Weed Science 2010 58:317–322

Hexazinone and Fertilizer Impacts on Sheep Sorrel (*Rumex acetosella*) in Wild Blueberry

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Sheep sorrel is an invasive, creeping perennial weed of lowbush blueberry fields. It is one of the most prominent weeds in blueberry fields in Nova Scotia and is responsible for decreasing yields. Three levels of fertilizer (0, 20, 40 kg N ha^{-1}) and two levels of hexazinone (0 or 1.92 kg ai ha^{-1}) were applied to experimental plots to determine their effects on sheep sorrel density. Sprout-year hexazinone reduced sheep sorrel densities, which led to increased yields. Fertilizer increased weed density in the absence of herbicides, had no effect on density in the presence of herbicides, tended to have no impact on floral buds, and did not increase yields. Fruiting-year hexazinone decreased sheep sorrel densities in some situations, but did not result in yield increases.

Nomenclature: Hexazinone, Velpar; sheep sorrel, *Rumex acetosella* L.; lowbush blueberry, *Vaccinium angustifolium* Ait. and *Vaccinium myrtilloides* Michx.

Key words: Weed management, nitrogen, vegetative shoots, blueberry, floral buds, yield.

Commercial lowbush blueberry fields are developed from abandoned farmland or deforested areas (Hall et al. 1979). The lowbush blueberry grows naturally from a seedling and then spreads by rhizomatous activity (Barker et al. 1964; Hall 1957). Unlike most agricultural crops, lowbush blueberries are managed instead of planted and hence are marketed as ‘‘wild’’ blueberries. Commercial blueberry production occurs on a 2-yr production cycle. In the first year, fields are pruned (vegetative or prune year) by burning or flail mowing to stimulate vegetative growth. Flowering, fruit development, and harvest occurs in the second year (fruiting or crop year) (Barker et al. 1964). Weeds compete with lowbush blueberries, decrease yields, inhibit harvest operations, and decrease berry quality. Farmers rely predominately on herbicides for weed control because traditional weed management practices such as field cultivation or crop rotation cannot be applied in a perennial crop. The herbicide hexazinone is applied to fields to provide broad-spectrum weed control that was unattainable before it was introduced. The use of hexazinone has been reported to increase yields (Yarborough and Bhowmik 1989; Yarborough and Ismail 1985; Yarborough et al. 1986). Blueberry farmers also apply fertilizers believing it will maximize rhizome growth and berry yields (Percival et al. 2003).

Fertilizer input may increase the number of floral buds, which are a measure of yield potential (Jeliazkova and Percival 2003). However, blueberry plants respond slowly to fertilizer inputs (Eaton 1994) and weeds typically respond with greater vigor (Barker at al. 1964). When weeds are controlled, blueberry yields can increase by 50 to 100% (Yarborough and Bhowmik 1989; Yarborough and Ismail 1985) as a result of increased fruiting shoots and floral buds per shoot. Floral buds form on blueberry stems in the vegetative year and give rise to racemes of flowers in the fruiting year. The development of floral buds is imperative as they are related to fruit development and yield. Weed competition can negatively affect floral bud development (Penney and McRae 2000). Weeds typically grow above the blueberry canopy and absorb most of the sunlight; thus the blueberry plant does not receive enough sunlight to produce adequate floral bud numbers and subsequently yields decrease (Chandler and Mason 1946; Smagula and Ismail 1981). Adding fertilizer will have little effect on yield unless competing weeds are effectively controlled (Penney and McRae 2000). Inputs of the herbicide hexazinone can increase blueberry stem density and yields (Penney and McRae 2000; Yarborough and Bhowmik 1989).

Hexazinone is a photosynthesis inhibitor that is applied PRE to blueberry. It is a wide-spectrum herbicide used to control grasses and broadleafs in blueberry fields (McCully et al. 2005). Multiple applications of 1.5 to 2.0 kg ai ha^{-1} of hexazinone can sufficiently control most weed species over the 2-yr production cycle (Jensen 1985). Hexazinone persists in soil only 1 to 6 mo depending on the soil type (Jensen and Kimball 1987), and as a result, broadleaf species such as sheep sorrel can recover. Growers rely on repeated applications of hexazinone, which have resulted in weeds becoming resistant to recommended rates (Jensen and Yarborough 2004).

Sheep sorrel is one of the most common invasive weeds in lowbush blueberry fields. It was the most abundant weed present of the 125 species in Nova Scotian blueberry fields in 2000 and 2001 (Jensen and Sampson, unpublished data). This was a 43% increase in abundance from 1984 to 1985 when it was considered the fourth most abundant species (McCully et al. 1991). Sheep sorrel is a perennial plant that reproduces vegetatively from adventitious shoots emerging from roots (ramets) (Escarre et al. 1994; Putwain et al. 1968) and sexually via seed (Putwain et al. 1968). Both seeds and vegetative shoots can contribute to an increase in population size, but in pastures seed contribution is considered insignificant (Putwain et al. 1968). Many perennial species tend to rely on vegetative reproduction for expansion and growth as seedling survival is poor (Meyer and Schmid 1999; Putwain et al. 1968). Most of the studies on sheep sorrel have been conducted within pastures (Escarre and Thompson 1991; Putwain and Harper 1972; Putwain et al. 1968) or greenhouses (Doust and Doust 1987; Harris 1972). Greenhouse studies have shown that fertilizer inputs can increase sheep sorrel biomass and panicle number per plant (Fan and Harris 1996). Hexazinone can control populations of sheep sorrel, but tolerant populations have been documented (McCully et al. 2005), possibly due to low herbicide rates being used, resistance, or re-establishment from seed. Little information is published on sheep sorrel populations within lowbush blueberry fields, and it is unknown how blueberry management affects sheep sorrel.

DOI: 10.1614/WS-D-09-00081.1

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The objectives of the experiment were to (1) determine the effects of hexazinone and fertilizer on sheep sorrel shoot density over time and on blueberry yield parameters, and (2) determine the effects of hexazinone applied in the fruiting year on sheep sorrel density and blueberry yield in the fruiting year.

Materials and Methods

Study Sites. In 2007, field experiments were conducted in vegetative-year blueberry fields at Kemptown, NS (45°29′N, 63°10′W), Sackville, NB (45°54′N, 64°14′W), and Mt. Pleasant, NS (45°46′N, 63°50′W). In 2008, the experiment was repeated in an adjacent vegetative field at Mt. Pleasant. For the remainder of the text, the 2007 and 2008 Mt. Pleasant sites will be referred to as Mt. Pleasant07 and Mt. Pleasant08, respectively.

Soil at Kemptown is of the Queens type composed of 10 to 30 cm of silt to clay loam on top of 30 to 50 cm of firm silt to clay loam over compacted loam to clay loam derived from shale and sandstone (Webb et al. 1991). It contains 6.5% organic matter and has a pH of 4.6. Soil at Mt. Pleasant is a sandy loam over a gravelly sandy loam of the Hansford type (Nowland and MacDougall 1973) with a pH of 4.7 and 4.1 to 4.3% organic matter. Soil at Sackville is a sandy loam of the Aulac type (Aalund and Wicklund 1953) with 4.7% organic matter and a pH of 4.5.

Experimental Design. In the vegetative year the experimental design was a 2 by 3 factorial design in four blocks. Treatments consisted of the addition of hexazinone[1] at two levels (0 or 1.92 kg ai ha^{-1}) in conjunction with the addition of a synthetic ammonium sulfate fertilizer[2] at three levels (0, 20, or 40 kg N/ha) applied as the standard 14-18-10 mix. Fertilizer inputs were based on N levels, but phosphorous and potassium were also present. The fertilizer was applied once at the beginning of the vegetative year, by hand. Hexazinone was sprayed with a hand-held, CO_2-pressurized sprayer[3] fitted with TeeJet 8002VS nozzles[4] at a rate of 1.92 kg ai ha^{-1} in a water volume of 200 L ha^{-1}. Agrochemicals were applied at the beginning of the vegetative year before blueberry emergence. Plots were 4 by 6 m with a 1-m buffer that served as a walkway between rows of treatments.

In the fruiting year, the plots from the previous vegetative year at Kemptown and Mt. Pleasant07 were split into two 2 by 6 m plots, and hexazinone was randomly applied at the registered fruiting-year rate of 1 kg ai ha^{-1} in early May 2008 or not applied (0 kg ai ha^{-1}).

Data Collection. *Sheep Sorrel Density*. In the vegetative year, a 30- by 30-cm permanent quadrat was positioned randomly within each 4- by 6-m plot. Sheep sorrel counts were conducted weekly until July 1 and biweekly from July 1 to August 31. Counts at Sackville did not commence until June 1. In the fruiting year, sheep sorrel densities were assessed 1 mo after fruiting-year application in two randomly placed 30- by 30-cm quadrats within each subplot.

Floral Buds. Twenty blueberry stems were collected in the fall of the vegetative year from each plot at all four vegetative-year sites using a line transect that extended diagonally across each plot. The transect was marked at 40-cm intervals and one stem directly below each mark was collected. Floral buds were counted on each stem.

Blueberry Yield. Blueberry yield was estimated at Kemptown and Mt. Pleasant07 in the fruiting year of 2008 from one 1-m^2 quadrat that was randomly placed within each 2 by 6 m experimental plot. All berries within the quadrat were harvested with a hand rake and cleaned in the field using wind to remove leaves. Yield was based on fresh weight using a battery-operated scale[5] in the field.

Statistical Analysis. The data were first analyzed as a nested design using PROC MIXED in SAS,[6] with blocks nested within sites. A nested design was used because treatments were randomized within blocks but not across sites and because sites differed in field age, management history, sheep sorrel susceptibility to hexazinone, and organic matter content (Shen 1995). Sites were then analyzed separately because of the known differences between sites that were of interest and because blocks nested within sites were significant ($P < 0.0001$). Sheep sorrel density data were analyzed using the PROC MIXED procedure with repeated measures in SAS. Floral bud numbers, blueberry yield, and fruiting-year sheep sorrel densities were also analyzed using the PROC MIXED procedure in SAS. Differing data transformations were required at each site, and were used where necessary to achieve normality and constant variance. Data were then back-transformed for interpretation and figure creation. Least-squares means differences were used to test for treatment differences using a probability level of $P \leq 0.05$.

Results and Discussion

Vegetative-Year Data. The effects of hexazinone and fertilizer on sheep sorrel density varied across sites. Sheep sorrel density at Kemptown decreased over time when hexazinone was applied ($P < 0.001$), whereas fertilizer had no effect ($P = 0.44$). Differences in density between treatments was first observed 42 days after treatment (DAT) (Figure 1). This date corresponds to June 20 or Julian day 171. By the last observation date at Kemptown, shoot density decreased from 218 to 117 shoots m^{-2} in plots treated with hexazinone (Figure 1). Hexazinone applications applied in the vegetative year also tended to reduce sheep sorrel densities in the fruiting year where fruiting-year hexazinone was not applied (Table 1). Lack of differences with sheep sorrel densities may be attributed to high variability between plots. At Sackville, sheep sorrel densities in the vegetative year also declined over time where hexazinone was applied ($P = 0.017$) and fertilizer had no significant effect ($P = 0.36$) (Figure 2). Sheep sorrel densities in the fruiting year were not assessed at Sackville. Differences in density between treatments were first observed 55 DAT (Figure 2). At the end of the summer, sheep sorrel density was 35% lower where hexazinone was applied (Figure 2). Hexazinone tended to lower sorrel densities at Kemptown, but only prevented population increase at Sackville. The organic matter content at Kemptown was significantly higher than at Sackville (6.5% and 4.7%, respectively). Soil organic matter increases the sorption and decreases the bioavailability of *s*-triazine herbicides (Brouwer et al. 1990; Laird et al. 1994; Ma and Selim 1996; Stevenson

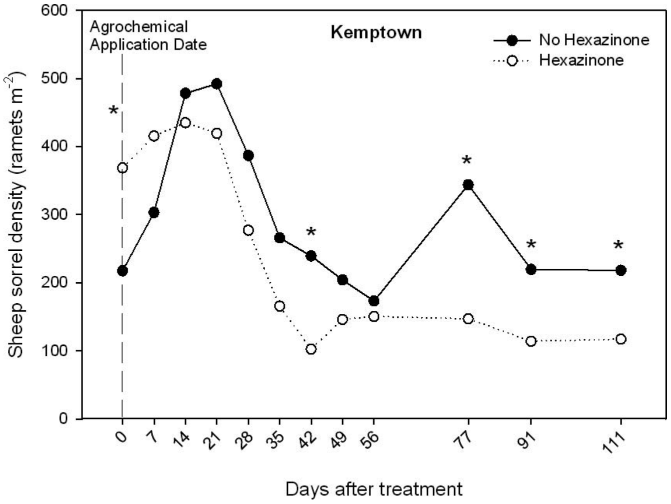

Figure 1. Vegetative-year sheep sorrel shoot density at Kemptown, NS affected by vegetative-year hexazinone and time. An asterisk (*) indicates a significant difference ($P \leq 0.05$) in sheep sorrel density between the two treatments at that date.

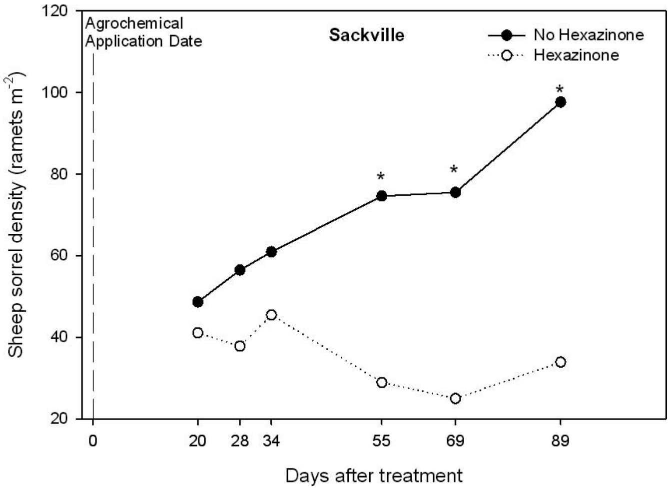

Figure 2. Vegetative-year sheep sorrel density at Sackville, NB affected by vegetative-year hexazinone and time. An asterisk (*) indicates a significant difference ($P \leq 0.05$) in sheep sorrel density between the two treatments at that date.

1972), which may explain why sheep sorrel densities at Kemptown were much higher compared with Sackville.

The two Mt. Pleasant sites (2007 and 2008) had similar initial densities (Figure 3). There was a significant three-way interaction between time, fertilizer, and hexazinone at both sites ($P = 0.014$ and $P = 0.005$, respectively). Fertilizer essentially doubled sheep sorrel density at both sites, but hexazinone decreased density to near zero at all levels of nitrogen (Figure 3). Hexazinone first affected sheep sorrel density 28 DAT at Mt. Pleasant07 (June 13/Julian day 164) and 21 DAT at Mt. Pleasant08 (May 19/Julian day 141). Thus hexazinone can control sheep sorrel populations as soon as 21 DAT. At both sites, hexazinone affected sheep sorrel density 1 and 2 wk earlier in the fertilized plots compared with when no fertilizer was added at Mt. Pleasant07 and Mt. Pleasant08, respectively (Figure 3). Compared with the control, sheep sorrel densities were higher in plots treated with 20 and 40 kg N ha^{-1} plots at Mt. Pleasant07 and Mt. Pleasant08, respectively (Figure 3). Increasing the fertilizer level stimulated weed growth where hexazinone was not applied, confirming what Hepler and Ismail (1985) reported. At Mt. Pleasant07, 20 kg N ha^{-1} caused a larger early-season increase in sheep sorrel density (104 and 135 ramets m^{-2}) compared with plots that received 40 kg N ha^{-1} (78 and 88 ramets m^{-2} at 7 and 21 DAT, respectively), which may have been due to competition from grasses, as there was an abundance of grasses within these plots. Sheep sorrel numbers were reduced to zero as early as 48 DAT (June 16/Julian day 167) and remained at zero for the rest of the summer, regardless of nitrogen fertilizer level at Mt. Pleasant08 (Figure 3).

Table 1. Effect of vegetative-year hexazinone and fruiting-year hexazinone applications on sheep sorrel density in two fruiting-year blueberry fields at Kemptown, NS and Mt. Pleasant, NS. Hexazinone was applied in early April 2007, before blueberry emergence during the vegetative year and in early May 2008 during the fruiting year. Fruiting-year sheep sorrel density counts were conducted 1 mo after herbicide application (early June 2008).

Vegetative-year hexazinone	Fruiting-year hexazinone	Site	
		Kemptown	Mt. Pleasant07
(kg ai ha^{-1})	(kg ai ha^{-1})	—— # ramets m^{-2} ——	
0	0	1544 a[a]	361 a
0	1.0	1371 a	328 ab
1.92	0	1140 a	229 b
1.92	1.0	1306 a	120 c

[a] Least-squares means within a column with the same letter are not significantly different ($P \leq 0.10$).

In the control plots, regardless of fertilizer level, sheep sorrel densities peaked early in the season with a sharp decline thereafter (Figures 1 and 3), most likely due to the ramets competing with each other. Another peak in density was then observed late in the summer with the densities tending to level off over time (Figures 1 and 3). At Sackville, this trend was not observed as the densities were markedly lower, and the densities only exhibited the first peak in population (Figure 2). Ramet numbers did not reach a high enough density to compete with each other and exhibit a drop in numbers; thus the sharp decline is not exhibited (Figure 2) as it was at the other sites. At Kemptown, initial densities were around 200 to 400 shoots m^{-2}, initial densities at Sackville were much lower at 40 to 45 shoots m^{-2}, and tended to increase almost linearly where hexazinone was not applied. Initial densities at Mt. Pleasant07 were similar to Sackville and tended to increase where hexazinone was not applied. At Mt. Pleasant08, however, densities without hexazinone tended to decline 21 DAT (May 12/Julian day 141). This could be attributed to the abundance of grasses that were difficult to control at this site, as sheep sorrel does not compete well with grasses (Putwain and Harper 1970).

Floral Buds. The number of floral buds was affected by the interaction between hexazinone and fertilizer at Kemptown ($P = 0.029$), by hexazinone at Sackville ($P = 0.017$), and were not affected by fertilizer ($P = 0.92$; $P = 0.90$) or hexazinone ($P = 0.061$; $P = 0.12$) at Mt. Pleasant in 2007 and 2008, respectively. At Kemptown, floral bud numbers significantly decreased where fertilizer was applied without hexazinone applications and tended to increase with fertilizer where hexazinone was applied (Table 2). Although not statistically significant, the other three sites showed similar trends as Kemptown (Table 2). These results are similar to results reported by Eaton (1994), who found that average floral bud

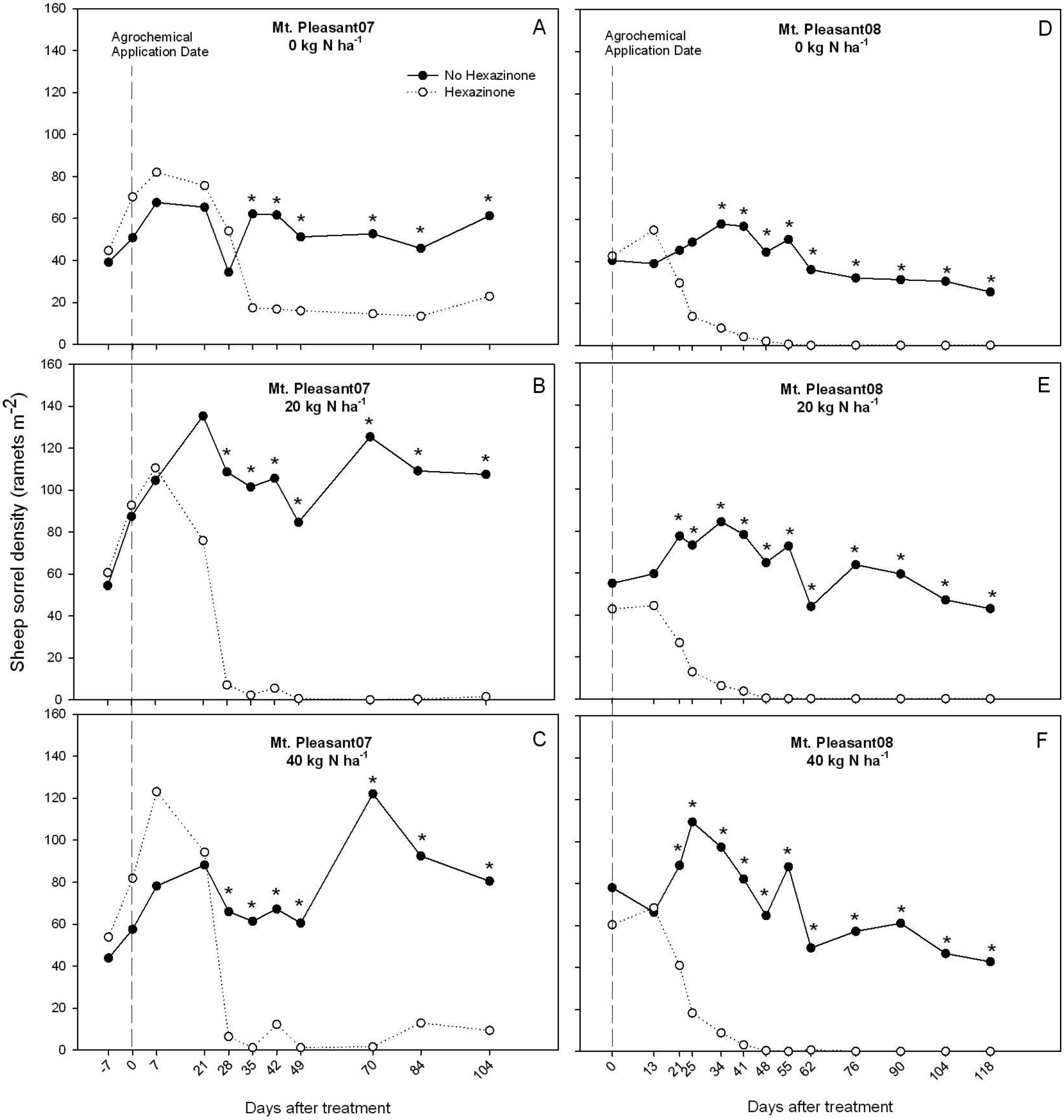

Figure 3. Vegetative-year sheep sorrel density at Mt. Pleasant07 (A, B, C) and Mt. Pleasant08 (D, E, F) affected by hexazinone, fertilizer, and time. Agrochemical application was applied in the vegetative year. (A & D) 0 kg N ha^{-1}, (B & E) 20 kg N ha^{-1}, (C & F) 40 kg N ha^{-1}. An asterisk (*) indicates a significant difference ($P \leq 0.05$) in sheep sorrel density between the two treatments at that date.

numbers increased by 18% with herbicide application compared with the control and by 84% where herbicide was applied in combination with N–P–K fertilizer. At Kemptown, plots treated with hexazinone and 20 kg N ha^{-1} had the largest number of floral buds, but these were not significantly different from the control (Table 2). At Sackville, weed control achieved by hexazinone applications significantly increased the number of floral buds by 68%—from 4.5 buds per stem without hexazinone to 6.6 with hexazinone (Table 2). Yarborough and Bhowmik (1989) reported similar findings, where weed control by hexazinone resulted in an 88% increase in floral bud numbers compared with the control. Although not supported statistically, trends in this study were similar to those of Penney and McRae (2000), who reported that floral bud numbers increased with weed control, but fertilizer without weed control decreased bud numbers. Weed control by hexazinone consistently increased floral bud numbers at all study sites (Table 2) because of removal of

Table 2. Impact of 14-18-10 fertilizer (three levels) and hexazinone (two levels) on the average number of floral buds per blueberry stem at vegetative-year blueberry fields at Kemptown, Mt. Pleasant07, and Mt. Pleasant08, NS, and Sackville, NB. Agrochemical application was conducted in early April 2007, during the vegetative-year before blueberry emergence. Floral bud counts were conducted in the fall of the vegetative year.

Hexazinone	Fertilizer	Site			
		Kemptown	Sackville	Mt. Pleasant07	Mt. Pleasant08
(kg ai ha^{-1})	(kg N ha^{-1})	floral buds stem^{-1}			
0	0	3.9 ± 0.3 a[a]	4.8 ± 1.2 b	3.1 ± 0.3 a	3.5 ± 0.2 a
0	20	2.0 ± 0.7 b	4.7 ± 0.3 b	3.1 ± 0.7a	2.7 ± 0.3 a
0	40	2.0 ± 0.7 b	4.0 ± 0.2b	2.9 ± 0.5 a	3.2 ± 0.5 a
1.92	0	2.9 ± 1.3 ab	6.4 ± 1.3a	3.8 ± 0.8 a	3.3 ± 0.5 a
1.92	20	4.4 ± 0.4 a	5.2 ± 0.9a	4.3 ± 0.9 a	4.5 ± 0.7 a
1.92	40	3.0 ± 0.4 ab	8.3 ± 1.1a	4.1 ± 1.0 a	3.9 ± 1.1 a

[a] Least-squares means ± SE ($n = 4$) within a column with the same letter are not significantly different ($P \leq 0.05$).

competing vegetation, but fertilizer did not have a consistent effect and only increased floral bud numbers at one of the four sites.

Fruiting-Year Data. Fertilizer applied in the vegetative year had an inconsistent impact on sheep sorrel density in the fruiting year (data not shown). Compared with the control, 40 kg N ha^{-1} increased density by 32% at Kemptown ($P = 0.062$), but decreased density by 43% at Mt. Pleasant07 ($P = 0.0007$). Grasses present within the fertilized plots at Mt. Pleasant07 may have either limited the amount of physical space for sheep sorrel establishment, or prohibited seedlings from establishing. Grasses germinate within or below the residue layer, and typically increase or replace broadleaf weeds that rely on soil disturbance for germination and establishment (Young et al. 2006). Vegetative-year hexazinone applications tended to decrease sheep sorrel densities in the fruiting year, although this difference was not always significant (Table 1). Hexazinone applications were applied in the fruiting year to further control sheep sorrel to prevent mechanical impedance during harvest and thereby prevent fruit damage. Applications of hexazinone applied in the fruiting year did not reduce sheep sorrel densities in the fruiting year at Kemptown ($P = 0.62$), but decreased densities at Mt. Pleasant ($P = 0.037$). Excluding where hexazinone was applied in the fruiting year, sheep sorrel populations recovered significantly in the fruiting year from the previous vegetative year (Table 1). Where vegetative-year hexazinone applications reduced sheep sorrel populations, applying hexazinone in the fruiting year further reduced sheep sorrel densities by about half (Table 1). This is similar to the findings of Jensen and Specht (2002), where 94% control of sheep sorrel was obtained with 1.0 kg ai ha^{-1} hexazinone.

Blueberry Yield. The application of hexazinone in the fruiting year reduced sheep sorrel densities, but did not increase blueberry yields at Kemptown ($P = 0.73$) or Mt. Pleasant07 ($P = 0.43$) (see data below). We conclude that the use of hexazinone in the fruiting year does not result in a yield increase. Control of sheep sorrel by vegetative-year hexazinone applications increased blueberry yield at Kemptown ($P = 0.056$) and Mt. Pleasant07 ($P = 0.0041$), whereas fertilizer had no significant effect ($P = 0.59$ and $P = 0.79$, respectively). The interaction between fertilizer and vegetative-year hexazinone was not significant at Kemptown ($P = 0.26$) or at Mt. Pleasant07 ($P = 0.88$). These results are similar to the findings of Hepler and Ismail (1985) where nitrogen had no effect on yield, and weed control by the herbicide terbacil was the only factor that increased yields. Blueberry yield at Kemptown was 4,100 kg ha^{-1} and 2,800 kg ha^{-1} with and without hexazinone, respectively. At Mt. Pleasant07, blueberry yields were 11,000 kg ha^{-1} where hexazinone was applied and 8,400 kg ha^{-1} where it was not applied. Even where sheep sorrel control by hexazinone was low, blueberry yields increased where hexazinone was applied (see data above). The control of sheep sorrel in the vegetative year at Kemptown and Mt. Pleasant07 (Figures 1 and 3A–C) resulted in the observed yield increases. Floral buds were able to develop during the vegetative year when the taller sheep sorrel plants were controlled. Sheep sorrel populations did recover in the fruiting year, but this did not affect yield as floral buds had already developed from the previous vegetative year. Hexazinone reduced sheep sorrel density by 50% at Kemptown (Figure 1), resulting in a twofold increase in yield. Given that hexazinone did not significantly increase floral bud numbers at Mt. Pleasant07, this yield increase could be attributed to several factors including differences in berry size or fewer flowering sheep sorrel ramets interfering with harvesting operations.

Hexazinone decreased sheep sorrel density at all sites. Fertilizer increased sheep sorrel density in the absence of hexazinone, tended to have no impact on floral buds, and failed to increase yields. The addition of fertilizer in combination with weed control by hexazinone resulted in higher floral bud numbers and increased blueberry yield by as much as 75%. Hexazinone applied in the fruiting year was only effective at decreasing sheep sorrel densities in the fruiting year if hexazinone had effectively lowered densities in the previous vegetative year. Fruiting-year applications of hexazinone may have potential to control sheep sorrel, but the window of opportunity for use is small, and applications did not result in higher yields.

Sources of Materials

[1] Hexazinone, Velpar 75DF, E. I. DuPont Canada Company, P.O. Box 2300, Streetsville Mississauga, ON, Canada L5M 2J4.

[2] Fertilizer, 14-18-10 Fertilizer, Cavendish Agri Services, 100 Midland Drive, Dieppe, NB, Canada E1A 6X4.

[3] R&D CO_2 pressurized sprayer, 419 Hwy 104, Opelousas, LA 70570.

[4] TeeJet 8002VS nozzle, Rittenhouse, 1402 Fourth Ave., St. Catharines, ON, Canada L2R 6P9.

[5] Ohaus CD-11 Industrial Indicator, 19A Chapin Road, P.O. Box 2033, Pine Brook, NJ 07058.

[6] SAS, SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513.

Acknowledgments

Special thanks to Scott White and Angela Hughes for their excellent technical assistance in the field. We also acknowledge all the summer students who were involved in this project. This research was funded by the Nova Scotia Technology Development 2000 program, the Wild Blueberry Producer's Association of Nova Scotia, and Oxford Frozen Foods.

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Received December 7, 2009, and approved March 2, 2010.