PREFACE TO CHAPTER 6

Various turf management activities may influence weed population dynamics and interfere with weed control. A bioherbicide approach could be enhanced if combined with cultural management practices. Mowing is a mechanical stress that could differentially affect weed communities and select certain weed species. Repeated mowing could change weed species composition and abundance. Weed shifts toward more tolerant populations to certain chemical and cultural practice are major management concerns. In Chapter 6, the same two field study sites mentioned in the previous chapter were monitored for two years to investigate the effect of mowing heights, in combination with the *S. minor* biocontrol and the standard chemical herbicide, on the population dynamics of dandelion and other broadleaf weed species and the impact on turf quality.

The results of Chapter 6 have been prepared in manuscript form to be submitted to the Journal of Plant Interactions. The manuscript is co-authored by Professor Alan K. Watson, my supervisor. I designed the experimental set-up, performed the experiments and the statistical analysis, and wrote the manuscript. Professor Watson supervised the work, provided financial and technical resources, and corrected the manuscript.

CHAPTER 6

Impact of mowing and weed control on broadleaf weed population dynamics in turf.

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6.1. Abstract

1. Turfgrass is a man made setting adversely affected by common dandelion (*Taraxacum officinale*) and other broadleaf weeds. Control of these weeds in temperate turfgrass has been readily achieved with phenoxy and like herbicides. The herbicide option has been revoked through municipal and provincial legislation in many regions of Canada, necessitating the need for alternative approaches.

2. Various turf management activities may influence weed population dynamics and interfere with weed control. The effects of a biocontrol agent, *Sclerotinia minor*, a chemical herbicide, Killex™, and defoliation stress at three different mowing heights on broadleaf weed dynamics were examined in two turfgrass stands for two consecutive years.

3. Mowing did not reduce the average or the monthly population densities of dandelion or the percentage ground cover of broadleaf weeds. In the second year, mowing significantly reduced the density of white clover (*Trifolium repens)*, but significantly increased broadleaf plantain (*Plantago major)*, particularly at the closest mowing height (3-5 cm).

4. Apart from the 3-5 cm mowing height, no differences in efficacy were obtained between the *S. minor* and Killex™ treatments on the densities of dandelion, white clover, broadleaf plantain, and prostrate knotweed (*Polygonum aviculare).* Common mallow (*Malva neglecta*) increased in herbicide treated plots and other species including yellow woodsorrel (*Oxalis stricta*), yellow toadflax (*Linaria vulgaris*), and lambsquarters (*Chenopodium album*) increased in abundance in plots mowed at the closest height (3-5 cm) and in plots treated with Killex™.

5. The reduction in dandelion densities and percentage broadleaf ground cover one month after Killex™ application persisted throughout the study period, unaffected by mowing height except in September of the 1st year when the density of dandelion was significantly greater at the 3-5 cm mowing height compared with the other heights. Significant differences between Killex™ and *S. minor* treatments on dandelion population dynamics were rarely present and did not favour either treatment. After *S. minor* treatment, turf quality gradually improved over the study period at both sites with lower values at the 3-5 cm mowing height. There were no signs of damage to the grass species due to repeated *S. minor* treatments. Similarly, Killex™ treatment improved turf quality even at the 3-5 cm mowing height, but grass damage in three out of 12 plots was followed by smooth crabgrass (*Digitaria ischaemum*) invasion.

6. The *S. minor* (IMI 344141) formulation combined with regular mowing at ~ 7 cm was as effective as Killex™ for broadleaf weed suppression.

Keywords: *Taraxacum officinale*, common dandelion, *Sclerotinia minor*; weed population dynamics, turfgrass, biological control.

6.2. Introduction

Weeds are symptomatic of a weakened turf, not the cause of it (McCarty et al. 2001). Weed growth occurs in turf under adverse environmental conditions and when the soil has been exposed or disturbed by compaction, planting, or maintenance activities (McCarty et al. 2001). Mowing is the most basic turfgrass cultural practice and affects most other cultural operations (Turgeon 1985). Mowing is stressful to turfgrass, removing much of the photosynthesizing tissues leading to exhaustion of carbohydrate reserves during regrowth (Fry & Huang 2004). The exact tolerated mowing height for a specific turfgrass is difficult to predict because it is a result of interactions between turfgrass genotype, climate, cultural practices, time of the year, and other environmental influences (Turgeon 1985; Fry & Huang 2004). As a consequence of mowing, population abundance and diversity of weeds may change and create new competitive environments amongst existing weed species and between the crop (turfgrass) and the weeds (Busey 2003). Practices that favour crop growth will generally disfavour weed abundance (Radosevich et al. 1997). Cultural management practices have been used to control weeds in turfgrass for some time and reliance on cultural management to control turfgrass weeds may reduce dependence on synthetic pesticides (Busey 2003).

Herbicides, like 2,4-D (2,4-dichlorophenoxy acetic acid) and three-way mixes of 2,4-D + mecoprop ((±)-2-(4-chloro-2-methylphenoxy) propanoic acid) + dicamba (3,6-dichloro-2-methoxybenzoic acid) have been widely used to control broadleaf weeds in turfgrass. However, herbicide use on lawns has come under severe pressure from environmental and public health perspectives (Robbins & Birkenhlotz 2003), resulting in various levels of government enacting legislation inhibiting or banning the use of pesticides in urban areas (Riddle et al. 1991; Schnick et al. 2002; Cisar 2004).

In response to herbicide use restrictions, good management practices are being promoted and alternative approaches including biological are being researched (Neumann & Boland 2002, Stewart-Wade et al. 2002a, Zhou et al. 2004). *Sclerotinia minor* Jagger is an Ascomycete with suppressive effects on dandelion and other broadleaf weeds in turfgrass systems (Ciotola et al. 1991, Riddle et al. 1991, Brière et al. 1992, Schnick et al. 2002, Stewart-Wade et al. 2002b, Abu-Dieyeh & Watson 2006: Chapter 5). Several authors (Burpee 1990; Kennedy & Kremer 1996; Radosevich et al. 1997; Cousens & Croft 2000) have emphasized the importance of studying the ecology and population dynamics of weeds to enhance weed biocontrol programs. In general, any weed control method removes or suppresses targeted species, but this activity may result in modification or disruption of the habitat of other organisms (Radosevich et al. 1997). Therefore an ecological approach broadens management options and decreases the probability of failure (Booth et al. 2003). Combining a fungal pathogen with defoliation has been shown to increase suppressive effects on weeds, compared with the pathogen alone (Green et al. 1998; Kluth et al. 2003).

In this study, interactions between mowing heights and two different control strategies, a common three-way mix herbicide, Killex™, and a biological control, *S. minor*, on the population dynamics of dandelion and other broadleaf weeds were investigated. The field experiments were conducted for two years in two low-maintenaned turf environments.

6.3. Materials and Methods

6.3.1. The fungus formulation

Sclerotinia minor (IMI 344141) was isolated from diseased lettuce plants (*Lactuca sativa* L.) from south western Quebec and the stock culture was maintained as sclerotia at 4^{o}C. The mycelia of the germinated sclerotia were used to inoculate autoclaved barley grits (1.4-2.0 mm diameter) as described in Abu-Dieyeh and Watson (2006: Chapter 5).

S. minor granular formulations were freshly prepared two weeks prior to treatment application. Viability and virulence of the fungal inoculum were assessed prior to use by placing ten granules from each bag on the surface of PDA plates and another ten granules onto excised dandelion leaves. The diameter of colonies and lesions caused by the fungus were measured after 24 and 48 h of incubation. Previous unpublished quality control studies indicate viable batches to have colony diameters of 14-30 mm after 24 h and 40-70 mm after 48 h and virulent batches to have an average lesion diameter >15 mm after 48 h of incubation.

6.3.2. Site description and plot layout design (see Abu-Dieyeh & Watson 2006: Chapter 5)

The field experiments were conducted in two different Sites on the Macdonald Campus of McGill University, in Ste-Anne-de Bellevue, QC (45^{o}25'N latitude, 73^{o}55'W longitude, 39.00 m elevation). Each field experiment was conducted from May to October for two consecutive years. The climate data for the years of study are summarized in Table 6.1.

Study Site-1 (2003-2004 experiment) was approximately 600 m^2 on a loamy sand soil (coarse sand = 9%, fine sand 73%, silt= 12%, clay= 6%) with a pH of 7.15 and 8% organic matter. The lawn was established in 1973 and received low maintenance throughout its history except for repeated mowing during the growing season (May to October). The grass sward was approximately 60% Kentucky bluegrass (*Poa pratensis* L.), 30% perennial ryegrass (*Lolium perenne* L.), patches of timothy (*Phleum pratense* L.), and rare occurrences of annual blue grass (*Poa annua* L.). The lawn flora was highly diversified with 17 broadleaf species observed throughout the study period and dominated by dandelion (*Taraxacum officinale* Weber). Dandelion density was 50-60 plants m^{-2} prior to the spring treatment application.

Study Site-2 (2004-2005 experiment) was located in an open lawn area of approximately 600 m^2 that was established in 1980 and managed with low maintenance. The turf at Site-2 was superior in visual quality compared with Site-1 with mainly Kentucky bluegrass (~90%) and 10% red fescue (*Festuca rubra* L.). Herbicides had not been applied for the past 10 years and the major broadleaf species were dandelion (60-70 plants m^{-2}), white clover (*Trifolium repens* L.), and broadleaf plantain (*Plantago major* L.). The soil was loamy sand (12% coarse sand, 75% fine sand, 7% silt and 6% clay) with a pH of 7.2 and 6.6% organic matter.

Field experiments were established in May, one in 2003 and the other in 2004, and maintained until the end of October of the following years. The study sites (20 x 30 m) were marked with metal posts and plastic ropes and the corners of each plot were permanently marked by wooden sticks to maintain plot integrity for the duration of the study. The experimental unit (plot) was one meter square with 0.8 m alleys between plots. The distance between any two blocks was 2-3 m. The experimental design was a split plot with four replications. Mowing heights were the main plots and weed control treatments were the subplots. The three levels of mowing heights, 3-5 cm, 7-10 cm, and 12-15 cm were initiated two weeks prior to weed control treatment applications. Plots were mowed weekly, except for two weeks after treatment, with a gas powered rotary push mower. Grass clippings were returned during July and August to act as a source of nitrogen (Kopp & Guillard 2002), but removed during the six-weeks-post treatment periods to avoid cross contamination between blocks.

Four levels of weed control were imposed on 15-May and on 15-September at each study site in each year (a total of four applications per site) : 1) untreated control, 2) a broadcast foliar application of Killex™ at 1.7 kg a.i. ha^{-1} (200 ml m^{-2} of 0.6% of original concentration), 3) a broadcast application of 60 g m^{-2} granular formulation of *S. minor*, and 4) a broadcast application of 120 g m^{-2} granular formulation of *S. minor*. The herbicide was broadcast applied onto the grass surface using a 1.18 L vacuum sprayer (Home and Garden sprayer. Model no 1998. RLF10-Master Premium, Root-Lowell Manufacturing Co, Lowell, MI). The *S. minor* formulation was broadcast applied using a 200 ml plastic specimen bottle fitted with a perforated lid (~10 mm diameter) with suitable openings to pass the barley grits. If there was no rainfall on the day of application or the grass was not wet, the entire field was sprinkler irrigated for two hours prior to late afternoon treatment applications. No additional irrigation or fertilization management was applied during the course of the study. The spring and fall treatment application dates, May 15 and September 15, represent near peak dandelion densities, usual period for herbicide application, and climatic conditions at these times are advantageous for the fungus.

6.3.3. Measurements and data analysis

The numbers of dandelions and other broadleaf weed species were counted in each plot and the percentage ground cover of broadleaf weeds was estimated in each plot the day before the weed control treatments and the last week of each month thereafter. For white clover (*Trifolium repens*) the number was estimated by measuring how many 10 cm diameter patches of white clover covered the ground of a plot. In each monthly assessment survey, turfgrass quality was also visually assessed using a growth rating of 0-100 based on combinations of color and density where 0 = no growth and 100 = complete uniform turf (Johnson and Murphy 1992). As the study sites are low-maintained turf, the acceptable visual quality according to the used scale is 50%.

Season average densities were also calculated for species that were presented uniformly between the blocks and found continuously through the season. Season average densities were calculated as an average of the eight assessments done in each season from May to October including the two pre application assessments done in the mid of May and September. The rationale for "season average density" values was to account for the indirect effects due to new environments created by the treatments, especially changes in grass ground cover and vigour, and to account for the species that establish after spring treatments and complete their life cycles before the fall treatment in September.

Statistical analyses were conducted using the SAS statistical package (SAS Institute Inc., Cary, NC, USA, 2002). Monthly data from the two field sites were subjected to

Levene test of SAS. Because of differences in environmental conditions between years of study and/or differences in turf establishment between sites most of the monthly data from the two field experiments were heterogeneous, data were not combined, but analyzed for significance and mean comparisons separately. The 120 g m^{-2} *S. minor* treatment was excluded from the data analysis of dandelion density, percentage ground cover, and broadleaf diversity as no significant differences were obtained in comparison with the 60 g m^{-2} treatment. Normality for each parameter was tested on model residuals using the Shapiro-Wilk test. Data were analyzed using GLM procedure of repeated measures to determine the significant interactions among mowing heights and different weed control treatments through time. Within each year of study, the pre application and post application season average of dandelion density data, season average density data of other broadleaf weeds and season average turfgrass quality data were analyzed using ANOVA for a split plot design. A split-plot in time was used to compare the densities between the two years. Differences in treatment means were determined using Tukey's test at $P = 0.05$.

6.4. Results and Discussion

Turfgrass systems are man-made and/or man–interfered environments. The abundance and diversity of weed species in such systems are mainly affected by the history of cultural management practices of the stand, turfgrass species, and climatic and edaphic factors (Fry & Huang 2004; McCarty et al. 2001). Since mowing is a necessity for any turfgrass planting, the exact tolerated mowing height is the factor of interest rather than mowing itself. We have previously reported the effectiveness of combining the 7-10 or

12-15 cm mowing height with *S. minor* on reducing dandelion population densities at 2 and 6 weeks after application (Abu-Dieyeh and Watson 2006: Chapter 5), but in this two-year-study, population dynamics of dandelion and other broadleaf weed species were monitored monthly in two sites to investigate the interactions between mowing height and the weed control treatments. Seventeen species of broadleaf weeds were recorded in Site-1 with dandelion the dominant species. White clover, broadleaf plantain, common mallow (*Malva neglecta* Wallr.), prostrate knotweed (*Polygonum aviculare* L.), yellow woodsorrel (*Oxalis stricta* L.), yellow toadflax (*Linaria vulgaris* Miller), lambsquarters (*Chenopdium album* L.), and birdsfoot trefoil (*Lotus corniculatus* L.) were uniformly dispersed over the study area but with minor abundance (Table 6.2). Other species listed in Table 6.2 were occasional or rare. In Site-2, the turf was better established, less diversified, and dominated by dandelion followed by white clover and broadleaf plantain (Table 6.3). Annual species such as prostrate knotweed and black medic (*Medicago lupulina* L.) were observed during July and August in both years in untreated plots but densities were negligible and not reported.

6.4.1. Effect of mowing heights on weed dynamics

In the absence of weed control, season-long mowing at any of the studied heights in the first year of study did not reduce season average of dandelion population densities in the second year (Tables 6.2 & 6.3), However, at the 3-5 cm mowing height, the season average dandelion density increased in the second year in study Site-1 (Table 6.2). Moreover, at this close height pre and post application dandelion densities increased in the 2nd year by 24-32% and 15-44% respectively (Table 6.4), indicating the adverse impact of mowing at this height. The second year season average density of white clover was significantly less than the first year at all mowing heights, but broadleaf plantain was significantly higher, except at the 12-15 cm mowing height (Tables 6.2 & 6.3). Population densities of other species including prostrate knotweed, yellow woodsorrel, and mouseear chickweed (*Cerastium fontanum* Braumg.) increased in the second year in plots mowed at 3-5 cm (Table 6.2).

Mowing is stressful to plants as it removes much of the photosynthetic cells and exhausts the carbohydrate storage reserves (Fry & Huang 2004). But certain perennial weeds can replenish root carbohydrate stores very rapidly (Foster 1989; Donald 1990) and in some cases cuttings can be advantageous for certain weeds as it removes the old and dead tissues and increases the new shoots (Oesterheld & McNaughton 1991). Cutting of certain perennial weeds can increase net photosynthetic rate, relative growth rate, branching or tillering after release from apical dominance (Strauss & Agrawal 1999). Different plants respond differently to periodic mowing and sufficient and frequent cuttings are needed to prevent root reserves to be replenished between cuts for certain perennials (Hatcher & Melander 2003).

In our study, perennial weeds responded differently to mowing, as mowing had no impact on dandelion but mowing significantly suppressed white clover. According to Warwick & Briggs (1979) close mowing favours short ecotypes or plant species which have the potential to grow in a rosette habit like broadleaf plantain. These are similar to our findings as plantain increased in the second year in plots mowed at the closest height (3-5 cm) (Table 6.3). Low mowing heights are always associated with more weeds (Busey 2003) and may change the species composition, abundance and diversity (Meyer

& Schmid 1999; Carter et al. 2000; Wilson & Clark 2001; Busey 2003). This may explain the trend of increasing the colonization of more than one species at the 3-5 cm compared with higher mowing heights (Table 6.2).

Regular mowing at 2.5 cm every two weeks in other turfgrass environments (buffalograss, bentgrass, and Bermuda grass) did not control dandelion (Timmons 1950). The close mowing at 3-5 cm reduced the season average dandelion population by 20% compared to other heights (7-10 & 12-15 cm) (Abu-Dieyeh & Watson 2006: Chapter 5), but our results from this study indicated that the reduction was temporary and occurred at the beginning of the study after that the population recovered or increased (Table 6.2). The replenishment of dandelion under the low mowing height was due to continuous seedling establishment (Abu-Dieyeh & Watson 2006: Chapter 5) forming a younger flat rosette habit population of dandelion more tolerated to close mowing. Defoliation of dandelion by grazing or mowing increases the rosette radius, decreases the root length, and the plant changes from upright to flat growth form (Struik 1967). After grazing, dandelion leaf density (number of leaves m^{-2}) was higher in short pastures than tall pastures (Carlassare & Karsten 2003). Those authors explained this success of dandelion under short canopies by increasing the overall meristematic points in the protected leaf axillary buds located close to ground and below the grazing level and this allows dandelion to tolerate close and frequent defoliation. A decrease in dandelion population density under increasing grass heights was attributed to shading effects from the grass canopy (Molgaard 1977). Shading increased dandelion leaf length and specific leaf area (the ratio of leaf area to leaf dry mass) and due to this dandelion was less susceptible to competition for light (Haugland 1993). In our study no significant reduction in the season average dandelion densities occurred at the 12-15 cm mowing height compared with the lower heights (Tables 6.2 & 6.3). Our results point out the adaptability of dandelion rosettes to different mowing heights without major effects from close (down to 3 cm) to high (up to 15 cm) mowing levels.

Perennial dandelions started to regenerate from over wintered roots in April followed by high seedling recruitment as temperatures increased with the dandelion population peaking during May. The population then gradually declined reaching its minimum during August (Figure 6.1). In September, the lower temperature and higher rainfall favoured the gradual increase in density to form a second peak at the end of the month. Subsequently, the dandelion population density gradually declined under the effect of cooler temperatures (Figure 6.1).

Dandelion was the prevalent weed species in both sites and had the highest percentage ground cover throughout the growing season in all untreated plots irrespective of mowing height (Figure 6.2). In untreated plots of Site-1, the average number of species per plot for the entire study was 4.4 (averaged over the two years and the four blocks), with a minimum of two reported in May and June and a maximum of nine species reported in August while in Site-2 the average was 3.1 with a minimum of two reported in May and June and a maximum of five reported in July and August. Mowing heights without weed control treatment had no significant effects on weed diversity. During summer months (July and August) other broadleaf weeds took the opportunity to flourish, mainly annuals like prostrate knotweed, lamb's-quarters, shepherd's-purse, and mouseear chickweed, attaining higher densities and frequencies than in other months. As a result the highest broadleaf weed diversity occurred during summer months when the dandelion population was at its minimum (Figure 6.3). This would be the result of the reduced competitive pressure from the dominant species (dandelion) on other broadleaf weeds.

Turfgrass survive and predominate in ecosystems with periodic defoliation by fire, grazing, or mowing, but mowing below the tolerance level may be harmful to a turfgrass species and give weeds competitive advantage (Busey 2003). In this study, mowing alone at any level did not improve turf quality at either sites in the two years (Table 6.5), which indicates that turf quality was more determined by the level of weed infestation rather than regular mowing at a specific height. Close mowing may not be stressful to the present grass species but may disturb the competitive relationship between the interacting species and/or increase light penetration throughout the thin canopy and consequently encourage certain broadleaf weeds to germinate and flourish. Mowing alone is not a quick and effective method of perennial weed control (Busey 2003; Hatcher & Melander 2003), but combining mowing with another control strategy like a herbicide (Lowdey & Marrs 1992) or a pathogen (Kluth et al. 2003) could be more effective.

6.4.2. Interactions between mowing heights and herbicide treatment

The common herbicide, Killex™, was effective in controlling dandelion and other broadleaf weeds under all studied mowing heights. Although the epinastic bending of dandelion leaves and floral scapes could be seen one week after application, the clear suppression of dandelion population was not obtained until six weeks after application (Figure 6.1). The effectiveness of 2,4-D, in Killex™ as a foliage herbicide is determined by the sorption capacity of the plant cuticular wax (Baker & Bukovac 1971) and this may slow the rate of its translocation particularly in well established dandelion population and consequently postpone its effectiveness. A low population density of dandelion (less than five plants m^{-2}) was maintained until August of the first year without significant differences between mowing heights. The surviving dandelions were mainly those grown close to plot borders which might receive a concentration of herbicide active ingredient beyond the threshold value needed to kill dandelion.

Dandelion has been classified as intermediate in susceptibility to 2,4-D due to the ability of older or well established plant to tolerate it based on the sorption capacity of the cuticle (Baker and Bukovac 1971). Six-weeks after application, only one to two seedlings recruitments were recorded (Abu-Dieyeh & Watson 2006: Chapter 5) due to herbicide persistence in the soil. 2,4-D persistence data is highly variable and its half-life in soil varies from 2 to 296 days and could last for one year in grass clipping compost (Cox 1999). Treating dandelion with the herbicide, when the population is in its reproductive stage, had been shown to reduce germination potential to 4.8% and 18.4% after spring and fall treatments, respectively (Abu-Dieyeh et al. 2005). Moreover the herbicide treatment significantly reduced the dandelion seed bank (10 cm depth) compared with the untreated, control plots (Chapter 7). All the above evidences indicated that the low infestation post to Killex™ treatment was mainly due to the killing effect of the herbicide on dandelion seeds at least in the superficial layer of soil surface. Since buried dandelion seeds are not able to germinate (Dunn & Moyer 1999), the August or September recruits were mainly new comers that had the ability to germinate in a microsite on the soil surface where the herbicide was partially or completely degraded.

In the second year at Site-1 prior to the spring treatment applications, a new seedling flush was recorded with a significantly higher density under the 3-5 cm mowing height (28-40 plants m^{-2}) compared with the 7-10 and 12-15 cm mowing heights (12-29 plants m^{-2}) (Figure 6.1). Each of the pre and post application dandelion densities between the two years were significantly ($P \leq 0.01$) reduced in the two sites without significant effect from mowing height (Table 6.4). However, the reduction was the least under the closest height (3-5 cm) only at Site-1, and excluding this case, the reduction in dandelion densities was 70-98 %.

Site-1 had inferior grass establishment and less grass vigour than Site-2 increasing the chances of seedling establishment, particularly into the more open grass canopy under close mowing. Other studies suggested that the establishment of dandelion seedlings was strongly inhibited in areas of dense grass cover due to insufficient open ground and light penetration (Molgaard 1977). Chances of seedling establishment are decreased 23 times in areas with lush grass vegetation compared with open areas (Ford 1981).

Within each site, no significant differences due to mowing height occurred for monthly dandelion densities, percentage broadleaf ground cover or even plot broadleaf weed diversity. Importantly, starting from August of the first year and up to the following season, the common mallow population density and frequency significantly increased in the herbicide treated plots compared with *S. minor* or untreated plots without significant effect from the mowing heights (Figure 6.4A). However the mallow density decreased significantly in the second year in untreated and *S. minor* treated plots (Figure 6.4A) mainly due to season-long mowing (Table 6.2). In Site-1, other species like prostrate knotweed, yellow toadflax, yellow woodsorrel, and lambsquarters flourished in herbicide treated plots (Table 6.2) and consequently the percentage ground cover of broadleaf weeds increased during September and October (Figure 6.2). This implication is likely to be ecologically important as these species escape or tolerate the herbicide and so could be candidates of co-dominance or dominance replacement of dandelion in turfgrass environments.

The effectiveness of the herbicide treatment in suppressing broadleaf weeds resulted in significant improvement in turf quality at both sites under all mowing heights (Table 6.5). Turfgrass generally grows into the voids after weeds have been chemically controlled (Turgeon 1985), but at Site-1 grass damage was observed in three plots (out of a total of 12) during the summer of 2003 and all the three plots were invaded by smooth crabgrass [*Digitaria ischaemum* (Schreb.) Muhl.] (2-5 plants per plot). Grass damage and *Digitaria* invasion were not observed after herbicide treatment in the superior quality turf in Site-2 indicating that grass with inferior quality is subjected to crabgrass invasion if more stress is encountered due to the herbicide. The frequent use of 2,4-D as early as 1950 had shifted cropping systems from broadleaf weed to annual grass domination (Aldrich 1984).

6.4.3. Interactions between mowing heights and biocontrol treatment

Two weeks after application, the *S. minor* treatment was more rapid and caused significantly greater reduction of the dandelion population than the herbicide under all mowing heights (Figure 6.1). *Sclerotinia minor* is a necrotrophic fungus causing rapid collapse and death of infected plants (Abawi & Grogan 1979; Melzer et al. 1997) and requires high moisture and a temperature range of 5-25°C to cause disease (Melzer & Boland 1994). The different microenvironments created by different mowing heights did not affect the performance of *S. minor* two weeks after application. Microenvironments caused by higher grass canopies increased disease incidence of certain turfgrass pathogens (Fagerness & Yelverton 2001; Martin et al. 2001), but this is may be not the case with a necrotrophic biological control agent during periods with optimal environmental conditions. Treatment dates and irrigation (in case there was no rainfall) provided appropriate requirement for dandelion infection by *S. minor* negating a possible mowing height effect.

The effect of the *S. minor* treatment was similar between the two mowing heights (7-10 and 12-15 cm) in reducing dandelion population densities, but it was significantly less under the 3-5 cm mowing height. The increased survival of the dandelion population at the 3-5 cm mowing height level than in the other heights was mainly due to more numerous and earlier dandelion recruits and to some regrowth (~ 20%) from undamaged crowns of well established dandelions (Abu-Dieyeh & Watson 2006: Chapter 5).

Natural dandelion populations have two peaks per season, one in May and the other in September, however, if the favourable climate prevail during summer due to rainfall, other flushes could occur due to the ability of dandelion seeds to germinate any time during the growing season (as reviewed by Stewart-Wade et al. 2003b). Removing most of the dominant weed species (dandelion) in plots treated with *S. minor* disturbed the area and this basically encouraged weed seed germination (Radosevich et al. 1997). Soil in these plots became bare with scattered patches of grass allowing more sunlight to intercept the grass canopy boosting dandelion seed germination (Letchamo & Gosselin

1995; Noronha et al. 1997; Dunn & Moyer 1999). The availability of growth resources in open canopies may change the normal population fluctuation due to frequent seedling recruitments. One month after the first application, a new flush of dandelion seedlings was observed under all mowing heights at both sites, led to a short population peak at the end of June (Figure 6.1). The magnitude of dandelion recruitment appeared to be linked with the mowing factor, site and year of study. Recruitment was higher in the 3-5 cm high mowed plots compared to other mowing heights, and higher in Site-2 as compared to Site 1. The total monthly rainfall reported in June and July of 2004 (the first year of site-2) was about 2-fold the amount reported for the same two months in 2003 (the first year of site-1) (Table 6.1) and this may explain why the recruitment size was greater in Site-2.

If summer conditions favoured germination, another short peak may form at the end of August as happened in Site-2 due to more frequent rainfall during July 2004 than in 2003. Rainfall is expected to be a requirement of seed germination during the summer season especially in a non-irrigated turf stand. The flushes produced under the 3-5 cm mowing height were significantly greater in size than those formed with other mowing heights and maintained in greater values across the second year (Figure 6.1).

Apart from the 3-5 cm mowing height, the response of monthly dandelion population to *S. minor* treatment was almost similar to the herbicide. Contrary to the herbicide, *S. minor* has no residual activity in soil and higher densities under *S. minor* treatment are expected around the normal peak months of dandelion population. Using 7-10 or 12-15 cm mowing heights, *S. minor* had the same effect like that of the herbicide in reducing the monthly diversity of broadleaf weeds by 1-3 species per plot compared with untreated plots (Figure 6.3) and also reduced the season average densities of the other two major competitive species white clover (Tables 6.2 & 6.3) and plantain (Figure 6.4B). In addition, both had the same level of suppression on prostrate knotweed in the second year (Figure 6.4C). The herbicide was significantly more effective than *S. minor* in reducing percentage weed ground cover at the 3-5 cm mowing height. However, with the other heights (7-10 and 12-15 cm), superior reduction in weed ground cover occurred with the fungus in Site-1 and the herbicide in Site-2 (Figure 6.2). Unlike the herbicide, *S. minor* treatment did not increase the population of other competitive species and no grass damage or crabgrass invasion were observed. The turf quality of *S. minor* treated 7-10 or 12-15 cm mowed plots improved gradually over the season and maintained acceptable quality for the two years (Table 6.5).

The strong biocontrol effect of *S. minor* on dandelion, white clover, and plantain and also the decrease in abundance of other competitive species could mainly be due to the direct pathological effect of the fungus and/or the indirect effect exerted by the improved grass growth. In Chapter 4, our data showed that 32 broadleaf weeds in turfgrass system were susceptible to *S. minor* infection if in direct contact with the barley-based formulation of *S. minor*. Under *S. minor* treatment no changes in species composition of broadleaf weeds were observed because of the mowing heights but changes in the abundance of certain broadleaf weeds were observed at 3-5 cm grass height mainly due to mowing at this low level rather than the fungus. So that species like prostrate knotweed, lambsquarters, and mouseear chickweed were more likely to flourish during the season (Figure 6.4D; Tables 6.2 & 6.3).

In conclusion, the application of *S. minor* and a regular, medium height (~7cm) mowing regime were highly effective in controlling broadleaf weeds in temperate Kentucky bluegrass turf.

Table 6.1. Weather data for Ste-Anne-de-Bellevue, Quebec during the years of study 2003, 2004 and 2005. Environment Canada Meteorological Data. Ste-Anne-de-Bellevue Station.

	Temperature ^{o}C			Relative humidity (%)			Rainfall (mm)
Month / year	Average	Min	Max	Average	Min	Max	Total monthly
May-03	12.8	2.1	28.2	70.1	15.1	100.0	136.2
May-04	7.2	-0.7	29.0	68.3	22.1	100.0	123.0
May-05	11.5	-1.4	26.1	68.1	20.8	100.0	62.6
June-03	17.9	6.6	32.4	69.7	26.5	100.0	123.9
June-04	17.2	4.4	29.0	65.2	25.7	99.1	226.2
June-05	21.1	8.31	32.8	72.5	23.2	100.0	708.6
July-03	20.4	11.2	30.3	73.2	26.5	100.0	357.4
July-04	20.5	10.5	31.0	74.6	30.1	99.0	574.2
July-05	22.2	16.8	31.7	73.7	36.2	97.8	93.4
August-03	22.0	14.1	29.1	78.9	34.6	100.0	53.0
August-04	19.3	7.7	29.1	77.6	44.7	99.5	181.9
August-05	21.4	7.8	32.1	73.3	26.8	100	199.1
September-03	16.8	5.3	28.9	76.6	30.9	100.0	415.7
September-04	15.9	4.7	26.2	78.6	41.5	100.0	96.0
September-05	17.3	3.7	29.1	77.0	39.6	100.0	243.1
October-03	7.4	-1.8	28.9	80.1	30.9	100.0	221.9
October-04	8.9	-2.3	24.6	76.8	32.9	100.0	84.6
October-05	10.8	-2.8	26.5	83.0	36.5	100.0	217.6

Table 6.2. Season average population densities of broadleaf weeds found in the plots at the study Site -1 during 2003 and 2004. A = annual; P = perennial; A, P = annual or short-lived perennial. Within each weed control treatment and year, means with a common letter are not significantly different at *P* = 0.05 according to Tukey's test. * Significant at *P* = 0.05 and ** significant at *P* = 0.01 between the two years.

			Average population densities(1) of broadleaf weeds (no. plants m^{-2})								
Species	Life form	Year of study	Untreated			Killex™ (2)			*S. minor* (60 g m^{-2})		
			3-5 cm	7-10	12-15	3-5	7-10	12-15	3-5	7-10	12-15
Taraxacum officinale (Dandelion)	P	1st	39ab	45a	50 a	20cd	19cd	26 c	30bc	17cd	15 d
		2nd	52a*	50a	50 a	11c**	5c**	7c**	31b	10c*	10 c
Trifolium repens (White clover)	P	1st	25a	15ab	13 b	3c	3c	3.5c	8.7bc	4.6c	3.3 c
		2nd	12a*	4bc*	8ab	1d	1d	2.2cd	3bcd*	1.9d	1.8 d
Plantago major (Broadleaf plantain)	P	1st	0.9	1.9	2.3	1.1	0.4	1.0	0.7	1.0	0.6
		2nd	1.9	2.0	2.1	0.2	0.0	0.3	1.0	0.1	0.6
Malva neglecta (Common mallow)	P	1st	3.3	2.3	3.0	8.2	8.1	8.3	3.4	1.6	4.2
		2nd	1.8	0.3	3.2	5.0	6.6	8.2	1.3	0.8	0.8
Polygonum aviculare (Prostrate knotweed)	A	1st	11.6	8.9	4.7	5.4	5.2	8.3	12.0	3.2	9.8
		2nd	15.8	6.5	5.6	2.0	1.9	4.0	4.1	0.8	3.2
Conzya canadensis (Canada fleabane)	A	1st	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		2nd	0.6	0.2	0.0	0.0	0.0	0.0	1.3	0.0	0.2
Cichorium intybus (Chicory)	P	1st	0.0	0.2	0.4	0.0	0.0	0.0	0.1	0.3	0.7
		2nd	0.0	1.1	1.4	0.0	0.0	0.0	0.3	1.0	1.4
Convolvulus arvensis (Field bindweed)	P	1st	0.3	0.0	0.0	0.3	0.0	0.0	0.1	0.0	0.0
		2nd	0.0	0.0	0.0	0.5	0.0	0.2	0.7	0.0	0.0

Cerastium fontanum	A, P	1st	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(Mouseear chickweed)		2nd	3.6	3.2	0.6	1.3	0.3	0.4	6.0	0.3	1.0
Capsela bursa-pastoris	A	1st	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(Shepherd's-purse)		2nd	0.5	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Oxalis stricta	P	1st	1.6	0.9	0.6	1.3	0.0	0.3	0.8	0.7	0.1
(Yellow woodsorrel)		2nd	3.2	2.4	0.8	4.8	2.1	2.8	1.5	1.3	0.2
Linaria vulgaris	P	1st	1.3	6.3	1.1	0.1	3.3	6.0	2.8	0.1	0.2
(Yellow toadflax)		2nd	0.4	5.8	3.3	0.0	8.4	13.8	1.5	0.9	0.8
Chenopodium album	A	1st	5.7	2.3	1.5	0.9	4.2	2.3	2.9	0.3	1.6
(Lambsquarters)		2nd	1.1	0.9	0.2	0.1	1.8	0.3	1.2	0.1	0.4
Lotus corniculatus	P	1st	0.4	1.8	2.2	0.3	0.0	0.1	0.8	0.3	0.3
(Birdsfoot trefoil)		2nd	0.9	0.8	1.2	0.5	0.0	0.0	1.5	0.1	0.3
Ambrosia artemisiifolia	A	1st	0.4	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
(Common ragweed)		2nd	0.7	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Pyrrhopappus carolinianus	A, P	1st	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
(Carolina false dandelion)		2nd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Medicago lupulina	A	1st	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(Black medic)		2nd	0.9	0.3	1.8	0.0	0.0	0.0	1.2	0.1	0.5

(1)Average of the eight assessments done from May to October, including the two in the mid of May and September.

(2)Broadcast foliar application at 1.7 kg a.i. ha^{-1}

Table 6.3. Season average population densities of broadleaf weeds found in the plots at the study Site -2, during 2004 and 2005. A = annual; P = perennial; A, P = annual or short-lived perennial. Within each weed control treatment and year, means with a common letter are not significantly different at *P* = 0.05 according to Tukey's test. * Significant at *P* = 0.05 and ** significant at *P* = 0.01 between the two years.

		Average population densities [1] of broadleaf weeds (no. plants m^{-2})								
	Year of	Untreated			Killex™ [2]			*S. minor* (60 g m^{-2})		
Species	study	3-5 cm	7-10	12-15	3-5	7-10	12-15	3-5	7-10	12-15
Taraxacum officinale	1st	49 a	54 a	50 a	18 b	19 b	18 b	30 ab	22 b	19 b
(Dandelion)	2nd	59 a	55 ab	50 b	3 de**	1.3 e**	3 de**	22 c	8 d**	9 d**
Trifolium repens	1st	32 ab	47.5 a	39.3 ab	13.5 c	16.3 c	15.3 c	21.5 c	18.7 c	14 c
(White clover)	2nd	12 a**	18.2 a**	17.9 a**	2.3 b**	0.4 b**	0.8 b**	4.6 b**	2 b**	1.2 b**
Plantago major	1st	3.1 a	2.1 a	1.3 ab	0.8 b	0.5 b	0.3 b	0.5 b	1.4 ab	0.4 b
(Broadleaf plantain)	2nd	6.2 a **	3.3 b*	3.2 b	0.03 c	0.0 c	0.0 c	1.0 c**	0.2 c*	0.03 c**

[1] Average of the eight assessments done from May to October, including the two in the mid of May and September.

[2] Broadcast foliar application at 1.7 kg a.i./ha

Table 6.4. Effect of mowing heights x weed control treatments on dandelion pre and post application densities over the two years. Within the same column, means with a common letter are not significantly different at P = 0.05 according to Tukey's test. * Significant at P = 0.05 and ** significant at P = 0.01 between the two years.

		Dandelion population density (no. plants m^{-2})											
		Site-1						Site-2					
	Mowing	Pre application[(1)]			Post application[(2)]			Pre application			Post application[(a)]		
Treatment	Height (cm)	1st year	2nd year	% Differ.[(3)]	1st year	2nd year	% Differ.	1st year	2nd year	% Differ.	1st year	2nd year	% Differ.
Untreated	3-5	51a	61a	24a	35ab	50a *	44ab	47a	62a	32a	50a	58a	15a
	7-10	62a	55a	-6.5abc	43a	49a	14abcd	58a	62a	15ab	54a	54ab	1a
	12-15	58a	58a	0.3ab	49a	49a	1bcd	56a	47ab	-12c	50a	51b	1a
Killex™ (1.7 kg ha^{-1})	3-5	57a	33cde	-39bcd	14cd	8c	-46ef	47a	1d**	-97d	14c	4d**	-73cd
	7-10	54a	16f **	-70d	13cd	4c *	-71f	60a	1d**	-98d	13c	2 **	-90cd
	12-15	75a	21ef **	-70d	19cd	5c **	-74f	53a	2d**	-97d	13c	3d**	-74cd
S. minor (60 gm^{-2})	3-5	57a	40bc	-28bcd	24bc	30b	27abc	45a	41b	-11c	25b	19c	-20b
	7-10	53a	22ef *	-58 d	8cd	8c	-30def	55a	18c**	-67d	17bc	7d**	-60cd
	12-15	59a	28cdef *	-52cd	9d	7c	-12cde	51a	17c**	-65d	14c	7d**	-48c

[(1)] dandelion density recorded in the assessment done on the day before the spring (mid of May) weed control treatment.

[(2)] the average density obtained from the six monthly assessments (May-October) done after the spring treatment.

[(3)] % Difference = (the two years difference/1st year density) x 100%

Table 6.5. Response of turfgrass quality, averaged over the season, to mowing heights x weed control treatments in the two study sites. Within the same column, means with a common letter are not significantly different at P = 0.05 according to Tukey's test. A visual rank scale of 0-100% was used with 0% for no grass and 100% for optimum grass quality.

Treatment	Mowing Height (cm)	Site-1 Pretreatment	Site-1 Posttreatment 2003	Site-1 Posttreatment 2004	Site-2 Pretreatment	Site-2 Posttreatment 2004	Site-2 Posttreatment 2005
Untreated	3-5	20 a	15 e	11 d	40 a	31 e	23 e
	7-10	26 a	23 de	25 cd	43 a	28 e	23 e
	12-15	23 a	14 e	29 bcd	48 a	36 de	26 e
Killex™ (1)	3-5	25 a	47 abc	50 abc	40 a	63 ab	57 bc
1.7 kg a.i./ha	7-10	19 a	38 bcd	55 ab	45 a	74 a	67 ab
	12-15	16 a	41 abcd	53 ab	42 a	70 a	73 a
Sclerotinia minor	3-5	23 a	36 cd	33 bcd	46 a	50 bcd	40 d
60 gm^{-2}	7-10	23 a	54 abc	70 a	42 a	61 abc	67 ab
	12-15	29 a	55 cd	69 a	43 a	66 a	70 a
Sclerotinia minor	3-5	26 a	36 cd	35 bcd	40 a	46 cd	47 cd
120 gm^{-2}	7-10	29 a	58 a	63 a	46 a	69 a	69 a
	12-15	27 a	54 abc	69 a	42 a	65 ab	72 a

Figure 6.1. Effect of mowing height and weed control treatments on dandelion density throughout the study period at the two study sites (1 & 2). Mowing heights were initiated two weeks prior to spring treatment application and maintained throughout the experiment. Mowing heights were 3-5 cm (A), 7-10 cm (B), and 12-15 cm (C). Within each graph, means with a common letter at each time are not significantly different at P = 0.05 according to Tukey's test. Arrows indicate dates of weed control treatment application. Asterisks (*) refer to the assessment conducted at the middle of the indicated month.

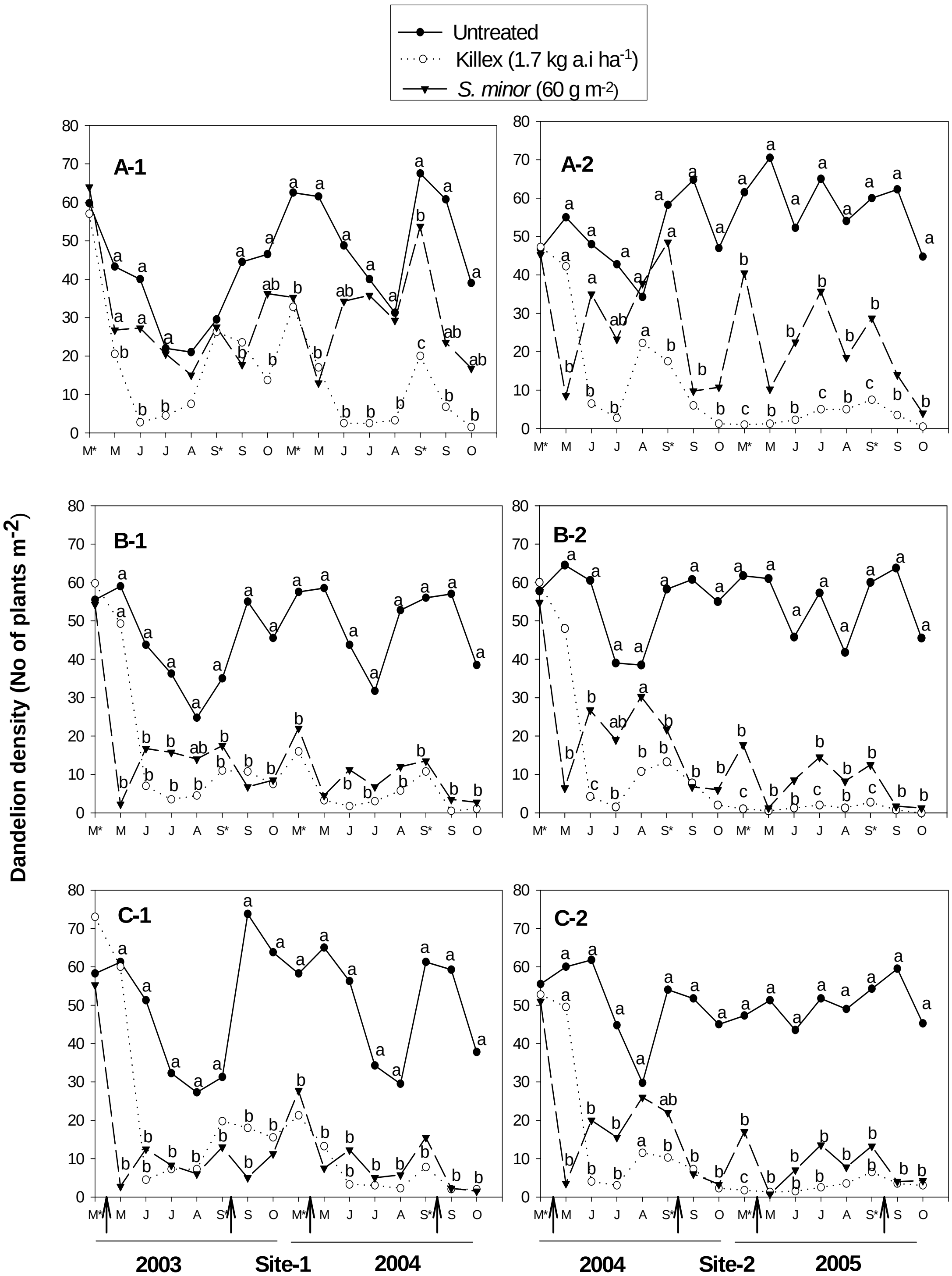
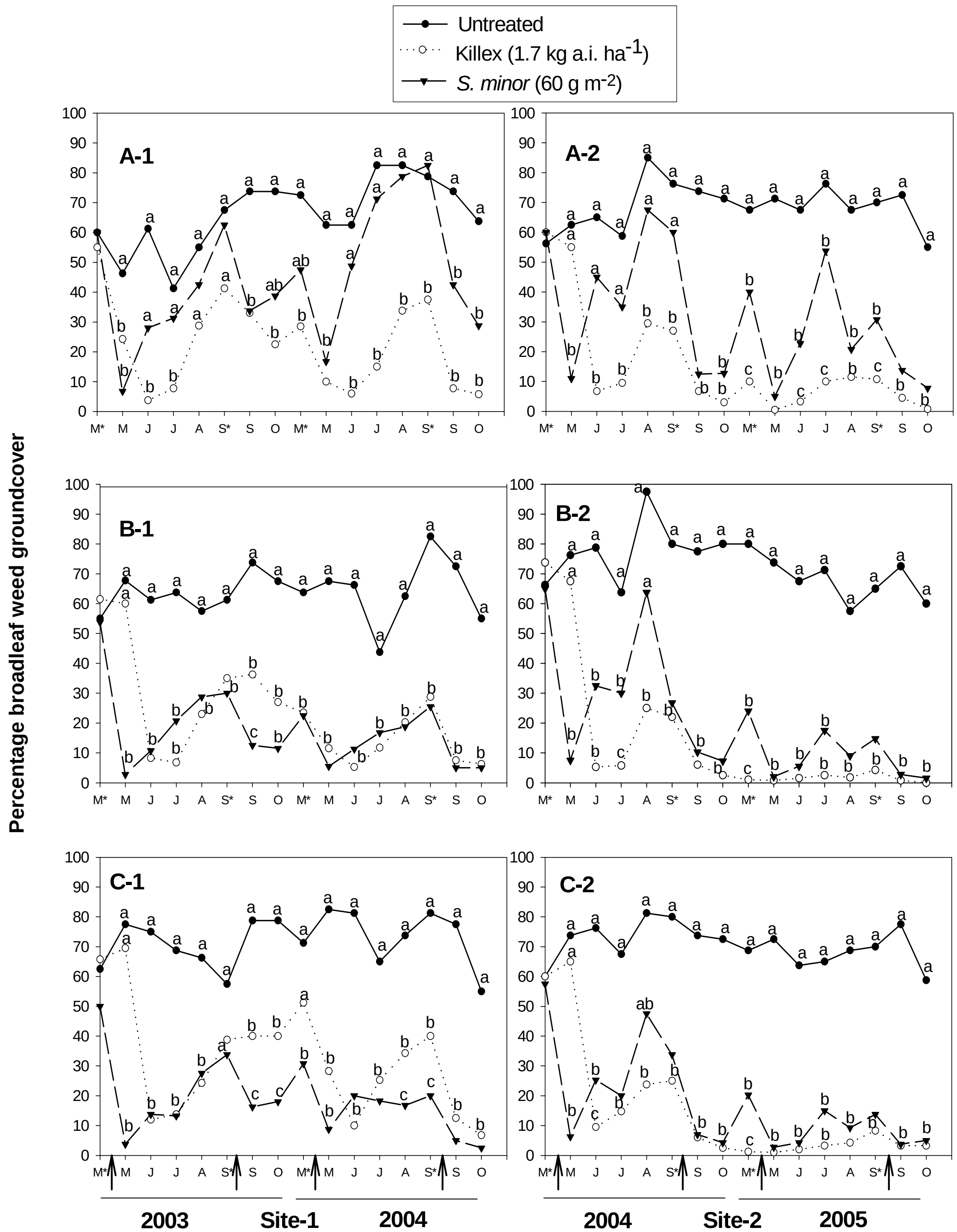

Untreated
Killex (1.7 kg a.i ha-1)
S. minor (60 g m-2)
A-1
A-2
B-1
B-2
C-1
C-2
Dandelion density (No of plants m-2)
M* M J J A S* S O M* M J J A S* S O
2003
Site-1
2004
Site-2
2005

Figure 6.2. Effect of mowing height and weed control treatments on broadleaf weed ground cover throughout the study period in the two study sites (1 & 2). Mowing heights were initiated two weeks prior to spring treatment application and maintained throughout the experiment. The applied mowing heights were 3-5 cm (A), 7-10 cm (B), and 12-15 cm (C). Within each graph, means with a common letter at each time are not significantly different at $P = 0.05$ according to Tukey's test. Arrows indicate dates of weed control treatment application. Asterisks (*) refer to the assessment conducted at the middle of the indicated month.



Untreated
Killex (1.7 kg a.i. ha-1)
S. minor (60 g m-2)
A-1
A-2
B-1
B-2
C-1
C-2
Percentage broadleaf weed groundcover
2003
Site-1
2004
2004
Site-2
2005

Figure 6.3. Effect of weed control treatments on broadleaf weed diversity throughout the study period in the two study Sites (1 & 2). Within each graph, means with a common letter at each time are not significantly different at P = 0.05 according to Tukey's test. Arrows indicate dates of weed control treatment application. Asterisks (*) refer to the assessment conducted at the mid of the indicated month.

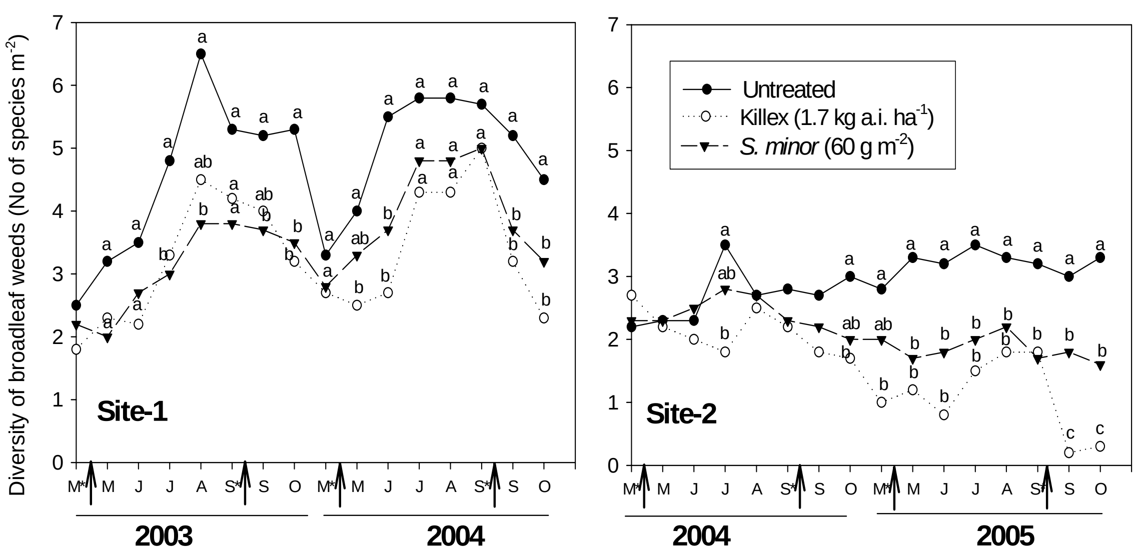
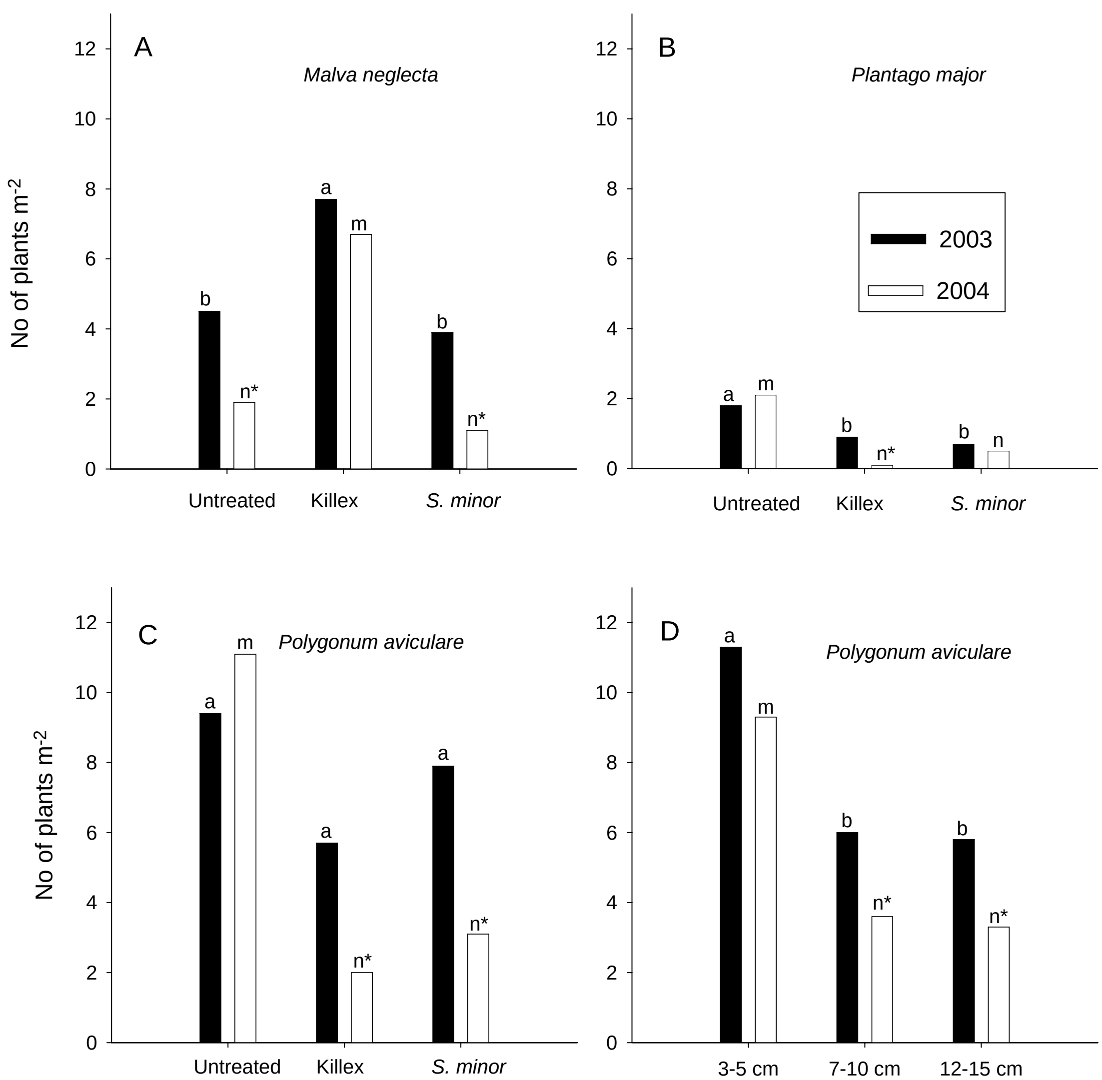


Figure 6.4. Response of season average of population densities of different broadleaf weeds to weed control treatments (A, B and C) and to mowing heights (D). Mowing heights were initiated two weeks prior to spring treatment application and maintained throughout the experiment. Within each graph and each year, bars with a common letter are not significantly different at P = 0.05 according to Tukey's test. * Significant difference between the two years at P = 0.05. *S. minor* rate = 60 g m^{-2}; Killex™ herbicide rate = 1.7 kg a.i./ha.



6.5. Acknowledgments

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