Introduction 50
Materials and Methods 54
Results 57
Conclusion 58
References

IV. HYBRID BERMUDAGRASS RESPONSE TO GRANULAR FORMULATIONS OF SODIUM AND POTASSIUM AZIDE

Abstract 64
Introduction 65
Materials and Methods 69
Results 71
Conclusion 73
References

V. PLANT PARASITIC NEMATODE RESPONSE TO SODIUM AND POTASSIUM AZIDE APPLIED TO BERMUDAGRASS

Abstract 81
Introduction 82
Materials and Methods 86
Results 88
Conclusion 90
References

LIST OF TABLES

Table 1.1	Physiochemical properties of sodium azide.....................................	34
Table 1.2	Physiochemical properties of potassium azide	34
Table 2.1	Procedure for impregnating sodium azide (NaN_3) on/into Profile granules.	45
Table 2.2	Creeping bentgrass putting green root length density (RLD) as affected by sodium azide (NaN_3) rates and urea at Grand National Golf Club, Opelika, AL, 2006 and 2007.	46
Table 2.3	Creeping bentgrass putting green ring nematode numbers as affected by sodium azide (NaN_3) rates, application number, and urea, at Grand National Golf Club, Opelika, AL, 2006 and 2007...	47
Table 2.4	Creeping bentgrass putting green turf injury as affected by sodium azide rates, application number, and urea at Grand National Golf Club, Opelika, AL, 2006 and 2007.	48
Table 3.1	Procedure for impregnating sodium (NaN_3) and potassium (KN_3) azide on/into Profile/Biodac granules..	60
Table 3.2	Ring nematode numbers in a creeping bentgrass putting green as affected by sodium (Na) and potassium (K) azide impregnated on Profile or Biodac granules at FarmLinks Golf Club, Sylacauga, AL, 2007 and 2008...	61
Table 3.3	Percent turf injury on a creeping bentgrass putting green as affected by multiple applications of sodium (Na) and potassium (K) azide impregnated on Profile or Biodac carriers at FarmLinks Golf Club, Sylacauga, AL, 2007 and 2008.	62

Table 3.4 Root length density (RLD) on a creeping bentgrass putting green as affected by multiple applications of sodium and potassium azide impregnated on Profile or Biodac carriers at FarmLinks Golf Club Sylacauga, AL, 2008. 63

Table 4.1 Procedure for impregnating sodium (NaN_3) and potassium (KN_3) azide on/into Profile/Biodac granules. 77

Table 4.2 Root length density (RLD) on a Mini-Verde bermudagrass putting green as affected by multiple applications of sodium and potassium azide impregnated on two granular carriers at Auburn, AL, 2007 and 2008. 78

Table 4.3 Percent turf injury on a Mini-Verde bermudagrass putting green as affected by multiple applications of sodium (Na) and potassium (K) azide impregnated on two granular carriers at Auburn, AL, 2007 and 2008. 79

Table 4.4 Plant parasitic nematode numbers on a Mini-Verde bermudagrass putting green as affected by multiple applications of sodium (Na) and potassium (K) azide impregnated on two granular carriers at Auburn, AL 2007 and 2008. 80

Table 5.1 Procedure for impregnating sodium (NaN_3) and potassium (KN_3) azide on/into Profile/Biodac granules. 94

Table 5.2 Plant parasitic nematode numbers on Tifdwarf hybrid bermudagrass as affected by potassium (K) azide, granular carriers, and application number at Kiva Dunes Golf Club, Gulf Shores, AL 2007 and 2008. 95

Table 5.3 Root length density (RLD) on Tifdwarf hybrid bermudagrass as affected by potassium (K) azide, granular carriers, and nematicides at Kiva Dunes Golf Club, Gulf Shores, AL 2007 and 2008 96

Table 5.4 Plant parasitic nematode numbers on Tifgreen hybrid bermudagrass as affected by sodium azide (Na), granular carriers, and application number at Kiva Dunes Golf Club, Gulf Shores, AL 2007 and 2008. 97

Table 5.5 Root length density (RLD) on Tifgreen hybrid bermudagrass as affected by sodium azide on granular carriers at Kiva Dunes Golf Club, Gulf Shores, AL, 2007 and 2008. 98

LIST OF FIGURES

Figure 1.1 Chemical structure of sodium azide 34

Figure 1.2 Chemical structure of potassium azide 34

I. LITERATURE REVIEW

INTRODUCTION

The environment of man has been enhanced through the development of turfgrass. During the thirteenth century in England, the culture of lawn turfs evolved (Turfgrass Council of North Carolina, 1999). Turfgrasses are the primary vegetative covers on and around airports, athletic fields, cemeteries, churches, commercial buildings, golf courses, home lawns, schools, parks and roadsides (Duble, 1996). The beneficial contributions of turfgrasses can be divided into functional, recreational, and ornamental categories. The functional aspects are to provide erosion control, dust stabilization, heat dissipation, noise abatement, glare diffusion, safety in athletics, healthy playing surface for recreational activities, and visual pollution prevention. In the United States, more than 12 million tons of dust and dirt are released in the atmosphere annually and are trapped by turfgrasses (Novark, 2005). Also, every hectare of golf course greens and fairways sequester one ton of carbon from the air (Novark, 2005). Turfgrass adds real value to daily human lives for beauty, for sports, and for our own personal recreation and leisure-time activities.

Economic Impacts

Turfgrass is a changing and rapidly growing industry. In the United States, it is estimated that turfgrasses cover 50 million acres, making turf the fourth largest U.S. crop in acreage (Morris, 2006). The annual value of the turfgrass industry in the United States is estimated at $40 to 60 billion (Hall et al., 2005). Millions of individuals in America are provided a livelihood directly and indirectly through the turfgrass industry. The desire to spend money managing turfgrass areas in order to enhance the environment for human activities is proof that man considers turfgrass to be an important aspect in his quality of life.

Impact of Golf Course Industry

Golf gained popularity in the United States in the early 1900's (Beard, 1982). This popular sport continues to grow and there are now more than 17,000 golf courses in the United States (Morris, 2005). The game now appeals to a broader range of people than ever before with more than 36 million men, women, and youth playing (Shea, 2008). In 2002, the economic impacts were positively affected with an estimated $23.3 billion dollars in output impacts, $14.5 billion in value added, and 361,690 jobs created (Haydu et al., 2002).

Golf Course Greens

Golf became first established in America in 1888 and since that time the modern golf green has become a complex system of engineered growing, shaped by soil physics, soil chemistry, and constantly evolving turfgrass technology (Hurdzan, 1985). Golf course putting greens present the greatest challenge on the golf course and they also represent the highest intensity of turfgrass culture (Turgeon, 1991). Putting greens are constructed according to the United States Golf Association Green Section Method which was first published in 1960 and revised in 2004. These specifications combine a perched water table to provide a reserve supply of water in the root zone with a high sand content root zone which possesses good internal soil drainage and minimal proneness to soil compaction (Beard, 1982). The subgrade is constructed at an elevation of 45 centimeters below the planned finished grade. A herringbone subsurface drainage system is installed in trenches that are cut into the subgrade. Gravel is placed above and below the drain lines. A 10-centimeter pea gravel layer is placed over the drain lines as well as over the entire putting green surface. A 3.8 to 5 centimeter coarse sand layer is put over the gravel layer. The root zone mix is placed over the coarse sand layer. Well-decomposed organic material is added to the root zone mix normally at 5 to 20% composition. The high sand content and drainage potential make putting greens an ideal environment for plant parasitic nematode development in which they can freely move and feed.

Plant Parasitic Nematodes

Turfgrass managers, most notably golf course superintendents, often encounter problems with plant parasitic nematodes. These microscopic roundworms cause damage resulting in root systems which are less able to absorb nutrients and water. Nematodes feed by puncturing host root cells and sucking out their contents with a needle-like stylet. Cell contents are broken down after the nematode injects saliva into the host tissue. Some adults as well as larvae penetrate the root (endoparasitic) before feeding and others feed just below the root surface on host cells (Hagan, 1997). The majority of the parasitic nematodes affecting turf are ectoparasitic, however some endoparasitc species also cause damage (Crow, 2007). Parasitic nematodes are ubiquitous in turfgrass soils and turf can normally withstand these nematodes if they are below damaging threshold levels. The most common species of nematodes in turfgrass are sting (*Belonolaimus longicaudatus* Rau), ring (*Mesocriconemoides* spp.), lance (*Hoplolaimus galeatus* Cobb), and stubby root (*Paratricodorus* spp.). Threshold limits (number of nematodes/100 cm^3 soil) in Florida for each are: sting 10-20, ring 150-300, lance 80, and stubby root 100 (Crow, 2007).

Environmental factors such as high temperatures, drought, or shallow frequent watering, low mowing heights, excessive or under fertilization and compacted soils can create stress for turf, resulting in evident nematode symptoms. The general above ground symptoms are loss of vigor and chlorotic, yellow turf that may become wilted, turn brown, become thin, and die (Crow, 2007). These symptoms normally occur in patchy, circular patterns as the turf declines. Below ground, damaged roots appear unhealthy, short, dark, and in severe cases the roots rot. Nematode damage may be confused with nutrient deficiencies and not respond to fertilizer applications since nutrient uptake is limited (Mitkowski, 2001). These symptoms can also be confused with those of other pathogens. The only positive method of nematode diagnosis is to collect soil samples for analysis.

Sikora, et al. (1999) conducted a study in Alabama to determine which nematode genera were most prevalent with bermudagrass (*Cynodon dactylon* x *C. transvaalensis* Burtt-Davy) and bentgrass [*Agrostis stolonifera* var. *palustris* (Huds) Farw.] putting greens, and ascertain their infestation levels. The genera most frequently found were *Criconemella*, *Helicotylenchus*, *Hoplolaimus*, and *Meloidogyne*; and average numbers of nematodes/100 cm^3 soil on putting greens for these genera were 34.1, 33.7, 25.9, and 11.1, respectively.

Mitkowski (2007) completed a study to predict nematode populations on golf course greens to determine if certain management practices and other factors influenced nematode numbers. Only a few parameters were found to influence nematode numbers between golf courses; these practices were putting green age and grass species. The older a green was, the more plant parasitic nematodes could be found. Higher nematode numbers were found on annual bluegrass (*Poa annua* L.) and velvet bentgrass (*Agrostis canina* L.).

Two chemical controls were available for established turf. Fenamiphos, Nemacur®, Ethyl 3-methyl-4-(methylthio)phenyl(1-methylethyl)phosporamidate, was registered in the United States in 1973. This organophosphate targets the nervous system of nematodes and insects and has a high degree of mammalian toxicity. It is considered one of the most toxic of its class to birds and aquatic life (Mitkowski, 2007) and was prohibited for sale as of May of 2007. The registration cancellation was effected on June 2008. Also, it could only be applied one time per year with a 24-hour reentry period. Fenamiphos was the only nematicide available for established turf in many geographic locations. The cancellation of the registration for fenamiphos generated interest in identifying alternatives to nematicide use for turfgrass.

Curfew® (1,3-dichloropropene), 1,3-D, is the only chemical control available for established turf. It is classified as a probable human carcinogen and is under U.S. Environmental Protection Agency review. It is a restricted use chemical and can only be applied by certified applicators. The reentry interval is 24 hours; therefore, the course or greens must be closed for this period of time resulting in loss of revenue. Applications can only be made in eight states including Alabama. This leaves turf mangers in most locations without nematicides for established turf. The prohibition of fenamiphos and the expense and application method for 1,3-D pose a problem for turf managers. Therefore, a need exists for alternative controls for established turf; particularly products that are more turf manager friendly.

Giblin-Davis et al. (1988) evaluated three nematicides for the control of phytoparasitic nematodes in 'Tifgreen' bermudagrass. The treatments included fenamiphos at 13.5 kg ai/ha, oxamyl at 13.5 kg ai/ha and 30% formaldehyde at 6.4 L /ha. The site was naturally infested with *Belonolaimus longicaudatus, Hoplolaimus galeatus*, *Mesocriconema* spp., and *Meloidogyne* spp. They found that 42 days after treatment, turfgrass vigor ratings and dry root weights in plots treated with fenamiphos were higher than the control, oxamyl, or formaldehyde treatments. Dry root weights were increased more than 25% in the fenamiphos treatments compared to other treatments. *B. longicaudatus* population densities were suppressed in fenamiphos, fenamiphos plus formaldehyde, and oxamyl-treated plots. The other nematode species evaluated were not affected by any of the treatments or treatment combinations.

Trenholm et al. (2005) conducted greenhouse and field studies to evaluate the use of 1,3-D and fenamiphos to reduce irrigation requirements in soil infested with sting nematodes. The effects of these two compounds were evaluated on quality and persistence of 'Tifway' bermudagrass. Bermudagrass treated with 1,3-D had 40% higher quality ratings and 27% less leaf wilting during drought stress than other treatments. Spectral reflectance values indicated better physiological functioning under stress, were highest in 1,3-D-treated plots. There were no statistical differences in root weights in field-treated plots, however rooting was deepest in1,3-D treatments. Sting nematode population densities were reduced 92% and 74% by 1,3-D compared to untreated controls in the two trials, respectively.

Crow et al. (2005) conducted studies to examine the effectiveness of the nematicidal fumigant 1,3-D at managing sting nematode on 'Tifdwarf' bermudagrass putting greens. Fenamiphos was included as an industry standard treatment in all experiments. Sting nematode numbers, root lengths, and turf color and density were compared. 1,3-D reduced numbers of sting nematodes in three of four experiments and increased root lengths in two of three experiments. Turf color and density varied, but were generally improved.

Blackburn et al. (1996) conducted greenhouse studies to evaluate avermectin B_1 which is a mixture of avermectins containing >80% [B_1a (5-0-dimethyl avermectin Ala) plus < 20% avermectin B_1b (5-0-demethyl-25-de (1-methyl propyl)-25-(1-methyl ethyl) avermectin Ala)], isazofos (0-5-chloro-1-isopropyl-1H-1,2,4-triazol-3-y10, 0-diethyl posphor othioate), and fenamiphos for efficacy against *Hoplolaimus galeatus*, and *Tylenchorhynchus dubius* infesting *Poa annua* L. Avermectin B_1 rates of 7.5 and 15.2 kg ai/ha consistently reduced nematodes compared to controls and performed as well or better than fenamiphos.

Studies have shown that enhanced microbial degradation can occur with fenamiphos as a result of chronic applications to the point of rendering the material ineffective (Striling et al., 1992). The estimated soil half-life of fenamiphos is 30 days. Ou et al. (1994) demonstrated that after 20 years of continuous annual applications to golf putting greens, the soil half-life was reduced to 0.9-1.6 days. This study was conducted a on a golf course fairway and green to determine whether the degradation of fenamiphos was enhanced by long-term applications. After 20 years of continuous applications of fenamiphos, half-life values for total toxic residue (fenamiphos +

fenamiphos sulfoxide + fenamiphos sulfone) in soil samples collected were very small and were further shortened after the annual application of fenamiphos. The major metabolite in the samples was fenamiphos sulfoxide with practically no fenamiphos sulfone detected. Fenamiphos was rapidly oxidized to fenamiphos sulfoxide and rapid subsequent degradation to CO_2 and H_2O.

Skipper et al. (2001) used five golf courses in South Carolina to determine fenamiphos degradation. According to the golf course superintendents, these courses had experienced poor performance by fenamiphos in recent years due to lack of nematode control. The results indicated the degree of enhanced biodegradation varied from course to course and from green to green within the same course. However, the highest rate of decomposition of fenamiphos occurred at day 35, with 70 to 80% being degraded.

Giblin-Davis et al. (1993) conducted field experiments to compare two formulations of fosthiazate (10G and 7.5EC) with fenamiphos 10G for control of *B. longicaudatus,* and *Meloidogyne* spp. in fairway-managed bermudagrass. One year, fosthiazate (10G and 7.5EC) was applied at rates of 1.5 and 2.2 g ai/m^2. The following year, fosthiazate (10G and 7.5EC) was applied at the rate of 0.7 and 1.5 g ai/m^2. Fenamiphos was applied at 2.2 g ai/m^2 both years. In both years, both formulations and both rates of fosthiazate were as effective as or more effective than fenamiphos 10G in reducing soil populations of both nematode species evaluated. The lower rate of fosthiazate was as effective as fenamiphos in improving turfgrass quality rating for 56 days post-treatment.

Characteristics of Azides

Sodium and potassium azides are salts of hydrazoic acid (HN_3) and in earlier years were studied for their pest controlling properties. These materials in pure form are white crystalline solids and are odorless, and possess a high degree of water solubility (Toxline, 2001) (Tables 1.1 and 1.2). Sodium azide consists of a positive Na^+ ion and negative azide ion while potassium azide consists of a positive K^+ ion and negative azide ion (Fig 1.1 and 1.2). Three nitrogen atoms joined together make up the azide group, creating a very unstable arrangement. Hence, azide will react to gain the more stable configuration of nitrogen gas, which has only two atoms of nitrogen bonded together. While azides of heavy metals such as Cu, Pb, Hg, are unstable and explosive, those of Na and K are considered safe and stable under ordinary conditions.

According to American Pacific Corporation (2007), which owns the liquid formulation of sodium azide (SEP-100), the manufacturing or synthesizing is a two-step process. The Wislicensus process involves reacting sodium metal, Na, with ammonia, NH_3 to produce sodium amide

$$2Na + 2NH_3 \rightarrow 2NaNH_2 + H_2$$

and reaction of sodium amide with nitrous oxide

$$2NaNH_2 + N_2O \rightarrow NaN_3 + NaOH + NH_3$$

Uses

Sodium azide currently has many uses. One very important use is as a selective pesticide in chemical preservatives in hospitals and laboratories. Sodium azide is used to inhibit gram negative bacterial growth in stock solutions and bulk reagents. It is a hypotensor (Merck Index, 1989) and was used in the 1950's for the treatment of certain types of cancers in humans and more recently in formulations such as the drug AZT for HIV treatment. Other uses include; detonators for powerful explosives, anticorrosion solutions, and air craft safety chutes. Until recently, it was used in automobile airbags. The pesticidal properties have been known for some time. The early history of azides was reviewed in 1936 by Keilin. He found that hydrazoic acid (HN_3) is very toxic and formulated sodium azide is stable and safe to handle.

Mode of Action

Azides are potent metabolic inhibitors affecting the activities of a variety of oxidative enzymes, notably those involved in the electron transport system of respiration. After contact with the azide anions, the cells of the body are prevented from using oxygen. This inhibits the function of cytochrome oxidase by binding irreversibly to the heme cofactor. In animals, according to Nelson and Cox (2005): "The electron carriers of the respiratory chain are organized into membrane-embedded supramolecular complexes that can be physically separated." Gentle treatment of the inner mitochondrial membrane with detergents allows the resolution of four unique electron-carrier complexes, each capable of catalyzing electron transfer through a portion of the chain. Complexes I and II catalyze electron transfer to ubiquinone from two different electron donors: NADH (Complex I) and succinate (Complex II). Complex III carries electrons from reduced ubiquinone to cytochrome *c*, and Complex IV completes the sequence by transferring electrons from cytochrome *c* to O_2. Sodium azide inhibits the process involved in Complex IV, blocking the electron transfer from NADH to oxygen. Cytochrome oxidase carries out the following irreversible reaction:

$$O_2 + 4H^+ + 4\,e^- \rightarrow 2H_2O$$

The four electrons are transferred into the complex one at a time from cytochrome *c*. Cytochrome oxidase consists mainly of transmembrane-helices in the intramembrane domains. Cytochrome oxidase is made up of metal centers which include heme a, heme a_3, Cu_A (consisting of two adjacent Cu atoms) and Cu_B. Oxygen reacts at a binuclear center, consisting of heme a_3 and Cu_B The axial ligands of the hemes in Complex IV are histidine N atoms.

Effects on Humans

Sodium azide is more harmful to the heart and brain in humans than to other organs due to the constant oxygen requirement of these organs. In humans, exposure to small amounts of azide may induce: rapid breathing, restlessness, dizziness, weakness, headaches, nausea and vomiting, rapid heart rate, red eyes, clear drainage from the nose, coughing, skin burns and blisters. Exposure to large amounts may induce: convulsions, low blood pressure, slow heart rate, loss of consciousness, lung injury, and respiratory failure, leading to death (National Toxicology Program, 2007).

SEP-100

Currently, SEP-100® manufactured by American Pacific Corporation is a liquid formulation of sodium azide. It is currently in the registration process by Environmental Protection Agency (EPA). It has been evaluated for pesticidal activities. Trials have shown that SEP-100 has broad spectrum activity and can effectively control soil borne organisms such as nematodes, weeds, fungi, bacteria, and insects (Richards, 2004). High rates of SEP-100 delivered to turf in aqueous sprays produces unacceptable injury.

Rodriguez-Kabana et al. (2005) conducted greenhouse studies to evaluate the effects of herbicidal activity of pre-plant combinations of SEP-100 with metam sodium,

sodium thiosulfate, methyl disulfide and EPTC for control of annual morningglory (*Ipomoea* spp.). Results indicated that metam sodium can be used after application of SEP-100 to neutralize residual sodium azide in the soil. Sodium azide rates could be reduced with the inclusion of EPTC and provide satisfactory herbicidal activity. Also, the combination of EPTC and sodium azide increased herbicidal activity.

Rodriguez-Kabana and Akridge (2003) conducted a study was to evaluate the efficacy of SEP-100 as an alternative for methyl bromide in green pepper (*Capsicum annuum* L.) production. Pre-plant applications were applied through drip irrigation at rates of 56, 84, 112, 140, 168, 196, and 224 kg ai/ha. The results indicated that all rates of SEP-100 had pre-plant nematacidal properties in controlling root knot (*Meloidogyne incognita* Kofoid), purple nutsedge (*Cyperus rotundus* L.), and *Panicum* spp. However, sodium azide rates ≥ 112 kg ai/ha consistently equaled or out-performed methyl bromide at the rate of 336 kg ai/ha.

Rodriguez-Kabana et al. (2003) conducted field studies to evaluate SEP-100 as a pre-plant treatment for control of root-knot nematode, nutsedge, and damping off and root rot caused by species of *Rhizoctonia* and *Fusarium* in tomato (*Lycopersicon esculentum* Mill.) production. Pre-plant applications were applied through drip irrigation and the rates included 56, 84, 112, 140, 168, 196, and 224 kg ai/ha. Control of root-knot nematodes and nutsedges with all rates of sodium azide was achieved. Sodium azide rates ≥ 84 kg ai/ha equaled or out performed methyl bromide at the rate of 336 kg ai/ha in controlling nematodes, weeds and other soil borne pests. *Fusarium* was not controlled with methyl bromide; however; sodium azide controlled the disease when applied at the rate ≥112 kg ai/ha. A similar study was conducted by Rodriguez-Kabana et al. (2004) in cantaloupe (*Cucumis melo* L.) production evaluating control of the same pests. Sodium azide rates were 0-224 kg ai/ha and methyl bromide was used as a positive control and the rate was 392 kg ai/ha. Sodium azide rates ≥ 56 kg ai/ha eliminated root knot nematodes and controlled damping off and root rot caused by *Rhizoctonia* and *Fusarium*. Sodium azide rates ≥ 84 kg ai/ha effectively controlled weeds. Cantaloupe yield was increased with 56 and 84 kg ai/ha rates.

Guertal et al. (2003) conducted preliminary studies with SEP-100 in container microplots and in the field to determine optimal rates and placement methods for control of hybrid and common bermudagrass [*Cynodon dactylon* (L.) Pers] and nutsedges. Microplot studies consisted of sodium azide applied to common bermudagrass at the rate of 112 kg ai/ha and treatments included clear plastic cover, incorporation of azide, and leaching of azide with 2 cm of irrigation applied after application. The plastic covered plots had significant greater kill of bermudagrass than plots that were not covered. Bermudagrass eradication was increased with tillage. The results suggest that rates greater than 112 kg ai/ha are required for bermudagrass eradication and it is most effective when applied under plastic. However, bermudagrass under the tarps that received no spray was not killed. This indicates that sodium azide is/was not volatile. It is suggested the tarp prevented leaching of the chemical from the weed zone. The field studies consisted of sodium azide applied at rates of 84, 112, 140, and 168 kg ai/ha to soil from which Tifway hybrid bermudagrass had been harvested 3 months prior to application. Watermelon (*Citrullus vulgaris* Schrad) seed and centipedegrass [*Eremochloa ophiuroides* (Munro) Hack.] plugs were planted into treated plots on a weekly basis to provide an indication for sod producers the plant-back interval required.

The results indicated that the two highest rates of sodium azide controlled bermudagrass most effectively, but control of nutsedge was not achieved. Watermelon seedling and sod plug damage occurred for 3 weeks after application.

Walker et al. (2003), conducted a field study to evaluate weed control and effect on plant back of seeded bermudagrass, zoysiagrass (*Zoysia* spp.), and tall fescue (*Festuca arundinacea* Schreb.) with SEP-100 and this was compared to methyl bromide/chloropicrin (pic) (67/33) and metam potassium. Sodium azide was applied to the soil surface at the rates of 113, 141, and 168 kg ai/ha and was immediately tarped. Methyl bromide was shank injected at 392 kg ai/ha and tarped. Metam potassium was sprayed on the soil surface at the rate of 55 gal/A and incorporated and then tarped. The existing weeds included high densities of yellow and purple nutsedge, and varying densities of common bermudagrass and summer annual broadleaf weeds. The data indicated that commercially acceptable control of nutsedge was provided by treatments of methyl bromide/pic and the three rates of SEP-100. The two higher rates of SEP-100 and methyl bromide/pic provided the best germination and growth rate of tall fescue. Methyl bromide/pic and metam potassium provided the best germination and growth rate for zoysiagrass. Bermudagrass germination and growth rate was best with methyl bromide/pic.

Walker et al. (2005) conducted another field study to determine the potential to reduce sodium azide rates for disease and sedge control with halosulfuron in tomato (*Lycopersicon esculentum* Mill.) production. The site was infested with nutsedge and *Fusarium* crown and root rot. Sodium azide was surface applied at the rate of 56 kg ai/ha and incorporated by tilling. Halosulfuron was applied preemergence to the surface at

0.054 kg ai/ha before tarping. Halosulfuron was also postemergence-applied to weeds and tomato. Methyl bromide was injected at 448 kg ai/ha and all treatments were tarped. The results indicated that sedge control and tomato tolerance was highest with SEP-100 plus halosulfuron post treatment. SEP-100 treatments resulted in excellent tomato vigor.

Rodriguez-Kabana et al. (2005) conducted a study to investigate combining SEP-100 with three herbicides in order to reduce the rate of sodium azide needed to replace methyl bromide for control of weed and other soil-borne pests. The herbicides were EPTC, s-metalachlor, and halosulfuron-methyl. Predominant weeds in the pots were crabgrass [*Digitaria sanguinalis* (L.) Scop.], yellow nutsedge, pigweed (*Amaranthus* spp.) and morningglories. Sodium azide was applied at 0 and 33.6 kg ai/ha alone and in combination with EPTC at 6.72 kg ai/ha. The data indicated that combinations of sodium azide and EPTC provided excellent control of yellow nutsedge and other weeds better than either compound alone. Sodium azide was applied at 0 and 44.8 kg ai/ha alone and in combination with halosulfuron-methyl at rates of 10.2, 25.4, 50.8, 88.9, and 101.6 kg ai/ha. Results demonstrated that combinations of both compounds resulted in excellent nutsedge control and best overall activity of all three combinations. Sodium azide was applied at 0 and 44.8 kg ai/ha alone and in combination with s-metholachlor rates of 1.12 to 5.6 kg ai/ha. Combinations of sodium azide and s-metholachor provided excellent control of yellow nutsedge and other weeds better than either compound alone. The overall data indicated that low rates of sodium azide < 56 kg ai/ha, was effective against plant pathogenic nematodes and fungi, can be combined with all three herbicides evaluated and be effective in controlling nutsedge and other weeds.

Field studies were conducted to evaluate SEP-100 weed efficacy using rate, tillage, tarp effects, and glyphosate on common noxious weeds (Walker et al., 2003). The weed species present were hybrid bermudagrass, perennial sedges, and torpedograss (*Panicum repens* L.). The tarp and tillage trial included sodium azide at a rate of 112 kg ai/ha. SEP-100 data resulted in unacceptable control of torpedograss with tarp and tillage effects. The tillage trial consisted of 224 kg ai/ha of sodium azide and glyphosate at a rate of 3.36 kg ae/ha. The results indicated a glyphosate pre-treatment plus SEP-100 eliminated weeds after 10 days. The tillage and glyphosate pre-treatment trial included sodium azide rates of 112 and 168 kg ai/ha and glyphosate at a rate of 3.36 kg ae/ha. Results suggested glyphosate pre-treatment could substitute for the clear plastic tarp. This study suggested sodium azide is not volatile.

Greenhouse and field experiments were conducted by Rodriguez-Kabana and Robertson (2000) to study the herbicidal activity of SEP-100 against purple and yellow nutsedge, crabgrass, and pigweed. The rates of sodium azide used in a greenhouse experiment were 20-80 mg ai/kg soil for the control of nutsedges. Nutsedge was controlled at all rates and the most efficacious long-term control (67 days) was with 60 and 80 mg ai/kg. Another greenhouse experiment used SEP-100 postemergence rates of 20-160 mg ai/kg for the control of nutsedge, crabgrass, and pigweed. All rates of azide resulted in weed mortality 24 hours after application and soil was weed free for 35 days after application. The field experiment compared the efficacy of SEP-100 to methyl bromide for control of purple nutsedge. The rates of azide were 56, 84, 112, 168, and 224 kg ai/ha and the methyl bromide standard was applied at 27 gm/m^2. One month after application, there were no weeds present in plots treated with the highest rate of SEP-100.

The 112 and 168 kg ai/ha rates reduced the weed population to < 7 plants/m^2. Sodium azide rates ≥ 84 kg ai/ha out-performed methyl bromide for weed control ($P \leq 0.05$).

Walker et al. (2006) evaluated the non-tarped treatment of sodium azide plus EPTC for control of common and hybrid bermudagrass and yellow nutsedge. Sodium azide was applied at a rate of 58 kg ai/ha as a soil preemerge and EPTC was applied as a preplant at 7.5 kg ai/ha and soil incorporated. Irrigation was applied immediately after application at 0.76 cm. Complete control of common and hybrid bermudagrass was obtained and nutsedge control averaged 94%.

Aqueous Formulations of Sodium and Potassium Azide

Santos et al. (2005) conducted field experiments to compare methyl bromide alternatives for soilborne disease, nematode and weed management in fresh market tomato production. Sodium azide was one of the possible alternatives evaluated and was drip applied at 85 and 170 kg/ha. These studies showed that during two of the seasons, sodium azide at 85 kg/ha was consistently equal to methyl bromide. Sodium azide controlled populations of nematodes *Tylenchorhynchus* spp. and *Belonolaimus* spp and nutsedge.

A microplot experiment was conducted to evaluate the efficacy of pre-plant applications of a proprietary formulation of sodium azide for control of plant parasitic nematodes and weeds in tomato production (Rodriguez-Kabana and Robertson, 2000). Sodium azide was stabilized in the formulation with a mixture of amines and commercially available protein. Soil was infested with root-knot, stubby-root, stunt nematode, and spiral nematodes. The predominant weeds in the plots were crabgrass, yellow nutsedge, pigweed and morningglories. Sodium azide was drench applied at 1, 1.5, 2, 3, 4, and 5 g/ 0.3 m^2 plot and tarped immediately. At planting time, there were no weeds in plots treated with all but the three lowest rates of sodium azide. Three months after treatment, there were no plant parasitic nematodes in treated plots for all rates tested. Yield and number of fruits increased directly in response to sodium azide rates. The data suggest that sodium azide/amine-protein formulation could serve as plant nutrients and stimulate beneficial soil microbial activities.

An aqueous solution of sodium azide, Agrizide, was used as a pre-plant treatment for control of plant parasitic nematodes and weeds in 'Black Beauty' eggplant *(Solanum melongena* L.) production in microplots (Rodriguez-Kabana, 2001). Soil was naturally infested with root-knot, stubby-root, stunt, and spiral nematodes. The predominant weeds in the plots were crabgrass, yellow nutsedge, pigweed and morningglories. Sodium azide was drench applied at rates of 0, 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, and 5.0 g/ 0.3m^2 plot and tarped immediately. When the experiment concluded, there were no plant parasitic nematodes and no significant weed infestation in plots treated with the three highest rates of sodium azide, however there were significant ($P \leq 0.05$) populations of weeds and nematodes in plots treated with < 2.0 rates. Number of fruits and yield increased in response to increasing rates that ranged from 0-1.5 g/plot.

Rodriguez-Kabana and King (2001) also conducted field experiments with Agrizide to determine the efficacy of pre-plant applications of sodium azide for control of root-knot nematode, coastal bermudagrass, yellow nutsedge and other weeds in pepper and tomato. Agrizide was drench applied at rates of 100 and 200 kg/ha and was applied to pre-acidified and non-acidified soil using three different water levels consisting of 3, 10, and 15 L/m^2. The soil was tarped immediately after application. Tomatoes and peppers were planted 6 weeks after treatment. Nematodes and weeds were controlled > 90% at both rates. The acidified soil demonstrated more azide efficacy than non-acidic soil. The 15 L/m^2 water level was more effective than 3 and 10 L/m^2 water levels. Phytotoxicity was not evident on either pepper or tomato.

Rodriguez-Kabana and Roberson (2000) performed greenhouse studies with a proprietary liquid formulation of sodium azide to evaluate the nematicidal and herbicidal properties. Soil was obtained from a cotton (*Gossypium hirsutum* L.) field infested with reniform nematode (*Rotylenchus reniformis* Cobb). The rates of sodium azide were 1, 2, 3, 4, and 5 mg/kg soil. As rates of sodium azide increased up to 4 mg/kg, nematodes decreased. The 5 mg/kg rate provided 100% reduction of nematode numbers; however the effective nematicidal rates did not provide weed control. Rates ≥ 140 mg/kg soil resulted in 80% control of crabgrass, purple nutsedge, and Jimsonweed (*Datura stamonium* L.). Crabgrass was the least sensitive of the weeds to sodium azide applications.

The nematicidal properties of aqueous solutions of sodium azide were evaluated in laboratory, greenhouse and field trials (Bradbury et al., 1957). They tested the efficacy of sodium azide against the potato-root eelworm (*Heterodera rostochiensis* Wollenweber) and root-knot nematode. They found sodium azide to be an effective nematicide in the laboratory, but results varied in greenhouse and field trials.

Granular Formulations

Sodium azide (NaN_3) and potassium azide (KN_3) are compounds that are being evaluated for control of nematodes on highly maintained turf. A formulation of both inorganic azides has been developed and impregnated on a granular carriers consisting of

Profile® (Profile Products LLC., 750 Lake Cook Rd., Suite 440, Buffalo Grove, IL 60089) and Biodac® (Kadant Inc., One Technology Park Dr., Westford, MA 01886). Profile is an inorganic soil amendment which is kiln-fired clay ceramic and is very stable. The chemical composition includes 74% SiO_2, 11% Al_2O_3, 5% Fe_2O_3, and less than 5% of CaO, MgO, K_2O, Na_2O, and TiO_2 (Profile Products, 2002). This soil amendment is currently used on golf course putting greens during construction or aerification. Profile permanently improves most soils by increasing water and nutrient holding pores and air and drainage pores.

Biodac is an absorbent granule made from pulp residue and is currently used as a carrier for pesticides. It is also used as an absorbent for oil and grease. Biodac is a gray, cellulose complex consisting of 47-53% paper fiber, 28-34% kaolin clay, and 14-20% calcium carbonate and no more than 1% titanium dioxide (Ilyina et al., 2000).

Preliminary studies conducted at Auburn University during 2006-2008 have shown that both granular formulations of sodium and potassium azide have nematicidal effects and are possible alternatives for controlling nematodes and weeds. Early studies have been done to evaluate granular formulations of both sodium and potassium azide for controlling fungi and other soil microbial populations. Published data are not available on turf tolerance with granular formulations of sodium and potassium azides. During 2006-2008 (Wells and Walker, unpublished) conducted approximately 20 preliminary field studies to determine tolerance on bentgrass and hybrid bermudagrass. These studies indicated that bentgrass could tolerate a 5.6 kg ai/ha rate with multiple applications. Bermudagrass tolerated multiple applications of 11.2 kg ai/ha and injury was within the acceptable level (<30%).

Bigelow et al. (2001) evaluated creeping bentgrass response consisting of establishment, turf quality and root mass density to inorganic soil amendments with Profile being one of the amendments tested. This study found that amending medium-coarse sized sand with organic amendments had significant beneficial effects on turfgrass establishment and visual quality ratings. During one year of the study, rootzone amendments had significant beneficial effects on root mass density; however this was not the case during the other year of the study.

Ilyina et al. (2000) conducted a study to evaluate Biodac as a possible carrier for microorganisms that could be useful for bioremediation applications. The possible side effects on soil capacity to retain moisture and influence plant growth were reported. Biodac was found to be hydrophilic, porous and to absorb water at 1.15 ml/g due to the high cellulose content. Moisture was retained in soil treated with Biodac by 30%. No adverse side effects on plants were observed in treated soils and the best plant height and weight were observed in Biodac-treated soils. Biodac granules contain kaolin with Al^{3+} ions which can have an inhibitory effect on plant growth. This study did not detect this negative potential with quantities that were applied.

A study was done to determine the efficacy of a granular formulation of potassium azide for control of *Rhizoctonia solani* and *Verticillium* wilt of potato (*Solanum tuberosum*) with spring and fall applications using mechanical incorporation versus no incorporation (Davis et al., 1972). Potassium azide rates were 0, 58, 84, 112, and 168 kg ai/ha. They found that when potassium azide was mechanically incorporated into soil at rates ≥ 89.8 kg ai/ha, spring applications significantly reduced symptom development of *R. solani* and *Verticillium* wilt of potato. Treatments involving injection of potassium azide into soil with an anhydrous ammonia propellant reduced *Verticillium* wilt at 67.2 kg ai/ha, but produced no evident control of *Rhizoctonia*. Fall application of potassium azide at 56 and 112 kg ai/ha and mechanically soil incorporated provided no control of *Rhizoctonia*.

Kelley and Rodriguez-Kabana (1975) conducted a study in pine (*Pinus* spp.) nursery beds to evaluate the effect of preplant applications of potassium azide on soil microflora and on soil enzyme activities where either plastic sealing or water sealing techniques were used. Potassium azide rates were applied at 0, 56, 112, 168, and 224 kg ai/ha and tilled into soil. One half of the plots were watered sealed and the other half was sealed with plastic. The results indicated that 2 weeks after azide incorporation, soil samplings revealed reduced populations of bacteria and fungi and a corresponding decline in invertase and amylase activities. These effects were more pronounced in plastic-sealed plots and were proportionate to the amount of azide used. There was little effect on phosphatase activity. Sixteen weeks after treatment, bacterial populations did not significantly differ from controls and were higher in plastic-sealed plots. Fungal populations changed little and remained significantly lower in water-sealed plots. Kelley and Rodriguez-Kabana (1973), also conducted studies in pine nursery beds to compare sodium azide and methyl bromide effects on soil microflora. Sodium azide was applied preplant at rates of 22.4, 67.2, and 134.5 kg ai/ha and methyl bromide rates were applied at 650 kg ai/ha. Treatments of sodium azide were sealed with water or plastic. The results indicated that the number of fungi generally decreased in response to the amount of azide added more so in water-sealed plots. Methyl bromide plots consistently had the lowest numbers of fungi. Numbers of bacteria increased in proportion to sodium azide rates during the first 58 days and methyl bromide plots had the highest numbers. Methyl bromide eliminated all plant parasitic, predatory, and saprophagous nematodes. Plots treated with sodium azide were 35-75% below those in control plots with no significant differences between azide treatments with more reductions occurring in water-sealed plots. Kelley and Rodriguez-Kabana (1979) conducted a 2-year field study in a pine tree nursery to compare the nematicidal effects of a granular formulation of sodium azide to that of methyl-bromide. This study indicated that the methyl-bromide treated plots were free of nematodes throughout the 2-year period. However, those treated with azide were not as effective. These plots had decreasing numbers of nematodes for 24 weeks after treatment; but were no different from the controls after 34 weeks.

Leksan and Coffman (1973) evaluated the effects of sodium azide on disease control of *Rhizoctonia* and *Pythium* and weeds to include purslane (*Portulaca oleracea* L.) and goosegrass (*Eleusine indica* L.). Sodium azide 8G was applied at rates of 0, 33.6, 67.2, and 34.4 kg ai/ha, and the soil was tilled and application was watered in. Methyl bromide was applied at the rate of 2.24 kg ai/100 square feet and tarped. The amount of rainfall during the experiment totaled 19.4 cm. Successful planting into azide-treated soils could be done 23 days after application at rates of 33.6 and 67.2 kg ai/ha. These rates controlled *Rhizoctonia* and *Pythium* as well as purslane and goosegrass at levels comparable to methyl bromide.

Colby and Feeny (1967) evaluated herbicidal interactions of potassium azide with calcium cyanamid in greenhouse and field studies. Technical grade potassium azide was sprayed in 110 gallons per acre of water or was applied as a 10% granule formulated on Attaclay. The results indicated that in the greenhouse, the combinations were synergistic against several weed species including yellow nutsedge, and crabgrass. In the field, the combinations reduced the number of weed seeds germinating from treated soil over a 6-month period.

Unruh et al. (2002) evaluated potassium azide as an alternative to methyl bromide for the management of common turfgrass weeds. Potassium azide was applied at the rate of 112 kg/ha. This study found that potassium azide was as effective as methyl bromide in controlling many grassy and broadleaves. The weeds controlled were 'Coastal' bermudagrass, yellow and purple nutsedges, Alexandergrass (*Brachiaria plantaginea* L.), broadleaf signalgrass [*Brachiaria platphylla* (Griseb.) Nash], tall morningglory (*Ipomoea purpurea* L.) and sharppod morningglory (*Ipomoea cordatotriloba* Dennstedt) and various other weeds. Potassium azide failed to provide acceptable control of redroot pigweed (*Amaranthus retroflexus* L.).

Preliminary data collected in 2006 (Walker and Crow, unpublished) has shown the nematicidal effects of sodium azide greatly reduced sting and lance nematode numbers on hybrid bermudagrass. Sodium azide was applied two times at a 22.4 kg ai/ha rate. Both nematode populations were reduced below the damaging level and turf quality and root length densities improved with treatments compared to non-treated controls.

Disclaimer

The use of trade, firm, or corporation names in this publication is solely for the purpose of providing specific information and does not imply endorsement or recommendation by the authors or Auburn University.

RESEARCH JUSTIFICATION

Chemical control measures effectively reducing plant parasitic nematodes on established turf are limited. The registration was recently cancelled for fenamiphos, Ethyl 3-methyl-4-(methylthio)phenyl(1-methylethyl)phosporamidate. Currently, Curfew [1,3 dichloropropene, (1,3-D)] is the only chemical control available for established turf. Fenamiphos was prohibited for sale in May 2007 and could only be applied one time per year. 1,3-D can only be applied by certified applicators using specialized equipment; applications can only be made in Florida, Georgia, Alabama, North and South Carolina, Louisiana, Mississippi, and Texas. The prohibition of fenamiphos and the expense and application method for 1,3-D pose a problem for turf managers. Therefore, a need exists for alternative controls for nematodes in established turf. Specifically for a product that turf managers can apply themselves.

GENERAL OBJECTIVES

The general research objectives were:

i) Determine tolerance of hybrid bermudagrass and creeping bentgrass managed as golf putting greens to granular formulation of sodium and potassium azide.

ii) Determine efficacy of sodium and potassium azide on plant parasitic nematodes.

iii) Determine potential for interactions of sodium and potassium azide and urea on creeping bentgrass growth with repeated applications.

REFERENCES

Ahmad, M. and T.A. Chen. 1980. Effect of certain environmental factors and host plants on reproduction of *Hoplolaimus galeatus*. Plant Disease 64:479-480.

American Pacific Corporation. 2007. "American Pacific and Gowan Enter Joint Venture, License, and Supply Agreements for Azide-Based Pest Management Products". PR News Today.

Beard, J.B. 1982. Turf management for golf courses. pp 102-118. MacMillian Publishing Co. New York.

Bigelow, C.A., D.C. Bowman, and D.K. Cassel. 2004. Physical properties of three sand size classes amended with inorganic materials or sphagnum peat moss for putting green rootzones. Crop Science 44:900-907.

Bigelow C.A., D.C. Bowman, K.K. Cassel and T.W. Rufty. 2001. Creeping bentgrass response to inorganic soil amendments and mechanically induced subsurface drainage and aeration. Crop Science 41:797-805.

Blackburn, K.S., R. Alm, and T.S. Yeh. 1996. Avermectin B_1, isazofos, and fenamiphos for control of *Hoplolaimus galeatus* and *Tylenchorhynchus dubius* infesting *Poa annua*. J. of Nematology 28(45):687-694.

Bowman, D.C., D.A. Devitt, and W.W. Miller. 2002. The effect of moderate salinity on nitrate leaching from bermudagrass turf: A lysimeter study. Water, Air, and Soil Pollution 175:1-4.

Bradbury, F.R., A. Campbell, and C.W. Suckling. 1957. The nematicidal properties of azides. Annals of Applied Biology 45(2):241-250.

Busey, P., M. Giblin-Davis, and B.J. Center. 1991. Resistance in *Stenotaphrum* to the sting nematode. Crop Science 33:1066-1070.

Colby, S.R. and W.Feeney. 1967. Herbicidal interactions of potassium azide with calcium cyanamid. Weed Sci. 15(1):20-23.

Crow, W.T. 2007. Nematode management for golf courses in Florida. University of Florida Cooperative Extension Service Fact Sheet ENY-008 (IN124). University of Florida, Gainesville, Florida.

Crow, W. 2005. Plant-parasitic nematodes on golf course turf. Outlooks on Pest Management 10:1564-1568.

Crow, W.T. and R.H. Walker. 2006. Unpublished. Nematode control on Tifdwarf bermudagrass.

Crow, W.T., D.W. Lickfeldt, and J.B. Unruh. 2005. Management of sting nematode (*Belonolaimus longicaudatus*) on bermudagrass putting greens with 1,3-dichloropropene. International Turfgrass Soc. Res. J. 10:734-741.

Crow W.T., and J.K. Welch. 2004. Root reductions of St. Augustinegrass (*Stenotaphrum secundatum*) and hybrid bermudagrass (*Cynodon dactylon* x *C. transvaalensis*) induced by *Trichodouus obtusus* and *Paratrichodorus minor*. Nematropica 34:(11)31-37.

Davis, J.R., R.H. Callihan, and M.D. Groskopp. 1972. Efficacy of potassium azide for control of *Rhizoctonia solani* and *Verticillium* wilt of potato. Plant Disease Reporter 56(5):400-404.

Divergence. 2006. "What is a nematode". www.divergence.com/al.ncga/php

Duble, R.L. 1996. Turfgrasses their management and use in the southern zone. p 3-5. 2nd ed. Texas A&M University Press. College Station, TX.

Fry, J. and B. Huang. 1999. "Help bentgrass beat the heat". 1999. Penton Media. www.grounds_mag. com.

Giblin-Davis, R.M., J.L. Cisar, and F. Bilz. 1993. Evaluation of fosthiazate for the suppression of phytoparasitic nematodes in turfgrass. Nematropica 23:167-175.

Giblin-Davis, R.M., J.L. Cisar, F.G. Bilz, and K.E. Williams. 1992. Host status of different bermudagrasses (*Cynodon* spp.) for the sting nematode, *Belonolaimus longicaudatus*. Supplement to J. of Nematology 24:749-756.

Giblin-Davis, R.M., J.L. Cisar, and F. Bilz. 1988. Evaluation of three nematicides for the control of phytoparasitic nematodes in 'Tifgreen II' bermudagrass. Annals of Applied Nematology 2:46-49.

Guertal, E.A., R. Rodriguez-Kabana,and R.H. Walker. 2003. SEP 100 (sodium azide) efficacy against hybrid and common bermudagrass. *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, CA. Abstr .106.*

Hagan, A. 1997. Nematode pests of turf: Their identification and control. Alabama Cooperative Extension Systems Circular ANR-0523.

Hall, C.R., A.W. Hodges, and J.J. Haydu. 2005. Economic impacts of the green industry in the United States. University of Tennessee, Knoxville, TN.

Harrison, J.M. and C.D. Green. 2008. Comparison of centrifugal and other methods for standardization of extraction of nematodes from soil. Annals of Applied Biology 82(2):299-308.

Haydu, J.J., A.W. Hodges, and C.R. Hall. 2002. Economic impacts of the turfgrass and lawncare industry in the United states. University of Florida. IFAS Extension FE632.

Henn, R.A. and R.A. Dunn. 1989. Reproduction of *Hoplolaimus galetus* and growth of seven St. Augustinegrass (*Stenotaphrum secundatum*) cultivars. Nematropica. 19:81-87.

Hixon, A. C. and W.T. Crow. 2003. First report of plant-parasitic nematodes on seashore paspalum. Plant Disease 88:680.

Hurdzan, M.J. 1985. Evolution of the modern green, part I. American Society of Golf Course Architects (ASGCA). 221 North LaSalle St. Chicago, IL.

Ilyina, A.D., S.J. Villarreal, R.E. Rivera, G.Y. Garza, and M.J. Rodriguez. 2000. Using of biodac (absorbent granules produced from paper industry residues) as carrier to microorganisms for soil inoculation. Biocatalysis 41(6):135-138.

Joo, Y.K., N.E. Christian, D. Li, and D.D. Minner. 1998. Effects of soil amendments on the chemical and physical soil parameters of a sand-based golf green. 1998. Iowa Turfgrass Research Report.

Keilin, D. and E.F. Hartree. 1936. On the mechanism of the decomposition of hydrogen peroxide by catalase. Proceedings of the Royal Society of London. Series B, Biological Sciences 124(837):397-405.

Kelley, W.D., and R. Rodriguez-Kabana. 1979. Nematicidal activity of sodium azide. Nematropica 8:49-51.

Kelley, W.D., and R. Rodriguez-Kabana. 1976. Sodium azide as a soil fumigant in forest tree nurseries. Proceedings of the American Phytopathological Society 2:47-48.

Kelley, W.D., and R. Rodriguez-Kabana. 1975. Effects of potassium azide on soil microbial populations and soil enzymatic activities. Canadian Journal of Microbiology 21(4):565-570.

Leksan, C.F. and D.R. Coffman. 1973. Sodium azide trial YBF 65. PPG Industries, Inc. Chemical Division. Barberton, Ohio.

Luc, J.E., W.T. Crow, J.L. Stimac, J.B. Sartain, and R.M. Giblin-Davis. 2007. Effects of *Belonolaimus longicaudatus* management and nitrogen on turf quality of golf course fairways. J. Nematology 39(1):62-66.

Luc, J.E. and W.T. Crow. 2004. Nematode and nitrogen management. Golf Course Management. (72)8:86-88.

Luc, J.E. and W.T. Crow. 2004. Sting nematode: Not a steward of the environment. Golf Course Management 72(9):86-88.

Merk Index. 1989. www.library.dialog.com/bluesheets/html/b10304 html

Milesi, C., S.W. Running, C.D. Elvidge, J.B. Dietz, B.T. Tuttle, and R.R. Nemani. 2005. Mapping and modeling the biogeochemical cycling of turfgrasses in the United States. Environmental Management 36:438.

Miller, G.L. 2000. Physiological response of bermudagrass grown in soil amendments during drought stress. HortScience 35:213-216.

Mitkowski, N. 2006. Coping with nemaotdes sans fenamiphos. Turfgrass Trends 16(12):1-4.

Mitkowski, N., 2001. Root-knot nematodes on turf in the northeastern United States. Turfgrass Trends 10(12):1-4.

Morris, K. 2005. The national turfgrass research initiative. USGA Green Section Record. September/October.

Murray, J.J., T.E. Poole, and S.A. Ostazeski. 1986. Techniques for determining reproduction of *Meloidogyne graminis* on Zoysiagrass and Bermudagrass. Plant Disease 70(6):559-560.

Myers, R.F, R.E. Wagner, and P.M. Halisky. 1992. Relationship between cultural factors and nematodes on Merion Kentucky bluegrass. J. of Nematology 24(1):205-211.

National Toxicology Program. 2007. Toxicology and carcinogenesis studies of sodium azide in rats. TR-389.

Nelson, David L. and Michael M. Cox. 2005. Principles of Biochemistry. 4th ed. p 696-697. W. H. Freeman and Company. New York, NY.

Novark, J. 2005. Overview of the turfgrass industry. TPI Turfnews November/December. 213-216.

Ou, L.T., J.E. Thomas, and D.W.Dickson. 1994. Degradation of fenamiphos in soil with a history of continuous fenamiphos applications. J. Soil Sci. 58:1139-1147.

Parocetti, J.V., and G.F. Warren. 1970. Behavior of poassium azide in soil. Weed Sci. 18:555-560.

Profile Products. 2002. The best way to amend your sand. www.profileproducts.com.

Rau, G.J. 1958. A new species of sting nematode. Proceedings of the Helminthological Society 25:95-98.

Richards, D.J. 2004. A sodium azide-based broad spectrum pesticide. *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, Orlando, FL. Abstr. 48.*

Robbins, R.T., and K.R. Barker. 1974. The effects of soil type, particle size, temperature, and moisture on reproduction of *Belonolaimus longicaudatus*. J. Nematology 6:1-6.

Rodriguez-Kabana, R., L.J. Simmons, R.H. Walker, and J.L. Belcher. 2005. Combinations of sodium azide and commercially available herbicides for weed control. *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, CA. Abstr. 19.*

Rodriguez-Kabana, R., L.J. Simmons, R.H. Walker, and J.L. Belcher. 2005. Herbicidal activities of sodium azide (SEP 100) with metam Na and other sulfur containing compounds. *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, CA. Abstr. 23.*

Rodriguez-Kabana, R., J.R. Akridge and J.E. Burkett. 2004. Sodium azide [SEP 100] for control of root-knot nematode, weeds, and soil borne disease in cantaloupe production. *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, Orlando, FL. Abstr. 49.*

Rodriguez-Kabana, R., J.R. Akridge and J.E. Burkett. 2003. Sodium azide [SEP 100] for control of nutsedge, root-knot nematode, and *fusarium* crown rot in tomato production. *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, CA. Abstr. 21.*

Rodriguez-Kabana, R., and J.R. Akridge. 2003. Sodium azide [SEP 100] for control of nematodes and weed problems in green pepper production. *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, CA. Abstr. 46.*

Rodriguez-Kabana, R., 2001. Preplant applications of sodium azide for control of nematodes and weeds in eggplant production. *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, CA. Abstr.6.*

Rodriguez-Kabana, R., and R.G. Robertson. 2001. Efficacy of aqueous formulations of sodium azide with amine-protein stabilizers for control of nematodes and weeds in tomato production. *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, Orlando, FL, Abstr. 8.*

Rodriguez-Kabana, R., and M.H. Pope. 1981. A simple incubation method for the extraction of nematodes from soil. Nematropica 11(2):175-185.

Santos, B.M., J.P. Gilbreath, T.N. Motis, J.W. Noling, J.P. Jones, and J.A. Norton. 2005. Comparing methyl bromide alternatives for soilborne disease, nematode and weed management in fresh market tomato. Crop Protection 25(7):690-695.

Shea, P.A. 2008. Golf: The bridge between generations and gender. Green Section Record. May/June, pp. 13-19.

Sikora, E.J., E.A. Guertal, and K.L Bowen 1999. Golf course nematodes–the hidden enemy. Highlights of Agricultural Research 46(3)10-11.

Skipper, H.D., R.O. Ankumah, N. Gaskin, D.D. Brown, J. Hamilton, L.W. Grimes, J. H. Kim and T.L. Lalande. 2001. Microorganisms making a meal of your pesticide. Carolinas Green.

Sledge, E.R. and A.M. Golden. 1964. *Hypaoperine graminia* (Nematoda: Heteroderidae) a new genus and species of plant parasitic nematode. Proc. Helminth. Soc. Wash. 31:83-88.

Stirling, A.M., G.R. Stirling, and I.C. Macrae. 1992. Microbial degradation of fenamiphos after repeated application to a tomato-growing soil. Nematologica 38:245-254.

Toxline. 2001. Toxicology Literature Online Databank (http://toxnet.nlm.nih.gov).

Trenholm, L.E., D.W. Lickfeldt, W.T. Crow. 2005. Use of 1,3-dichloropropene to reduce irrigation requirements of sting nematode-infested bermudagrass. HortScience 40(5):1543-1547.

Turfgrass Council of North Carolina. 1999. North Carolina Turfgrass Survey.

Turgeon, A.J., 1991. Turfgrass management. 3rd Edition. Prentice Hall, Englewood Cliffs, New Jersey. p. 418.

Unruh, J.B., J. Brecke, J. A. Dusky, and J.S. Godbehere. 2002. Fumigant Alternatives for methyl bromide prior to turfgrass establishment. Weed Technol. 16(2):379-387.

Vencill, W.K. 2002. Herbicide Handbook. 8th ed., Lawrence, KS: Weed Science Society of America.

Walker, R.H., J. Belcher, D. Teem, and R. Rodriguez-Kabana. 2006 . Preplant bermudagrass control in warm-season sod without methyl bromide. *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, Orlando, FL. Abstr. 62.*

Walker, R.H., J.L. Belcher, R. Rodriguez-Kabana, E.A. Guertal, and L. Simmons. 2005. SEP 100: Pest efficacy and crop tolerance. *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, CA. Abstr. 21.*

Walker, R.H., R. Rodriguez-Kabana, J.L. Belcher, E.A. Guertal, and D.H. Teem. 2003. Weed Efficacy of SEP 100: Rate, Tillage and Tarp Effects. *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, CA. Abstr. 105.*

Wehtje, G.R., J.N. Shaw, R.H. Walker and W.Williams. 2003. Using inorganic soil amendments to improve a native soil. HortScience. 38 (4):613-617.

Wolfe, R.J. and S. Kline. 1994. Field evaluation of a methoprene/biodac formulation on saltmarsh mosquitoes in Delaware. Northeastern Mosquito Control Association 94-5.

Table 1.1 Physiochemical properties of sodium azide.	
Other names	Sodium trinitride
Molecular formula	NaN_3
Molar mass	65.01 g/mol
Appearance	White solid
CAS number	[26628-22-8]
Properties	
Density and phase	1.85 g/cm^3, solid
Solubility in water	41.7 g/100 ml (17C)
Melting point	275C decomposition
Boiling point	300C decomposition
*data given for material in standard state at 25C, 100kPa	

(Toxline, 2001)

Table 1.2 Physiochemical properties of potassium azide.	
Other names	Potassium azide
Molecular formula	KN_3
Molar mass	81.12 g/mol
Appearance	Crystalline solid
CAS number	[26628-22-8]
Properties	
Density and phase	1.85 g/cm^3, solid
Solubility in water	54 g/100 g (17C)
Melting point	350C decomposition
Boiling point	300C decomposition
*data given for material in standard state at 25C, 100kPa	

(Toxline, 2001)

Figure 1.1. Chemical structure of sodium azide (Vencill, 2002).

Figure 1.2. Chemical structure of potassium azide (Vencill, 2002).

II. CREEPING BENTGRASS RESPONSE TO SODIUM AZIDE AND UREA TREATMENTS

ABSTRACT

Broad spectrum pest efficacy, particularly nematodes, has been shown with SEP-100®, a stabilized liquid formulation of sodium azide (NaN_3) developed jointly by Auburn University and American Pacific Corporation. The need for selective nematode control in established turfgrasses, golf putting greens in particular, served as an impetus to explore the use of reduced rates and granular formulations of sodium azide for turf safety and nematode control. Sodium azide was impregnated (10% active by weight) onto/into a fired ceramic clay sold under the trade name Profile® (750 Lake Cool Rd., Suite 440, Buffalo Grove, IL 60089). Profile is a commonly used inorganic amendment for golf putting greens used to add water and nutrient holding capacity to sand-based putting greens. Initial research with the sodium azide granular formulation applied to creeping bentgrass [*Agrostis stolonifera* L. (Huds.) Farw.] showed increased greening of the turf. The question arose as to whether turf greening was due to added nitrogen or nematode control since the sodium azide molecule contains approximately 46% nitrogen. Small-plot, replicated experiments were conducted 2006-07 at the Grand National Golf Club, Opelika, Alabama on a sand-based putting green with 'Dominant' creeping bentgrass infested with ring nematode (*Mesocriconema* spp.). Sodium azide treatments

were 0, 5.6, 11.2 and 16.8 kg ai/ha. Treatments were arranged in a randomized complete block design with urea at 0 and 10.9 kg ai/ha as the split-plot. A total of three applications were made at 2 to 4-week intervals. Visual turf injury ratings over time, nematode control and root-length density data were collected. Results for 2006 showed only slight injury with the 5.6 rate either alone or with urea. Injury was borderline acceptable with the 11.2 and 16.8 rates alone or with urea 1 week after treatment but decreased to 16% or less 3 weeks after treatment. After three applications, nematode control for 2006 was excellent with all treatments except the control, urea alone and the 5.6 rate plus urea. Root-length density was non-significant among treatments but there was a trend for higher values with the 5.6 and 11.2 rates (864, 852 cm roots/cm^3 soil) applied alone versus the control or urea alone, 628 and 600, respectively. In 2007, only two azide treatments provided acceptable injury levels; the 5.6 rate and 5.6 rate plus urea. Unacceptable injury from the higher rates was believed to be due to application to a canopy wet with dew and failure to irrigate immediately after application. The unfortunate 3-hour delay in irrigation was unavoidable due to system malfunction. All treatments provided excellent ring nematode control with the exceptions of the 5.6 rate alone but infestation was below the threshold level after the three applications. Root-length density data for 2007 showed significant improvement with the 5.6 rate alone and urea alone. Little response was observed for either year from added urea nitrogen and thus turf improvement was believed to be a result of pest control and not nitrogen contained in the sodium azide molecule.

INTRODUCTION

The most commonly used cool season turfgrass for golf course putting greens is creeping bentgrass [*Agrostis stolonifera* L.(Huds.) Farw.] (Beard 1982). In the Southeast, during summer months when climatic conditions are hot and humid, it is not uncommon for bentgrass root systems to decline. The mineral nutrient required in greatest quantity by turfgrass to promote overall health is nitrogen (Bowman et al., 2002). Adequate applications of nitrogen can help turf recover from environmental stresses. However, applying excessive nitrogen to creeping bentgrass during the summer months when turf is stressed has potential to cause turf decline and excessive top growth at the expense of roots (Fry and Huang, 1999). Sodium azide was being researched for control of nematodes in highly maintained turf such as creeping bentgrass putting greens. The azide molecule contains approximately 46% nitrogen as does urea (46-0-0). However, it has not been shown if nitrogen in the azide molecule produces adverse effects.

Luc et al. (2007) conducted field experiments to evaluate the effects of nematicide and fertility on performance of 'Tifway' bermudagrass (*Cynodon dactylon* x *C. transvaalensis* Burtt-Davy) infested with sting nematode (*Belonolaimus longicaudatus* Rau). Luc demonstrated that N fertilizer level had no effect on *B. longicaudatus*. Turf performance improved with increasing N fertilizer level in nematicide-treated plots in some cases, but had no effect on turf performance in non-treated plots.

Ring (*Mesocriconema* spp.) nematodes are classified according to the number of annulations over their entire body, which ranges from 33 to194. The body is cigar shaped and the adult size ranges from 0.2 to 1.0 millimeter in length. The stylet knobs are directed forward. These ectoparasitic nematodes feed at root tips and the head can be embedded in root tissue. Males are almost never observed in this species. Ring nematodes are commonly found in Alabama golf course putting greens and the threshold limit in Alabama is 500/100 cm^3 soil (Sikora et al., 1999).

A formulation of sodium azide was developed at Auburn University and impregnated in/on a granular carrier consisting of Profile (Table 2.1). Profile is an inorganic soil amendment which is kiln-fired clay ceramic and is very stable. This soil amendment is currently used on golf course putting greens during construction or aerification to improve water and nutrient holding capacity of sand-based root zones. The formulation disperses readily into the turf canopy and after irrigation is not visible on the turf surface.

Preliminary data collected in 2006 (Walker and Crow, unpublished) showed the nematicidal effects of sodium azide by greatly reducing sting and lance (*Hoplolaimus galeatus*) nematode populations in 'Tifgreen' bermudagrass and increased root length densities.

The objectives of the study were to determine if nitrogen from NaN_3 or urea contributed to enhanced root growth and reduced nematode populations. Urea was applied at 10.9 kg ai/ha which was comparable to the 11.2 kg ai/ha rate of sodium azide. Turf tolerance was also evaluated.

MATERIALS AND METHODS

Ten percent active sodium or potassium azide on Profile carrier was prepared by dissolving technical grade NaN_3 or KN_3 in water and stabilizing with Na_2CO_3. The aqueous mixture was gradually added to dry Profile as it rotated in a rotary drum mixer.

The granules were dried and stored in air-tight plastic containers that excluded light. More specific details can be found in Table 2.1.

Research was conducted at Grand National Golf Club in Opelika, Alabama on a 'Dominant' bentgrass type putting green constructed to United States Golf Association specifications. The green was constructed in 1990 of 90% sand and 10% peat. The average pH was 6.9. Field trials were initiated 27 July, 2006 and 27 June, 2007. Plots used in 2007 were located adjacent to plots used in 2006.

Experimental design was a randomized complete block split plot design with sodium azide being applied on the main plot and urea being applied as a standard to the sub-plot. Main plots were 1.3 x 3 m and split plots were 0.65 x 1.75 m. Sodium azide and urea was applied in separate applications with sodium azide applied first day and urea the following day. Sodium azide was applied with a Gandy (Gandy Company, 528 Gandrud, Owatonna, MN 55060) drop spreader with a single pass in one direction. Sodium azide 10G treatments included 0, 5.6, 11.2, and 16.8 kg ai/ha. Urea (46-0-0) SG was applied at the rate of 0 and 10.9 kg ai/ha. Eighty four grams of urea was dissolved in 1 L of water and foliar applied. Treatments were applied by making a single pass with a CO_2 pressured sprayer calibrated to deliver 281 L/ha at 179 kPa. The spray boom was 1 m with 4 Teejet (Teejet Technologies, P.O. Box 7900, Wheaton, IL 60187) 8002 flat fan type nozzles calibrated to deliver 280 L/ha. Three applications were made and dates were 27 July, 7 Sept. and 20 Sept. 2006 and 27 June, 1 Aug., and 15 Aug. 2006. Irrigation immediately followed each application at 0.635 centimeters with an additional 0.635 centimeters approximately 6 hours later.

Samples for root length density (RLD) were collected 1 month after final application. A soil profiler measuring 9 cm^3 was used and four cores per plot were collected. Roots were placed in polyethylene bags and cooled until returned to the laboratory. Roots were refrigerated at 4C and washed and scanned within a 3-week period. Roots were prepared for scanning by placing them in a 2 mm wire mesh screen and tap water was run over roots to remove roots from sand/organic matter. Roots were removed from the thatch layer and washing continued until all soil material passed through the sieve. The clean roots were placed in sample bottles containing tap water. Roots were dyed with a Congo red dye (Near Anar Chemicals, GIDC Phase II, Vetva, Ahmnedabad, 382445) and stored at 4C until scanned. Before scanning, the roots were placed in a sieve and rinsed with tap water. The roots were then placed on a Comair root scanner (Commonwealth Aircraft Corporation Limited, Melbourne, Australia) which was calibrated to known lengths and widths. The scanner has a built-in algorithm to calculate root length. Root length density was determined by dividing total root length in centimeters by the volume of the soil sampler in cubic centimeters.

Soil samples were collected for nematode assays prior to the initial application, 2 weeks after the first application, and 2 weeks after the last application. Six cores were collected per plot with a 1.9 x 10 cm soil probe. A 100 cm^3 of soil is required for analysis. The modified funnel technique, developed by Rodriguez-Kabana and Pope (1981) was used in 2006. Gravity screening followed by surface centrifugal flotation was used for nematode analysis in 2007 (Harrison and Green, 2008).

Turf injury was visually evaluated for the phytotoxic effects using a scale of 0-100%; with 0 being no injury and 100% death. An injury rating of 1-30% was considered slight and is the acceptable range for turfgrass, 31-69% was moderate, and >70% was severe injury. Turfgrass injury was visually rated beginning 1 week after initial application and continuing after final application until turf had recovered to an acceptable level (<31% injury) which was 2 weeks in 2006 and 9 weeks in 2007. The injury data presented began 1 week after the third application. Previous studies at Auburn University had shown this to be the time when injury occurred.

All data were analyzed using a general linear model with analysis of variance at ($P \leq 0.05$ level). There were significant interactions between years for all data; therefore, all data were analyzed and presented by year.

RESULTS

The root-length data indicated that for both years, after three applications, the 5.6 kg ai/ha rate of sodium azide produced the highest RLD and was significantly higher than the non-treated control (Table 2.2). The urea only treatment produced the lowest RLD in 2006. There were no significant differences in treatments when sodium azide was applied alone or when sodium azide + urea were applied in 2006. In 2007, the 5.6 kg ai/ha treatment of sodium azide produced RLD significantly higher than all treatments with the exception of urea only treatments.

Nematode results for both years indicated that after three applications of sodium azide as the rates increased, ring nematode populations decreased (Table 2.3). Complete control of ring nematodes was obtained both years with the 16.8 kg ai/ha rate. After three applications, all sodium azide treatments reduced nematode populations below the threshold limit both years. In 2006, after three applications of sodium azide, the non-treated control was significantly higher than the 11.2 and 16.8 kg ai/ha rate. For both years, urea only treatments had higher nematode numbers compared to azide treatments.

In 2006, turf injury was acceptable (<30%) with 5.6 and 11.2 kg ai/ha of sodium azide and sodium azide + urea after three applications (Table 2.4). The 16.8 kg ai/ha with and without urea resulted in 31% injury 1 WAT. However, bentgrass had recovered 2 WAT to an acceptable level. Urea treatments produced 6% injury 1 WAT following the third application. In 2007, moderate to severe injury occurred with the 11.2 and 16.8 kg ai/ha with and without urea after three applications. Injury ranged from 48-65% and decreased to 31-55% 3 WAT. This injury could be attributed to sodium azide being applied to a wet grass. Also, sodium azide was not watered in with irrigation until approximately 3 hours after application and temperatures reached 38C. The 11.2 kg ai/ha rate produced unacceptable injury; injury recovered to an acceptable level 4 WAT. The 16.8 kg ai/ha rate injury recovered to an acceptable level 9 WAT. Urea only treatments produced no injury in 2007.

CONCLUSIONS

Sodium azide impregnated on Profile fired ceramic clay granule proved suitable for use on a bentgrass putting green for control of ring nematodes. The 5.6 kg ai/ha rate applied three times at 2 to 4-week intervals was only slightly injurious; reduced ring nematode levels below threshold limits; and generally improved root-length density. Three applications at 11.2 kg ai/ha applied in 2006 produced injury that potentially could be tolerated under conditions of severe ring nematode infestations. The 16.8 kg ai/ha rate was too injurious both years. Unacceptable bentgrass injury can occur when applications are made to wet turf and/or not immediately irrigated into the turf. Irrigation of 0.6 to 1.0 cm water should follow immediately after application and repeated 6 hours later, after which normal irrigation practices should be employed. It is concluded that the nitrogen contained in the sodium azide molecule does not produce adverse effects to bentgrass health. Additional research is needed to determine optimum timing between applications. The interval between applications for the 5.6 rate might need to be reduced to 10 days. Research is also needed to determine if there are interactions between sodium azide and plant growth regulators that are commonly used on creeping bentgrass putting greens.

Disclaimer

The use of trade, firm, or corporation names in this publication is solely for the purpose of providing specific information and does not imply endorsement or recommendation by the authors or Auburn University.

REFERENCES

Beard, J.B. 1982. Turf management for golf courses. pp 102-118. MacMillian Publishing Co. New York, NY.

Bowman, D.C., D.A. Devitt, and W.W. Miller. 2002. The effect of moderate salinity on nitreate leaching from bermudagrass turf: A lysimeter study. Water, Air, and Soil Pollution 175:1-4.

Fry, J. and B. Huang. 1999. "Help bentgrass beat the heat". 1999 Penton Media. www.grounds_mag.com.

Harrison, J.M. and C.D. Green. 2008. Comparison of centrifugal and other methods for standardization of extraction of nematodes from soil. Annals of Applied Biology 82(2):299-308.

Luc, J.E., W.T. Crow, J.L. Stimac, J.B. Sartain, and R.M. Giblin-Davis. 2007. Effects of *Belonolaimus longicaudatus* management and nitrogen on turf quality of golf course fairways. J. Nematology 39(1):62-66.

Profile Products. 2002. The best way to amend your sand. www.profileproducts.com.

Rodriguez-Kabana, R., and M.H. Pope. 1981. A simple incubation method for the extraction of nematodes from soil. Nematropica 11(2):175-185.

Sikora, E.J., E.A. Guertal, and K.L Bowen 1999. Golf course nematodes-the hidden enemy. Highlights of Agricultural Research 46(3):10-11.

Table 2.1. Procedure[1] for impregnating sodium azide (NaN_3) on/into Profile granules.

Weigh 1760 grams Profile[2] and place in stainless steel mixer and pulsed to break-up lumps.
Weigh 150 grams technical grade NaN_3.
Weight 40 grams anhydrous Na_2CO_3, put in beaker with 700 ml demineralized water.
Place magnetic stirrer in beaker and stir until totally dissolved.
Add NaN_3 to Na_2CO_3 solution and mix; bring solution to 800 ml with demineralized water.
Add 100 ml solution at a time into Profile in rotating drum mixer.
Pour granules onto flat trays and spread thin and break-up clumps.
Turn fan on mixture on medium speed to dry granules.
During drying process, stir granules to prevent clumps.
After drying place azide granules in light-excluding, air-tight containers.

[1] Procedure developed by Rodrigo Rodriguez-Kabana, Dept. of Entomology and Plant Pathology, Auburn University.

[2] Profile particle range 0.25-1.0 mm.

Table 2.2. Creeping bentgrass putting green root length density (RLD) as affected by sodium azide (NaN_3) rates and urea at Grand National Golf Club, Opelika, AL, 2006 and 2007.

		10/20/2006‡	9/17/2007‡
Treatment	Kg ai/ha (x3)§	RLD cm roots/cm^3 soil†	
Control	0	628	1471 c
NaN_3	5.6	864	1990 a
NaN_3 + urea	5.6 + 10.9	746	1519 bc
NaN_3	11.2	852	1288 cd
NaN_3 + urea	11.2 + 10.9	720	1412 cd
NaN_3	16.8	733	1138 d
NaN_3 + urea	16.8 + 10.9	740	1244 cd
Urea	10.9	600	1810 ab
LSD		NS	524

† Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

‡ Samples collected 1 month after third application.

§ Application dates 7/27, 9/7 and 9/20, 2006; 6/27, 8/1 and 8/15, 2007.

Table 2.3. Creeping bentgrass putting green ring nematode numbers as affected by sodium azide (NaN_3) rates, application number, and urea at Grand National Golf Club, Opelika, AL, 2006 and 2007.

		2006			2007		
		Application Number and Sample Dates					
		0	1‡	3	0	1	3
		27-Jul	10-Aug	3-Oct	27-Jun	11-Jul	29-Aug
Treatment ‡	Kg ai/ha (x3)	Ring Nematodes/100 cm^3 soil†					
Control	0	128	2135	313 ab	378	149 b	344 a
NaN_3	5.6	65	572	0 b	541	539 ab	144 ab
NaN_3 + urea	5.6 + 10.9	120	1215	258 ab	378	199 b	57 b
NaN_3	11.2	100	1516	4 b	453	125 b	28 b
NaN_3 + urea	11.2 + 10.9	83	1936	0 b	967	234 b	4 b
NaN_3	16.8	68	495	0 b	321	68 b	0 b
NaN_3 + urea	16.8 + 10.9	63	880	0 b	422	32 b	1 b
Urea	10.9	150	2275	378 a	575	907 a	256 a
LSD		NS	NS	373	NS	570	284

† Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

‡ Application dates 7/27, 9/7 and 9/20, 2006; 7/27, 8/1 and 8/15, 2007.

Table 2.4. Creeping bentgrass putting green turf injury as affected by sodium azide (NaN_3) rates, application number and urea at Grand National Golf Club, Opelika, AL, 2006 and 2007.

		% Injury and Rating Dates§					
		2006‡			2007‡		
		1 WAT	2 WAT	3 WAT	1 WAT	2 WAT	3 WAT
Treatment	Kg ai/ha (x3)¶	27-Sep	3-Oct	10-Oct	24-Aug	31-Aug	7-Sep
Control	0	5 c†	4 de	3 d	0 e	3 e	0 d
NaN_3	5.6	13 bc	11 abc	6 cd	21 d	16 d	5 d
NaN_3 + urea	5.6 + 10.9	15 b	9 cd	6 cd	15 d	13 de	3 d
NaN_3	11.2	25 a	13 abc	9 c	53 bc	47 bc	31 b
NaN_3 + urea	11.2 + 10.9	26 a	11 bc	11 bc	48 c	43 c	36 c
NaN_3	16.8	31 a	16 a	16 a	65 a	58 ab	49 ab
NaN_3 + urea	16.8 + 10.9	31 a	15 ab	14 b	63 ab	60 a	55 a
Urea	10.9	6 bc	0 e	1 d	0 e	0 e	0 d
LSD		9.5	4.4	5.4	12.8	12.5	14.2

† Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

‡ 1 WAT, 2 WAT, 3 WAT = weeks after third and final treatment.

§ % injury scale; 0-30 = slight, 31-70 = moderate, 71-99 = severe, 100 = death.

¶ Application dates 7/27, 9/7 and 9/20, 2006; 6/27, 8/1 and 8/15 2007.

III. SODIUM AND POTASSIUM AZIDE FORMULATIONS FOR RING NEMATODE CONTROL ON A BENTGRASS PUTTING GREEN

ABSTRACT

Granular formulations of sodium (NaN_3) and potassium (KN_3) azides were developed at Auburn University and evaluated for their nematicidal efficacy in an established mix of ‘A1-A4’ bentgrass [*Agrostis stoloniferas* L. (Huds.) Farw.] putting green in 2007 and 2008. The study site had ring (*Mesocriconema* spp) nematode populations which were considered damaging based on thresholds used by Auburn University Plant Diagnostics Lab and University of Florida Nematode Assay Lab (Crow, 2007). Both sodium and potassium azides were impregnated in/on granular carriers consisting of Profile® fired clay and Biodac®, a cellulose-based product. Profile is currently used as a soil amendment for putting greens and Biodac is a common carrier for pesticides. Small particle size carriers were chosen so they would readily disperse into the closely mowed turf canopy. The objectives of this research were to determine nematode efficacy, turf injury, and root length density (RLD) for both sodium and potassium azides on both carriers. Many golf course superintendents are reluctant to apply additional sodium to putting greens in coastal areas and the potassium formulation was developed for this reason. Results indicated that after three applications for a total of 28 kg ai/ha for both years ring nematodes populations were significantly lower than the

non-treated control. In 2007, injury 1 week after treatment (WAT) of the third application of sodium azide on Profile and Biodac was 34% and 31% respectively, which was above the 30% acceptable level. Injury was below the acceptable level 2 WAT. Potassium treatments were within the acceptable level. In 2008, all treatments were above the acceptable level and ranged from 33-42%, 1 WAT of the third application. This injury was within the acceptable range 2 WAT. Root length density was only measured in 2008 and results indicated that potassium azide on Biodac produced the best RLD followed by potassium azide on Profile. They were significantly higher than the non-treated controls.

INTRODUCTION

The golf course industry in Alabama is a major component of the economy of the state. Therefore, it is important that golf courses be intensively maintained, especially putting greens. Plant parasitic nematodes are microscopic organisms that can affect turf health and growth by feeding on or in roots. Root-zone media in United States Golf Association (USGA) specification putting greens are composed of 80-90% sand creating an ideal environment for nematode populations.

The most widely used cool-season turfgrass for golf course putting greens is creeping bentgrass [*Agrostis stolonifera* L. (Huds). Farw.] (Beard, 1982). During summer months in the Southeastern United States, bentgrass quality typically declines resulting in root system loss. Bigelow et al. (2001) evaluated creeping bentgrass response to inorganic soil amendments. Profile one of the amendments evaluated and it produced significant beneficial effects on root mass density 1 year of the study. However, amendment effects were less noticeable the following year.

Golf course putting greens are currently constructed using root-zone media consisting of medium to coarse sand. Sand, which is highly permeable resists compaction and normally, aeration, infiltration, and percolation are adequate. However, sand has poor nutrient and water retention. Therefore, golf greens are frequently amended during construction or aerification to improve resiliency and nutrient and water retention (Beard, 1982). Inorganic amendments such as Profile, having high water retention and are used in place of sphagnum peat moss because of resistance to biodegradation (Bigelow et al., 2004).

Profile® (Profile Products LLC., 750 Lake Cook Rd., Suite 440, Buffalo Grove, Il 60089) is fired clay which is stable and currently used as a soil amendment during golf greens construction and during aerification. It increases water holding capacity due to its porosity being 74%; 39% capillary (water) pores, and 35% non-capillary (air) pores (Profile Products, 2002). Profile permanently improves most soils by increasing water and nutrient holding pores and air and drainage pores. The chemical composition includes 74% SiO_2, 11% Al_2O_3, 5% Fe_2O_3, and less than 5% of CaO, MgO, K_2O, Na_2O, and TiO_2 (Wehtje et al., 2003).

Miller (2000) evaluated the physiological response of Tifdwarf bermudagrass (*Cynodon dactylon* x *C. transvaalensis* Burtt-Davy) grown in soil amendments during drought stress. Profile was one of the amendments added to sand and native soil. The turf grown in Profile had the highest quality among the amendments. The data suggested that the total volume these amendments occupied in the root zone, have a positive influence on soil moisture, which resulted in an increase in drought avoidance.

Wehtje et al. (2003) in a greenhouse experiment used four inorganic soil amendments to improve a native soil and to evaluate Tifway bermudagrass performance. They found that neither Profile nor any of the amendments influenced bermudagrass growth compared to non-amended soil when water and nutrients were plentiful.

Joo, et al. (1998) evaluated the effects of soil amendments on the chemical and physical soil parameters of a ‘Crenshaw’ creeping bentgrass sand-based golf green. Profile was found to be a most effective amendment for increasing cation exchange capacity of the media. Profile also doubled the amount of exchangeable potassium and increased magnesium by approximately 50%; it also increased water retention and decreased bulk density as compared to the control.

Bigelow et al. (2004) conducted a laboratory study of three United States Department of Agriculture sand size classes (fine, medium, and coarse) to determine physical properties with and without inorganic amendments. Profile was one of the amendments used and resulted in higher total porosity and overall water retention compared to other amendments tested.

Field experiments conducted by Bigelow et al. (2001) evaluated creeping bentgrass response consisting of establishment, turf quality and root mass density to inorganic soil amendments with Profile being one of the amendments tested. They found that amending medium-coarse sized sand with organic amendments had significant beneficial effects on turfgrass establishment and visual quality ratings. During one year of the study, rootzone amendments had significant beneficial effects on root mass density, however this was not the case during the other year of the study.

Biodac® (Kadant Inc., One Technology Park Dr., Westford, MA 01886) is an absorbent granule made from pulp residue and is used as a carrier to deliver chemicals, for agricultural, lawn and garden, and also used as an absorbent for oil and grease; it is a gray colored, cellulose complex consisting of 47-53% paper fiber, 28-34% kaolin clay, and 14-20% calcium carbonate and no more than 1% titanium dioxide (Ilyina et al., 2000).

Ilyina et al. (2000) evaluated Biodac as a possible carrier for microorganisms that are used for bioremediation applications. They reported the possible side effects on soil capacity to retain moisture and influence plant growth. They found Biodac to be hydrophilic, porous and to absorb water at 1.15 ml/g due to the high cellulose content. Soil treated with Biodac affected soil capacity to retain moisture by 30%. No adverse side effects on plants were observed in treated soils and the best plant height and heaviest plants were observed in Biodac-treated soils. Biodac granules contain kaolin with Al^{3+} ions which can have an inhibitory effect on plant growth. This study did not detect this negative effect with quantities that were applied.

Ring nematodes (*Mesocriconema* spp.) are characterized by the number of annulations over their entire body, which range from 33 to194. The bodies are cigar shaped and the adult size ranges from 0.2 to 1.0 millimeter in length. The stylet knobs are directed forward. These ectoparasitic nematodes feed at root tips and the head can be embedded in root tissue. Males are almost never observed in this species. Ring nematodes are commonly found in Alabama golf course putting greens and the threshold limit in Alabama and Florida is 300-500/100 cm^3 soil (Sikora et al., 1999; Crow, 2005).

Myers et al. (1992) evaluated a relationship between cultural factors and nematodes on Kentucky bluegrass (*Poa pratensis* L.). Ring nematodes were found to be positively correlated with sand content of the soil and negatively correlated with the silt content. The mean number of spring tillers was closely correlated with the populations of ring nematodes. In vertically-mowed plots, ring nematode numbers increased during July; a response probably due to enhanced root growth. Soil pH had little effect on nematode populations.

The objectives of this research were to determine nematode efficacy, turf injury, and root length density (RLD) of both sodium and potassium azides on Profile and Biodac in a creeping bentgrass putting green.

MATERIALS AND METHODS

Ten percent active sodium or potassium azide on Profile/Biodac carrier was prepared by dissolving technical grade NaN_3 or KN_3 in water and stabilizing with Na_2CO_3. The aqueous mixture was gradually added to dry Profile/Biodac as it rotated in a rotary drum mixer. The granules were dried and stored in air-tight plastic containers that excluded light. More specific details can be found in Table 3.1.

Research was conducted at FarmLinks Golf Club in Sylacauga, Alabama on number 17 putting green which had a mature stand of 'A1-A4' bentgrass mixture. The green was constructed in 2002 and was a USGA specification green with 85% sand and 15% Profile. The soil pH was 7.2. Field trials were initiated 25 September 2007 and 14 July 2008. Separate plots were used in 2008 located adjacent to previous year plots.

Regular scheduled maintenance was conducted on this green during the course of the study.

Experimental design was a randomized complete block design with four replications in 2007 and six replications in 2008. The plot size was 1.2 x 3 m. Treatment applications were made three times at approximately 2-week intervals. In 2007, the first treatments were applied on 25 September and consisted of 11.2 kg ai/ha of sodium azide on Profile and Biodac carriers and 11.2 kg ai/ha of potassium azide on Profile and Biodac carriers and a non-treated control. The second treatment was applied 9 October and consisted of 5.6 kg ai/ha of sodium azide on Profile and Biodac carriers and 5.6 kg ai/ha of potassium azide on Profile and Biodac carriers and a non-treated control. The third application was scheduled for 22 October; however, due to rain it was not made until 11 November. Applications were made with a 0.91-m Gandy® (Gandy Company, 528 Gandrud, Owatonna, MN 55060) drop spreader with a single pass in one direction. The turf was irrigated immediately after application with 0.635 centimeters of water and an additional 0.635 centimeters within a 6-hour period. In 2008 applications were made 14 July, 29 July, and 12 August and rates of treatments and irrigation were same as for 2007.

Soil samples were collected for nematode assays prior to each application and 1 week after the final application. Six cores 1.9 cm-diameter by 10.16 cm-deep were collected randomly to form a composite sample from each plot. A 100 cm^3 of soil is required for analysis using a modified funnel technique, (Rodriguez-Kabana and Pope, 1981).

Turf injury was visually evaluated for phytotoxic effects using a scale of 0 to 100% where 0 is no injury and 100 is plant death. An injury rating of 1-30% was considered slight and within the acceptable range for turfgrass, 31-69% moderate, and >70% severe injury. Injury ratings were conspicuous 1 week after the first application and continued after the last application until injury was <30%.

Root length densities (RLD) were measured only in 2008. Soil samples were collected 1 month after final application. A soil profiler measuring 9 cm^3 was used and four samples per plot were collected. Roots were placed in polyethylene bags and cooled until returning to the laboratory. Roots were refrigerated at 4C and prepared for analysis within a 1-week period. The roots were placed in a 2 mm wire mesh screen and tap water was run over roots to remove soil. Roots were separated from the thatch layer and washing continued until all soil and extraneous material passed through the sieve. The clean roots were placed in sample bottles containing tap water and stored at 4C until scanned the following week. Before scanning, the roots were placed in a sieve and rinsed with tap water. The roots were then placed on a Comair root scanner (Commonwealth Aircraft Corporation Limited, Melbourne, Austrailia) which was calibrated to known lengths and widths. The scanner has a built-in algorithm to calculate root length. Root length density was determined by dividing total root length in centimeters by the volume of the soil sampler in cubic centimeters.

All data were analyzed using a general linear model with analysis of variance at ($P \leq 0.05$) level. There were significant interactions between years for all data; therefore, all data was analyzed by year.

RESULTS

In both years, after three applications for a total of 28 kg ai/ha ring nematodes were significantly reduced in all azide treatments (Table 3.2). All treatments reduced ring nematode populations numerically below the threshold limit for both years; however there were no significant difference among treatments. In 2007, potassium azide on Biodac resulted in the lowest numerical number with a mean of eight nematodes per plot. In 2008, all azide treatments were significantly lower than the non-treated control.

Turf injury data for 2007 collected 1 WAT showed potassium azide on Biodac produced significantly lower turf injury which averaged 21%. The three other azide treatments produced injury that ranged from 23 to 34%. Data for the same year collected 2 WAT showed turf injury was acceptable for all azide treatments but significantly lower for both potassium azide treatments. When evaluated 3 WAT, the same injury trends as the previous rating were evident with injury ranging from 0 to 6%, Table 3.2. Data for the 2008 experiment showed sodium azide on Profile produced significantly higher injury than the non-treated control, which averaged an unacceptable 42% 1 WAT. The three remaining azide treatments also produced unacceptable injury 1 WAT ranging from 33 to 37%. Data for 2 and 3 WAT was acceptable for all azide treatments but sodium azide on Profile produced significantly higher injury averaging 28 and 13%, respectively.

Root length densities were measured only in 2008 (Table 3.4). Results indicated that when comparing potassium to sodium formulations, potassium on Profile and Biodac had the best RLD and were superior to non-treated control and sodium azide on Biodac.

CONCLUSIONS

Profile and Biodac proved to be excellent granular carriers for both sodium and potassium azide. Preparation of the granular formulations was relatively easy and the granules appeared to have excellent shelf life. Additionally, both granules quickly disappeared into the turf canopy after irrigation. However, mowing studies need to be conducted to determine if any of the granules will be collected in the clippings following application and irrigation.

Creeping bentgrass turf injury was generally unacceptable 1 week after the third and final application all of which totaled 28 kg ai/ha (11.2, 5.6, 11.2 kg ai/ha). However, turf injury was acceptable 2 WAT for all treatments and both years. Turf injury symptoms were an overall chlorosis (yellowing). There was also a trend for sodium azide on both carriers to be more injurious than both potassium azide formulations. This was confirmed with the RLD data for 2008 which showed generally higher root length density for both potassium azide treatments. Additional experimentation needs to be conducted to determine if a system using only the 5.6 kg ai/ha rate would provide acceptable nematode efficacy. Additional observations have shown little or no bentgrass injury with this rate applied three times at 2 to 3 week intervals.

Disclaimer

The use of trade, firm, or corporation names in this publication is solely for the purpose of providing specific information and does not imply endorsement or recommendation by the authors or Auburn University.

REFERENCES

Beard, J.B. 1982. Turf management for golf courses. pp 102-118. MacMillian Publishing Co. New York, NY.

Bigelow, C.A., D.C. Bowman, and D.K. Cassel. 2004. Physical properties of three sand size classes amended with inorganic materials or sphagnum peat moss for putting green rootzones. Crop Science 44:900-907.

Bigelow C.A., D.C. Bowman, K.K. Cassel and T.W. Rufty. 2001. Creeping bentgrass response to inorganic soil amendments and mechanically induced subsurface drainage and aeration. Crop Science 41:797-805.

Crow, W.T. 2007. Nematode management for golf courses in Florida. University of Florida Cooperative Extension Service Fact Sheet ENY-008 (IN124). University of Florida, Gainesville, Florida.

Crow, W.T. 2005. Plant-parasitic nematodes on golf course turf. Outlooks on Pest Management 10:1564-1568.

Ilyina, A.D., S.J. Villarreal, R.E. Rivera, G.Y. Garza, and M.J. Rodriguez. 2000. Using of biodac (absorbent granules produced from paper industry residues) as carrier to microorganisms for soil inoculation. Biocatalysis 41(6):135-138.

Joo, Y.K., N.E. Christian, D. Li, and D.D. Minner. 1998. Effects of soil amendments on the chemical and physical soil parameters of a sand-based golf green. Iowa Turfgrass Research Report.

Miller, G.L. 2000. Physiological response of bermudagrass grown in soil amendments during drought stress. HortScience 35(3):213-216.

Myers, R.F, R.E. Wagner, and P.M. Halisky. 1992. Relationship between cultural factors and nematodes on Merion Kentucky bluegrass. J. of Nematology 24(1):205-211.

Profile Products. 2002. The best way to amend your sand. www.profileproducts.com.

Sikora, E.J., E.A. Guertal, and K.L Bowen. 1999. Golf course nematodes–the hidden enemy. Highlights of Agricultural Research 46(3)10-11.

Rodriguez-Kabana, R., and M.H. Pope. 1981. A simple incubation method for the extraction of nematodes from soil. Nematropica 11(2):175-185.

Wehtje, G.R., J.N. Shaw, R.H. Walker and W.Williams. 2003. Using inorganic soil amendments to improve a native soil. HortScience 38(4): 613-617.

Table 3.1. Procedure[1] for impregnating sodium (NaN_3) and potassium (KN_3) azide on/into Profile/Biodac granules.

Weigh 1760 grams Profile/Biodac[2] and place in stainless steel mixer and pulse to break-up clumps.
Weigh 150 grams technical grade NaN_3 or KN_3.
Weight 40 grams anhydrous Na_2CO_3, put in beaker with 700 ml demineralized water.
Place magnetic stirrer in beaker and stir until totally dissolved.
Add NaN_3 or KN_3 to Na_2CO_3 solution and mix; bring solution to 800 ml with mineralized water.
Add 100 ml solution at a time into granules in rotating drum mixer.
Pour granules onto flat trays and spread thin and break-up clumps.
Turn fan on mixture on medium speed to dry mixture.
During drying process, use cutter to cut and separate mixture to prevent clumps.
After drying place azide granules in light-excluding, air-tight containers.

[1] Procedure developed by Rodrigo Rodriguez-Kabana, Dept.of Entomology and Plant Pathology, Auburn University.

[2] Profile particle range 0.25-1.0 mm; Biodac 0.84-3.0 mm.

Table 3.2. Ring nematode numbers on a bentgrass putting green as affected by sodium (Na) and potassium (K) azide impregnated on Profile or Biodac granules at Farm Links Golf Club, Sylacauga, AL, 2007 and 2008.

	2007				2008			
	Application Number and Sample Dates‡							
	0	1§	2	3	0	1	2	3
	9/25/2007	10/9/2007	11/6/2007	11/14/2007	7/14/2008	7/29/2008	8/19/2008	8/26/2008
Treatment§	Ring Nematodes/100 cm^3 soil†				Ring Nematodes/100 cm^3 soil†			
Control	1940¶	2013	1283 a	1210 a	2105	4347 a	3115 a	1212 a
Na Profile	1218	830	298 ab	85 b	3698	318 b	10 b	8 b
Na Biodac	2068	1638	70 b	70 b	3393	338 b	137 b	65 b
K Profile	598	673	125 b	60 b	2958	297 b	47 b	32 b
K Biodac	1255	780	298 ab	8 b	3775	138 b	52 b	32 b
LSD	NS	NS	1131	135	NS	1349	1820	392

† Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

‡ Respective formulations applied at 11.2, 5.6, and 11.2 kg ai/ha for applications 1, 2, and 3.

§ Application dates 2007; 9/25, 10/9, and 11/6, 2008; 7/14, 7/29, and 8/19.

¶ Ring nematode threshold numbers 300-500/100 cm^3 soil.

Table 3.3. Percent turf injury on a creeping bentgrass putting green as affected by multiple applications of sodium (Na) and potassium (K) azide impregnated on Profile or Biodac carriers at FarmLinks Golf Club, Sylacauga, AL, 2007 and 2008.

		% Injury¶					
		2007§			2008		
Treatment	Kg ai/ha#	1WAT‡	2 WAT	3 WAT	1 WAT	2 WAT	3 WAT
		11/13/2007	11/21/2007	11/28/2007	8/26/2008	9/2/2008	9/9/2008
Control	0	0 c†	0 c	0 c	0 c	0 c	0 b
Na Profile	11.2, 5.6, 11.2	34 a	20 a	6 a	42 a	28 a	13 a
Na Biodac	11.2, 5.6, 11.2	31 a	19 a	4 ab	37 ab	19 b	3 b
K Profile	11.2, 5.6, 11.2	23 a	13 b	3 bc	33 b	18 b	0 b
K Biodac	11.2, 5.6, 11.2	21 b	10 b	0 c	33 b	18 b	0 b
LSD		6.6	4.4	3.4	5.2	5.9	6.4

† Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).
‡ 1 WAT, 2 WAT, 3 WAT = weeks after third and final treatment.
§ Application dates 2007; 9/25, 10/9, and 11/6, 2008; 7/14, 7/29, and 8/19.
¶ % injury scale; 0-30 = slight, 31-70 = moderate, 71-99 = severe, 100 = death.
# Rates applied at application 1, 2, and 3, respectively.

Table 3.4. Root Length Density (RLD) on a creeping bentgrass putting green as affected by multiple applications of sodium and potassium azide impregnated on Profile or Biodac carriers at FarmLinks Golf Club, Sylacauga, AL, 2008.

Azide§	Rate kg ai/ha‡	Carrier	RLD cm roots/cm^3 soil¶
Control	0		467 c†
Sodium	11.2, 5.6, 11.2	Profile	576 bc
Sodium	11.2, 5.6, 11.2	Biodac	562 c
Potassium	11.2, 5.6, 11.2	Profile	729 ab
Potassium	11.2, 5.6, 11.2	Biodac	870 a
LSD			158

† Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).
‡ Rates applied at application 1, 2, and 3, respectively.
§ Application dates 7/14, 7/29, and 8/19.
¶ Roots collected 9/19, 1 month after third application.

IV. HYBRID BERMUDAGRASS RESPONSE TO GRANULAR FORMULATIONS OF SODIUM AND POTASSIUM AZIDE

ABSTRACT

Turfgrass putting greens according to United States Golf Association specifications contain 80 to 90% sand with the remaining 10 to 20% either organic or inorganic amendments. The amendments are necessary to enhance water and nutrient holding capacity. This rooting mix is an excellent habitat for plant parasitic nematodes. Turfgrass species can withstand nematode damage if populations are below threshold limits. However, chemical treatment is generally required on putting greens that have been established longer than 3 years. Curfew ® (1,3-dicholoropropene) is the only commercially available nematicide and it requires specialized equipment for application. There is a need for nematicides that are efficacious and that can be applied without specialized equipment. Sodium and potassium azide have been shown to provide excellent nematode control in non-turf situations. Liquid formulations of sodium azide (NaN_3) and potassium azide (KN_3) are too injurious when applied to established turf. Therefore, granular formulations were prepared using Profile® fired ceramic clay and cellulose-based Biodac® as carriers. Objectives of these studies were to determine effects of these granular formulations on root length density (RLD), visual turf injury, and nematode efficacy when applied to 'Mini-Verde' hybrid bermudagrass (*Cynodon*

dactylon x *C. transvaalensis* Burtt-Davy) managed as a golf putting green. Plant parasitic nematodes at this site were below threshold limits which allowed excellent potential to evaluate turf tolerance without confounding effects from nematodes. Sodium and potassium azide on Profile and Biodac carriers was applied at 22.4 kg ai/ha three times at approximately 2 to 3 week intervals.

Root length densities in 2007 were numerically higher for azide treatments compared to the control. In 2007, sodium azide on Profile produced the highest RLD. Turf injury was within the acceptable level (<31%) for both years at all ratings. Plant parasitic nematodes were below the threshold limit at all samplings.

INTRODUCTION

Golf course putting greens are currently constructed using root-zone media consisting of medium to coarse sand. Sand, which is highly permeable resists compaction and normally aeration, infiltration, and percolation are adequate. However, sand has poor nutrient and water retention. Therefore, golf greens are normally amended during construction or aerification to improve resiliency and nutrient and water retention (Beard, 1982). Inorganic amendments having high water retention are used in place of sphagnum peat moss because they are resistant to biodegradation (Bigelow et al., 2004).

Profile® (Profile Products, 2002 LLC 750 Lake Cook Rd., Suite 440 Buffalo Grove, IL 60089) fired clay is stable and currently used as a soil amendment during golf greens construction and during aerification. It increases water holding capacity due to the porosity being 74%; 39% capillary (water) pores and 35% non-capillary (air) pores (Profile Products, 2002). Profile permanently improves most soils by increasing water and nutrient holding pores as well as air and drainage pores. The chemical composition includes 74% SiO_2, 11% Al_2O_3, 5% Fe_2O_3, and less than 5% of CaO, MgO, K_2O, Na_2O, and TiO_2 (Wehtje et al., 2004)

Miller (2000) evaluated the physiological response of 'Tifdwarf' bermudagrass (*Cynodon dactylon* x *C. transvaalensis*) grown in soil amendments during drought stress. Profile was one of the amendments added to sand and native soil. The Profile amended soil produced the best quality turf. The data suggested that the total volume these amendments occupied in the root zone has a positive influence on soil moisture, which resulted in an increase in drought resistance.

Wehtje et al. (2003) evaluated the effects of four inorganic soil amendments mixed with a native soil on 'Tifway' bermudagrass performance. Profile was one of the amendments chosen; none of the amendments influenced bermudagrass growth compared to non-amended soil when water and nutrients were plentiful.

Joo et al. (1998) evaluated the effects of soil amendments on the chemical and physical soil parameters of a 'Crenshaw' creeping bentgrass sand-based golf green. Profile was found to be the most effective amendment in increasing cation exchange capacity of the media. Profile also doubled the amount of exchangeable potassium and increased magnesium by approximately 50%. Water retention increased and bulk density decreased with Profile amended soils as compared to the control.

Bigelow et al. (2004) conducted a laboratory study of three United States Department of Agriculture sand size classes (fine, medium, and coarse) to determine physical properties with and without inorganic amendments. Profile was one of the amendments used and resulted in higher total porosity and overall water retention compared to other amendments tested.

Bigelow et al. (2001) conducted field experiments to evaluate creeping bentgrass response consisting of establishment, turf quality and root mass density to inorganic soil amendments with Profile being one of the amendments tested. Amending medium-coarse sized sand with organic amendments had significant beneficial effects on turfgrass establishment and visual quality ratings. During one year of the study rootzone amendments had significant beneficial effects on root mass density. However, this was not the case during the other year of the study.

Biodac® (Kadant Inc., One Technology Park Dr. Westford, MA 01886) is an absorbent granule made from pulp residue and is used as a carrier to deliver chemicals in agricultural and turf settings. It is also used as an absorbent for oil and grease. It is a gray, cellulose complex consisting of 47-53% paper fiber, 28-34% kaolin clay, and 14-20% calcium carbonate and no more than 1% titanium dioxide (Ilyina et al., 2000).

A study by Ilyina et al. (2000) evaluated Biodac as a possible carrier for microorganisms that could be useful for bioremediation applications. Biodac was found to be hydrophilic, porous and to absorb water at 1.15 ml/g due to the great cellulose content. Soil treated with Biodac increased soil capacity to retain moisture by 30%. No adverse side effects on plants were observed in treated soils and the best plant height and weight were observed in Biodac-treated soils. Biodac granules contain kaolin with Al^{3+} ions which can have an inhibitory effect on plant growth. This study did not detect this negative potential with quantities that were applied.

Wolfe and Kline (1994) evaluated Biodac as a carrier for larvacides. It was chosen to utilize a recycled paper carrier, the product's uniform size, and its non-abrasive, free-flowing, dust-free characteristics. Methoprene was impregnated on Biodac as a mosquito control. The study found that during mixing and application, the granules were free flowing and presented no problems. The granules were found to be very absorbent and the methoprene mix covered the granules evenly. Biodac showed good potential as a larvicidal carrier and appeared to be effective and economically attractive.

Turfgrass growth including root growth and health can be affected by plant parasitic nematodes. Crow (2005) compared nematicidal alternatives; botanical nematicides and root biostimulates, to the nematicide fenamiphos for management of nematodes on bermudagrass. Results from this study indicated that neither botanical nematicides nor biostimulates increased root production.

Crow and Welch (2004) conducted a glasshouse study to compare reductions in root length on 'Tifeagle' bermudagrass caused by stubby root nematodes (*Trichodorous obtusus* Cobb; *Paratricidourous minor* Christie), and sting nematode (*Belonolaimus longicaudatus* Rau). This study found that all three nematode species caused reductions in bermudagrass roots with sting and stubby root causing the greatest reductions.

The root-knot nematode (*Meloidogyne graminis* Sledge) affect turfgrass and is widespread and potentially destructive (Sledge and Golden, 1964). Root-knot nematodes are 'egg laying machines' and populations of eggs can range from 500 to 2000 per female (Mitkowski, 2001). The critical time to control root-knot nematodes is in the spring before nematodes have entered the roots. Murray et al. (1986) conducted a greenhouse study to evaluate grass species and cultivars for resistance to *M. graminis*. Of the fifteen bermudagrass cultivars tested, only two cultivars were resistant to *M. graminis*.

Sikora et al. (1999) determined the nematode genera most commonly associated with bermudagrass and bentgrass putting greens and ascertained their infestation levels in Alabama. The genera most frequently found were *Criconemella*, *Helicotylenchus*, *Hoplolaimus*, and *Meloidogyne*. The average nematode number/100 cm^3 soil on putting greens was 34.1, 33.7, 25.9, and 11.1, respectively.

The objectives of this study were to evaluate root length densities (RLD), visual turf injury, and nematicidal efficacy as influenced by granular formulations of sodium and potassium azides. Azide salts were impregnated on Profile fired ceramic clay or Biodac cellulose compound.

MATERIALS AND METHODS

Ten percent active sodium or potassium azide was prepared by dissolving technical grade NaN_3 or KN_3 in water and stabilizing with Na_2CO_3. The aqueous mixture was gradually added to dry Profile/Biodac as it rotated in a rotary drum mixer. The granules were dried and stored in air-tight plastic containers that excluded light. More specific details can be found in Table 4.1.

Research was conducted at Auburn University Turf Research Unit in Auburn, Alabama on a hybrid bermudagrass 'Mini-Verde' putting green. The green was a United States Golf Association type green with 80% sand and 20% peat. The average pH was 6.6. Trials were initiated 25 July 2007 and 3 September 2008.

Experimental design was a randomized complete block with four replications. In 2007, individual plots were 1.2 x 3 m and treatments were applied with a Gandy drop spreader with a 0.91-m length. Applications were made with a single pass in one direction. In 2008 the plots were 1.5 x 1.5 m and applications were applied through an applicator box developed by Scotts® (Scotts International, B.V. Scotts Professional, P.O. Box 40, 4190 Geldermalson, The Netherlands). This box has a solid aluminum outside frame with a series of mesh screens on the inside for granule dispersion. Granules were put in a quart glass jar with lids that had multiple holes of uniform size. The granules were shaken from the jar through the screens onto the turf. Treatments included a non-treated control and 22.4 kg ai/ha of sodium azide on Profile, sodium azide on Biodac, potassium azide on Profile, and potassium azide on Biodac. Treatments were applied three times at 2-4 week intervals and the application dates were 25 July, 8 August, 6 September in 2007 and 3 September, 18 September, 2 October in 2008. Irrigation immediately followed each application at 0.635 centimeters of water with an additional 0.635 centimeters approximately 6 hours later.

Soil samples for RLD were collected 1 week after final application. A soil profiler measuring 9 cm^3 was used and four samples per plot were collected. Roots were placed in polyethylene bags and cooled until returning to the laboratory. Roots were refrigerated at 4C until prepared for analysis. Roots were placed in a 2 mm wire mesh screen and tap water was run over roots to remove soil from roots. Roots were removed from the thatch layer and washing continued until all soil material passed through the sieve. The clean roots were placed in sample bottles containing tap water and refrigerated at 4C until scanned. Before scanning, the roots were placed in a sieve and rinsed with tap water. The roots were then placed on a Comair root scanner (Commonwealth Aircraft Corporation Limited, Melbourne, Australia) which was calibrated to known lengths and widths. The scanner has a built-in algorithm to calculate root length. Root length densities were determined by dividing total root length in centimeters by the volume of the soil sampler in cubic centimeters.

Turf injury was visually evaluated for the phytotoxic effects using a scale of 0-100%; with 0 being no injury and 100% is death. An injury rating of 1-30% was considered slight and is within the acceptable range for turfgrass, 31-69% moderate, and >70% severe injury. Turfgrass injury was visually rated beginning 1 week after initial application and continuing after final application until turf had recovered to an acceptable level (<30% injury). Injury data presented is for ratings beginning 1 WAT after the third application.

Soil samples were collected for nematode assays prior to the initial application and 2 weeks after each application. Six samples were collected per plot with a 1.9 x .10 cm soil probe. A modified funnel technique, developed by Rodriguez-Kabana and Pope (1981) was used for nematode extraction.

All data were analyzed using a general linear model with analysis of variance at ($P \leq 0.05$ level). Data was analyzed by year because there were significant interactions between years.

RESULTS

Root length density results for 2007 indicated that three applications of the four formulations at 22.4 kg ai/ha had no detrimental effects to the bermudagrass with any treatment and significantly higher RLD for sodium azide impregnated on Profile and Biodac compared to the non-treated control. Root length densities for both formulations of potassium azide were numerically higher but statistically equivalent to the non-treated control. Data for 2008 showed almost identical results but only sodium azide on Profile produced significantly higher RLD than the non-treated control, Table 4.2.

Turf injury did not average greater than 28% for any treatment during either 2007 or 2008. This level of injury was produced by sodium azide on Biodac and occurred 1 WAT of the last of three applications in 2007, and was significantly higher than others. Turf injury for 2008 was significantly higher for all four formulations than the control for both 1 and 2 WAT evaluations. However, the highest level of injury was only 13% 1 WAT, produced by sodium azide on Profile. Data for 3 WAT showed no injury level greater than 3% and was not significantly different than the control, Table 4.3.

Populations of ring, root-knot, and sheath nematodes were below the threshold limit at all samplings (Table 4.4). Threshold limits were 300, 80, and 80, respectively. However, in 2007, after three applications (22.4 kg ai/ha) for a total of 67.2 kg ai/ha, the non-treated control was numerically higher for ring and significantly higher for root-knot than all azide treatments. In 2008, root-knot populations were significantly higher in the control than in all azide treatments after three applications. For both years, some azide treatments provided significant reductions in sheath nematodes but infestation levels were very low.

CONCLUSION

Plant parasitic nematode populations were not considered damaging during this study. The data suggests that sodium azide had a positive effect on RLD even without nematode pathogen pressure. The data suggests azide controlled plant diseases. Kelley and Rodriguez-Kabana (1973 and 1975) found soil fungi and bacteria to decrease in response to granular sodium and potassium azide treatments. Rodriguez-Kabana et al. (2004) also showed that the liquid formulation of sodium azide (SEP-100) controlled *Rhizoctonia* and *Fusarium*. This study found no adverse effects from Profile and Biodac. Sodium azide on Profile® treatments produced the highest RLD. This agrees with a study done by Miller (2000) in which he evaluated physiological responses of 'Tifdwarf' grown in Profile amended soil had higher quality compared to other amendments. Bigelow et al. (2001) also found that Profile had significant beneficial effects on root mass density and visual quality ratings. In 2007, sodium azide on Biodac produced RLD slightly less than sodium azide on Profile and was not significantly different. This agrees with a study done by (Ilyina et al., 2000). They observed no adverse side effects on plants in treated soils and the best plant height and weight were observed in Biodac treated soils. Turf injury for 2007 and 2008 was below the tolerable level < 30% 1 WAT of the third application. This agrees with Morris (2005) in which trials were established at eight locations in the United States. The National Turfgrass Evaluation Program evaluated turf quality, genetic color, spring density, summer density and fall density of five entries of bermudagrass. Mini-Verde had the highest mean ratings of all evaluations. Plant parasitic nematodes found at this site were ring, sheath, and root-knot. However, they were below the damaging threshold limit. This agrees with Sikora, et al. (1999) that some of the genera most frequently found in Alabama were *Criconemella* and *Meloidogyne*.

Disclaimer

The use of trade, firm, or corporation names in this publication is solely for the purpose of providing specific information and does not imply endorsement or recommendation by the authors at Auburn University.

REFERENCES

Beard, J.B. 1982. Turf management for golf courses. pp 102-118. MacMillian Publishing Co. New York, NY.

Bigelow, C.A., D.C. Bowman, and D.K. Cassel. 2004. Physical properties of three sand size classes amended with inorganic materials or sphagnum peat moss for putting green rootzones. Crop Science 44:900-907.

Bigelow C.A., D.C. Bowman, K.K. Cassel and T.W. Rufty. 2001. Creeping bentgrass response to inorganic soil amendments and mechanically induced subsurface drainage and aeration. Crop Science 41:797-805.

Crow, W.T. 2005. Plant-parasitic nematodes on golf course turf. Outlooks on Pest Management 10:1564-1568.

Crow W.T., and J.K. Welch. 2004. Root reductions of St. Augustinegrass (*Stenotaphrum secundatum*) and hybrid bermudagrass (*Cynodon dactylon* x *C. transvaalensis*) induced by *Trichodouus obtusus* and *Paratrichodorus minor*. Nematropica 34(11):31-37.

Ilyina, A.D., S.J. Villarreal, R.E. Rivera, G.Y. Garza, and M.J. Rodriguez. 2000. Using of biodac (absorbent granules produced from paper industry residues) as carrier to microorganisms for soil inoculation. Biocatalysis 41(6):135-138.

Joo, Y.K., N.E. Christian, D. Li, and D.D. Minner. 1998. Effects of soil amendments on the chemical and physical soil parameters of a sand-based golf green. 1998. Iowa Turfgrass Research Report.

Kelley, W.D., and R. Rodriguez-Kabana. 1975. Effects of potassium azide on soil microbial populations and soil enzymatic activities. Canadian Journal of Microbiology 21(4): 565-570.

Miller, G.L. 2000. Physiological response of bermudagrass grown in soil amendments during drought stress. HortScience 35(3):213-216.

Mitkowski, N., 2001. Root-knot nematodes on turf in the northeastern United States. Turfgrass Trends 10(12):1-4.

Morris, K. 2005. The national turfgrass research initiative. USGA Green Section Record. September/October.

Profile Products. 2002. The best way to amend your sand. www.profileproducts.com.

Rodriguez-Kabana, R., J.R. Akridge and J.E. Burkett. 2004. Sodium azide [SEP 100] for control of root-knot nematode, weeds, and soil borne disease in cantaloupe production. *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, Orlando, FL. Abstr. 49.*

Rodriguez-Kabana, R., and M.H. Pope. 1981. A simple incubation method for the extraction of nematodes from soil. Nematropica 11(2):175-185.

Sledge, E.R. and A.M. Golden. 1964. *Hypaoperine graminia* (Nematoda: Heteroderidae) a new genus and species of plant parasitic nematode. Proc. Helminth. Soc. Wash. 31:83-88.

Sikora, E.J., E.A. Guertal, and K.L Bowen 1999. Golf course nematodes-the hidden enemy. Highlights of Agricultural Research 46(3):10-11.

Trenholm, L.E., D.W. Lickfeldt, W.T. Crow. 2005. Use of 1,3-dichloropropene to reduce irrigation requirements of sting nematode-infested bermudagrass. HortScience 40(5):1543-1547.

Wehtje, G.R., J.N. Shaw, R.H. Walker and W.Williams (2003). Using inorganic soil amendments to improve a native soil. HortScience 38 (4): 613-617.

Wolfe, R.J. and S. Kline. 1994. Field evaluation of a methoprene/biodac formulation on saltmarsh mosquitoes in Delaware. Northeastern Mosquito Control Association 94-5.

Table 4.1. Procedure[1] for impregnating sodium (NaN_3) and potassium (KN_3) azide on/into Profile/Biodac granules.

Weigh 1760 grams Profile/Biodac[2] and place in stainless steel mixer and pulse to break-up clumps.

Weigh 150 grams technical grade NaN_3 or KN_3.

Weight 40 grams anhydrous Na_2CO_3, put in beaker with 700 ml demineralized water.

Place magnetic stirrer in beaker and stir until totally dissolved.

Add NaN_3 or KN_3 to Na_2CO_3 solution and mix; bring solution to 800 ml with demineralized water.

Add 100 ml solution at a time into granules in mixer and mix until clump free.

Pour granules onto flat trays and spread thin and break-up clumps.

Turn fan on mixture on medium speed to dry granules.

During drying process, stir granules to prevent clumps.

After drying place azide granules in light-excluding, air-tight containers.

[1]Procedure developed by Rodrigo Rodriguez-Kabana, Dept. of Entomology and Plant Pathology, Auburn, University.
[2] Profile particle range 0.25-1.0 mm. Biodac 0.84-3.0 mm.

Table 4.2. Root length density (RLD) on a Mini-Verde bermudagrass putting green as affected by multiple applications of sodium and potassium azide impregnated on two ganular carriers at Auburn, AL, 2007 and 2008.

Azide	Rates kg ai/ha‡	Carrier	10/6/2007§	11/2/2008§
			cm roots/cm^3 soil†	
Control			227 b	196 b
Sodium	22.4 x 3¶	Profile	383 a	254 a
Sodium	22.4 x 3	Biodac	369 a	205 ab
Potassium	22.4 x 3	Profile	276 ab	207 ab
Potassium	22.4 x 3	Biodac	306 ab	185 b
LSD			115	56

† Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).
‡ Rates applied at application 1, 2, and 3, respectively.
¶ Application dates 2007; 7/25, 8/8, and 9/6, 2008; 9/3, 9/18, and 10/2.
§ Samples collected 1 month after final application.

Table 4.3. Percent turf injury on a Mini-Verde bermudagrass putting green as affected by multiple applications of sodium (Na) and potassium (K) azide impregnated on two granular carriers at Auburn, AL, 2007 and 2008.

		% Injury and Rating Dates 2007§			% Injury and Rating Dates 2008		
		9/13	9/21	9/28	10/9	10/16	10/23
Treatment	Kg ai/ha¶	1 WAT‡	2 WAT	3 WAT	1 WAT	2 WAT	3 WAT
Control		0 c†	0 b	4 b	0 b	0 c	0
Na Profile	22.4 x 3	14 b	5 b	11 a	13 a	8 a	3
Na Biodac	22.4 x 3	28 a	13 a	11 a	8 a	3 bc	1
K Profile	22.4 x 3	13 b	3 b	9 ab	9 a	5 ab	3
K Biodac	22.4 x 3	11 bc	3 b	9 ab	10 a	4 b	3
LSD		12	6	5	7	4	NS

† Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

‡ 1 WAT, 2 WAT, 3 WAT = weeks after third and final treatment.

§ % injury scale; 0-30 = slight, 31-70 = moderate, 71-99 = severe, 100 = death.

¶ Application dates 2007; 7/25, 8/8, and 9/6, 2008; 9/3, 9/18, and 10/2.

Table 4.4. Plant parasitic nematode numbers on a Mini-Verde bermudagrass putting green as affected by multiple applications of sodium (Na) and potassium (K) azide impregnated on two granular carriers at Auburn, AL, 2007 and 2008.

2007												
Application Number and Sample Dates§												
	0	1	2	3	0	1	2	3	0	1	2	3
	7/25	8/8	9/6	9/13	7/25	8/8	9/6	9/13	7/25	8/8	9/6	9/13
Nematodes/100 cm^3 soil†												
Treatment‡	Ring				Root-knot				Sheath			
Control	0	8	68	155	33	9	33 a	42 a	1	10 a	10 a	7
Na Profile	0	0	73	0	28	5	22 ab	11 b	1	1 b	0 b	0
Na Biodac	0	5	0	0	32	11	3 b	3 b	1	10 a	3 ab	0
K Profile	0	5	0	0	40	18	8 b	6 b	9	11 a	0 b	7
K Biodac	0	8	0	0	53	18	18 ab	3 b	6	3 b	5 ab	5
LSD	NS	NS	NS	NS	NS	NS	20	30	NS	7	8	NS
2008												
	9/3	9/18	10/2	10/16	9/3	9/18	10/2	10/16	9/3	9/18	10/2	10/16
Control	8	8 ab	0	45	1 b	11	4	27 a	1	0 b	10 a	7
Na Profile	0	5 b	0	8	1 b	0	0	0 b	1	1 b	0 b	1
Na Biodac	0	0 b	0	0	7 ab	1	0	0 b	1	10 a	3 ab	0
K Profile	0	25 a	0	0	17 a	3	0	.5 b	9	11 a	0 b	7
K Biodac	5	5b	0	0	11ab	1	0	0b	1	3b	5 ab	5
LSD	NS	19	NS	NS	12	NS	NS	19	NS	7	7	NS

† Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

‡ Rates applied at 22.4 kg ai/ha for application 1, 2, and 3.

§ Application dates 7/25, 8/8, and 9/6 2007; 9/3, 9/18, and 10/2 2008.

V. PLANT PARASITIC NEMATODE RESPONSE TO SODIUM AND POTASSIUM AZIDE APPLIED TO BERMUDAGRASS

ABSTRACT

Field studies were conducted in 2007 and 2008 to evaluate nematicidal efficacy of granular formulations of sodium and potassium azide. Treatments were applied to a 'Tifdwarf' bermudagrass (*Cynodon dactylon* x *C. transsvelennsis* Burtt Davy) putting green and a 'Tifgreen' bermudagrass tee. Azide salts were impregnated in/on granular carriers consisting of Profile® fired clay and Biodac®, a cellulose-based product. Profile is currently used as a soil amendment for putting greens and Biodac is a common carrier for pesticides. The objectives of these studies were to determine nematode efficacy and root length densities (RLD) after sodium and potassium azide applications and to compare turf response to the granular carriers Profile and Biodac. Fenamiphos, Nemacur®, Ethyl 3-methyl-4-(methylthio)phenyl(1-methylethyl)phosporamidate, was applied as a standard to the putting green. Curfew®, 1,3 dichloropropene, (1,3-D) was applied in 2008 to half of the putting green and root length densities (RLD) were compared to potassium azide on Profile, potassium azide on Biodac, and fenamiphos treatments. Sodium azide on Profile and sodium azide on Biodac were applied to the tee.

Nematode populations from the putting green in 2007 indicated that after three applications of potassium azide/Profile and potassium azide/Biodac for a total of 44.8 kg ai/ha, numbers of sting (*Belonolaimus longicaudus* Rau), and dagger (*Xiphinema* spp.)

were reduced while those for root-knot (*Meloidogyne* spp.) and lance (*Hoplolaimus galeatus* Cobb) increased. In 2008, lance, root-knot, and sting were reduced and sheath (*Hemicycliophora* spp.) increased with potassium azide on Profile. Lance increased while root-knot, sting, and sheath decreased with potassium azide on Biodac. Fenamiphos treatments for both years resulted in reductions in lance, sting, and dagger. Potassium azide on Biodac produced the best RLD and was better than the non-treated control. Results on nematodes from the tee indicated that sting was reduced both years with sodium azide on both carriers. Ring were only observed in 2008 and the numbers decreased with sodium azide/Profile and increased with sodium azide/Biodac. In 2007, RLD were highest with sodium azide/Biodac and in 2008 RLD were highest with sodium azide/Profile.

INTRODUCTION

Sting nematode, (*Belonolaimus longicaudatus* Rau), is one of the most damaging plant parasitic nematode on turfgrass (Crow, 2005). Initially, the sting nematode was found in Florida and affected many crops, including hybrid bermudagrass (*Cynodon dactylon* x *C. transvaalensis* Burtt-Davy) (Rau, 1958). Sting nematodes are very large and adults are > 3 millimeters in length and have a very long stylet. Sting has an ectoparasitic feeding habit feeding primarily on root tips creating a "stubby" root appearance. The root system appears cropped-off below the soil surface and severe infestations can cause complete destruction of the turf root system. In the United States sting nematode is native to coastal plains of the Southeast and has been spread in contaminated plant material as far West as California (Crow, 2005). Sting is very sensitive to soil texture, being limited to soils with >80% sand content (Robbins and Barker, 1974). The threshold limit for sting nematodes in Alabama for both bermudagrass and bentgrass is 10/100 cm^3 soil (Sikora et al., 1999).

Male and female sting species are found in soil and sexual reproduction takes place. After mating, and as long as a food source is available, the female lays eggs in pairs in the soil (Crow, 2005). After about 5 days the eggs hatch and the young must locate a plant root and begin feeding. The juveniles grow and undergo three molts before becoming adults with the total life cycle from egg to adult taking approximately 18 to 24 days.

Sting nematodes cause root-growth stunting by damaging lateral roots as soon as they are formed thus decreasing water and nutrient uptake, which decreases rates of evapotranspiration (Busey et al., 1991). Giblin-Davis et al. (1992) reported sting nematodes as a pathogen of many bermudagrasses and found two populations of sting readily reproduced on 'Tifdwarf' bermudagrass and caused extensive root damage.

Lance nematodes (*Hoplolaimus galeatus* Cobb) are destructive pathogens on turfgrasses as well as a variety of other agricultural crops (Ahmad and Chen, 1980). Lance is a migratory parasite and enters the root tissue feeding and physically damaging roots by tunneling through the root cortex cell walls (Henn and Dunn, 1989).

Hixon et al. (2003) determined turf tolerance to both sting and lance nematodes on Tifdwarf bermudagrass. Both species reproduced well on bermudagrass. At 120 days after inoculation, sting reduced root growth by 35-45%.

Giblin-Davis et al. (1988) evaluated three nematicides for the control of phytoparasitic nematodes in 'Tifgreen' bermudagrass. The treatments included fenamiphos at 13.5 kg ai/ha, oxamyl at 13.5 kg ai/ha and 30% formaldehyde at 6.4 L ai/ha. The site was naturally infested with sting, lance, root-knot, and ring. They found that 42 days after treatment, turfgrass vigor ratings and dry root weights in plots treated with fenamiphos were higher than the control, oxamyl, or formaldehyde treatments. Dry root weights were increased more than 25% by fenamiphos treatments compared to other treatments. *B. longicaudatus* population densities were suppressed in fenamiphos, fenamiphos plus formaldehyde, and oxamyl-treated plots. The other nematode species evaluated were not affected by any of the treatments.

Trenholm et al. (2005) in greenhouse and field studies evaluated the use of 1,3-D and fenamiphos to reduce irrigation requirements in soil infested with sting nematodes. The effects of these two compounds were evaluated on quality and persistence of 'Tifway' bermudagrass. Bermudagrass treated with 1,3 D had 40% higher quality ratings and 27% less leaf wilting during drought stress than other treatments. Spectral reflectance values, which indicate better physiological functioning under stress were best in 1,3-D-treated plots. There were no statistical differences in root weights in field treated plots; however rooting depth was highest in plots with 1,3-D treatments. Sting nematode population densities were reduced 92% and 74% by 1,3-D compared to untreated controls in the two trials, respectively.

Crow et al. (2005) conducted studies to examine the effectiveness of the nematicidal fumigant 1,3-D at managing sting nematode on Tifdwarf bermudagrass putting greens. Fenamiphos was included as an industry standard treatment in all experiments. Sting nematode numbers, root lengths, and turf color and density were compared. Results indicated that 1,3-D reduced numbers of sting nematodes in three of four experiments and increased root lengths in two of three experiments. Turf color and density varied, but were improved in many cases.

Blackburn et al. (1996) conducted greenhouse studies to evaluate avermectin B_1, isazofos, and fenamiphos for efficacy against lance, and stunt (*Tylenchorhynchus dubius* Biitschli) nematode infesting annual bluegrass (*Poa annua* L.). They found that avermectin B_1 at rates of 7.5 and 15.2 kg ai/ha reduced nematode populations compared to controls and performed as well or better than fenamiphos.

Giblin-Davis et al. (1993) compared two formulations of fosthiazate (10G and 7.5EC) with fenamiphos 10G for control of *B. longicaudatus* and *Meloidogyne* spp. in a bermudagrass fairway. One year, fosthiazate (10G and 7.5EC) was applied at the rate of 1.5 and 2.2 g ai/m^2. The following year, fosthiazate (10G and 7.5EC) was applied at the rate of 0.7 and 1.5 g ai/m^2. Fenamiphos was applied at 2.2 g ai/m^2 both years. In both years, both formulations and both rates of fosthiazate were as effective as or more effective than fenamiphos 10G in reducing soil populations of both nematode species evaluated. The lower rate of fosthiazate was as affective as fenamiphos in improving turfgrass quality rating for 56 days post-treatment.

Studies have shown that enhanced microbial degradation can occur with fenamiphos as a result of continuous exposure to the point of rendering the material ineffective (Stirling et al., 1992). The estimated soil half-life of fenamiphos is 30 days. Ou et al., (1994) demonstrated that after 20 years of continuous annual applications to golf course greens, the soil half-life was reduced to a range of 0.9 to 1.6 days, which resulted in a loss of nematode efficacy.

The objectives of these studies were to determine nematode efficacy and root length densities (RLD) after sodium and potassium azide applications and to compare turf response to the granular carriers Profile® and Biodac®. Fenamiphos was applied as a standard to the putting green.

MATERIALS AND METHODS

Ten percent active sodium or potassium azide was prepared by dissolving technical grade NaN_3 or KN_3 in water and stabilizing with Na_2CO_3. The aqueous mixture was gradually added to dry Profile/Biodac as it rotated in a rotary drum mixer. The granules were dried and stored in air-tight plastic containers that excluded light. More specific details can be found in Table 5.1.

Field studies were conducted in 2007 and 2008 at Kiva Dunes Golf Club in Gulf Shores, Alabama. Trials were conducted on a Tifdwarf hybrid bermudagrass green and a Tifgreen hybrid bermudagrass tee. Granular formulations of sodium and potassium azide (10G) were applied with a Gandy® (Gandy Company, 528 Gandrud, Owatonna, MN 55060) drop spreader in one direction. Immediately after each application, irrigation was applied at 0.635 centimeters and followed by an additional 0.635 centimeters, approximately 6 hours later. Data were analyzed using analysis of variance (ANOVA) and means were separated at the $P < 0.05$ level of significance when F values were significant.

Tifdwarf Putting Green Experiment. A field trial was initiated on 26 June 2007 on a United States Golf Association specification putting green. The soil contained plant parasitic nematodes to include species of lance, root-knot, sting and dagger and all were below the threshold limits at the first sampling. Experimental design was a randomized complete block with four replications. Plot size was 1 x 1 meter. Soil pH was 6.9. Granular formulations of potassium azide on Profile or Biodac were applied on 26 June, 17 July, and 9 August. The first two applications consisted of 0 and 11.2 kg ai/ha and the third application was 0 and 22.4 kg ai/ha. Fenamiphos was used as a standard and applied on 26 June at a 112 kg ai/ha which is a 10 x recommended labeled rate. In 2008, this trial was repeated on the same putting green with treatments applied to different areas than in 2007. The same parasitic nematodes were in the soil in 2007 with the exception of species of dagger and sheath which were found in 2008. Application dates were 13 May, 20 May, and 28 May for potassium azide and rates were the same as 2007. Fenamiphos was applied on 13 May and 28 May at 11.2 kg ai/ha. Plot size was 1.5 x 1.5 meters. In 2008, 1,3 D had been applied to half of the putting green at 46.77 L/ha on 11 May.

Tifgreen Tee Experiment. The trial was initiated 17 July 2007 on a golf course tee infested with sting and ring nematodes. Experimental design was a randomized complete block with four replications. Plot size was 1 x 4.5 meters. Sodium azide on Profile and Biodac were applied at a 0 and 22.4 kg/ha on 17 July and 9 August 2007. Applications were made in 2008 on 8 July and 22 July, 2008 on a different tee box.

For all experiments, soil samples were collected prior to the initial application, 2 weeks after the first application, and 2 weeks after each application. Six samples were collected per plot with a 1.9 cm soil probe. A 100 cm^3 of soil is necessary for analysis. The depth was approximately 10 cm to encompass root lengths. The modified funnel technique developed by Rodriguez-Kabana and Pope (1981) was used for nematode extraction.

Root samples were collected 1 month after final application. A soil profiler measuring 9 cm^3 was used and four samples per plot were collected. Roots were placed in polyethylene bags and cooled until returning to the laboratory. Roots were refrigerated at 4C until preparation for analysis. Roots were placed in a 2 mm wire mesh screen and tap water was run over roots to remove soil from roots. Roots were separated from the thatch layer and washing continued until all soil material passed through the sieve. The clean roots were placed in sample bottles containing tap water and stored at 4C until scanned. Before scanning, the roots were placed in a sieve and rinsed with tap water. The roots were then placed on a Comair root scanner (Commonwealth Aircraft Corporation Limited, Melbourne, Austrailia) which was calibrated to known lengths and widths. The scanner has a built-in algorithm to calculate root length. Root length density was determined by dividing total root length in centimeters by the volume of the soil sampler in cubic centimeters.

RESULTS

Lance, root-knot, sting and daggar nematodes were identified as the predominant plant parasitic species infesting the Tifdwarf putting green at Kiva Dunes. After three applications of potassium azide on Profile or Biodac totaling 44.8 kg ai/ha in 2007, few differences in nematode numbers were observed. These differences occurred with daggar nematode which showed higher numbers for potassium azide on Profile and fenamiphos treatments before plots were treated. After treatment, both azide treatments showed lower dagger nematode numbers than fenamiphos at the 19 August 2007 sampling date, but were not different from the non-treated control. The fenamiphos treatment was 10 times the labeled use rate which was due to a miscommunication error. Although no differences were observed among treatments for root-knot nematode control, numbers of this species did increase at the 2 September sampling. Results for the 2008 experiment showed absolutely no significant effects for any of the treatments, Table 5.2. This putting green is more than 10 years old and has an accumulation of a thatch-mat that ranges from 6 to 10 cm in depth. This layer may have prevented the timely leaching of a sufficient concentration of azide into the sandy layer below to control nematodes. Under these conditions, larger amounts of irrigation may have been needed to flush the azide out of this organic mat. However, new roots were observed growing out of the organic mat and into the underlying sand with all of the nematode treatments. This is generally substantiated by the 2008 data for RLD in Table 5.3. Potassium azide on Biodac had significantly more RLD than the non-treated but was equivalent to fenamiphos. However, potassium azide on Profile was no different than the non-treated. The Profile granule is porous with many small cavities within each granule. This is thought to physically trap the impregnated potassium azide by making it less available to the leaching process. Conversely, the Biodac granule is wetted easily, which should increase the leaching of potassium azide from each granule. Additional research on the effects of the thatch-mat layer on azide movement is needed.

Nematode species infesting the Tifgreen bermudagrass tee box at Kiva Dunes were identified as sting in 2007 and sting and ring in 2008. In 2007, sting numbers ranged from 3 to 12/100cm^3 of soil prior to treatment. No evidence of sting nematode infestation was observed with either azide treatment when sampled 9 August and 23 August, 2007 after treatment with sodium azide on Profile and Biodac. However, this did not constitute a significant difference from the non-treated control which averaged 4/100 cm^3 of soil, Table 5.3. In 2008, neither sodium azide treatment provided significant reductions in sting and ring nematode numbers. However, there was no evidence of sting or ring nematode infestation in the 23 August 2008 sampling with sodium azide on Profile, Table 5.4. The thatch-mat layer on the tee box ranged from 0.5 to 1 cm in depth. This tee box is for a Par 3 hole and irons are used to strike the golf ball. With each iron strike a divot of turf is removed from the tee area and thus there is not much chance for a thatch-mat layer to develop. With the lack of this organic layer, differences between the Profile and Biodac formulations were expected to be minimal. Root length density data from the tee box area for 2007 and 2008 are shown in Table 5.5. In both years, there was either a strong trend for, or in some instances, significant improvements in RLD by both azide formulations. Sodium azide on Biodac produced best results in 2007 and sodium azide on Profile produced best RLD in 2008.

CONCLUSION

Nematode numbers infesting each of the sites at Kiva Dunes Golf Club were generally low for both the putting green and tee box. Both azide formulations, fenamiphos, and 1,3-D nematicide treatments had little effects on reducing nematode numbers. However, RLD was improved with potassium azide on Biodac on the putting green. Root length data for the tee box experiment showed that in both years there was a strong trend for, and in some instances significant improvements in RLD by both azide formulations. Sodium azide on Biodac produced best RLD results in 2007 and sodium azide on Profile produced best RLD in 2008. The data from the putting green experiment suggest that the 6 to 10 cm thatch-mat layer negatively affected nematicide movement into the soil profile by preventing a lethal dose from leaching into the lower sand layer. Additional research is required to determine effects of the thatch-mat layer on efficacy of both azide formulations. The lack of reduction in nematode numbers yet RLD improvement may suggest the azide formulations may have provided control of fungal root infesting pathogen(s). Future research may need to investigate this as well.

Disclaimer

The use of trade, firm, or corporation names in this publication is solely for the purpose of providing specific information and does not imply endorsement or recommendation by the authors or Auburn University.

REFERENCES

Ahmad, M. and T.A. Chen. 1980. Effect of certain environmental factors and host plants on reproduction of *Hoplolaimus galeatus*. Plant Disease 64:479-480.

Blackburn, K., S.R. Alm, and T.S. Yeh. 1996. Avermectin B_1, isazofos, and fenamiphos for control of *Hoplolaimus galeatus* and *Tylenchorhynchus dubius* infesting *Poa annua*. J. of Nematology 28(45):687-694.

Busey, P., R.M. Giblin-Davis, and B.J. Center. 1991. Resistance in *Stenotaphrum* to the sting nematode. Crop Science 33:1066-1070.

Crow, W.T. 2005. Plant-parasitic nematodes on golf course turf. Outlooks on Pest Management 10:1564-1568.

Crow, W.T., D.W. Lickfeldt, and J.B. Unruh. 2005. Management of sting nematode (*Belonolaimus longicaudatus*) on bermudagrass putting greens with 1,3-Dichloropropene. International Turfgrass Soc. Res. J. 0:734-741.

Giblin-Davis, R.M., J.L. Cisar, and F. Bilz. 1993. Evaluation of fosthiazate for the suppression of phytoparasitic nematodes in turfgrass. Nematropica 23:167-175.

Giblin-Davis, R.M., J.L. Cisar, F.G. Bilz, and K.E. Williams. 1992. Host status of different bermudagrasses (*Cynodon* spp.) for the sting nematode, *Belonolaimus longicaudatus*. Supplement to J. of Nematology 24:749-756.

Giblin-Davis, R.M., J.L. Cisar, and F. Bilz. 1988. Evaluation of three nematicides for the control of phytoparasitic nematodes in 'Tifgreen II' bermudagrass. Annals of Applied Nematology 2:46-49.

Henn, R.A. and R.A. Dunn. 1989. Reproduction of *Hoplolaimus galeatus* and growth of seven St. Augustinegrass (*Stenotaphrum secundatum*) cultivars. Nematropica. 19:81-87.

Hixon, A. C. and W.T. Crow. 2003. First report of plant-parasitic nematodes on seashore paspalum. Plant Disease 88:680.

Ou, L.T., J.E. Thomas, and D.W.Dickson. 1994. Degradation of fenamiphos in soil with a history of continuous fenamiphos applications. J Soil Science 58:1139-1147.

Rau, G.J. 1958. A new species of sting nematode. Proceedings of the Helminthological Society. 25:95-98.

Robbins, R.T., and K.R. Barker. 1974. The effects of soil type, particle size, temperature, and moisture on reproduction of *Belonolaimus longicaudatus*. J. Nematology 6:1-6.

Rodriguez-Kabana, R., and M.H. Pope. 1981. A simple incubation method for the extraction of nematodes from soil. Nematropica 11(2):175-185.

Sikora, E.J., E.A. Guertal, and K.L Bowen 1999. Golf course nematodes-the hidden enemy. Highlights of Agricultural Research 46(3):10-11.

Stirling, A.M., G.R. Stirling, and I.C. Macrae. 1992. Microbial degradation of fenamiphos after repeated application to a tomato-growing soil. Nematologica 38:245-254.

Trenholm, L.E., D.W. Lickfeldt, W.T. Crow. 2005. Use of 1,3-dichloropropene to reduce irrigation requirements of sting nematode-infested bermudagrass. HortScience 40(5):1543-1547.

Table 5.1. Procedure[1] for impregnating sodium (NaN_3) and potassium (KN_3) azide on/into Profile/Biodac granules.

Weigh 1760 grams Profile/Biodac[2] and place in stainless steel mixer and pulse to break-up clumps.
Weigh 150 grams technical grade NaN_3 or KN_3.
Weight 40 grams anhydrous Na_2CO_3, put in beaker with 700 ml demineralized water.
Place magnetic stirrer in beaker and stir until totally dissolved.
Add NaN_3 or KN_3 to Na_2CO_3 solution and mix; bring solution to 800 ml with demineralized water.
Add 100 ml solution at a time into granules in mixer and mix until clump free.
Pour granules onto flat trays and spread thin and break-up clumps.
Turn fan on mixture on medium speed to dry granules.
During drying process, stir granules to prevent clumps.
After drying place azide granules in light-excluding, air-tight containers.

[1]Procedure developed by Rodrigo Rodriguez-Kabana, Dept. of Entomology and Plant Pathology, Auburn, University.
[2] Profile particle range 0.25-1.0 mm. Biodac 0.84-3.0mm.

Table 5.2. Plant parasitc nematode numbers on Tifdwarf hybrid bermudagrass as affected by potassium (K) azide, granular carriers, and application number at Kiva Dunes Golf Club, Gulf Shores, AL, 2007 and 2008.

	2007															
	Application Number and Sample Dates‡															
	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
	6/26	7/17	8/9	9/16	6/26	7/17	8/19	9/2	6/26	7/17	8/19	9/2	6/26	7/17	8/19	9/2
	Nematodes/100 cm^3 soil†															
Treatment¶	Lance				Root-knot				Sting				Dagger			
Control	0	0	0	0	8	6	3	152	8	13	24	1	19 b	4	11 ab	0
K Profile	3	10	17	62	35	7	27	160	24	3	9	0	54 a	7	7 b	0
K Biodac	8	12	4	16	8	0	32	94	14	3	9	0	17 b	0	2 b	1
Fenamiphos§	4	3	8	3	44	4	7	209	38	8	34	4	61 a	10	20 a	0
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	33	NS	11	NS
	2008															
	Lance				Root-knot				Sting				Sheath			
	5/13	5/20	5/28	6/11	5/13	5/20	5/28	6/11	5/13	5/20	5/28	6/11	5/13	5/20	5/28	6/11
Control	11	5	2	1	42	15	69	59	33	19	1	0	27	28	25	13
K Profile	11	7	6	2	72	5	76	30	11	13	0	0	39	10	95	81
K Biodac	3	6	15	8	77	7	77	51	3	10	1	0	80	29	34	60
Fenamiphos	26	2	6	3	45	5	47	48	1	8	0	0	70	2	67	118
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD (P <0.05).

‡ Rates azide applied at 11.2, 11.2, and 22.4 for application 1, 2, and 3 respectively.

§ Fenamiphos 2007; 112 kg ai/ha applied 6/26, 2008; 11.2 kg ai/ha applied 5/13 and 5/28.

¶ Application dates 2007; 6/26, 7/17, and 8/9, 2008; 5/13, 5/20, and 5/28

Table 5.3. Root Length Density (RLD) on Tifdwarf hybrid bermudagrass putting green as affected by potassium (K) azide, granular carriers, and nematicides at Kiva Dunes Golf Club, Gulf Shores, AL, 2008.

Treatment#	Rate	Carrier	RLD cm roots/cm^3 soil 9 July §
Control			101 b†
K azide	11.2, 5.6, 11.2 kg ai/ha‡	Profile	101 b
K azide	11.2, 5.6, 11.2 kg ai/ha	Biodac	174 a
Fenamiphos	11.2, 11.2 kg ai/ha¶		115 b
1,3-D	46.75 L/ha		137 ab
LSD			58

† Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

‡ Azide rates applied at 11.2, 11.2, and 22.4 kg ai/ha for application 1, 2, and 3 respectively.

§ Samples collected ~ 6 weeks after last application.

¶ Fenamiphos 11.2 kg ai/ha applied 5/13 and 5/28, 2008.

Application dates 5/13, 5/20, and 5/28.

Table 5.4. Plant parasitic nematode numbers on a Tifgreen hybrid bermudagrass tee as affected by sodium azide (Na), granular carriers, and application number at Kiva Dunes Golf Club, Gulf Shores, AL, 2007 and 2008.

	2007			2008			2008		
	Application Number and Sample Dates								
	0	1§	2	0	1	2	0	1	2
	7/17	8/9	8/23	7/17	8/9	8/23	7/8	7/22	8/5
Treatment‡	Nematodes/100 cm^3 soil †								
	Sting			Sting			Ring		
Control	4	2	4	4	2	8	10	7	67
Na Profile	12	0	0	2	3	0	33	3	0
Na Biodac	3	0	0	8	5	2	7	0	13
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

‡ Rates applied at 11.2 and 11.2 kga i/ha for applications 1 and 2.

§ Application dates 7/17 and 8/9 2007; 7/8 and 7/22, 2008.

Table 5.5. Root Length Density (RLD) on a Tifgreen hybrid bermudagrass tee as affected by sodium (Na) azide and granular carriers at Kiva Dunes Golf Club, Gulf Shores, AL, 2007 and 2008.

			9/9/ 07‡	8/27/08
Treatment	Carrier	Kg ai/ha§	cm roots/cm^3 soil†	cm roots/cm^3 soil
Control			11 b	142 b
Na	Profile	11.2 x 2	222 ab	369 a
Na	Biodac	11.2 x 2	296 a	236 b
LSD			236	108

† Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

‡ Samples collected 1 month after last application.

§ Application dates 2007; 7/17 and 8/9, 2008; 7/8 and 7/22.