SPRINGTIME DANDELION CONTROL IN TURFGRASS USING CONVENTIONAL AND ORGANIC METHODS

by

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Abstract

Common dandelion (*Taraxacum officinale* Weber) is an important perennial weed in turfgrass. Fall is considered the optimal time for postemergence herbicidal control of dandelions; however, applications in spring, when volatility damage to surrounding plants is an additional concern, are often needed. Therefore, we conducted research to determine the volatility of common broadleaf herbicides, and their efficacy when applied at spring and fall application timings. Volatility was determined by applying herbicides to turfgrass and using potted tomatoes as indicator plants. Tomatoes exposed to turfgrass treated with Trimec Classic, Confront, Surge, Escalade 2, and Imprelis exhibited little or no volatility damage, while exposure to Speedzone, 4 Speed XT, and Cool Power caused significant damage. In general, herbicides causing little or no damage were amine formulations. Two field studies determined the effect of spring and fall application timing on dandelion control with several herbicides. Herbicide applications in the spring coincided with dandelion anthesis stages: pre-bloom, peak bloom, and post-bloom. Results were dependent on dandelion pressure in the studies. In 2010, with lower pressure, there were no differences among herbicides at any spring timing when dandelion control was evaluated after one year; all herbicides gave ≥ 80% control. In 2011, with higher dandelion pressure, Imprelis SL and 4 Speed XT provided ≥ 96% dandelion control at the spring pre- and post-bloom timings, which was better than Surge, Escalade 2, Cool Power, and Confront. The best choices for spring efficacy combined with minimal to no volatility were Escalade 2 and Trimec Classic. Finally, because interest in organic dandelion control is increasing, we compared several organic weed control tactics with a conventional herbicide. In a two-year field study, the conventional herbicide gave much better control (> 96%) than any organic method. Horticultural vinegar corn gluten meal, and fertilizer-only gave < 25% control, while hand-weeding gave 58 to 71% control. While hand-weeding was the best of the organic tactics, the time required was considered prohibitive for turfgrass managers, unless initial weed levels were very low.

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Dedication

I would like to dedicate this work to my beautiful daughter Olivia. I will continue to work hard for you.

Chapter 1 - Volatility of Broadleaf Weed Herbicides applied to Turfgrass

Introduction

Volatilization occurs when pesticides applied to plant and/or soil surfaces evaporate and result in an invisible gas (Cooper et al., 1995). Volatility is a concern because herbicides are highly selective and may cause severe injury when they come into contact with non-target plants (Turgeon et al., 2009). The invisible gas makes it difficult for field managers to determine the source of plant damage, and they may attribute the injury to other factors, such as drift. Volatilization may account for up to 90% of pesticide loss, which also decreases pesticide efficacy (Bedos et al., 2002).

Environmental factors such as temperature, humidity, and wind speed play a crucial role in volatilization (Bedos et al., 2001; Cooper et al., 1995; Que Hee and Sutherland, 1974; Taylor, 1978). All of these factors must be considered when making herbicide applications, however, the most important factor influencing herbicide volatility may be the formulation of the active ingredient (Grover, 1976; Que Hee and Sutherland, 1974).

Temperature

Increasing temperatures increase volatilization because the vapor pressure of a compound is exponentially dependent on temperature (Bedos et al., 2002). Previous research reported a three- to four-fold increase in herbicide volatility for every 6.7°C temperature change (Taylor, 1978). Behrens and Lueschen (1979) studied volatility injury from dicamba on soybeans. They reported substantially greater soybean injury when the temperature increased from 15 to 30°C. Because of this temperature effect, it is often recommended that volatile herbicides be applied during the late afternoon or evening, when temperatures are decreasing, to decrease the potential of herbicide volatility (Turgeon et al., 2009).

Humidity

Humidity has been shown to impact volatilization, but researchers disagree on its effect. Behrens and Lueschen (1979) reported that small reductions in relative humidity caused a significant increase in dicamba volatility in closed chamber experiments. Reduced volatility under high humidity may occur because the hydrophilic parts of the plant cuticle expand in humid conditions, which results in greater herbicide absorption (Grover, 1991). Increased herbicide absorption would, in turn, cause a decrease in the amount of active ingredient available for volatility. However, Grass et al. (1994) observed that increasing relative air humidity from 31 to 78% in a wind tunnel increased the percentage of triflurafin volatility from 66 to 96% from the soil respectively.

Wind speed

Increasing wind speed also increases volatilization. Rudel and Waymann (1995) found that increasing wind speed from 0.4 to 2.0 m s^{-1} increased the volatility of lindane from 52 to 62%. The effect of wind speed and direction is difficult to regulate in field studies; however, researchers agree volatilization rates increase with wind speed (Bodes et al., 1995; Cooper et al., 1995; Que Hee and Sutherland, 1974).

Chemical formulation

Chemical formulation of the herbicide is arguably the most influential factor associated with volatility. Formulation refers to different functional groups on the molecule resulting in unique chemical properties, such as, solubility, vapor pressure, Kow, and pKa values. The active ingredient in herbicides belonging to the synthetic auxin family can be formulated as an ester, amine, or salt. The formulation influences plant uptake and translocation of the herbicide, and also volatilization. The plant's lipophilic cuticle is the primary reason different chemical formulations react differently (Skoss, 1955). Ester formulations are oil-based, allowing them to more easily penetrate the epicuticular and cuticular waxes. However, esters are vulnerable to volatility due to their high vapor pressure. In contrast, amine formulations have a low vapor pressure, but cannot easily pass through the plant's lipophilic cuticle. This may reduce their efficacy, especially on tough weeds. Grover (1976) reported the rates of volatilization from amine formulations of 2,4-D were 60- to 400-fold less than ester formulations. Further, research has shown that volatility of 2,4-D may be virtually eliminated by using amine formulations instead of esters (Que Hee and Sutherland, 1974).

Most of the previous volatility research evaluated a single herbicidal active ingredient being applied in large-scale crop fields, such as 2,4-D, dicamba, or MCPP. Turfgrass managers often use the same herbicide active ingredients as field crop producers, but with a distinct difference: herbicide use in large-scale agriculture often entails applications to hundreds or thousands of acres, so single active ingredient herbicides are usually used to decrease the cost of control. By contrast, turfgrass managers often use herbicides containing multiple active ingredients and apply to a smaller acreage. Unfortunately, there has been no research published in the refereed literature describing the volatility of herbicides containing multiple-active ingredients.

Recently, new ester formulations of 2,4-D and other phenoxy herbicides have been released for use on turfgrass that may have a lower potential to volatilize. Therefore, the objective of our research was to evaluate the volatility of eight commonly used turfgrass broadleaf herbicides when applied to tall fescue (*Festuca arundinacea* Schreb.), a common cool-season turfgrass. To our knowledge, this study will be the first to evaluate several newer herbicides containing "low-volatile" esters in combination with other active ingredients. This research should provide turfgrass managers with the information needed to select a herbicide when volatility is a concern.

Materials and Methods

Greenhouse Studies

Hybrid tomato (*Lycopersicon lycopersicum* (L.) H. Karst. cv. Jetstar) (Henry Field's Seed and Nursery Company, Aurora, Indiana) plants were exposed to herbicide-treated tall fescue in two separate greenhouse studies (Study 1 and Study 2) conducted at the Plant Science Research Center at Kansas State University in Manhattan, KS. Study 1 was conducted from July to August, 2010. Study 2 was conducted from June to July, 2011. Both studies were repeated (experiment 1 & 2) within the given dates. The experimental design was a randomized complete block with three replications. Replications were treated on successive days because of time and space constraints.

In Study 1, treatments consisted of a water control and eight herbicides: Trimec Classic® (PBI/Gordon Corporation, Kansas City, MO 64101), Speedzone® (PBI/Gordon Corporation, Kansas City, MO 64101), Escalade 2® (Nufarm, Burr Ridge, IL 60527), Surge® (PBI/Gordon Corporation, Kansas City, MO 64101, Confront® (Dow AgroSciences, Indianapolis, IN 46268) , 4 Speed XT™ (Nufarm, Burr Ridge, IL 60527), Cool-Power® (PBI/Gordon Corporation, Kansas City, MO 64101), and 2,4-D butyl ester. Active ingredients and the respective percentages contained in each herbicide are shown in Table 1. The highly volatile herbicide 2,4-D butyl ester was included as a volatile standard. Each herbicide was applied to the tall fescue at its highest label rate recommended for dandelion (*Taraxacum officinale* Weber) control. The main objective of Study 2 was to investigate Imprelis SL™ (DuPont, Wilmington, DE 19898) volatility compared to other herbicides. Therefore, Study 2 was conducted similar to Study 1, but only five herbicides were included: Trimec Classic®, Speedzone®, Surge®, Imprelis SL™, 2,4-D butyl ester, and a water control. Again, each treatment was applied at its highest label rate recommended for dandelion control.

Hybrid tomatoes were used as indicator plants to detect volatility. The tomatoes were grown from seed in 10 cm plastic pots containing Metro-Mix®360 growing medium (SunGro, Vancouver, British Columbia). One tomato seed was planted per pot. The tomatoes were double potted and aligned so the drainage holes were not exposed to prevent root absorption of the herbicides when the potted plants were placed on the herbicide-treated turfgrass. Tomato planting dates were staggered to ensure plant size was consistent for each replication. Tomato plants were 15-20 cm tall and had three to four true leaves when exposed to herbicide-treated turfgrass.

Turf-type tall fescue was grown in 25.4 x 50.8 cm flats. The flats were watered daily to prevent drought stress and fertilized weekly using a 20-10-20 fertilizer solution (Jacks Professional, Allentown, PA). Flats were mown twice a week to maintain a height of 5 cm. Herbicide treatments were made using a Links spray chamber operating at 206 KPa to deliver a spray volume of 185.5 L ha^{-1}, with a XR110015LP (Spraying Systems, Corp., Wheaton, IL) nozzle positioned 45.7 cm above the turf canopy.

After its respective herbicide was applied, each tall fescue flat was removed from the chamber and allowed to sit for three minutes before placing in a 90-liter Sterilite® container. The three minute waiting period ensured that no herbicide microdroplets remained suspended in the air over the tall fescue flats before tomato plants were placed on the turfgrass. Two pots of tomatoes were anchored on top of each treated turfgrass flat by using three sod staples. Lids were placed on the containers and the containers were kept in a laboratory at 22.7°C for 24 hours. The tomatoes were then removed from the containers and placed in the greenhouse for an 18-day observation period. Tomatoes were watered daily to prevent drought stress and fertilized weekly using a 20-10-20 fertilizer solution (Jacks Professional, Allentown, PA).

Measurements and statistical analysis

Tomato plants were visually rated 1, 3, 7, 10, 13, 16, and 18 days after treatment (DAT) using a scale of 1 to 9 for quality (1 = dead, 9 = green, healthy, turgid plants), epinasty (1 = no epinasty, 9 = entire plant exhibiting severe epinasty), and callus formation (1 = no callus formation, 9 = entire main stem covered in tumor-like growth). After 18 days, shoots were harvested and dried for approximately 48 hours in an electric drying cabinet (Model 2185632, Hamilton; Two Rivers, WI) at 100°C. Shoots were weighed using a Model B120S scale (Sartorius, Goettingen, Germany) and dry weights were recorded. All data for visual ratings of quality, epinasty, callus formation, and shoot dry weight were subjected to ANOVA and Fisher's protected LSD range test (MSTAT, 1993). Because the greenhouse studies 1 and 2 were repeated, data for each study were analyzed with experiment number as a factor to determine if data from the two experiments could be combined. With the exception of the dry weight data in Study 1, there were no treatment by experiment interactions. Therefore, dry weight data for study 1, experiment 1 and 2 are presented separately, but all other data were combined across experiment and the combined means were presented.

Field Studies

Tomato plants were exposed to tall fescue plots treated with broadleaf weed herbicides in a field study conducted at Rocky Ford Turfgrass Research Center in Manhattan, KS from September to October, 2011. The experimental design was a randomized complete block with three replications. Replications were treated on successive days because of time and space constraints.

Treatments consisted of a water control and three herbicides: Imprelis SL, Speedzone, and 2,4-D butyl ester. 2,4-D butyl ester was included as a volatile standard. Herbicides were applied at their highest label rate recommended for dandelion control. The main objective of the field study was to determine if volatility results from the greenhouse were representative of volatility under field conditions.

Hybrid tomatoes were used as indicator plants and were grown and prepared as described for the greenhouse studies.

Tall fescue was mown once a week at 7.6 cm and irrigated as needed to prevent drought stress. The herbicides were applied to a 3.65 x 3.65 m plot of turf type tall fescue using a $C0_2$ powered backpack sprayer operating at 206 kPa to deliver a spray volume of 351 L ha^{-1}. Each treated plot of tall fescue had a buffer zone of 60 m to prevent contamination from adjacent treated plots. Three minutes after the tall fescue plots were sprayed, a tomato was placed at 1, 2, and 4 m from the treated area. The spraying order of the plots was dependent upon the wind direction. Plots were sprayed in an order that prevented herbicide drift from coming into direct contact with previously placed tomatoes. Tomatoes were placed at these distances at all four cardinal directions: north, south, east, and west. The tomatoes were removed from the field after 12 hours and placed in the greenhouse for an 18-day observation period. Tomatoes were watered daily to prevent drought stress and fertilized weekly using a 20-10-20 fertilizer solution (Jacks Professional, Allentown, PA).

Tomato plants were visually rated 2, 7, 10, and 16 days after treatment (DAT) for quality, epinasty, and callus formation using a scale of 1 to 9. After 18 days, shoots were harvested and dried for approximately 48 hours in an electric drying cabinet (Model 2185632, Hamilton, Two Rivers, WI) at 100°C. Shoots were weighed using a Model B120S scale (Sartorius, Goettingen, Germany) and dry weights were recorded. All data were subjected to ANOVA and Fisher's protected LSD range test (MSTAT, 1993).

Results

Greenhouse Study 1: Tomato visual quality, epinasty, callus formation, and dry weight

Tomato quality for Confront, Surge, and Escalade II was not statistically different from the water for all rating dates; all had tomato quality ratings ≥ 7.6 at all rating dates (Table 2). Additionally, Trimec Classic was not statistically different from the untreated control until 16 DAT. Conversely, tomato plants exposed to turf treated with Speedzone, 4 Speed XT, and Cool Power had significantly lower quality (≤ 5.1) at all rating dates when compared to the untreated control. Tomatoes exposed to 2,4-D butyl ester had the lowest visual quality (≤ 2.8) at all rating dates and was significantly lower than all other treatments at 1, 10, and 16 DAT.

Epinasty of tomatoes exposed to Trimec Classic, Escalade 2, Surge, and Confront was not different from the water control at all rating dates; all treatments had minimal epinasty, with ratings (≤ 1.8) at all rating dates (Table 3). However, tomatoes treated with Speedzone, 4 Speed XT, Cool Power, and 2,4-D butyl ester had significantly more epinasty at all rating dates (≥ 4.6) when compared to the water control.

No callus formation occurred on tomatoes treated with Trimec Classic, Confront, Escalade 2, Surge, or the water control (Table 4). No callus formation was observed at 1 DAT; all treatments had a callus formation rating of 1.0. When callus formation was present, it appeared as a tumor-like growth on the tomato main stem (Figure 1). At 3 DAT, Speedzone was the only treatment that resulted in significantly more callus formation than the water control, although the amount was small with a rating of only 1.5. By 16 DAT however, Cool Power, Speedzone, and 4 Speed XT all received callus ratings ≥ 4.5, which was significantly higher than the water control and all the other herbicide treatments.

In experiment 1, tomato dry weight was the highest for the water control; Surge and Confront were the only herbicides that did not cause a significant reduction in dry weight compared to the untreated control (Table 5). Tomatoes exposed to 2,4-D butyl ester had the lowest dry weight of all the treatments.

In experiment 2, there was no difference in tomato dry weight after exposure to turf treated with Surge, Trimec Classic, Confront, and the untreated control (Table 5). Tomatoes exposed to Speedzone, 4 Speed XT, and Cool Power had a significant reduction in dry weight compared to the untreated control. 2,4-D butyl ester had s smaller tomato plant dry weight than all other treatments.

Greenhouse Study 2: Tomato visual quality, epinasty, callus formation, and dry weight

In Study 2, Trimec Classic, Imprelis SL, and Surge did not reduce tomato quality compared to the untreated control; all had tomato quality ratings ≥ 7.7 for each rating date (Table 6). Conversely, tomatoes exposed to Speedzone and 2,4-D butyl ester had significantly lower quality ratings (≤ 6.0) than the untreated control at all ratings dates. While Speedzone reduced quality compared to the untreated control, quality was still higher than that caused by 2,4-D butyl ester at all rating dates except for 1 DAT. Tomatoes did not receive a quality rating ≥ 4.0 after exposure to 2,4-D butyl ester at any rating date.

Epinasty symptoms for tomatoes exposed to Surge, Imprelis SL, and Trimec Classic were not statistically different when compared to the untreated control; all four of these treatments received an epinasty rating ≤ 1.6 at all rating dates (Table 7). Speedzone and 2,4-D butyl ester caused significantly greater epinasty than the untreated control at all rating dates, with ratings from 3.4-7.2 . While Speedzone had lower epinasty than 2,4-D butyl ester on most rating dates, it still caused greater epinasty than Surge, Imprelis, and Trimec Classic on all rating dates.

Tomatoes exposed to Trimec Classic, Imprelis SL, and Surge had minimal to no callus formation and were not statistically different from the untreated control; all these treatments had callus ratings ≤ 1.1 at all rating dates (Table 8). Speedzone and 2,4-D butyl ester led to significantly more tomato callus formation compared to all other treatments at 3, 10, and 16 DAT. Overall, callus formation caused by Speedzone was slightly lower than 2,4-D butyl ester, with significantly lower ratings on one of four rating dates.

Tomato dry weight for the untreated control was 5.08 g, the highest for all six treatments; however, it was not statistically different compared to Trimec Classic, Surge, and Imprelis SL (Table 9). The dry weight for Speedzone was 3.87 g, which was a significant reduction compared to the untreated control. Tomatoes exposed to 2,4-D butyl ester had the lowest dry weight of 0.88g.

Field Volatility Study: Tomato visual quality, epinasty, callus formation, and dry weight

Tomato quality for Imprelis SL was not significantly different from the untreated control at all rating dates: all these treatments had quality ratings ≥ 7.6 (Table 10). Conversely, tomato plants exposed to Speedzone had significantly lower quality ratings at all rating dates compared to the untreated control. Tomatoes exposed to 2,4-D butyl ester had the lowest visual quality (≤ 5.3) at all rating dates.

Epinasty of tomatoes exposed to Imprelis SL was not statistically different from the untreated control at all rating dates: all these treatments had epinasty ratings of 1.0 (Table 11). Conversely, tomatoes exposed to Speedzone had significantly more epinasty (≥ 1.4) at all rating dates compared to the untreated control. Tomatoes exposed to 2,4-D butyl ester had the most epinasty (≤ 3.6) at all rating dates.

Tomatoes exposed to Imprelis SL had no callus formation and was not statistically different from the untreated control at all rating dates (Table 12). At 2 DAT there were no significant differences among all treatments; all had ratings of 1.0. At 7 and 10 DAT Speedzone had callus ratings of 1.3; a significant increase compared to the untreated control. There were no significant differences among Imprelis SL, Speedzone, and the untreated control at 16 DAT. Tomatoes exposed to 2,4-D butyl ester had significantly higher callus formation than all other treatments at 7, 10, and 16 DAT.

The untreated control had the highest dry weight (3.41g), but was not significantly different from Speedzone (Table 13). Tomatoes exposed to Imprelis SL had a dry weight of 3.10 g, which was lower than the untreated control, but not statistically different from Speedzone. Tomatoes exposed to 2,4-D butyl ester had the lowest dry weight (2.74 g).

Discussion

Throughout all studies tomato plants were highly sensitive to volatile gases produced by some of the turfgrass herbicides. Tomatoes exposed to the turfgrass flats treated with water remained healthy and vigorous, demonstrating that enclosing the plants in the Sterilite containers for 24 hours had no negative side effects on the plants in the greenhouse studies. Also, control plants placed randomly around the laboratory during the 24-hour exposure period showed no negative effects, confirming that there was no cross-contamination between treatments.

Tomatoes exposed to Trimec Classic, Surge, Confront, Escalade 2, and Imprelis SL exhibited minimal negative effects, while tomatoes exposed to Speedzone, 4 Speed XT, and Cool Power showed substantial negative effects in greenhouse studies. Overall, the 2,4-D butyl ester produced the greatest negative effects on tomato growth, which was expected because its high volatility potential is well-established (Noble and Hamilton, 1990).

All the herbicides in Studies 1 and 2 contained compounds from the synthetic-auxin family (Senseman, 2007); however, the herbicides that produced minimal negative effects on the tomatoes were formulated solely or primarily as amines (Table 1; Escalade 2 was a exception, as it contained a small percentage of the methylheptylester of fluroxypyr). In contrast, Speedzone, 4 Speed XT, and Cool Power contained primarily ester formulations of the synthetic-auxin compounds. Previous research found the rate of volatilization of 2,4-D formulated as an amine was 60- to 400-fold less than the ester formulations (Grover, 1976). Overall, tomatoes exposed to herbicides containing primarily amine formulations of synthetic-auxin herbicides had similar ratings in quality, epinasty, and callus formation were usually similar to the water control in the greenhouse and field studies. Exposure to Trimec Classic and Escalade 2 lead to a dry weight reduction in Experiment 1 of Study 1, but not in Experiment 2 of Study 1, or in Study 2. Trimec Classic and Escalade 2 have 41 and 67% more 2,4-D amine acid equivalent (ae), respectively, compared to Surge (Figure 2). Though amine formulations have significantly less volatility compared to ester formulations, a small amount of volatile gas is produced from amine formulations (Grover, 1976). The increased amount of product available for volatility likely caused the decrease in tomato plant dry weight for Trimec Classic and Escalade 2 when compared to the untreated control in Experiment 1 of Study 1. Overall, these results suggest that there was minimal to no volatility of these herbicides, which agrees with Grover's (1976) findings.

The rate of volatility is not the same for all ester formulations because manipulations to their chemical structure may have an effect on their tendency to volatilize. Previous work has developed three broad categories regarding herbicide volatility: High Volatile, Low Volatile, and Non-Volatile (Carter, 1960). Noble and Hamilton (1990) performed volatility testing with tomatoes and found that the methyl, ethyl, iso-butyl, and n-butyl esters of 2,4-D were rated as high-volatile and the 2-butoxyethyl and 2-ethylhexyl ester of 2,4-D and MCPA were low-volatile. 2,4-D butyl ester is categorized as a high-volatile ester, which is likely why it produced the greatest negative effects on the tomatoes. Speedzone, which contains 2,4-D, 2-ethylhexyl ester, caused significant negative effects to the tomatoes, but they were not as severe as with 2,4-D butyl ester. Cool Power and 4 Speed XT also contain formulations of low-volatile esters (Table 1), which likely accounts for their similarity to Speedzone concerning their volatility damage to tomatoes in our research.

Overall, the three herbicides containing low volatile ester formulations of 2,4-D and MCPA produced similar effects on the tomato plants; however, in some cases the effects were more severe depending on the herbicide. One factor contributing to the increased volatility damage with Cool Power and 4 Speed XT may be the increased amount of synthetic auxins they contain, compared to Speedzone. Cool Power and 4 Speed XT labeled rates for dandelion control contained 1.315 and 1.16 lbs ae A^{-1} of synthetic auxin herbicides respectively, compared to Speedzone which contained only 0.936 lbs ae A^{-1}. Behrens and Lueschen (1979) found that increasing the rate of dicamba resulted in significant increases in dicamba volatility injury to soybeans; however, they hypothesized that in a closed system the vapor pressure would reach a maximum and an additional rate increase would not increase volatility. Therefore, the increased amount of ae in Cool Power could explain why there was a significant reduction in quality at 10 DAT in Study 1 (Table 2), significantly lower dry weight in experiment 2 of Study 1 (Table 5), and significantly more callus formation at 16 DAT in Study 1 (Table 4) when compared to Speedzone, which contained 40% less ae.

Temperature is arguably the second most important component to consider when determining volatility. Previous research has shown that increasing temperatures will increase volatility (Que Hee and Sutherland, 1974; Behrens and Lueschen, 1979). This occurs because a compound's vapor pressure over an aqueous solution is exponentially dependent on temperature (Bedos et al., 2002). Therefore, an increase of 10°C can lead to a three-to four-fold increase in vapor pressure for most pesticides (Spencer and Cliath, 1990). In this study the tomatoes were placed in the laboratory at a constant temperature of 22.7°C for 24 hrs. From previous research, it is likely that tomato exposure to herbicide-treated turfgrass at temperatures ≥ 22.7°C would have resulted in increased volatility, and therefore, greater tomato damage.

In conclusion, Speedzone, 4 Speed XT, and Cool Power all contained low-volatile ester formulations of synthetic auxin herbicides, and the volatile gases escaping from turfgrass treated with these herbicides had a negative effect on tomato quality, epinasty, and callus formation in both the greenhouse and field volatility studies. Overall, the products containing low volatile esters had reduced volatility compared to 2,4-D butyl ester. Herbicides containing primarily amine formulations of synthetic auxins, such as, Trimec Classic, Surge, Confront, Escalade 2, and Imprelis SL produced minimal negative effects on tomato growth and were similar to the untreated water control with regard to tomato quality, epinasty, and callus formation. Therefore, turfgrass managers should consider using products containing amine formulations when volatility is a concern because of sensitive plants nearby, and/or when environmental conditions such as temperature favor volatility. Turfgrass managers should consider using spot applications of products containing low volatile esters when dealing with tough-to-control weeds to reduce the amount of area treated, and therefore, the amount of product available to volatilize.

Figure 1.1 Callus formation on a potted tomato plant 16 days after it had been enclosed in a chamber with Speedzone-treated tall fescue for 24 hours in 2010.

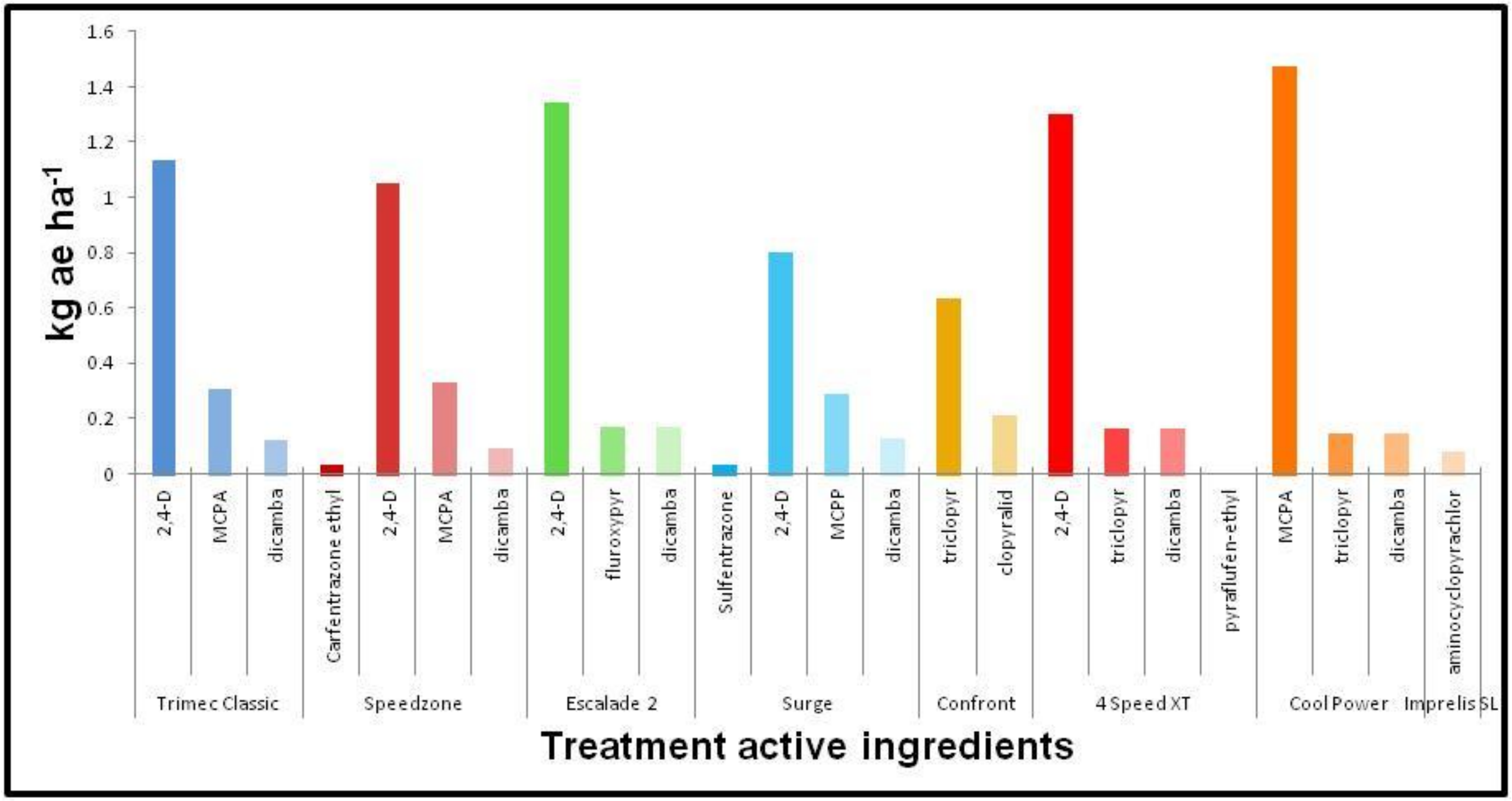

Figure 1.2 Herbicide acid equivalents (ae) used in greenhouse volatility studies.

Table 1.1 Active ingredients and their respective percentages for the herbicides used in greenhouse volatility studies.

Trimec Classic	
2,4-D, dimethylamine salt	25.93%
MCPP, dimethylamine salt	6.93%
Dicamba, dimethylamine salt	2.76%
Speedzone	
Carfentrazone-ethyl	0.62%
2,4-D, 2-ethylhexyl ester	28.57%
MCPP acid	5.88%
Dicamba acid	1.71%
Escalade II	
2,4-D, dimethylamine salt	39.53%
Fluroxypr, 1-methylheptyl ester	5.90%
Dicamba acid	4.10%
Surge	
Sulfentrazone	0.67%
2,4-D, dimethylamine salt	18.79%
MCPP, dimethylamine salt	6.80%
Dicamba, dimethylamine salt	3.02%
Confront	
Triclopyr, triethylamine salt	33.0%
Clopyralid, triethylamine salt	12.1%
4-Speed XT	
2,4-D, isooctyl ester	41.92%
Triclopyr, butoxyethyl ester	4.81%
Dicamba acid	3.46%
Pyraflufen ethyl	0.067%
Cool-Power	
MCPA, isooctyl Ester	56.14%
Triclopyr, butoxyethyl ester	5.00%
Dicamba acid	3.60%

Table 1.2 Effect of herbicide volatility on tomato plant visual quality after potted tomato plants were enclosed in a chamber with herbicide-treated tall fescue for 24 hours in Study 1.

	Quality^{w,x}			
Treatment^{y}	1 DAT^{z}	3 DAT	10 DAT	16 DAT
Water-control	8.6 a	8.5 a	8.5 a	8.6 a
Confront	8.6 a	8.5 a	8.1 a	8.5 ab
Surge	8.3 a	8.3 a	8.5 a	8.6 a
Trimec Classic	8.5 a	8.3 a	8.5 a	7.8 b
Escalade II	8.0 a	7.6 a	8.0 a	8.0 ab
Speedzone	3.0 b	3.3 b	5.1 b	4.6 c
4 Speed XT	2.6 b	3.1 b	4.6 bc	4.6 c
Cool Power	2.5 b	2.8 b	4.1 c	4.3 c
2,4-D butyl ester	1.6 c	2.8 b	2.5 d	1.5 d

^{w} Tomatoes were rated on a 1 to 9 scale (1 = dead, 9 = green, healthy, turgid plants).

^{x} Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

^{y} Treatments were ranked over 3 DAT.

^{z} DAT= days after treatment.

Table 1.3 Effect of herbicide volatility on tomato plant epinasty after potted tomato plants were enclosed in a chamber with herbicide-treated tall fescue for 24 hours in Study 1.

	Epinasty[w,x]			
Treatment[y]	1 DAT[z]	3 DAT	10 DAT	13 DAT
2,4-D butyl ester	7.6 a	7.5 a	6.3 a	4.6 a
Cool Power	6.8 b	6.6 ab	6.0 ab	5.8 a
Speedzone	6.6 b	6.6 ab	5.5 bc	5.5 a
4 Speed XT	6.6 b	6.3 b	5.1 c	5.1 ab
Escalade II	1.1 c	1.8 c	1.3 d	1.1 c
Trimec Classic	1.0 c	1.1 c	1.0 d	1.0 c
Surge	1.0 c	1.1 c	1.0 d	1.0 c
Confront	1.1 c	1.0 c	1.0 d	1.0 c
Water-control	1.0 c	1.0 c	1.0 d	1.0 c

[w] Tomato epinasty was rated on a 1 to 9 scale (1 = no epinasty, 9 = entire plant exhibiting severe epinasty).

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Treatments were ranked over 3 DAT.

[z] DAT = days after treatment.

Table 1.4 Effect of herbicide volatility on tomato plant callus formation after potted tomato plants were enclosed in a chamber with herbicide-treated tall fescue for 24 hours in Study 1.

	Callus Formation[w,x]			
Treatment[y]	1 DAT[z]	3 DAT	10 DAT	16 DAT
Cool Power	1.0 a	1.3 ab	5.1 a	6.0 a
Speedzone	1.0 a	1.5 a	4.6 ab	4.8 b
4 Speed XT	1.0 a	1.3 ab	4.0 b	4.5 b
2,4-D butyl ester	1.0 a	1.0 b	2.5 c	2.0 c
Trimec Classic	1.0 a	1.0 b	1.0 d	1.0 c
Confront	1.0 a	1.0 b	1.0 d	1.0 c
Escalade II	1.0 a	1.0 b	1.0 d	1.0 c
Surge	1.0 a	1.0 b	1.0 d	1.0 c
Water-control	1.0 a	1.0 b	1.0 d	1.0 c

[w] Tomato callus formation was rated on a 1 to 9 scale (1 = no callus formation, 9 = entire main stem covered in tumor-like growth).

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Treatments were ranked over 10 DAT.

[z] DAT = days after treatment.

Table 1.5 Effect of herbicide volatility on tomato plant dry weight after potted tomato plants were enclosed in a chamber with herbicide-treated tall fescue for 24 hours in Study 1.

	Dry Weight (g)[x,y]	
Treatments[z]	Experiment 1	Experiment 2
Escalade II	3.38 bcd	1.90 a
Surge	3.97 abc	1.77 ab
Water-control	5.28 a	1.76 ab
Trimec Classic	2.57 cd	1.69 abc
Confront	4.20 ab	1.52 bc
Speedzone	2.87 bcd	1.33 c
4 Speed XT	2.85 bcd	0.89 d
Cool Power	2.21 d	0.87 d
2,4-D butyl ester	0.62 e	0.32 e

[x] g = grams

[y] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[z] Treatments were ranked over Experiment 2.

Table 1.6 Effect of herbicide volatility on tomato plant visual quality after potted tomato plants were enclosed in a chamber with herbicide-treated tall fescue for 24 hours in Study 2.

	Quality[w,x]			
Treatment[y]	1 DAT[z]	3 DAT	10 DAT	16 DAT
Trimec Classic	8.8 a	8.5 a	8.4 a	8.3 a
Water-control	8.7 a	8.5 a	8.3 a	8.2 a
Imprelis SL	8.5 a	8.6 a	8.1 a	8.4 a
Surge	8.5 a	8.6 a	8.2 a	7.7 a
Speedzone	3.8 b	6.0 b	5.8 b	4.9 b
2,4-D butyl ester	3.5 b	4.0 c	3.3 c	1.9 c

[w] Tomatoes were rated on a 1 to 9 scale (1 = dead, 9 = green, healthy, turgid plants).

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Treatments were ranked over 1 DAT.

[z] DAT= days after treatment.

Table 1.7 Effect of herbicide volatility on tomato plant epinasty after potted tomato plants were enclosed in a chamber with herbicide-treated tall fescue for 24 hours in Study 2.

	Epinasty[w,x]			
Treatment[y]	1 DAT[z]	3 DAT	10 DAT	13 DAT
2,4-D butyl ester	7.2 a	6.5 a	5.5 a	5.5 a
Speedzone	6.6 a	3.9 b	3.4 b	4.0 b
Surge	1.1 b	1.1 c	1.5 c	1.6 c
Imprelis	1.1 b	1.1 c	1.3 c	1.2 c
Trimec Classic	1.0 b	1.1 c	1.1 c	1.0 c
Water-control	1.0 b	1.1 c	1.1 c	1.0 c

[w] Tomato epinasty was on a 1 to 9 scale (1 = no epinasty, 9 = entire plant exhibiting severe epinasty).

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Treatments were ranked over 10 DAT.

[z] DAT = days after treatment.

Table 1.8 Effect of herbicide volatility on tomato plant callus formation after potted tomato plants were enclosed in a chamber with herbicide-treated tall fescue for 24 hours in Study 2.

	Callus Formation[w,x]			
Treatment[y]	1 DAT[z]	3 DAT	10 DAT	16 DAT
2,4-D butyl ester	1.0 a	2.4 a	4.0 a	4.7 a
Speedzone	1.0 a	1.5 b	3.1 a	3.7 a
Surge	1.0 a	1.0 c	1.1 b	1.1 b
Trimec Classic	1.0 a	1.0 c	1.0 b	1.0 b
Imprelis	1.0 a	1.0 c	1.0 b	1.0 b
Water-control	1.0 a	1.0 c	1.0 b	1.0 b

[w] Tomato callus formation was on a 1 to 9 scale (1 = no callus formation, 9 = entire main stem covered in tumor-like growth).

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Treatments were ranked over 10 DAT

[z] DAT = days after treatment

Table 1.9 Effect of herbicide volatility on tomato plant dry weight after potted tomato plants were enclosed in a chamber with herbicide-treated tall fescue for 24 hours in Study 2.

Treatment	Dry Weight (g)[y,z]
Water-control	5.08 a
Trimec Classic	4.78 a
Surge	4.60 a
Imprelis	4.54 ab
Speedzone	3.87 b
2,4-D butyl ester	0.88 c

[y] g = grams

[z] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

Table 1.10 Effect of herbicide volatility on tomato plant visual quality after potted tomato plants were exposed to herbicide-treated tall fescue in the field for 12 hours in 2011.

	Quality[w,x]			
Treatment[y]	2 DAT[z]	7 DAT	10 DAT	16 DAT
Imprelis SL	7.7 a	7.7 a	7.7 a	7.8 a
Water-control	7.7 a	7.7 a	7.6 a	7.6 a
Speedzone	6.4 b	6.0 b	6.2 b	6.4 b
2,4-D butyl ester	5.3 c	5.3 c	5.1 c	5.0 c

[w] Tomatoes were rated on a 1 to 9 scale (1 = dead, 9 = green, healthy, turgid plants).

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Treatments were ranked over 10 DAT.

[z] DAT= days after treatment

Table 1.11 Effect of herbicide volatility on tomato plant epinasty after potted tomato plants were exposed to herbicide-treated tall fescue in the field for 12 hours in 2011.

	Epinasty[w,x]			
Treatment[y]	2 DAT[z]	7 DAT	10 DAT	16 DAT
2,4-D butyl ester	3.9 a	3.7 a	3.6 a	3.6 a
Speedzone	2.4 b	2.2 b	1.8 b	1.4 b
Imprelis SL	1.0 c	1.0 c	1.0 c	1.0 c
Water-control	1.0 c	1.0 c	1.0 c	1.0 c

[w] Tomato epinasty was on a 1 to 9 scale (1 = no epinasty, 9 = entire plant exhibiting severe epinasty).

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Treatments were ranked over 10 DAT.

[z] DAT= days after treatment.

Table 1.12 Effect of herbicide volatility on tomato plant callus formation after potted tomato plants were exposed to herbicide-treated tall fescue in the field for 12 hours in 2011.

	Callus formation[w,x]			
Treatment[y]	2 DAT[z]	7 DAT	10 DAT	16 DAT
2,4-D butyl ester	1.0 a	2.2 a	2.2 a	2.5 a
Speedzone	1.0 a	1.3 b	1.3 b	1.2 b
Imprelis SL	1.0 a	1.0 c	1.0 c	1.0 b
Water-control	1.0 a	1.0 c	1.0 c	1.0 b

[w] Tomato callus formation was on a 1 to 9 scale (1 = no callus formation, 9 = entire main stem covered in tumor-like growth).

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Treatments were ranked over 10 DAT.

[z] DAT= days after treatment.

Table 1.13 Effect of herbicide volatility on tomato plant dry weight after potted tomato plants were exposed to herbicide-treated tall fescue in the field for 12 hours in 2011.

Treatment	Dry Weight (g)[y,z]
Water-control	3.41 a
Speedzone	3.16 ab
Imprelis SL	3.10 b
2,4-D butyl ester	2.74 c

[y] g = grams

[z] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

Chapter 2 - Influence of Spring and Fall Herbicide Application Timing on Dandelion Control in Turfgrass with Standard and New Herbicides

Introduction

Common dandelion (*Taraxacum officinale* Weber) is one of the most widely recognized weeds of turfgrass. It is a simple perennial, forming a basal rosette of leaves and bright yellow flowers (Uva et al., 1997). Dandelions can reproduce through wind-dispersed seeds or from taproot fragments (McCarty et al., 2001). Dandelions are apomictic, so pollination is not needed to produce viable seeds (Uva et al., 1997). The wind-dispersed seeds can travel long distances and infest previously weed-free areas. Mechanical control of dandelion is difficult because the taproot must effectively be removed or destroyed. A study on dandelion control with 2,4-D and mechanical treatments found no measure of control was achieved with hand-weeding alone (Mann, 1981). Many turf managers have achieved acceptable dandelion control using selective herbicides (Christians, 2007; Gardner, 2009; Loughner and Nolting, 2010).

Fall is considered the best time for herbicidal control of perennial broadleaf weeds in turfgrass (Branham, 1990; McCarty et al., 2001; Reicher and Weisnenberger, 2007; Wilson and Michiels, 2003). There are different theories concerning the effectiveness of fall applications. Branham (1990) posited that herbicidal control in the fall is likely more effective because plants are moving carbohydrate reserves to underground storage structures, which is believed to aid in the movement of xenobiotics to their site of action. An alternative theory involves root carbohydrate levels: Wilson and Michiels (2003) found that fall dicamba treatments to Canada thistle (*Cirsium arvense* (L.) Scop,) and dandelion reduced quantities of low-degree-of-polymerization fructans in roots. They speculated that decreased root fructan concentrations can cause plants to be more susceptible to winter kill and to have inadequate energy reserves needed to reinitiate growth in the spring. If the latter scenario is correct, translocation of the active ingredient may not be directly involved with effective weed control in the fall.

Fall may be the optimal time for herbicidal control of perennial broadleaf weeds, but turf managers need herbicidal options in the spring to meet their clients' demands. There is evidence to suggest that acceptable perennial broadleaf control can be achieved in the spring. Tworkoski (1992) reported that maximum basipetal transport of herbicides in Canada thistle may occur in the early spring or fall.

Most products used for broadleaf weed control in turfgrass are pre-formulated products that contain several active ingredients. The multiple active ingredients allow turf managers to control a wide array of broadleaf weeds. Many of the active ingredients found in these products, such as 2,4-D, dicamba, MCPP, MCPA, clopyralid, fluroxypyr, triclopyr, quinclorac, and aminocyclopyrachlor are in the synthetic auxin class of herbicides (Senseman, 2007). Synthetic auxin herbicides are highly selective because grasses can inactivate these compounds by conjugation, while broadleaf weeds cannot and thus are controlled (Christians et al., 2009).

In recent years, many products have included an active ingredient from the protoporphyrinogen oxidase (PPO) inhibiting class, such as pyraflufen-ethyl, carfentrazone-ethyl, or sulfentrazone (Senseman, 2007). These compounds inhibit PPO, an enzyme in chlorophyll synthesis needed for catalyzing the oxidation of protoporphyrinogen IX to protoporphyrin IX (Senseman, 2007). PPO inhibitors are often included in tank mixes with synthetic auxin herbicides and provide rapid necrosis of foliage. Many researchers have reported acceptable control of perennial broadleaf weeds using such combination products (Olson and Hall, 1988; Haley et al., 1994; Watschke and Borger, 1999; Reicher and Weisenberger, 2007;

Loughner and Nolting, 2010). However, Ashigh and Hall (2010) reported reduced glyphosate activity when combined with the PPO inhibitor saflufenacil and hypothesized the rapid contact activity of saflufenacil limited the translocation of glyphosate. Similarly, a study conducted by Breeden and McElroy (2006) found that carfentrazone significantly reduced white clover (*Trifolium repens* L.) control when tank mixed with foramsulfuron, compared to foramsulfuron alone.

Turf managers need information on weed control options throughout the entire growing season to meet their clients' expectations. Because of the recent introduction of several new herbicides to the turfgrass market, and the lack of research investigating the effect of application timing on their efficacy, the objectives of our study were to determine the effect of spring and fall application timing on dandelion control with seven herbicides in 2010 and nine herbicides in 2011.

Materials and Methods

Site Characteristics and Experimental Design

Field studies were conducted in 2010 and 2011 on adjacent sites at the Rocky Ford Turfgrass Research Center in Manhattan, KS. The soil at both sites was a Chase Silt Loam (fine, smectitic, mesic, Aquertic Argiudoll) with a pH of 6.9. Soil tests indicated adequate levels of P and K. The 1.2 x 1.5 m plots were mown at 7.6 cm and irrigated as needed to prevent drought stress in 2010. In 2011, the site was irrigated as needed to prevent dormancy. The 2010 site contained turf-type tall fescue (*Festuca arundinacea* Schreb.) with an existing dandelion stand. The 2011 site was previously seeded to crested wheatgrass (*Agropyron cristatum* L.) and had an existing dandelion infestation. However, the crested wheatgrass density was poor and dandelions were much larger compared to the 2010 site. Dimension 2EW herbicide [dithiopyr, S,S'-

dimethyl 2-(difluoromethyl)-4-(2-methylpropyl)-6-(trifluoromethyl)-3,5-pyridinecarbothioate) Dow AgroSciences, Indianapolis, IN] was applied at 0.195 kg a.i. ha^{-1} on May 27, 2010 and May, 2011 to control large crabgrass (*Digitaria sanguinalis)*. A randomized complete block design with three replicates was used to evaluate seven herbicides in 2010 and nine herbicides in 2011 at six application timings. Each replication of the design contained six untreated control plots.

Treatments and Application

All herbicides were applied at their lowest label rate recommended for dandelion control (Table 1). The seven herbicides in 2010 were Trimec Classic, Speedzone, Escalade II, Surge, Confront, 4 Speed XT, Cool-Power. In 2011, Imprelis SL and Imprelis G were added for a total of nine herbicides. The spring application timings coincided with dandelion pre-bloom, peak bloom, and post-bloom. In 2010, treatments were applied on April 4 (pre-bloom), April 20 (peak bloom), May 27 (post-bloom), September 11, and October 6. The sixth herbicide timing consisted of a split application, the first on April 4, and second on October 6. In 2011, the treatments were applied on April 8 (pre-bloom), April 18 (peak bloom), May 31 (post-bloom), September 14, and October 11. The sixth treatment was a split application applied on April 8 and October 11. Herbicides were applied with a two nozzle (TeeJet XR8002VS, Spray Systems Co., Wheaton, IL), CO_2-pressurized backpack sprayer operating at 207 kPa to deliver a spray volume of 342 L ha^{-1}.

Measurements

Treatment efficacy was determined using a 1.01 × 1.62 m rating grid sectioned into 160 individual 10.16 × 10.16 cm squares.   The grid was placed over each treated plot, a count was registered for each square containing a dandelion, and the counts were recorded. Percent control was calculated by comparing the counts in treated plots with the mean count of the six untreated plots in the same replication.

In 2010, percent control data were determined at 30 days after treatment (DAT), end of season (Nov 10, 2010), and the following spring (Apr 27, 2011). In 2011, percent control data were determined at 30 DAT, 60 DAT, and end of season (Nov 12, 2011). Speed of activity data were recorded for the spring post-bloom application timing at 2, 4, 8, 10, and 18 DAT using a 1 to 9 scale (1= normal turgidity, no leaf curling or firing, 6= loss of turgity, % 50 of foliage necrotic, 9= complete necrosis of foliage).

All percent control data were arcsine-transformed, then subjected to ANOVA and means separated using Fisher's protected LSD range test (MSTAT, 1993). The transformed means were used to determine statistical differences, but the untransformed means are presented in Tables 3 to 8. A three-factor factorial analysis (Herbicide x Timing x Year) was conducted to determine if data from 2010 and 2011 could be combined. The timing x year interaction was significant (Table 2); therefore, data for each year is presented separately.

Results

Influence of application timing in 2010

At the spring pre-bloom timing Speedzone provided 94.4 % dandelion control 30 DAT, which was significantly greater than Confront, Trimec Classic and Cool Power. Speed XT, Surge, and Escalade 2 provided equivalent control to Speedzone (Table 3). Cool Power gave the lowest percent control of all treatments at the spring pre-bloom timing, at 80.2%.

4 Speed XT provided (96.3%) dandelion control 30 DAT at the spring peak-bloom timing, which was greater than Confront, Trimec Classic and Cool Power, but not different from

Speedzone, Surge, or Escalade 2 (Table 3). At 30 DAT, Cool Power provided the lowest dandelion control (65.5%) at the spring peak-bloom timing.

There were no differences at 30 DAT among herbicides applied at the spring post-bloom timing; all herbicides provided ≥ 97.7% dandelion control (Table 3).

At the late-summer application timing, no significant differences were observed between herbicides 30 DAT; all provided ≥ 96.6% dandelion control (Table 3).

No differences were observed 30 DAT among herbicides applied at the early-fall timing, even though percent dandelion control ranged from 48.5 to 94.9% (Table 3). Additionally, no significant differences were observed 30 DAT among herbicides applied at the spring pre-bloom + early-fall application timing; all herbicides had ≥ 98.8% dandelion control.

Percent dandelion control was recorded for all herbicides across all six application timings at the end of the growing season (EOS) on November 10 (Table 4). There were no differences among herbicides applied at any timing at the EOS rating. All herbicides provided ≥ 93.5% dandelion control at the spring pre-bloom timing, ≥ 88.7% control at the spring peak-bloom timing, ≥ 90.5% control at the spring post-bloom timing, and ≥ 99.1 % control at the late summer timing. Percent dandelion control ranged from 69.3 to 100.0% at the early fall application timing, but it is important to note that the herbicides had only been applied about one month prior to the EOS rating for this timing. All herbicides provided 100.0% EOS dandelion control when receiving both the spring pre-bloom + early fall applications.

Percent dandelion control was evaluated in the spring of 2011(April 8) for all herbicides applied at the six application timings in 2010 (Table 5). All herbicides provided ≥ 95.2% at the spring pre-bloom timing when rated the following spring. Dandelion control ranged from 79.8 to 100.0% at this time, but no differences were observed. All herbicides applied at the spring post-bloom timing in 2010 provided ≥ 95.1% dandelion control at the spring rating date in 2011. No differences among herbicides were observed at the late-summer application timing, in which dandelion control ranged from 81.3 to 98.0%. 4 Speed XT gave 99.1% dandelion control at the early-fall timing, but was not different from Confront, Trimec Classic, Escalade 2 and Cool Power. All herbicides provided ≥ 99.5% dandelion control when applied spring pre-bloom + early-fall.

Influence of application timing in 2011

In 2011, Imprelis SL and Imprelis G were added for a total of nine herbicides, applied at the same six application timings used in 2010. Percent dandelion control was recorded at 30 and 60 DAT, and EOS. Overall, performance of the herbicides across all timings showed a much greater range than in 2010 (Table 6).

When applied spring pre-bloom, 4 Speed XT provided the highest dandelion control 30 DAT (97.7%), which was greater than Imprelis G, Cool Power and Confront , while Imprelis SL, Trimec Classic, Escalade 2, Speedzone, and Surge provided equivalent control to 4 Speed XT (Table 6). Confront had the poorest control at 78.5%.

Imprelis SL applied at the spring peak-bloom timing provided 99.0% dandelion control 30 DAT. This was greater than all herbicides except Speedzone and Imprelis G. Trimec Classic, Confront, Cool Power, and Surge all had ≤ 50.6 % dandelion control.

Trimec Classic applied at the spring post-bloom timing provided 100.0% dandelion control 30 DAT, but was not different from Imprelis SL and 4 Speed XT. Imprelis G, Confront, and Cool Power were the only treatments with ≤ 89.7% dandelion control at the post bloom application timing, with Confront having the poorest control at 73.4%.

Imprelis SL applied at the late summer application timing provided 98.1% dandelion control 30 DAT, which was greater than Cool Power, Surge, and Imprelis G. All other herbicides provided equivalent control to Imprelis SL. Imprelis G when applied at the late summer timing provided the poorest dandelion control (42.9%).

No differences among herbicides were observed 30 DAT at the early fall application timing or at the spring pre-bloom + early fall application timing; this was despite the fact that control ranged from 61.7 to 98.0% and 57.8 to 100.0%, respectively.

At 60 DAT, Imprelis SL at the spring pre-bloom timing gave 99.4% dandelion control which was greater than all herbicides except 4 Speed XT (Table 7). The remaining herbicides provided ≥ 88.5% control, except for Cool Power and Confront, which gave 54.8 and 48.7% control, respectively.

At the spring peak-bloom timing, Imprelis SL gave 99.3% dandelion control 60 DAT, which was significantly greater than all herbicides except Speedzone or Imprelis G. By contrast, Trimec Classic, Surge, Cool Power, and Confront all provided ≤ 66.1% dandelion control.

When applied spring post-bloom, Imprelis SL gave 99.5% control 60 DAT, which was greater than all herbicides except 4 Speed XT, Trimec Classic, and Speedzone. All other herbicides gave ≤ 73.7% control, with Imprelis G and Confront giving ≤ 48.8%.

No significant differences at 60 DAT were recorded among herbicides when applied in late summer. Percent dandelion control when applied in late summer ranged from 81.9 to 98.2%. Data for early fall at 60 DAT were not collected in 2011 because the EOS was approximately 30 days after the early fall applications.

Percent dandelion control was recorded at EOS for the three spring application timings: pre-bloom, peak-bloom, and post-bloom. Data were not collected at EOS for the late summer and early fall application timings because EOS would have been equivalent to 60 DAT for late summer applications (presented in Table 7) and EOS was equivalent to 30 DAT for the early fall applications (presented in Table 6).

When herbicides were applied pre-bloom, no significant differences among herbicides occurred at EOS, even though percent control ranged from 41.8 to 71.5% (Table 8). When applied at peak bloom, Imprelis SL and Imprelis G provided significantly greater EOS control, giving 85.6 and 83.4% control, respectively, while the seven remaining herbicides provided ≤ 33.8% control. When applied post-bloom, there were no significant differences at EOS among the herbicides, though percent control ranged from 15.9 to 67.8%.

Speed of Activity

Speed of activity was recorded for the spring post-bloom application timing at 2, 4, 8, 10, and 18 DAT. Speedzone had the highest activity (5.6) at 2 DAT, but was not statistically different from 4 Speed XT (Table 9). Confront and Imprelis G had the lowest activity at 2 DAT. At 4 and 8 DAT Speedzone again had the most activity (7.0 and 8.0, respectively), which again was not statistically different from 4 Speed XT (6.0 and 7.3, respectively). Imprelis G and Confront continued to have the lowest activity at 4 and 8 DAT. The same trends continued at 10 and 18 DAT, although Escalade 2 showed equivalent activity to Speedzone and 4 Speed XT by 10 DAT, and all herbicides except Confront and Imprelis G began to show equivalent activity to either Speedzone or 4 Speed XT at 18 DAT. Confront and Imprelis G had the least overall activity through 18 DAT.

Discussion

Influence of application timing in 2010

Spring herbicide application dates coincided with dandelion anthesis stages, providing turf managers a phenological indicator to aid in determining the appropriate time to treat. All herbicides provided ≥ 48.5% dandelion control at all application and rating dates. Overall, control was maximal at 30 DAT for herbicides containing a PPO inhibitor such as Speedzone, 4 Speed XT, and Surge; however, many herbicides needed additional time to cause complete mortality. At 30 DAT, all herbicides provided excellent dandelion control when applied at the spring post-bloom, late summer, or spring pre-bloom + early fall timing. While early fall applications are recommended by experts (Fagerness, 2001), the early fall timing had the largest range of percent control (48.5 to 94.9%) values and showed no differences among treatments 30 DAT. This may be because in October plant growth was slower due to lower air and soil temperatures compared to summer condtions. A decrease in plant growth reduces the transpiration stream which is critical in the movement of xylem- and phloem-translocated synthetic auxin herbicides (Van Overbeek, 1956). It is likely that the cool temperatures delayed the speed of activity at the early fall timing, therefore, 30 DAT was not enough time to determine ultimate control. Percent dandelion control at the end of growing season produced noticeably different results when compared to the 30 DAT rating in 2010. All herbicide treatments had good to excellent dandelion control for each herbicide timing, except for the early fall timing for reasons mentioned above.

Excellent dandelion control was still recorded at several application timings when evaluated the following spring. Of the spring application timings, the spring pre-bloom and post-bloom timings gave the best control when rated the following spring. However, the range of percent control at the peak bloom timing increased at the spring rating in 2011 compared to the EOS rating in 2010. It is likely the source to sink movement was highly acropetal at peak-bloom, causing a decrease in the amount of free acid herbicide moving to the roots. At the pre-bloom timing the plant is likely moving a large amount of photosynthate from the leaves to initiate the growth of new viable roots. Tworkoski (1992) reported a shift in carbohydrate allocation in the early spring and fall in Canada thistle, resulting in maximum basipetal transport of herbicides. When herbicides were applied at the late-summer application timing, control was generally good the following spring, with no significant differences among herbicides. This finding supports extension recommendations in many states, including Kansas (Fagerness, 2001). When applied in early fall, all herbicides except Speedzone and Surge showed good control the following spring. The cause for the decline in control with Speedzone and Surge is unknown, but both products are mixes containing a PPO inhibitor, which has previously been shown to decrease weed control in certain instances (Breeden and McElroy, 2006). Interestingly, 4 Speed XT also contains a PPO inhibitor, and it had the highest dandelion control. Speedzone and Surge have less synthetic auxin acid equivalent compared to the other herbicides, which could also account for the decrease in control (Figure 1).

Influence of application timing in 2011

Unlike 2010, the level of dandelion control in 2011 was highly variable and not as long-term. The study areas were quite different from 2010 to 2011. The 2010 site had a dense stand of turf type tall fescue which resulted in small dandelions while the turf competition in the 2011 site was very poor and resulted in much larger, more mature dandelions. Several factors were likely responsible for the reduced dandelion control in 2011 compared to 2010. Younger plants are generally easier to control compared to older plants. Furthermore, the cuticle of younger plants is generally less developed, allowing for increased absorption of herbicidal compounds (Peterson et al., 2010). Derr and Serensits (2006) hypothesized that increased weed control in their first trial compared to the second was likely the result of younger plants and competition from tall fescue. The importance of a competitive turfgrass stand is critical for long-term weed control (Johnson and Boyer, 1981; Calhoun et al., 2005; Alumai et al., 2008). The poor turfgrass density in 2011 allowed reemerged dandelions to have direct access to sunlight in order to produce new photosynthate. Plants that resprouted in 2010 relied heavily on carbohydrate reserves from the taproot because the competition from turfgrass reduced the amount of photosynthate produced in the new leaves. Ultimately, plants that reemerged in 2010 may have depleted their carbohydrate reserves when attempting to reinitiate growth and resulted in better long-term control compared to 2011.

In 2011, two additional herbicides were added: Imprelis SL and Imprelis G. At 30 DAT the variability in herbicide performance was highest when herbicides were applied at the spring peak-bloom timing. This was likely because source to sink movement was more acropetal at this timing, as discussed previously. However, several herbicides, including Imprelis SL and G, and Speedzone, still gave excellent control. Compared to 2010, there was also greater separation in herbicide performance when applied spring pre- or post-bloom, likely caused by the larger dandelions, combined with less turfgrass competition, present in the 2011 study. At the late summer application timing all herbicides except Imprelis G good to excellent control 30 DAT; Imprelis G gave very poor control, which was not the case at the other application timings. The study area in 2011 was not under automatic irrigation, and was irrigated only to prevent the weeds from entering dormancy. Imprelis G is a granular product whose activity is solely dependent upon root uptake. The reduction in irrigation and seasonably dry conditions likely reduced the availability of aminocyclopyrachlor in the soil water solution and reduced dandelion control. Overall, Imprelis SL and Speedzone provided the most consistent dandelion control 30 DAT at all application timings.

At 60 DAT, overall control was poorer at for the pre- and post-bloom timings, compared to 30 DAT. Thirty DAT is likely not enough time for regrowth to occur; however, the 60 DAT rating date is able to capture regrowth. Dandelion regrowth from the taproot is likely why a reduction in dandelion control was observed at the pre- and post-bloom timings at 60 compared to 30 DAT.

Imprelis SL, Speedzone, and 4 Speed XT provided good to excellent control 60 DATwhen applied at all timings, including spring peak-bloom. Trimec Classic performed similarly at all but the peak bloom timing, where it gave poor control. 4 Speed XT and Speedzone contain ester formulations of synthetic auxins which are more soluble in the plant cuticle, resulting in increased absorption (Nice et al., 2004). Trimec Classic contains only amine formulations of synthetic auxin herbicides, and absorption relies heavily on water soluble paths through the cuticle (Gardner and Custis, 2007).

Unlike 2010, dandelion control at EOS was drastically reduced for all herbicides when applied at any of the three spring application timings. The difference from 2010 may have caused by the larger dandelions and reduced turfgrass competition in 2011, as noted previously. Other researchers have recorded good dandelion control several weeks after treatment, but many noticed regrowth from the taproot (Watschke and Borger, 1999; Mann, 1981), and this apparently occurred in our study as well.

Overall, this study showed that long term dandelion control can be achieved in the spring with several herbicides, especially if applied pre- or post-bloom, and turfgrass competition is present. Applicators should generally avoid applying herbicides when dandelions are at peak bloom to avoid variability in control. When turfgrass competition was present, Speedzone, 4 Speed XT, and Imprelis SL provided effective long-term control at all spring timings and when turfgrass competition was minimal, they still provided effective control through 60 DAT at all spring timings. spring pre- and post-bloom timings. In the same way, Trimec Classic was effective at all herbicide timings except peak bloom, and Surge and Escalade 2 were effective if applied pre-bloom or in late summer. Cool Power and Confront were the least effective herbicides in our research, and are not recommended for spring applications.

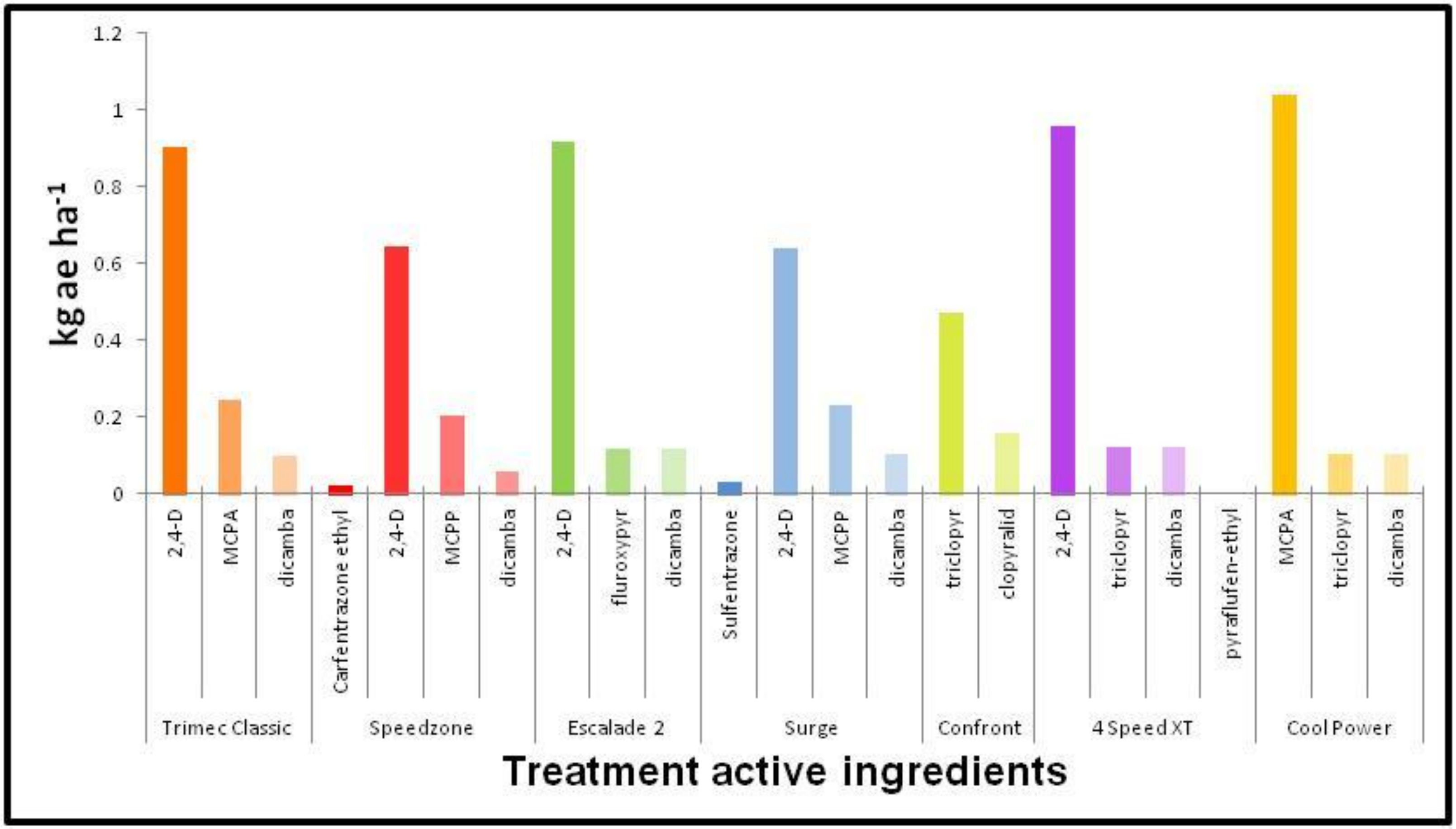

Figure 2.1 Amount of herbicide acid equivalent in rates recommended for common dandelion control used in application timing studies in 2010 and 2011.

Table 2.1 Herbicide active ingredients and lowest label rates recommended for common dandelion control for herbicides used in application timing studies in 2010 and 2011.

Herbicide	Active Ingredients	Product ha^{-1}
Trimec Classic	2,4-D, dimethylamine salt MCPP, dimethylamine salt Dicamba, dimethylamine salt	3.818 L
Speedzone	Carfentrazone-ethyl 2,4-D, 2-ethylhexyl ester MCPP acid Dicamba acid	3.500 L [1]
Escalade 2	2,4-D, dimethylamine salt Fluroxypr,1-methylheptyl ester Dicamba acid	2.386 L
Surge	Sulfentrazone 2,4-D, dimethylamine salt MCPP, dimethylamine salt Dicamba, dimethylamine salt	3.818 L
Confront	Triclopyr, triethylamine salt Clopyralid, triethylamine salt	1.750 L
4 Speed XT	2,4-D, isooctyl ester Triclopyr, butoxyethyl ester Dicamba acid Pyraflufen ethyl	3.500 L
Cool Power	MCPA, isooctyl Ester Triclopyr, butoxyethyl ester Dicamba acid	2.895 L
Imprelis SL	Aminocyclopyrachlor, potassium salt	0.328 L
Imprelis 0.05G	Aminocyclopyrachlor, potassium salt	2.240 kg

Table 2.2 Analysis of variance for percent dandelion control at the end of growing season in 2010 and 2011.

Source	*P*-value
Herbicide	0.0064
Timing	<0.0001
Herbicide x Timing	0.0114
Year	<0.0001
Herbicide x Year	NS
Timing x Year	<0.0001
Herbicide x Timing x Year	NS

Table 2.3 Percent dandelion control 30 days after treatment in 2010 when broadleaf herbicides were applied at different application timings[w].

	% dandelion control[x]					
Herbicide[y]	Spring Pre-Bloom	Spring Peak-Bloom	Spring Post-Bloom[z]	Late-Summer	Early-Fall[z]	Spring Pre-Bloom + Early Fall[z]
4 Speed XT	93.1 a	96.3 a	99.1	100.0	88.9	98.8
Speedzone	94.4 a	94.5 a	100.0	97.1	94.9	100.0
Surge	88.0 ab	91.8 ab	99.3	98.5	80.5	99.6
Escalade 2	88.5 ab	89.0 abc	100.0	100.0	67.1	100.0
Confront	82.0 b	80.6 bcd	97.7	96.6	44.4	99.5
Trimec Classic	80.5 b	75.7 cd	100.0	100.0	48.5	100.0
Cool Power	80.2 b	65.5 d	100.0	100.0	76.9	99.0

[w] Spring Pre-Bloom: April 7; Spring Peak-Bloom: April 20; Spring Post-Bloom: May 27; Late Summer: September 11; Early Fall: October 6.

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Herbicides are ranked over Spring Peak-Bloom timing.

[z] No significant differences among treatments

Table 2.4 Percent dandelion control at the end of growing season on November 10, 2010 when broadleaf herbicides were applied at different application timings[y].

	% dandelion control					
Herbicide[z]	Spring Pre-Bloom	Spring Peak-Bloom	Spring Post-Bloom	Late-Summer	Early-Fall	Spring Pre-Bloom + Early Fall
4 Speed XT	98.7	100.0	90.5	99.5	98.7	100.0
Trimec Classic	99.5	98.2	98.7	100.0	86.1	100.0
Surge	100.0	98.2	97.8	99.1	91.7	100.0
Escalade 2	100.0	96.9	98.7	100.0	91.7	100.0
Confront	100.0	95.6	99.1	100.0	69.3	100.0
Speedzone	93.5	93.5	96.9	99.1	100.0	100.0
Cool Power	99.1	88.7	96.5	100.0	91.3	100.0

[y] Spring Pre-Bloom: April 7; Spring Peak-Bloom: April 20; Spring Post-Bloom: May 27; Late Summer: September 11; Early Fall: October 6.

[z] Herbicides are ranked over Spring Peak-Bloom timing.

Table 2.5 Percent dandelion control across all herbicides and application timings[w] in 2010 in the following spring on April 8, 2011.

Herbicide	% dandelion control					
	Spring Pre-Bloom	Spring Peak-Bloom[z]	Spring Post-Bloom[z]	Late-Summer[z]	Early-Fall	Spring Pre-Bloom + Early Fall[z]
4 Speed XT	99.0	100.0	96.7	97.1	99.1 a	100.0
Surge	99.5	98.7	95.4	94.0	81.6 bc	99.5
Speedzone	95.2	93.7	95.1	81.3	83.8 c	100.0
Confront	100.0	93.0	98.1	94.7	89.8 abc	100.0
Escalade 2	99.0	89.8	97.0	98.0	96.8 ab	100.0
Cool Power	97.6	84.6	95.5	92.6	97.6 ab	100.0
Trimec Classic	98.6	79.8	98.0	97.5	90.8 ab	100.0

[w] Spring Pre-Bloom: April 7; Spring Peak-Bloom: April 20; Spring Post-Bloom: May 27; Late Summer: September 11; Early Fall: October 6.

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Herbicides are ranked over Spring Peak-Bloom timing.

[z] No significant differences among treatments.

Table 2.6 Percent dandelion control 30 days after treatment (DAT) in 2011 when broadleaf herbicides were applied at different application timings[w].

	% dandelion control					
Herbicide	Spring Pre-Bloom	Spring Peak-Bloom	Spring Post-Bloom	Late-Summer	Early-Fall	Spring Pre-Bloom + Early Fall
Imprelis SL	92.4 ab	99.0 a	96.2 abc	98.1 a	85.3	96.7
Trimec Classic	95.9 a	42.3 de	100.0 a	95.2 ab	75.6	59.7
Escalade 2	93.9 a	67.3 cd	94.0 bcd	92.3 ab	86.6	77.0
4 Speed XT	97.7 a	79.7 bc	99.0 ab	90.3 ab	98.0	100.0
Speedzone	96.4 a	90.7 ab	95.1 bcd	90.2 ab	95.2	98.6
Confront	78.5 c	42.7 de	73.4 f	90.5 ab	61.7	89.7
Cool Power	81.5 c	30.0 e	82.3 def	86.4 b	72.0	57.8
Surge	95.0 a	50.6 de	89.7 cde	82.5 b	87.9	92.7
Imprelis G	83.9 bc	89.1 ab	77.7 ef	42.9 c	82.8	90.3

[w] Spring Pre-Bloom: April 8; Spring Peak-Bloom: April 18; Spring Post-Bloom: May 31; Late Summer: September 19; Early Fall: October 6.

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Herbicides are ranked over late summer timing.

[z] No significant differences among treatments

Table 2.7 Percent dandelion control 60 days after treatment (DAT) in 2011 when broadleaf herbicides were applied at different application timings[w].

	% dandelion control[x]			
Herbicide[y]	Spring Pre-Bloom	Spring Peak-Bloom	Spring Post-Bloom	Late-Summer[z]
Imprelis SL	99.4 a	99.3 a	99.5 a	81.9
4 Speed XT	97.3 ab	86.0 bc	96.9 a	89.5
Trimec Classic	92.2 bc	61.2 de	96.4 a	98.4
Speedzone	88.5 c	93.8 ab	88.9 ab	91.6
Surge	89.8 c	66.1 de	73.7 bc	94.6
Escalade 2	90.7 c	77.7 cd	72.2 dc	96.8
Cool Power	54.8 d	52.5 e	67.7 bcd	84.7
Imprelis G	93.2 bc	92.5 ab	48.8 cd	90.5
Confront	48.7 d	61.4 de	35.2 d	98.2

[w] Spring Pre-Bloom: April 8; Spring Peak-Bloom: April 18; Spring Post-Bloom: May 31; Late Summer: September 19.

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Herbicides are ranked over Spring Peak-Bloom timing.

[z] No significant differences among treatments.

Table 2.8 Percent dandelion control at end of growing season in 2011 when broadleaf herbicides were applied at different application timings[w].

	% dandelion control[x]		
Herbicide[y]	Spring Pre-Bloom[z]	Spring Peak-Bloom[z]	Spring Post-Bloom[z]
Imprelis SL	61.8	85.6 a	59.9
Imprelis G	71.5	83.4 a	43.2
Speedzone	47.1	33.8 b	52.2
Surge	47.3	32.2 b	48.0
Escalade 2	41.8	31.9 b	31.4
Confront	45.3	29.0 b	15.9
Trimec Classic	42.5	21.3 b	67.8
4 Speed XT	50.9	19.9 b	54.4
Cool Power	53.5	13.8 b	43.2

[w] Spring Pre-Bloom: April 8; Spring Peak-Bloom: April 18; Spring Post-Bloom: May 31.

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Herbicides are ranked over Spring Peak-Bloom timing.

[z] No significant differences among treatments.

Table 2.9 Speed of activity when broadleaf herbicides were applied to dandelions on May 31, 2011.

	Speed of Activity (1-9)[w,x]				
Herbicide[y]	2 DAT[z]	4 DAT	8 DAT	10 DAT	18 DAT
Speedzone	5.6 a	7.0 a	8.0 a	8.0 a	8.3 a
4 Speed XT	4.6 ab	6.0 ab	7.3 ab	7.6 a	7.6 ab
Imprelis SL	4.3 bc	5.3 bc	5.6 d	6.0 bc	6.6 bc
Surge	3.3 cde	5.0 bc	6.0 cd	6.0 bc	7.0 b
Escalade 2	4.0 bc	4.6 bcd	6.6 bc	7.0 ab	7.6 ab
Cool Power	4.0 bc	4.6 bcd	6.3 cd	6.3 bc	6.6 bc
Trimec Classic	3.6 bcd	4.3 cd	5.6 d	5.6 c	6.6 bc
Confront	2.6 de	3.3 de	4.3 e	3.6 d	5.3 d
Imprelis G	2.3 e	2.0 e	4.3 e	3.6 d	5.6 cd

[w] Speed of activity rating scale: 1= no herbicidal activity, 9= complete necrosis of above ground tissue

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Herbicides are ranked over 4 DAT results.

[z] DAT= days after treatment.

Chapter 3 - A Comparison of Organic and Conventional Tactics for Dandelion Control in Turfgrass

Introduction

Organic crop production is one of the fastest growing agricultural sectors in the United States (USDA, 2010). Organic culture relies on biological, cultural, and mechanical pest management practices and prohibits the use of synthetic fertilizers and pesticides (Reganold et al., 1987). Weed control is arguably one of the biggest hurdles when adopting organic production. In field crops, organic production relies heavily on tillage and other mechanical weed control tactics. However, tillage is not a viable option for weed control in established turfgrass. Turf managers need organic weed control options to meet the needs of their clients, especially where governments have banned the use of synthetic pesticides. Many researchers have determined the importance of sound cultural practices such as proper irrigation, fertilization, and mowing for effective long-term weed control; however, the success of organic weed control may be more reliant on those practices compared to conventional methods.

A dense and competitive stand of turf is one of the most important factors in preventing weed encroachment (McCarty and Tucker, 2005). Proper fertilization and mowing height are key components of maintaining a competitive turfgrass stand. Derneoden et al. (1993) observed that increasing mowing heights from 5.5 to 8.8 cm reduced large crabgrass (*Digitaria sanguinalis* (L.) Scop.) invasion in conjunction with pre- and postemergence herbicides. In a mixed stand of Kentucky bluegrass (*Poa pratensis* L.) and fine fescue, Davis (1958) reported that increasing mowing heights from 1.9 to 5.1 cm decreased the percent cover of white clover (*Trifolium repens* L.), dandelion (*Taraxacum officinale* Weber), and large crabgrass. However, Gray and Call (1993) found that decreasing the mowing height of tall fescue (*Festuca arundinacea*

Schreb.) enhanced the control of Indian mockstrawberry (*Potentilla indica)*. Mowing height is an important cultural practice for weed control, but the optimal mowing height is ultimately dependent upon each weed species to be controlled.

Fertilization also has an impact on weed populations. Johnson and Bowyer (1982) reported a significant decrease in dandelion populations in nitrogen (N)-treated Kentucky bluegrass plots compared to untreated plots. They also reported significantly lower dandelion cover in plots treated with 300 kg N ha^{-1} compared to 150 kg N ha^{-1}. Murray et al. (1983) reported similar results, with a 73% reduction in dandelion cover in Kentucky bluegrass receiving 300 kg N ha^{-1} compared to no N. It is likely that N fertilization reduced dandelion populations by increasing the growth and competitiveness of the turfgrass (Busey, 2003). Interestingly, potassium (K) has been shown to have the opposite effect of N on dandelion populations in turfgrass. Tillman et al. (1999) found that dandelion cover was significantly lower in plots that did not receive K compared to K-treated plots, and suggested that dandelion may be a poor competitor for K. They hypothesized that dandelion populations could be reduced in low-K soils by planting a grass species that is a superior competitor for K.

Several products are available for organic broadleaf weed control in turf. Corn gluten meal (CGM), a byproduct of corn from the wet-milling process, is approximately 9% N by weight and has preemergence herbicidal activity (Bingaman and Christians, 1995). Of the several dipeptides isolated from CGM, alaninyl-alanine was found to cause epidermal necrosis on the roots of germinating perennial ryegrass (Unruh et al., 1995). For perennial weeds such as dandelion, CGM could prevent the germination of new seedlings, but may have little effect on established weeds.

Organic postemergence broadleaf weed control options are also available for use in turfgrass. *Sclerotinia minor* Jagger is a fungus that can control dandelions, but does not harm turfgrass species (Abu-Dieyeh and Watson, 2007). However, the efficacy of *S. minor* is highly dependent on dandelion age. Abu-Dieyeh and Watson (2007) found that the susceptibility of dandelions decreased with plant age and regrowth from taproots often occurred. Similarly, the opportunistic fungus *Phoma macrostoma* 94-44B is able to suppress dandelion growth without harming turfgrasses, but is not yet registered for use in turfgrass (Bailey et al., 2011).

Phoma. macrostoma and *S. minor* are biological control options, but chemical organic control options are also available. Research conducted at the Guelph Turfgrass Institute found that fall- applied Fiesta™, a chelated iron product, provided rapid burndown of dandelions and reduced percent dandelion coverage to <1%. However, almost 100% dandelion regrowth occurred the following spring (Charbonneau, 2010). Horticultural vinegar is an organic, non-selective weed control product. It is essentially a concentrated solution of acetic acid (10 to 20%). The acetic acid solution is applied directly to the weed and provides rapid burndown of the aerial foliage. However, the acetic acid does not destroy the underground structures, and plants often reemerge after several weeks (Dayan et al., 2009).

While there are several options for organic weed control in turfgrass, their efficacy in removing established perennial weeds from an existing turfgrass stand has not been well-established. The objectives of this study were: 1) to determine if organic weed control options including CGM, hand-weeding, and horticultural vinegar could provide acceptable control of established dandelions in a stand of tall fescue, compared with a “conventional” herbicide; 2) to determine the effect of the nitrogen component of CGM on its control of dandelions ; and 3) to evaluate the practical implementation of organic weed control tactics by conducting a cost-analysis.

Materials and Methods

Site Characteristics and Experimental Design

A 2-yr field study was conducted at Rocky Ford Turfgrass Research Center (Manhattan, KS) from May 2010 to November 2011. The soil at the site was a Chase Silt Loam (fine, smectitic, mesic, Aquertic Argiudoll) with a pH of 6.9. Soil tests indicated adequate levels of P and K. The site contained turf-type tall fescue with an existing dandelion infestation. The 1.2 × 1.5 m plots were mown twice weekly at 8.3 cm and irrigated as needed to prevent drought stress. The study area was treated with Dimension 2EW (dithiopyr, S,S'-dimethyl 2-(difluoromethyl)-4-(2-methylpropyl)-6-(trifluoromethyl)-3,5-pyridinecarbothioate) (Dow AgroSciences, Indianapolis, IN) at 0.195 kg a.i. ha^{-1} and 0.425 kg a.i. ha^{-1} on May 12, 2010and April 13, 2011, respectively, to control large crabgrass and goosegrass (*Eleusine indica* (L.) Gaertn.). A randomized complete block design with three replicates was used to evaluate ten treatments. Each block contained two untreated plots for comparison purposes.

Treatments and Applications

Ten treatments included four different organic weed control tactics: CGM (Voluntary Purchasing Groups Inc., Bonham, TX), hand-weeding, and horticultural vinegar (Bradfield Industries, Springfield, MO), and organic fertilizer only, and one conventional; each receiving a total of . Trimec Classic (PBI/Gordon Corporation, Kansas City, MO) was included as the conventional herbicide. For weed control in turf, the recommended annual rate for CGM is 1,951 kg product ha^{-1} (Galligan and Brown, 2002). Because the CGM contained 9% N, it was applied at either 1,075 or 2151 kg product ha^{-1}. Applications were split between spring and fall. These application rates provided an annual total of 96.8 and 193.6 kg N ha^{-1}, respectively. All other control tactics in the study were combined with low and high fertilizer rates to match the amount of N provided by the CGM treatments. Sustane, 8-2-4 (Sustane Natural Fertilizer, Inc. Cannon Falls, MN), was the N-source for all organic control tactics, excluding CGM. A polymer coated urea (PCU), 41-0-0 (POLYON, Agrium Technologies, Loveland, CO) was the N-source for the conventional herbicide treatment. All N was applied in split applications; half the total N was applied in spring (May 4, 2010 and April 12, 2011) and the other half in fall (September 21, 2010 and September 16, 2011) . All fertilizer applications were made on the same day for all treatments.

Dandelions were hand-weeded once yearly in the spring using a hand-weeding tool (Ames 1984900 ergo gel grip hand weeder). The objective was to remove the entire dandelion, taproot included, with minimal damage to surrounding plants. Removing the entire taproot was difficult and sometimes not possible; however, as much of the taproot as possible was removed, usually to a depth of approximately 5.1 cm. A stopwatch was used to record the time needed to hand-weed each plot.

Horticultural vinegar (Bradfield Industries, Springfield, MO) was spring-applied to dandelions using a two-nozzle CO_2 backpack sprayer at a rate of 342 L ha^{-1}. The product was applied undiluted. While this product is intended for spot treatment of weeds, the dandelions were so prevalent in the plots that spot treatment was not practical, so the entire plot was treated.

Trimec Classic was included as the conventional control tactic. Trimec Classic (PBI Gordon Corporation, Kansas City, MO) was applied at a rate of 4.5 L product ha^{-1} in the spring of 2010. Trimec Classic was not applied in 2011.

Two fertilization-only treatments were included as checks. For these treatments, Sustane, 8-2-4, was applied at the 96.8 and 193.6 kg N ha^{-1} rates, split between spring and fall, as described previously.

Measurements and statistical analysis

Percent dandelion control was determined using a 1.01 × 1.62 m rating grid sectioned into 160 individual 10.16 × 10.16 cm squares. At each rating date, the grid was placed over each plot and a count was registered for each square containing a dandelion. Percent control was calculated by comparing the counts in treated plots with untreated plots in the same block. There were two untreated plots in each block, and the mean number of counts was used for the percent control calculation. Percent control for each plot was recorded in the spring and fall.

Plots were rated for visual quality and color every two weeks from April to November. A 1 to 9 scale was used for both parameters; for visual quality, 1=brown, dead turf, 6=minimum acceptable turf quality, and 9=optimum turf quality; for color, 1=completely brown, 6=minimum acceptable turf color, and 9=optimal turf color.

Percent control data were arcsine transformed, then subjected to ANOVA and Fisher's protected LSD range test at $P \leq 0.05$ (MSTAT, 1993). Because N rate was not significant in the ANOVA for dandelion control, the combined means over N rate were used in the statistical analysis and were presented here. For presentation, the means were back-transformed.

Results

The single application of Trimec Classic in spring 2010 provided the highest dandelion control at all rating dates in both years, followed by hand-weeding (Table 1). No differences in control were recorded among CGM, horticultural vinegar, and fertilizer-only treatments at any rating date. The percent dandelion control spring rating in 2010 was the only occasion when Trimec Classic (81.6%) and hand-weeding (71.9%) were not different in. By fall 2010, control improved to 99.3% with Trimec Classic, while hand-weeding remained steady at 70.4%. In 2011, hand-weeding dropped to around 60% while Trimec Classic continued to give >96% control.

Hand-weeding was generally more effective than the other organic control tactics while not as effective as Trimec Classic. The fall 2010 rating was the only instance when hand-weeding (70.4%) and horticultural vinegar (23.7%) were not different in dandelion control (Table 1). Similarly, spring 2011 was the only rating date when hand-weeding (61.4%) was not greater than CGM (24.4%). Hand-weeding provided greater dandelion control than the fertilizer-only treatments at all rating dates.

Trimec Classic generally gave the highest turfgrass visual quality throughout the study (Figure 1). However, June 2 was the only rating date in 2010 when Trimec Classic (7.1) had significantly higher quality compared to hand-weeding (6.8). No significant differences in turf quality were recorded among all five treatments from July 1 to September 9 in 2010 (Figure 1). Trimec Classic had significantly higher quality on September 22 and October 6 compared to CGM, horticultural vinegar, and fertilizer-only treatments.

In 2011, Trimec Classic provided the greatest overall quality and was greater compared to hand-weeding treatments on four of the ten rating dates (Figure 1). Hand-weeding had greater overall quality than the other organic control tactics and higher quality compared to CGM on three rating dates and greater quality compared to fertilizer on five rating dates. Horticultural vinegar had the lowest quality at all ratings dates in 2011, and was less than all other organic treatments on three of ten rating dates.

When turfgrass quality was averaged for the entire growing season in 2010, Trimec Classic had greater mean quality than all treatments except hand-weeding (Table 2). In 2011, Trimec Classic had the greatest mean quality followed by hand-weeding. Hand-weeding had greater mean quality than all other organic weed control treatments, while horticultural vinegar had the least.

In 2010, significant differences in turfgrass color were observed on three rating dates (Figure 2). Plots treated with horticultural vinegar had poorer color than all other treatments on May 26 and June 3. Trimec Classic plots had poorer color compared to hand-weeding and fertilizer-only treatments on May 26 and poorer color compared to hand-weeding on June 3. On July 8, CGM had better color compared to horticultural vinegar plots. No significant differences in visual color were recorded after July 8 in the 2010 growing season.

In 2011, differences in visual color were recorded on six of ten rating dates (Figure 2). Overall, application of horticultural vinegar resulted in the poorest color, with lower color ratings than all other treatments on five of ten rating dates. Trimec Classic resulted in the best visual color throughout the growing season; however, it was never different from CGM. Significant color differences among Trimec Classic, CGM, hand-weeding, and fertilizer-only were recorded on only two out of ten rating dates in 2011.

In 2010, all treatments had a mean color of 5.9 except Bradfield vinegar (5.2), which was lower. In 2011, Trimec Classic, hand-weeding, and CGM had the highest mean color, and horticultural vinegar had the lowest mean color.

Discussion

Treatments varied greatly in their effect on dandelion populations in both years of the study. Except for the initial rating in spring 2010, the single application of Trimec Classic provided excellent weed control throughout the entire study. The slightly lower control at the spring rating in 2010 is likely because Trimec Classic was applied on May 14 and percent control data were recorded only 22 days after treatment (DAT). The three active ingredients in Trimec Classic (2,4-D, MCPA, and dicamba) are in the synthetic auxin herbicide class (Senseman, 2007). The synthetic auxin herbicides do not cause rapid necrosis; rather, several weeks are required before complete plant death occurs. The extended length of time needed for Trimec Classic to control dandelions is likely why hand-weeding had higher quality at the rating date on May 27, 2010.

Hand-weeding was the only organic weed control tactic that provided greater than 25% dandelion control at any rating date. Mann (1981) found that removing dandelion leaves at the soil surface had no effect on dandelion survival; however, a decrease in survival was found when roots were cut 2 cm below the crown. Removal of dandelions and the entire taproot was attempted in our hand-weeding treatments; however, removal of the entire taproot was difficult and fragments were undoubtedly left behind. Therefore, regrowth could have occurred through three avenues: germination of existing dandelion seed, regrowth from taproot fragments, or dandelions missed by hand-weeding. It is likely a small percentage of dandelions were simply missed by hand-weeding, but many researchers have witnessed regrowth from existing taproot fragments (Watschke and Borger, 1999; Mann, 1981). Regrowth from taproot fragments likely accounted for most of the dandelions found at the fall rating dates.

The ANOVA showed that fertilization rate had no effect on dandelion control in our two-year study, and the fertilization-only treatments provided minimal control. CGM and horticultural vinegar treatments did not provide more dandelion control than fertilization alone. Bingaman and Christians (1995) found CGM to be most effective in preemergence applications, but most dandelions in this study were already well-established. Therefore, the slight reduction in dandelions achieved with CGM was likely a result of increased turfgrass competition, since CGM is 9% N by weight. The importance of maintaining a healthy and competitive turfgrass stand has been found by many researchers to be one of the best defenses against weed invasion (Johnson and Boyer, 1981; Calhoun et al., 2005; Alumai et al., 2008).

Horticultural vinegar is a non-selective organic herbicide that provides rapid necrosis of all leafy plant material within hours after application (Figure 3). However, acetic acid acts strictly as a contact herbicide and is not translocated within the plant; therefore, the taproot is unaffected and most dandelions reemerged within two weeks (Figure 4). Horticultural vinegar could possibly provide long-term dandelion control if applied to dandelions when very little carbohydrate reserves are available in the taproot to reinitiate leaf growth. Multiple applications would likely be required for increased control. In our study, horticultural vinegar treatments were not significantly different from fertilizer-only treatments. Additionally, horticultural vinegar reduced quality and color at several rating dates throughout the growing seasons in 2010 and 2011 since it was non-selective.

In conclusion, hand-weeding was the only organic tactic that provided a significant level of dandelion control; unfortunately, the cost of control is about nine times higher than conventional methods because of labor inputs (Table 3). Also, removing the entire taproot is difficult; reducing its overall effectiveness. Hand-weeding may be a practical option when dandelion densities are low and the area to be treated is small. Horticultural vinegar is applied undiluted, making it an expensive option when treating large areas with high dandelion populations. Similar to hand-weeding, horticultural vinegar could be a viable option when dandelion densities are low, but many dandelions in our study reemerged within 21 DAT (Figure

4). Turfgrass managers will have difficulty removing established dandelions from lawns if CGM is the only tactic. Based on this two-year study, CGM did not show a herbicidal effect on dandelions. The minimal control achieved with CGM was probably due to its N content. Fertilizer only treatments were three times more expensive than conventional treatments and were not effective in reducing high dandelion densities over the course of this research.

A conventional herbicide applied one time, prior to organic tactics, could provide the initial long term broadleaf weed control that is needed to establish a competitive turfgrass stand. The stand could then be managed organically from that point forward. While this approach would not qualify as organic, it presently appears to be the only practical option for large turf areas with moderate to high perennial weed populations.

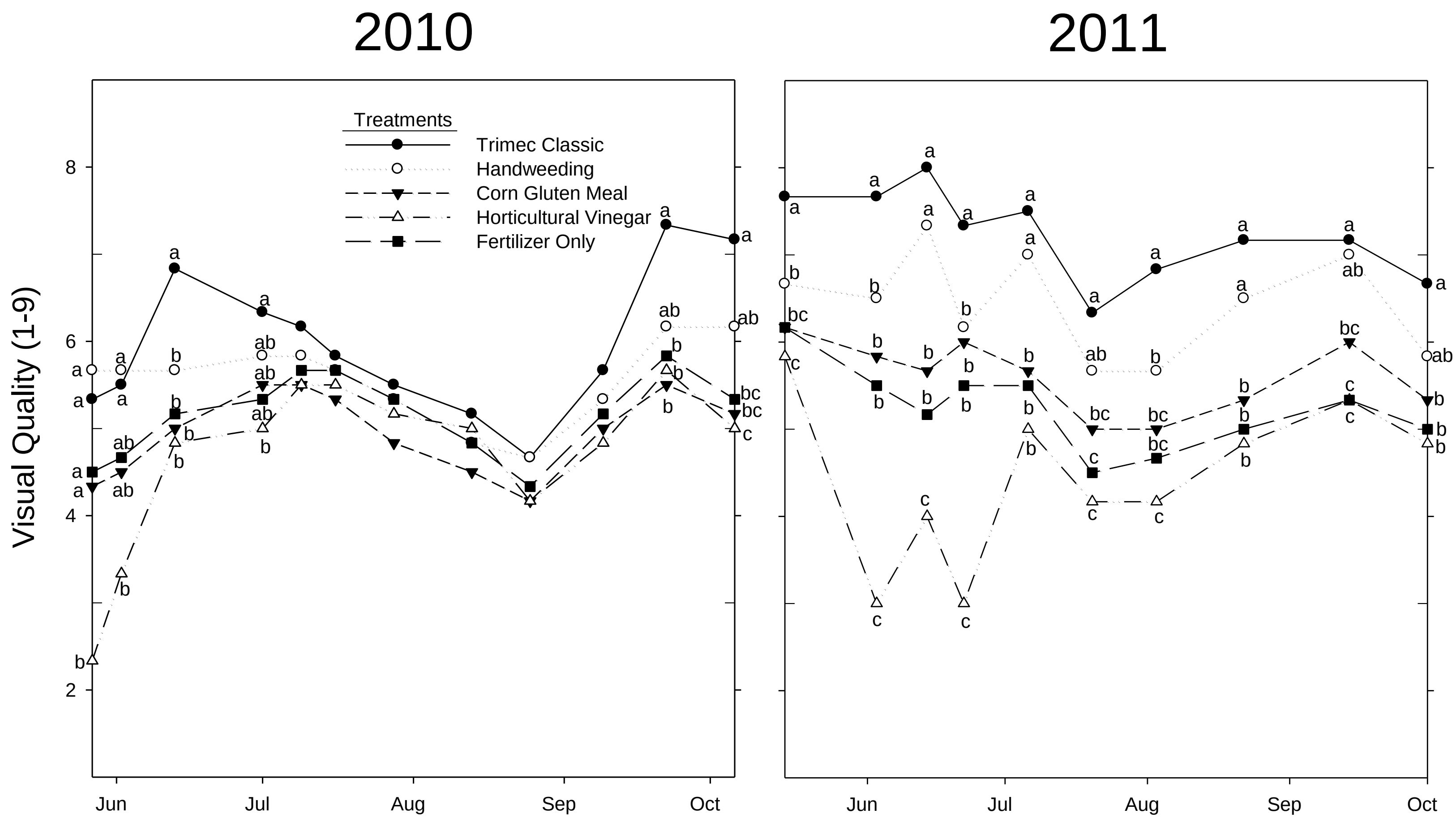

Figure 3.1 Turfgrass visual quality throughout the 2010 and 2011 growing seasons when organic and conventional weed control strategies were implemented. Means followed by the same letter on a date are not significantly different according to F-LSD (*P*≤0.05).

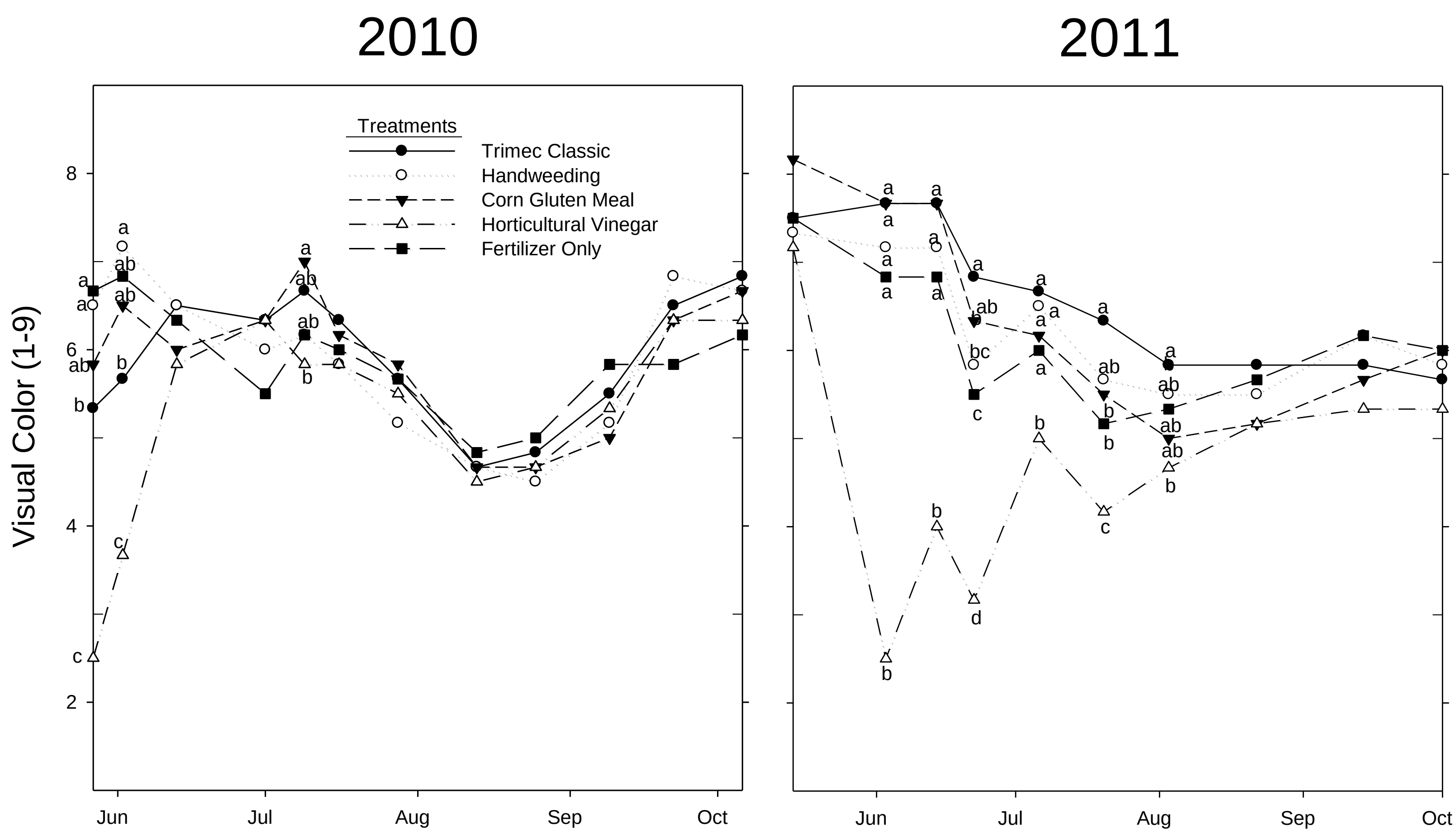

Figure 3.2 Turfgrass color throughout the 2010 and 2011 growing seasons when organic and conventional weed control strategies were implemented. Means followed by the same letter on a date are not significantly different according to F-LSD (*P*≤0.05).

Figure 3.3 Phytotoxicity of horticultural vinegar on tall fescue 1 day after treatment (DAT). The horticultural vinegar was applied on May 16, 2010.

Figure 3.4 Dandelion regrowth 21 days after treatment (DAT) with horticultural vinegar. The horticultural vinegar was applied on May 16, 2010.

Table 3.1 Dandelion (*Taraxacum officinale* Weber) control in field-grown turf-type tall fescue in 2010 and 2011 when using organic and conventional weed control tactics.

	% dandelion control[x]			
	2010		2011	
Treatment[y]	Spring[z]	Fall	Spring	Fall
Trimec Classic	81.6 a	99.3 a	99.3 a	96.6 a
Hand-weeding	71.9 a	70.4 b	61.4 b	58.5 b
Corn Gluten Meal	15.2 b	17.1 c	24.4 bc	14.6 c
Horticultural Vinegar	19.2 b	23.7 bc	18.2 c	11.1 c
Fertilizer Only	10.5 b	12.7 c	13.8 c	10.9 c

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Treatments were ranked over 2011.

[z] Spring rating in 2010 was recorded 22 days after treatment.

Table 3.2 Turfgrass mean quality and color in 2010 and 2011 when organic and conventional weed control strategies were implemented.

	Mean Quality[w,x]		Mean Color[y]	
Treatment[z]	2010	2011	2010	2011
Trimec Classic	5.9 a	7.2 a	5.9 a	6.5 a
Hand-weeding	5.5 ab	6.4 b	5.9 a	6.2 ab
Corn Gluten Meal	4.9 bc	5.6 c	5.9 a	6.3 ab
Fertilizer Only	5.1 bc	5.2 c	5.9 a	6.1 b
Bradfield Vinegar	4.6 c	4.4 d	5.2 b	4.6 c

[w] Turf quality was rated on a 1 to 9 scale (1 = brown, dead turf, 6 = minimum acceptable quality, 9 = optimal quality).

[x] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

[y] Turf color was rated on a 1 to 9 scale (1=completely brown, 6=minimum acceptable color, 9= dark green).

[z] Treatments were ranked over mean quality in 2011.

Table 3.3 Cost analysis of organic and conventional weed control tactics.

Treatment	Price[y] ($)	Rate	Price ($)/100 m^2
Trimec Classic	13.22/ L	3.8 L/ha	0.50
Hand-weeding	8.25/ hr	128 ft^2/hr	69.37
Corn Gluten Meal 9-0-0	1.67/ kg	96.8 kg N/ ha	36.36
Purcell Polyon 41-0-0	2.24/ kg	96.8 kg N/ ha	10.71
Sustane 8-2-4	1.32/ kg	96.8 kg N/ ha	32.30

Treatment	Total cost ($) / 100 m^2	% dandelion control fall 2011[z]
Trimec Classic + Purcell Polyon 41-0-0	11.21	96.6 a
Hand-weeding + Sustane 8-2-4	101.67	58.5 b
Corn Gluten Meal 9-0-0	36.36	14.6 c

[y] Prices are estimates based on quotes obtained on Feb. 20, 2012 from several retailers.

[z] Means followed by the same letter in a column are not statistically different ($P \leq 0.05$) by Fisher's LSD.

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