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Multiple Trinexapac-ethyl Applications Reduce Kentucky Bluegrass Sod Storage Temperatures

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Additional index words. plant growth regulators, *Poa pratensis*, sod heating, stress tolerance

Summary. Sod heating during storage can limit the distance sod may be shipped. Two experiments were conducted to determine the effect of multiple preharvest applications of trinexapac-ethyl [4-cyclopropyl-α-hydroxy-methylene)-3,5-dioxocyclohexanecarboxylic acid methyl ester] at 0.23 kg·ha^{-1} (0.21 lb/acre) on kentucky bluegrass (*Poa pratensis*) sod temperatures during the first 24 h of storage. Experimental design was completely randomized with three replications and a 2 (trinexapac-ethyl verses control) × 3 (8-h storage intervals) factorial arrangement of treatments. Trinexapac-ethyl treatments were applied 6 and 2 weeks before harvest in the first experiment and 10, 6, and 2 weeks before harvest in the second experiment. Two and three applications of trinexapac-ethyl reduced sod storage temperatures. The reduction in rate of heating in treated sod became significantly different than untreated sod within 4 h after harvest. Mean sod temperatures in both experiments were 3 °C (6 °F) cooler in treated sod after 12 h of storage than untreated sod. These results suggest that trinexapac-ethyl could be used by sod growers to extend storage times and increase shipping and market areas. A multiple application program can enable sod growers to maximize the enhancement effects of trinexapac-ethyl on sod storage life.

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Internal heating of sod stacked postharvest can cause plant tissue to deteriorate and is a limiting factor determining the distance sod can be shipped (King, 1970). Bermudagrass (*Cynodon dactylon*) sod when stacked on pallets was 12 °C (22 °F) above ambient, after storage for five days (Maw et al., 1998). Cool-season turfgrasses such as kentucky bluegrass and creeping red fescue (*Festuca rubra*) heat more rapidly than bermudagrass and have a shorter storage time (Darrah and Powell, 1977; King et al., 1982).

Several management practices have been used to increase sod storage life. Reduction of mowing height and removal of clippings have been shown to decrease sod heating in kentucky bluegrass and creeping red fescue (Darrah and Powell, 1977; King et al., 1982). King et al. (1982) reported increased sod heating when sod received 240 kg·ha^{-1} (214 lb/acre) of nitrogen compared with no nitrogen application. Temperatures of sod stacked on pallets when harvested early in the morning were also found to be lower than sod harvested later in the day (Darrah and Powell, 1977).

The primary use of trinexapac-ethyl is to reduce leaf elongation. It inhibits the 3β-hydroxylase enzyme late in the gibberellic acid biosynthesis pathway (Rademacher et al., 1992). A partial inhibition of respiration in plants by trinexapac-ethyl (Heckman, 2000) gives sod growers the potential to decrease metabolic activity of the sod system and delay high temperatures that lead to poor quality sod.

The use of plant growth regulators (PGRs) in the sod industry has been minimal compared to use in the golf industry. Trinexpac-ethyl is a PGR used to reduce canopy heights and mowing frequency. Nontarget effects of trinexapac-ethyl such as sod storage temperature reduction have only been briefly investigated. A single preharvest application of trinexapac-ethyl has

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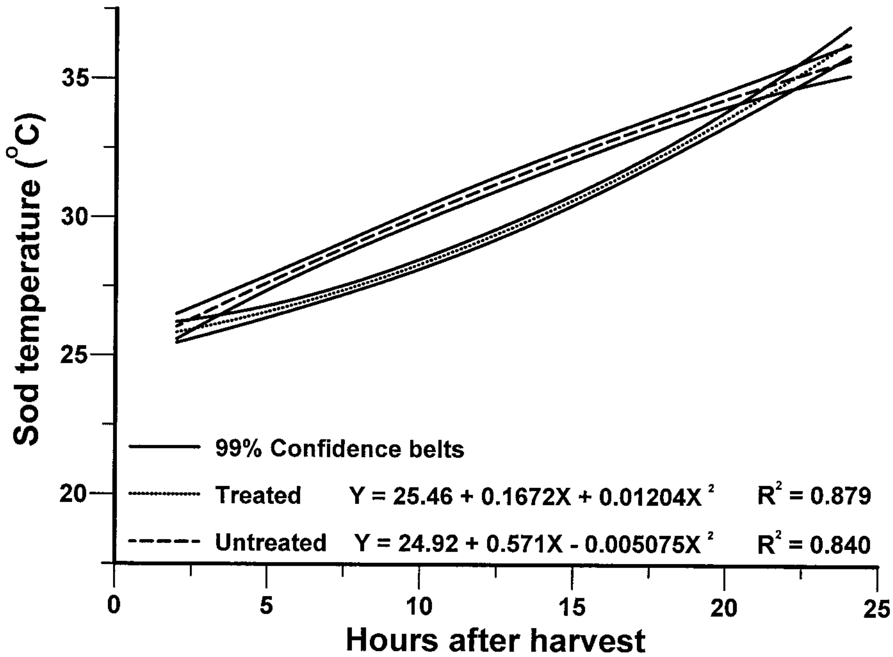

Fig. 1. Kentucky bluegrass sod temperatures from 2 to 24 h of storage in June 2000, near Mead, Nebr. after two applications of trinexapac-ethyl; °F = 1.8(°C) + 32.

been shown to reduce sod storage heating effectively after 16 h of storage (Heckman et al., 2000). A reduction of heat tolerance in kentucky bluegrass by trinexapac-ethyl is about 1 °C (2 °F) (Heckman et al., 2001), however, the reduction in storage temperatures was as much as 9 °C (17 °F) greater than the decrease in heat tolerance (Heckman, 2000).

Currently in Nebraska, sod is commonly cut, shipped, and installed within 24 h because sod heating is a major concern. Therefore, the most critical time for sod grower is the first 24 h after harvest. The use of multiple pre-harvest applications of trinexapac-ethyl on kentucky bluegrass sod storage temperatures is not documented. Possible accumulation of trinexapac-ethyl in the plant system from multiple applications may increase the effects on the sod during storage and significantly reduce heating during the initial stages of sod storage. The objective of this research was to identify the effect of multiple pre-harvest applications of trinexapac-ethyl on kentucky bluegrass sod temperatures during the first 24 h of storage.

Materials and methods

The first experiment was conducted at Todd Valley Farms near Mead, Nebr., on a 22-month-old kentucky bluegrass sod blend of the cultivars Abby, America, Eclipse, and Midnight. Sod was grown on a Tomek silty clay loam soil (mixed, mesic Typic Argiudoll) with supplemental irrigation as needed. On 11 May and 7 June 2000, sod was treated with 0.23 kg·ha^{-1} trinexapac-ethyl with a sprayer delivering 561 L·ha^{-1} (60 gal/acre). Sod was harvested with a mechanical sod cutter on 19 June 2000 into 51 × 102 cm (20 × 40 inches) sections, 1.9 cm (0.75 inches) thick. Sod was stacked on pallets forming 18 layers with two parallel sections of sod comprising one layer. Each layer was laid perpendicular to the succeeding one to stabilize the stacks. Nine treated stacks and nine untreated control stacks, with 18 layers in each stack, were used for the experiment. Thermocouples were placed in the center of each stack and connected to a data logger (CR 7; Campbell Scientific Inc., Logan, Utah) programmed to record temperatures in 15-min intervals. Sod was stored in a completely randomized design and exposed to ambient, full sun, weather conditions. Ambient weather conditions were monitored hourly at the John Seaton Anderson Turfgrass and Ornamental Research Facility about 5 km (3.1 miles) away from the storage site. Gravimetric soil water content was measured at the time of harvest. The center layer of sod from three stacks of each treatment were removed and visual quality was evaluated at 8-h storage intervals during storage. Visual quality ratings were made on a 1 to 9 scale where 9 was the best sod quality, 6 was acceptable for home lawn use, and <6 was unacceptable.

A second experiment was also conducted at Todd Valley Farms during Summer 2000. A 16-month-old kentucky bluegrass sod blend of Abby, Coventry, and Bristol grown on Tomek silty clay loam soil was used. Sod was treated in the same manner and at the

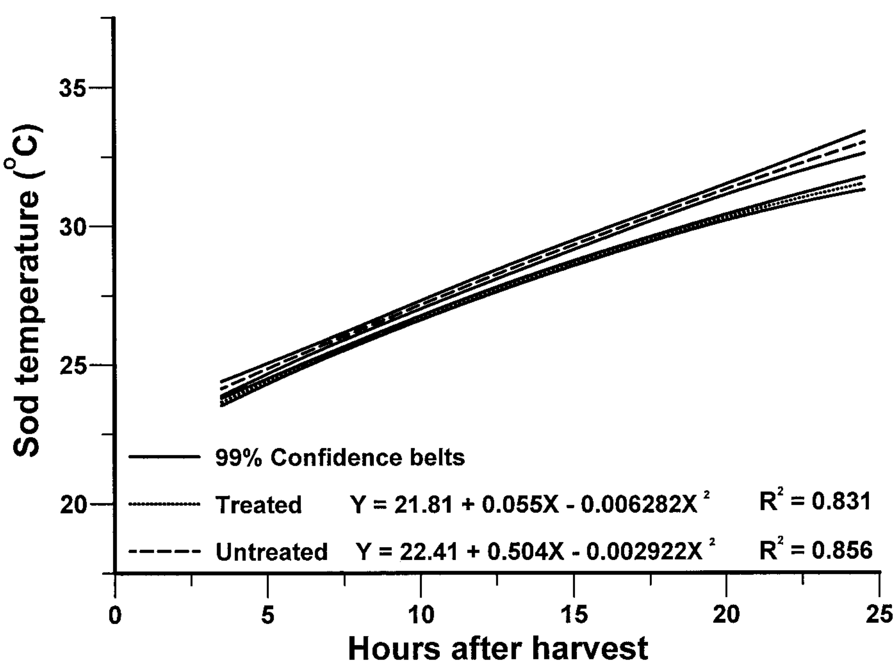

Fig. 2. Kentucky bluegrass sod temperatures from 3 to 24 h of storage in August 2000, near Mead, Nebr. after three applications of trinexapac-ethyl; °F = 1.8(°C) + 32.

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same rates as the first experiment on 7 June, 5 July, and 8 Aug. 2000. Sod was harvested as previously described on 17 Aug. 2000. All other conditions were the same as in the first experiment.

Experimental design was completely randomized with a 2 (trinexapac-ethyl versus control) × 3 (8-h storage intervals) factorial arrangement of treatments with three replications. Multiple linear regression was used to analyze sod temperatures and data were graphed using PlotIt software (Scientific Programming Enterprises, Haslett, Mich.). Confidence intervals ($P = 0.01$) were determined for every 15 min of sod storage. The confidence intervals were then graphed as confidence belts. Quality ratings were analyzed using ANOVA. Hartley's F-max test was used to test for heterogeneity of variance between the two experiments (Hartley, 1950).

Results and discussion

Heterogeneity of variance between the two experiments was detected and data were analyzed separately for each experiment. No 8-h storage interval × trinexapac-ethyl treatment interaction occurred; therefore, overall trinexapac-ethyl treatment effects were used.

There were lower sod storage temperatures in both experiments during the first 24 h in trinexapac-ethyl treated sod than untreated sod (Fig. 1 and 2). The average heating rate was 0.42 °C/h (0.75 °F/h) and was similar between the two experiments. However, the June 2000 results showed a slightly higher rate of heating. We believe that this may be due to higher water content in the soil and higher ambient air temperatures. Average gravimetric water content was 0.31 in June and 0.24 in August. Soil moisture content for both studies were within the typical range for sod that is harvested. This may have led to increased heat production from microorganisms since increased soil moisture contents have been shown to increase microbial respiration (Wilson and Griffin, 1975). Overall sod temperatures were also higher in June. Ambient air temperatures were higher in June than August (Fig. 3). Since the average rate of heating was similar between the two experiments, sod temperatures in June were higher than those in August throughout the sod storage period. Rate of sod heating became significantly lower in trinexapac-ethyl treated sod at 4 h of storage in the first experiment and less than 3 h of storage in the second experiment. This rate of divergence in sod heating was greater using multiple applications of trinexapac-ethyl than in earlier studies using a single application (Heckman, 2000).

The two primary components causing sod heating were plant and microbial respiration, with speculation that most is being supplied by the microorganisms (Christians, 1998). There is some evidence to believe that plant respiration is reduced by trinexapac-ethyl (Heckman, 2000). However, the potential effects of trinexapac-ethyl on microbial respiration are not known.

No differences in visual quality were detected in either experiment (data not shown). None of the sod reached the lethal temperatures of 35.5 and 36.1 °C (95.9 °F and 97.0 °F) for trinexapac-ethyl treated and untreated kentucky bluegrass that are reported by Heckman et al. (2001), therefore tissue damage was not expected.

Multiple applications of trinexapac-ethyl have been used for season-long reduction in mowing heights of bermudagrass (Fagerness and Yelverton, 2000). However, the use of multiple applications in cool-season sod production is not well documented. In sod research, a single pre-harvest application of trinexapac-ethyl can decrease sod heating after 16 h of storage (Heckman, 2000). This research shows that multiple pre-harvest applications of trinexapac-ethyl can greatly reduce sod heating in a shorter time period than a single application (Heckman, 2000). Data from this research combined with earlier results of studies using single pre-harvest applications of trinexapac-ethyl provides evidence that this PGR can be used as a management tool for sod growers to delay deterioration of sod during storage and possibly increase market areas. Trinexapac-ethyl can be used as a risk management strategy to keep sod at lower temperatures than untreated sod, thus reducing the potential for heat damage and subsequent replacement of poor quality sod. Current sod prices vary from \$1.60/m^2 to \$3.20/m^2 (\$0.15/ft^2 to \$0.30/ft^2) and a single trinexapac-ethyl applications can cost as little as \$0.01/m^2 (\$0.001/ft^2). The cost of replacing damaged sod can greatly exceed the cost of the PGR. Other benefits of trinexapac-ethyl treated sod include reduced mowing requirements and less water use initially following installation (Ervin and Koski, 2001). Growers using a multiple application program can receive greater effects of trinexapac-ethyl on sod storage life enhancement than the use of a single application.

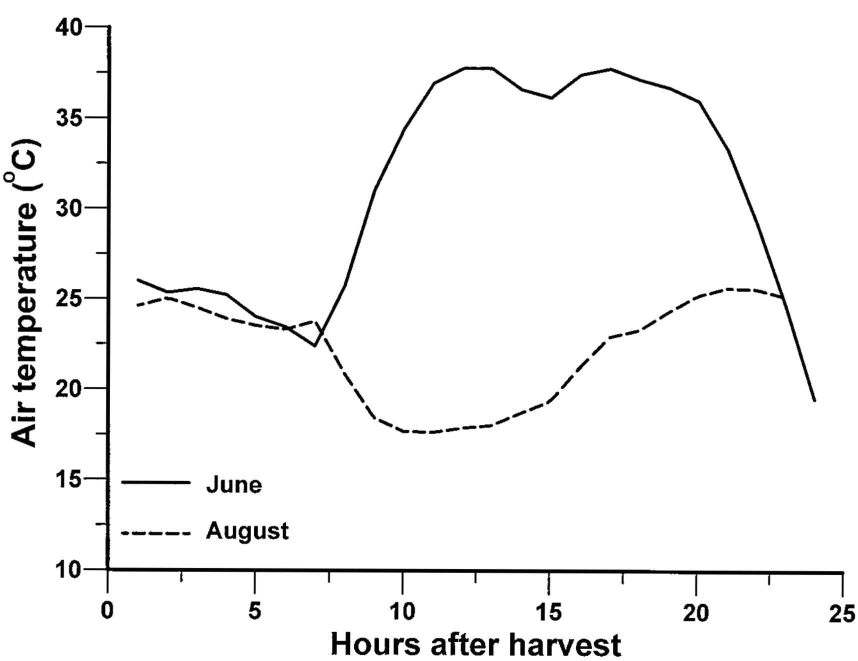

Fig. 3. Ambient air temperature during sod storage near Mead, Nebr.; °F = 1.8(°C) + 32.

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Controlled Atmosphere Storage and Aminoethoxyvinylglycine Postharvest Dip Delay Post Cold Storage Softening of 'Snow King' Peach

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ADDITIONAL INDEX WORDS. white flesh, firmness, ethylene, quality attributes, high CO_2 toxicity, low O_2 toxicity, *Prunus persica*

SUMMARY. 'Snow King' peaches (*Prunus persica*) harvested at commercial maturity were subjected to different carbon dioxide (CO_2) and oxygen (O_2) atmosphere combinations for a 2-week simulated transportation [0 °C (32 °F)] period after 1 week of cold storage in air (0 °C). In 1998, air or 5%, 10%, 15%, or 20% CO_2 combined with 3% or 6% O_2 were used during shipment. The trial was repeated in 1999, but for this year half of the fruit were treated with a 50 mg·L^{-1} (ppm) aminoethoxyvinylglycine (AVG) postharvest dip before storage and simulated shipment. In addition, O_2 levels during simulated shipment were reduced to 1.5% and 3%. At harvest and after the 2-week simulated shipment, fruit flesh firmness, soluble solids concentration (SSC), titratable acidity (TA), and chilling injury (CI) were evaluated. For both years, there were no significant differences in quality attributes among the different treatments after the simulated shipment period. SSC and TA did not change during 5 days postshipment ripening at 20 °C (68 °F). In 1998 all treatments softened rapidly during the postshipment ripening at 20 °C, and were ready to eat [13 N (1 N = 0.225 lb force)] after 3 days. In 1999, both the high CO_2 atmospheres during shipment and the AVG postharvest dip slowed the rate of softening during subsequent ripening at 20 °C. With respect to fruit softening, there was significant interaction between storage atmosphere and AVG treatment. AVG-treated fruit shipped under a 20% CO_2 + 3% O_2 atmosphere did not soften to the transfer point (firmness = 27 N) within our 5-day ripening period, while fruit not treated with AVG and shipped under the same atmosphere softened to the transfer point in 3 days. Control fruit (no AVG + air shipment) softened to the transfer point in 2 days. Our previous work found that when white flesh peaches soften to less than 27 N firmness they become very susceptible to impact bruise injury during retail distribution. We call this critical level of fruit flesh firmness the transfer point. Symptoms of CI, low O_2, or high CO_2 injury were not observed in any treatment in either year.

Recently, total production of white flesh peaches has increased rapidly. California white flesh peach and nectarine production has increased from 778,000 boxes [11.3-kg (25-lb) boxes] in 1996 to 7,009,626 boxes in 2000 (Calif. Tree Fruit Agreement, unpublished data). This amounts to about 17% of the total California peach and nectarine industry. In general, these cultivars have a lower titratable acidity than yellow flesh cultivars, although the acidity levels vary significantly among them (Crisosto et al., 2001a; Day et al., 1997). These low acid levels make white flesh stone fruit popular in the Asian markets, especially Taiwan. In the 2000 season, it was estimated that 91% of the 3.5 million boxes of peaches and nectarines exported to Taiwan were from white flesh cultivars (California Tree Fruit Agreement, unpublished data). Refrigerated container shipments to Taiwan, Hong Kong, and Japan take about 11 to 16 d. Rapid softening and deterioration of white flesh peaches at arrival and during distribution in Taiwan and Hong Kong have been observed. In our previous work, we found that when white flesh

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