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Evaluation of Amino Acids as Turfgrass Nematicides[1]

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Abstract: Laboratory experiments revealed that DL-methionine, sodium methionate, potassium methionate, and methionine hydroxyl analog at rates of 224 and 448 kg amino acid/ha reduced the number of *Belonolaimus longicaudatus* mixed life-stages and *Meloidogyne incognita* J2 in soil, whereas L-threonine and lysine were not effective in reducing the number of either nematode. Futhermore, greenhouse experiments demonstrated that DL-methionine, sodium methionate, potassium methionate, and methionine hydroxyl analog were equally effective against *B. longicaudatus* at rates of 112, 224, and 448 kg amino acid/ha, and the highest rate (448 kg amino acid/ha) of all amino acids was more effective in reducing the number of *B. longicaudatus* than the lower rate. However, phytotoxicity was observed on creeping bentgrass (*Agrostis palustris*) treated with 448 kg amino acid/ha of methionine hydroxyl analog and DL methionine. In addition, in one of two field experiments on bermudagrass (*Cynodon dactylon* × *C. transvaalensis*) turf percentage green cover was increased and the number of *B. longicaudatus* was reduced by 224 kg amino acid/ha of DL-methionine and potassium methionate compared to untreated controls in one of two trials.

Key words: amino acid, *Belonolaimus longicaudatus*, bermudagrass, *Cynodon*, methionine, nematode management, sting nematode, turfgrass.

Plant-parasitic nematodes have been viewed as one of the most important pathogen groups, causing significant damage to turfgrasses (Crow, 2007). Sting nematode (*Belonolaimus longicaudatus*), and root-knot nematodes (*Meloidogyne* spp.) are among the most damaging nematodes affecting turfgrasses (Crow, 2007). Currently, the primary methods for managing nematodes are still agricultural chemicals, such as fumigants and organophosphate nematicides. The negative effects of these chemical nematicides on humans and the environment are of increasing concern. The recent removal of the organophosphate nematicide fenamiphos, which was the most commonly used nematicide on turfgrasses, has increased the need for alternative nematode management strategies for use in turf.

Previous studies have reported that certain amino acids can act as nematicides, due to chemotherapeutic effects on plants or direct effects on nematodes (Andel, 1966; Crow et al., 2009; Evans and Trudgill, 1971; Overman and Woltz, 1962; Peacock, 1966; Talavera and Mizukubo, 2005). Among the amino acids evaluated for effects on plant-parasitic nematodes, DL-methionine produced the most consistent results. DL-methionine reduced the number of *Paratrichodorus minor* in soil, galling of tomato roots by *Meloidogyne incognita*, *Heterodera avenae* females on wheat, and *Globodera rostochiensis* females on potato in lab and greenhouse experiments (Evans and Trudgill, 1971; Overman and Woltz, 1962; Prasad and Webster, 1967). DL-methionine reduced hatching of *M. incognita* eggs and mobility of J2 in Petri dish experiments (Talavera and Mizukubo, 2005). Crow et al. (2009) found that applications of DL-methionine to turf reduced population densities of *B. longicaudatus* and *Mesocriconema ornatum* in field trials.

An essential amino acid, methionine is produced in plants and microorganisms solely in the form of L-methionine. When produced synthetically, D and L chiral forms of methionine are produced in approximately equal amounts (Fanatico, 2010). No harmful effects from DL-methionine on humans or the environment have been reported. Currently, methionine is classified by the United States Environmental Protection Agency (EPA) as a 4B substance and is defined as "other ingredients for which EPA has sufficient information to reasonably conclude that the current use pattern in pesticide products will not adversely affect public health or the environment" (Anonymous, 2004).

Large scale commercial production of DL-methionine, primarily as an amino acid supplement in animal feed, occurs in the United States (Fanatico, 2010). The current standard nematicide used on golf course putting greens in the southeastern U.S. is 1,3-dichloropropene (Curfew® Soil Fumigant, Dow Agrosciences, Indianapolis, IN). The 2010 cost for a putting green application of Curfew in 2010 was $7841/ha. Based upon economic considerations, DL-methionine has the potential to be used as a nematicide, at least on high-value crops like golf course turf.

Crow et al. (2009) found that DL-methionine could be effectively used for managing *B. longicaudatus* in the field. However, phytotoxicity was observed in one of two trials and the rates used (224 and 1,140 kg/ha) were high. Both of these problems may have been the result of the low solubility of DL-methionine (30 g/liter at 20 °C). Because methionine must be transported into the ground via irrigation water in order to contact the nematodes, low solubility could cause reduced infiltration thereby increasing the effective use rate. Accumulation of methionine at the turf surface might be the cause of the phytotoxicity observed. There also was concern that use of high rates of amino acids could have a detrimental effect on soil pH.

Liquid methionine formulations or analogues could potentially move into soil better than DL-methionine, lowering use rates and decreasing phytotoxicity. These

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include sodium methionate, potassium methionate, and methionine hydroxyl analog. In addition to methionine, several other amino acids also are being produced commercially on a large scale as animal feed supplements, including threonine and lysine. If effective, these amino acids also could be economically viable nematode management treatments for high-value crops like turf. The objective of our studies was to determine if lysine, threonine, sodium methionate, potassium methionate, or methionine hydroxyl analog are effective substitutes to DL-methionine for use as turfgrass nematicides.

Materials and Methods

In order to evaluate the potential of the different amino acid materials a series of experiments were conducted. In these experiments several amino acids from commercial sources and two experimental formulations were included. The following amino acids were obtained from commercial sources: DL-methionine (Evonik Degussa, Theodore, AL), L-threonine (Evonik Degussa, Theodore, AL), lysine (Biolys®, Evonik Degussa, Theodore, AL), and methionine hydroxyl analog (Alimet®; Novus International, St. Charles, MO). Two experimental methionine formulations also were included: sodium methionate and potassium methionate. Among these amino acid materials, DL-methionine, L-threonine, and lysine were dry powder materials, whereas methionine hydroxyl analog, sodium methionate and potassium methionate were liquids. The percentage amino acid content (w/w) of each treatment was: DL-methionine (99%), L-threonine (98.5%), lysine (50.7%), sodium methionate (46%), potassium methionate (35%), and methionine hydroxyl analog (88%). Application rates of each treatment were based on the weight of amino acid and not the weight of the formulation.

The first set of experiments involved bench screening of the materials to determine the relative nematicidal activity of the alternative amino acids compared with DL-methionine. After this, the top performers were selected to move forward to growth room experiments that further evaluated efficacy and also to study effects on plants. From these experiments the amino acid treatments that had the best performance was selected to move ahead to the final stage, field trials.

Bench trials: Laboratory bench trials were conducted twice using a randomized complete block design with eight replications at the Entomology and Nematology Department at the University of Florida, Gainesville, FL. All of the amino acids were evaluated at two rates (224 and 448 kg amino acid/ha), for their ability to suppress activity of *B. longicaudatus* (juveniles and adults) or *M. incognita* (J2) in soil. Soil infested with *B. longicaudatus* was collected from greenhouse pot cultures or an infested field site, for trials 1 and 2, respectively. The greenhouse pot culture of *B. longicaudatus,* originally isolated from a golf course in Sun City, FL, was maintained on 'FX 313' St. Augustinegrass (*Stenotaphrum secundatum*) in United States Golf Association (USGA) putting green specification sand (Anonymous, 1993). The *B. longicaudatus* infested field soil was collected from an athletic field in Spring Hill, FL planted to 'Tifway' bermudagrass (*Cynodon dactylon* × *C. transvaalensis*). Both trials in which *M. incognita* suppression was evaluated used infested field soil from an alyce clover (*Alysicarpus ovalifolius*) field located in Sumter County, FL. For field soils, 100 cm^3 of dry soil was used to determine soil texture by a hydrometer method (Bouyoucos, 1936). Another 2 g of dry soil was used to determine percentage organic matter using a loss-on-ignition method (Ben-Dor and Banin, 1989). After soil analysis, all the soil samples from the field were found to have >90% sand content. Soil from the field in Spring Hill contained 5% organic matter, whereas soil from Sumter County had <2% organic matter.

Soil containing *B. longicaudatus* was hand mixed to ensure that nematodes were evenly distributed in the soil. Next, 200 cm^3 aliquots were placed into 600 cm^3 plastic pots. Powder treatments were applied topically followed with 50 ml of water to carry the materials into the soil. Liquid materials were mixed into water and then 50 ml of solution was poured onto the soil. Untreated controls had 50 ml of water poured onto the soil. Three days after treatments were applied, the soil was removed from the pots and placed onto modified Baermann funnels (McSorley and Frederick, 1991) and collected after 24 hr. Room temperature for amino acid exposure and nematode extraction was maintained at 26 °C. Nematodes were counted using an inverted light microscope at ×40 magnification. Data were subjected to analysis of variance as a 7×3 factorial experiment with seven treatments and three rates using SAS software (SAS Institute, Cary, NC). Treatment means were separated according to Duncan's multiple-range test ($P \leq 0.05$).

Growth room trials: Two trials were conducted in a growth room on the campus of the University of Florida, Gainesville, FL. The trials were arranged in a randomized-block design and were identical except for the number of replications, eight replications for trial 1 and five replications for trial 2. These trials compared the effects of methionine formulations on *B. longicaudatus* in inoculated pots of creeping bentgrass (*Agrostis palustris*). Parameters evaluated included number of *B. longicaudatus* in soil, plant phytotoxicity, and soil pH.

Treatments were: 1) untreated control, 2) DL-methionine, 3) sodium methionate, 4) potassium methionate, and 5) methionine hydroxyl analog. Each amino acid was evaluated at three rates; 112, 224, and 448 kg amino acid/ha.

In each trial, 10-cm-diam. pots were filled with 400 cm^3 of USGA specification greens sand, and seeded with 'Penncross' creeping bentgrass at 0.08 g per pot. After seed germination, *B. longicaudatus* was collected from greenhouse cultures using a decant and sieve technique (Cobb, 1918). Each pot was inoculated with

100 mixed life stages of *B. longicaudatus* which were then allowed to reproduce for 4 wk. Following turf and nematode establishment, treatments were applied. The liquid materials were mixed with water and 50 ml of solution was applied topically to the pots as a drench. Powder DL-methionine was applied topically and then 50 ml water added to the surface. The untreated control treatment received 50 ml of water. Turfgrass was monitored visually for phytotoxic response three, eight, and fourteen days after treatment. A visual damage rating scale was used to evaluate phytotoxicity, where 0 = no phytotoxicity, -1 = slight phytotoxicity, -2 = moderate phytotoxicity, and -3 = severe phytotoxicity.

Fourteen days following treatment application the soil was analyzed for treatment effects on *B. longicaudatus* and soil pH. Soil was removed from each pot, mixed, and a 100 cm^3 subsample was removed for quantification of nematodes. Nematodes were extracted using the sugar floatation centrifugation method (Jenkins, 1964) and quantified as described above. An additional 20 cm^3 subsample was used for measuring soil pH (Mylavarapu, 2009) with a pH meter (AR10 pH/mV/degC Meter, Standardize accumet® Research, Fisher Scientific, USA). Data were subjected to analysis of variance as a 5×4 factorial experiment with 5 treatments and 4 rates using SAS software (SAS Institute, Cary, NC). Treatment means were separated according to Duncan's multiple-range test ($P \leq 0.05$). The results of both trails were analyzed for heterogeneity and the results did not differ among the trials except for the phytotoxicity measurements. Therefore, data other than the phytotoxicity data were combined from both trials prior to analysis.

Field trials: In 2010, two field trials were conducted to compare the effects of DL-methionine and potassium methionate on nematode suppression and turf health. Two sites were used for this experiment; both were located at the University of Florida Plant Science Research Unit (PSRU), Citra, FL. One site was planted with 'Tifdwarf' bermudagrass, and the other site was planted with 'Celebration' bermudagrass. Both sites were infested with population densities of *B. longicaudatus* in excess of the high risk thresholds for bermudagrass (25/100 cm^3 of soil) used by the Florida Cooperative Extension Service (Crow, 2011). The Tifdwarf bermudagrass site was managed under putting green conditions, whereas the Celebration bermudagrass site was managed as a tee box.

The experimental design was a randomized block with five replications. Thirty plots were used at each site. Plots were 1.5 m^2 with a 0.6 m untreated border between plots. The treatments included: DL-methionine and potassium methionate applied at rates of 112 and 224 kg amino acid/ha, fenamiphos (Nemacur® 10G, Bayer CropScience, Research Triangle Park, NC) applied at 11.2 kg a.i./ha, and an untreated control. DL-methionine and fenamiphos treatments were applied topically using a drop spreader (Gandy, Owatonna, MN). Potassium methionate was mixed with water and sprayed topically on the plots using a CO_2 powered backpack sprayer (Weed Systems, Hawthorne, FL). Fenamiphos was applied only once. Plots received DL-methionine or potassium methionate twice, on a 4 week interval. After treatment, each plot (including the untreated controls) was irrigated with 15 liter of water using a sprinkler can. An additional 0.6 cm of water was applied to the entire field after all the treatments were applied on the first application date only. The turf was maintained by the PSRU staff using standard maintenance practices. Turf was maintained at a 0.45 cm mowing height on the 'Tifdwarf' bermudagrass site, and 1.4 cm on the 'Celebration' bermudagrass site.

Nematode samples consisting of nine cores (10-cm-deep × 1.9-cm-diam.) were collected from each plot before treatment and 2 wk after each treatment application date. Leaves, stolons, rhizomes, and organic thatch layer were discarded and the soil was mixed by hand. Nematodes were extracted from a 100-cm^3 subsample of soil using the sugar floatation centrifugation method. Plant-parasitic nematodes were identified and counted using an inverted light microscope at ×40 magnification. Another 100-cm^3 of dry soil was used for soil texture and percent organic matter analysis as described previously. After soil analysis, soil at both sites was found to have >90% sand and <2% organic matter.

To evaluate turf health percentage green cover was used. Turf percentage green cover is a measurement of the percentage of the plot surface covered by green turf. A digital photo was taken of the center m^2 of each plot. The percentage of the pixels in each photo that were "green" was determined using a macro developed by faculty at the University of Arkansas (Karcher and Richardson, 2005) for use with SigmaScan Pro5 software (SPSS Inc., Chicago, IL). Percentage of the total pixels in the image that were green was the measure of turf percent green cover.

Treatments were applied on 16 June and 15 July at the Tifdwarf bermudagrass site and 23 June and 20 July at the Celebration bermudagrass site. Nematode samples were collected two weeks before the first application date and two weeks after each application date. Turf percentage green cover was measured approximately every two weeks.

To determine if individual treatments were effective, data were subjected to analysis of covariance with the initial nematode population density as the covariant using SAS software (Cary, NC). Each individual treatment was compared to the untreated control and the P-value for the comparison used to determine differences.

Results

Bench screens: There were no differences in nematode suppression ($P > 0.1$) among application rates for any of the amino acids, so only the amino acid effects are shown in Table 1. All methionine-based amino acid

Table 1. Effects of DL-methionine (DL Meth), potassium methionate (K Meth), sodium methionate (Na Meth), methionine hydroxyl analogue (MHA), lysine, and threonine each applied at 224 and 448 kg/ha of amino acid on number of *Belonolaimus longicaudatus* and *Meloidogyne incognita* three days after treatment in bench screen trials.

	B. longicaudatus/200 cm^3 of soil		*M. incognita* J2/200 cm^3 of soil	
Treatment[a]	Trial 1	Trial 2	Trial 1	Trial 2
Water (control)	9[b] a	26 ab	143 c	98 b
Threonone	4 b	30 a	235 a	123 a
Lysine	4 b	32 a	186 b	112 ab
DL Meth	<1 c	23 b	26 e	17 d
MHA	<1 c	<1 c	83 d	45 c
K Meth	<1 c	<1 c	21 e	20 d
Na Meth	<1 c	1 c	13 e	18 d

[a]Threonine, lysine, and DL-methionine were powder formulations, methionine hydroxyl analogue, potassium methionate, and sodium methionate were liquid formulations.

[b]Means within columns followed by common letters are not different according to Duncan's multiple-range test ($P \leq 0.05$). Data for both amino acid rates are combined and are means of 8 replications.

materials reduced population densities of *B. longicaudatus* compared to the water control in Trial 1 ($P \leq 0.05$) (Table 1). However, only the liquid formulations of the amino acid materials reduced the number of *B. longicaudatus* in Trial 2. Both rates of all methionine-based amino acids were effective ($P \leq 0.05$) in reducing the number of *M. incognita* recovered. However, methionine hydroxyl analog was not as effective as the other methionine-based amino acids against *M. incognita* in either trial. L-threonine and lysine reduced the number of *B. longicaudatus* compared to the water control in one of two trials, but did not reduce *M. incognita* J2 compared to the water control in either trial ($P \leq 0.05$), and in several cases increased the number of nematodes recovered.

Growth room trials: All of the tested amino acids reduced population densities of *B. longicaudatus* compared to the water controls ($P \leq 0.05$) (Table 2). There were no differences among amino acids with regard to nematode suppression ($P > 0.1$). Across amino acids there was a rate response ($P \leq 0.05$), the highest rate (448 kg amino acid/ha) of all amino acids was more effective in reducing the number of *B. longicaudatus* than the lowest rate (112 kg/ha).

Table 2. Effects of DL-methionine (DL Meth), potassium methionate (K Meth), sodium methionate (Na Meth), methionine hydroxyl analogue (MHA) on number of *Belonolaimus longicaudatus* two weeks after treatment to pots of inoculated creeping bentgrass (*Agrostis palustris*).

Treatment	Variable
	B. longicaudatus/100 cm^3
	Formulation
Untreated	188 a
K meth	33 b
Na meth	31 b
DL meth	31 b
MHA	22 b
	Rate
0 kg/ha	188 a
112 kg/ha	43 b
224 kg/ha	27 bc
448 kg/ha	18 c

Means within a variable followed by common letters are not different ($P \leq 0.05$) according to Duncan's multiple-range test. Data are combined from two trials and are means of 13 replications.

Three days after application, the grass treated with 448 kg amino acid/ha of methionine hydroxyl analog and DL-methionine began to exhibit phytotoxicity that remained throughout the rest of the trial (data not shown). Symptoms included chlorosis, turning into decline, and finally wilt by the end of the experiment. The phytotoxicity was more severe from the methionine hydroxyl analog than from DL-methionine ($P \leq 0.05$). No phytotoxicity was observed from any of the other treatments.

Statistical differences in soil pH were detected among treatments ($P \leq 0.05$). However, the lowest pH observed was 7.34 and the highest was 7.84. Because these reductions were only a few tenths on the pH scale, we did not consider them biologically significant and the data is not shown.

Field trials: Population densities of *B. longicaudatus* was significantly reduced by the high rate (224 kg amino acid/ha) of both DL-methionine and potassium methionate compared to the untreated control ($P \leq 0.05$) at the Celebration bermudagrass site on both post-application sampling dates (Table 3). At the Tifdwarf bermudagrass site, only the high rate of potassium methionate reduced population densities of *B. longicaudatus*, and only at the final sampling date. Fenamiphos did not affect population densities of *B. longicaudatus* compared to the untreated control in either trial.

None of the treatments had an effect on turf percentage green cover in the Tifdwarf bermudagrass trial (Table 4). However, all of the treatments except for fenamiphos improved turf percentage green cover compared to the untreated control at some point during the Celebration bermudagrass trial (Table 5).

Discussion

From the bench screening we determined that liquid methionine formulations suppressed *B. longicaudatus* and *M. incognita* J2 in soil equal to or better than DL-methionine. L-threonine and lysine were not as effective as methionine formulations against either nematode, indicating that the methionine-based amino acids are much more promising as nematicides. Therefore, only methionine-based amino acids were carried forward to greenhouse evaluation with plants.

In trial 2 of the *B. longicaudatus* benchscreen experiment, DL-methionine performed poorly against *B. longicaudatus*. There are several possible reasons for this finding. First, USGA specification sand used in trial 1 may have allowed for greater infiltration and therefore increased movement of DL-methionine than did the

TABLE 3. Effects of two rates each of DL-methionine (DL Meth) and potassium methionate (K Meth), and fenamiphos on population densities of *Belonolaimus longicaudatus* during field trials on 'Celebration' and 'Tifdwarf' bermudagrass (*Cynodon dactylon* × *C. transvaalensis*).

Treatment	Celebration 8 June (Pi)	Celebration 7 July	Celebration 4 August	Tifdwarf 8 June (Pi)	Tifdwarf 30 June	Tifdwarf 28 July
	B. longicaudatus/100 cm^3					
Untreated	36[a]	25	53	37	13	12
Fenamiphos[b]	38	18	41	41	6	18
DL Meth 112 kg/ha	37	26	41	42	17	8
DL Meth 224 kg/ha	36	6**[c]	17**	38	9	13
K Meth 112 kg/ha	37	20	34	38	14	9
K Meth 224 kg/ha	37	7**	8**	41	7	3*

[a]Data are means of 5 replications.
[b]Applied at a rate of 11.2 kg a.i./ha.
[c]*,**,***Different from untreated according to analysis of covariance $P = 0.1$, 0.05, 0.01, respectively.

field soil used in trial 2. Also, the field soil had more organic matter (5%) than the USGA specification sand, which may have inhibited DL-methionine movement in the soil.

Talavera and Mizukubo (2005) reported that *M. incognita* was directly affected by methionine. In our benchscreen experiments, no plants were used, only nematodes in soil. Therefore, chemotherapeutic effects can be ruled out, corroborating the direct effects observed by Talavera and Mizukubo (2005). Additional research on the mode of action of methionine on nematodes is currently underway.

In the greenhouse experiments, all the methionine formulations were equal in their ability to reduce population densities of *B. longicaudatus*. However, the high rate of both DL-methionine and methionine hydroxyl analog caused phytotoxicity to turf in this experiment. Phytotoxicity to turfgrass from DL-methionine also was noted in published (Crow et al., 2009) and unpublished experiments (W. T. Crow, unpublished data). Therefore, potassium and sodium methionate appear to have greater potential for management of plant-parasitic nematodes in established turf. Of these, sodium methionate is 6% sodium and potassium methionate is 7% potassium. Sodium accumulation is considered a detriment to turf growth, whereas potassium is a plant nutrient that is a component of most turfgrass fertility programs. Therefore, potassium methionate appears to be the best candidate for development as a turfgrass nematicide and was used in the field trials.

In the field experiment, DL-methionine and potassium methionate were equally effective in reducing population densities of *B. longicaudatus* and improving turf health. There is no evidence that the liquid methionine analog moved into the ground better than solid DL-methionine. The higher rate of either methionine formulation (224 kg amino acid/ha) reduced population densities of *B. longicaudatus* in soil and improved turf percentage green cover while fenamiphos did not. No phytotoxicity was observed from any of the treatments evaluated in the field trials, making it impossible to determine if potassium methionate had less potential for causing turf damage than DL-methionine. Further research creating ideal conditions for phytotoxicity, such as increasing use rates or applying less water, should focus on these comparisons. If methionine is to be developed as a commercial nematicide potassium methionate has several advantages over DL-methionine including: i) potassium methionate is relatively odor free whereas, DL-methionine has a strong,

TABLE 4. Effects of two rates each of DL-methionine (DL Meth) and potassium methionate (K Meth) and fenamiphos on turf percentage green cover during a field trial on 'Tifdwarf' bermudagrass (*Cynodon dactylon* × *C. transvaalensis*).

Treatment	15 June	1 July	15 July	28 July	10 Aug
	Percentage Coverage (%)				
Untreated	67[a,b]	91	78	69	74
Fenamiphos[c]	64	92	79	69	70
DL Meth 112 kg/ha	71	94	80	69	72
DL Meth 224 kg/ha	75	94	82	69	79
K Meth 112 kg/ha	58	91	71	61	76
K Meth 224 kg/ha	71	94	76	64	65

[a]Percentage of the plot covered by green turf on a scale of 0-100%.
[b]Data are means of 5 replications. Values were not significantly different compared to the untreated according to analysis of covariance ($P > 0.1$).
[c]Applied at a rate of 11.2 kg a.i./ha.

TABLE 5. Effects of two rates each of DL-methionine (DL Meth) and potassium methionate (K Meth) and fenamiphos on turf percentage green cover during a field trial on 'Celebration' bermudagrass (*Cynodon dactylon* × *C. transvaalensis*).

Treatment	23 June	7 July	20 July	28 July	8 Aug.
	Percentage Coverage (%)				
Untreated	69[a]	58	62	69	85
Fenamiphos[b]	74	68	59	66	85
DLMeth 112 kg/ha	64	74***[c]	67	79***	89*
DL Meth 224 kg/ha	67	70*	65	82***	92***
K Meth 112 kg/ha	66	72**	59	75	87
K Meth 224 kg/ha	72	76***	66	82***	92***

[a]Percentage of the plot covered by green turf on a scale of 0-100%.
[b]Applied at a rate of 11.2 kg a.i./ha.
[c]*,**,***Different from untreated according to analysis of covariance $P = 0.1$, 0.05, 0.01, respectively. Data are means of 5 replications.

persistent odor, ii) potassium methionate is easily applied using standard spray equipment whereas DL-methionine is a light powder which makes it difficult to apply, and iii) both potassium methionate and DL-methionine contain nitrogen and sulfur, however, potassium methionate contains an additional plant nutrient, potassium.

The turf nutrient component of the methionine treatments can make it difficult to separate visual effects caused by increased fertility and those related to nematode suppression. Turf percentage green cover was improved by both rates of either methionine formulation compared with the untreated control in the Celebration bermudagrass trial where these treatments resulted in significant nematode suppression. In the Tifdwarf bermudagrass trial there was no turf percentage green cover improvement and no nematode reductions associated with methionine treatments. This suggests that turf percentage green cover improvement could be, at least in part, a result of nematode effects.

It is unknown why the methionine treatments worked better in the Celebration bermudagrass trial than the Tifdwarf bermudagrass trial. One possibility is that unknown biotic factors such as disease or pests influenced the results. Meanwhile, differences among the grass cultivars at the two sites and their response to *B. longicaudatus* may have influenced the outcome. Further research should evaluate the effects of methionine across a range of environmental conditions as well as turf species and cultivars.

These studies indicate that liquid methionine formulations, potassium methionate in particular, have potential for development as turfgrass nematicides. However, additional research needs to be conducted before the true practicality of methionine-based nematicides can be determined. At this time the potential benefits of methionine-based formulations warrant further research.

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