ABSTRACT

ROBERTS, MEAGAN MARYKATHERINE. Biology and Control of Maryland Meadowbeauty (*Rhexia mariana* L.) in Blueberry (*Vaccinium* spp.) in North Carolina. (Under the direction of Katherine M. Jennings and David W. Monks).

North Carolina is the fifth largest producer of blueberries (*Vaccinium spp*.) in the U.S. with approximately 5,000 acres harvested in 2006. A study was conducted to determine if a positive correlation exists between the weed populations in field drainage ditches and weed populations in the field interior, and to inventory the weed species present in the ditches and the field interiors. Sixty-six species were inventoried over a two year period. A second study was conducted to define the seed biology of *Rhexia mariana* L., an aggressive perennial weed in blueberry, by determining temperature effects on germination, average seed number per capsule, seed number in the seed bank, and seed dormancy. Maximum seed germination was observed at day/night temperatures of 20/35C. Seed germination ranged from 47 to 86% and dormancy ranged from 14 to 53%. The number of seed capsules produced per infested area was different among locations and ranged from 500 to 1125 capsules/m^2. Across locations, seed capsules produced an average of 74 seeds each. On average, 27 *R. mariana* seeds were present in each 273cm^2 sample of soil. A single m^2 of *R. mariana* infestation has the potential to produced 12,375 seed capsules and 915,750 seeds. Of those seeds, roughly 604,395 would be viable, 519,779 could germinate as freshly mature seeds, and an additional 84,615 seeds would be dormant. An estimated 1000 *R. mariana* seeds could germinate from 1m^2 of the soil seed bank. A third study was conducted to determine the efficacy of flumioxazin on *R. mariana* and the tolerance of blueberry to flumioxazin. The data indicate that flumioxazin does not injure blueberry when applied PRE. Flumioxazin applied PRE in a single or a sequential application does not have a negative effect on blueberry yield, even at

rates that exceed the registered rate. Control of *R. mariana* with a single application of flumioxazin at the registered rate of 0.42 kg ai/ha ranged from 83 to 100% at 60 days after treatment (DAT). Sequential applications of flumioxazin at 0.21 kg ai/ha per application resulted in control greater than 96% 30 d after the last of two applications. The data indicates that flumioxazin applied PRE at the registered rate of 0.42 kg ai/ha in a single application or 0.21 kg ai/ha in a sequential application in a 12 month period would give effective control of *R. mariana.* A final study was conducted in which a grower survey was used to determine the current weed management practices employed by blueberry growers in North Carolina. A 41-question survey was mailed to 241 blueberry growers in February 2008. A total of 58 valid responses were returned and were entered into the data set. Respondents represent 24% of the survey population. Thirty-eight percent of the survey population grows a combination of rabbiteye and highbush blueberry types. The highbush variety 'Croatan' was the most frequently planted variety in total hectacreage, and the rabbiteye variety 'Premier' was the most common variety of that blueberry type. Growers use a combination of mechanical cultivation, hand removal, and herbicides to control weeds in blueberry. Greenbriar species (*Smilax spp*.) were reported as those species that are increasing in severity, are the hardest to manage, and that interfere most with harvest. Sethoxydim and hexazinone are the most common herbicides used in non-bearing and bearing blueberries, respectively. Growers indicated that their greatest concern in weed management is crop safety to herbicides. Results from all four studies will aid in the development of a comprehensive weed management plan to address the specific needs of North Carolina blueberry producers.

Biology and Control of Maryland Meadowbeauty (*Rhexia mariana* L.) in Blueberry (*Vaccinium* spp.) in North Carolina

by
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BIOGRAPHY

Meagan M. Roberts began her M.S. program in the Department of Horticultural Science at North Carolina State University in the fall of 2006. Under the guidance of Katherine Jennings and David Monks, Meagan not only completed her own studies, but also gained experience working in a variety of other small fruit and vegetable crops. Following completion of her degree in May of 2009, Meagan plans to pursue a graduate degree in education.

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF FIGURES

CHAPTER 1

An Analysis of the Distribution and Migration of Drainage Ditch Weed Species in Blueberry and Implications for Drainage Ditch Weed Management

Abstract

Individuals representing a total of 61 species were sampled in 2007 and 2008. Of the total species, two were biennial, 19 were annual and 40 were perennial. The most prevalent annual species was large crabgrass, with 586 occurrences. The most prevalent perennial species was needleleaf rosette grass with 971 occurrences. Thirteen of the 30 species species (43%) had a positive relationship between presence in the ditch and presence in the field when analyzed using correlation analysis, which did not consider factors other than population number. Six of the 30 species populations (20%) analyzed with ANOVA had a positive relationship between ditch and field populations when factors such as sampling year and field were included in the analysis. Transects with higher ditch population counts also tended to have higher field population counts. The data indicate that changes in the ditch populations of these six species may result in changes in the field populations. A total of four species had population densities that were affected by an interaction of ditch to plot distance by row position. Three species had populations affected by ditch to plot distance or row position alone. Only three species (10%) that had a positive relationship between ditch and field population numbers according to both the correlation and ANOVA analysis also had population densities affected by an interaction of ditch to plot distance and row position. The cumulative analyses of these three species (Maryland meadowbeauty, red sorrel and common toadflax) indicate the existence of sink populations in the field that are potentially being supplied by source populations in the ditches and that population densities tend to decrease as ditch to plot distance increases. Maryland meadowbeauty has the potential to be the most aggressive of the three species because it is perennial and can reproduce both sexually and

vegetatively. Overall, it is possible that blueberry growers could benefit from decreasing the intensity of drainage ditch management without increasing weed populations in their fields.

Introduction

In North Carolina, similarities between the weed species composition in field drainage ditches and field interiors have led researchers to believe that ditches contribute to the invasion and persistence of weed populations within adjacent blueberry fields (Jennings pers. comm.). The perception of field margins as a source of weed species is common (Marshall and Smith 1987**)** and research has shown that field margin weed populations can support weed populations in the field interior if suitable, unoccupied habitat is available and weeds in the margins are better at dispersal that individuals in the fields (Blumenthal and Jordan 2001). However, there is insufficient evidence to determine if field margins are the primary source of individuals for economically damaging weed infestations in the field (Blumenthal and Jordan 2001; Devlaeminck et al. 2005; Smith et al. 1999). Regardless, many blueberry growers intensely manage field ditches as a matter of practice by mowing or applying herbicide.

While the field margins may support semi-natural vegetation communities that can obstruct machinery or harbor pest species, unmanaged field margins may possess ecological, environmental, and aesthetic value (Boutin and Jobin 1998; Marshall and Arnold 1995; Marshall and Moonan 2002). It is possible that the benefits of unmanaged field edges are less obvious than the potential harms, especially when field margins may contain problem weeds (Sosnoskie et al. 2007), however financial and environmental implications exist.

Financially, growers spend additional money on labor and herbicides for ditch management. Environmentally, managing the ditches may decrease the density and diversity of plant species, thereby reducing the number of beneficial pollinators attracted to the fields. Unmanaged ditches provide a wider diversity of floral resources and therefore attract beneficial insects, such as bees, to crop fields (Tuell et al., 2008). The presence of increased numbers of native bee species is especially important for the pollination of blueberry. Additionally, blueberry fruit-set is positively correlated to increases in bee density (Dedej and Delaplane, 2003). Unmanaged field margins also provide habitat for wildlife species (Rands 1987; Sotherton et al., 1985).

In order to explore the perception of field drainage ditches as sources of weed species, an examination of the dispersal of weed species from ditches to blueberry field interiors was conducted. The objectives of this study were to determine if a positive correlation exists between weed species in field drainage ditches and weed species in the field interior, and to inventory the weed species present in the ditches and the field interior.

Materials and Methods

Weed species data were collected from 20 grower fields throughout the range of commercial blueberry production in southeastern North Carolina coastal plain. In each field selected for the study, the blueberry rows were planted perpendicular to managed drainage ditches. Three to five transects were placed in a blueberry row with a spacing of three rows between transects. Transects began on the slope nearest the field in the drainage ditches and ran 46 m into the blueberry field. Plots were placed at 1.5, 3, 8, 15, 23, 33.5, and 44 m along each transect beginning at the field edge and one plot was placed on the corresponding ditch bank (Figure 1.1). A total of eight plots were sampled on each transect. Distance from the field edge to the ditch bank was measured to calculate true plot distances from the ditch. Plots were 1.5 m by 3 m long and included two bedded rows with blueberry plants and one row middle, which is the unplanted area between the blueberry bush rows. Permanent plot markers were placed to allow for sampling over multiple years.

Sampling of all plots occurred in March and July of 2007 and 2008 to account for winter and summer annual weeds. In each plot, weeds were counted within a 0.37 m^2 quadrat that was placed once on each row bed and once in the row middle. A total of three quadrats were sampled per plot and quadrat location was noted in the data set. Stem counts were taken for all weed species occurring in each quadrat. Data were analyzed using frequency, analysis of variance (ANOVA), analysis of covariance, and correlations (SAS Institute Inc. 2004[1])

Results and Discussion

Species Inventory. Individuals representing a total of 61 species were sampled in 2007 and 2008. Of the total species, two were biennial, 19 were annual and 40 were perennial (Tables 1.1, 1.2 and 1.3). The most prevalent annual species was large crabgrass (*Digitaria sanguinalis* L. (Scop), with 586 occurrences. The most prevalent perennial species was needleleaf rosette grass [*Dichanthelium aciculare* (Desv. ex Poir.) Gould & C.A. Clark] with 971 occurrences. Nativity of each species was determined using the United States Department of Agriculture Natural Resources Conservation Service PLANTS Database (USDA, NRCS 2008). The data indicate weed populations occurring in North Carolina blueberry fields are dominated by perennial native species. This finding supports grower and researcher observations that weed communities in blueberry are dominated by perennials.

Effect of Ditch Populations on Field Populations. Those species that occurred fewer than 15 times in the species inventory were excluded from further analyses. Species that only occurred in the ditch were excluded from the analysis of covariance, which was used to examine the effect of ditch to plot distance and row position on population distributions, because ditch plots did not contain a row position and only had one distance value. A total of 30 species were included in the correlation and ANOVA analyses, and 29 species were included in the analysis of covariance.

Species Correlations between the Ditch and the Field. Correlations between species population counts in the ditch and the field were analyzed. Thirteen species had a positive correlation between presence in the ditch and presence in the field when no additional factors were included (Table 1.4). The data indicate that in the absence of influencing factors such as sampling year or grower field, that several species have field population numbers that may be influenced by changes in ditch population numbers. Because the correlation analysis did not take into account other factors, the analysis was considered exploratory.

Species Correlations using ANOVA. Species population numbers were analyzed using an ANOVA model where the dependent variable was field population number and ditch population number was fitted first among the other independent variables of year, field number, and a year by field interaction. Species populations were averaged over distance and row position. Using this model, which accounts for factors other than population number to examine the relationship between field and ditch populations, six species had a positive correlation between presence in the ditch and presence in the field (Table 1.5). The data indicate that when factors such as year and field effects are considered, the number of species with correlations between the ditch and the field population numbers are reduced. For those species with a positive relationship between ditch and field populations, transects with higher ditch counts also tended to have higher field counts. Ultimately, changes in the ditch population could possibly lead to changes in field population regardless of the influence of other factors.

While the majority of the weed species in blueberry fields appear to be perennial, only three of the species with a positive correlation between ditch and field populations are perennial (red maple, *Acer rubrum* L.; loblolly pine, *Pinus taeda* L.; Maryland meadowbeauty, *Rhexia mariana* L.). Red maple and loblolly pine are relatively slow growing tree species and generally do not become aggressively invasive. Conversely, Maryland meadowbeauty is an herbaceous perennial that has been documented as a native invasive species in Florida (Craine 2002) which suggests managing it in the ditches may be necessary to prevent invasion of adjacent fields.

Effect of Distance and Row Position on Species Occurrence. Species population numbers were analyzed using an analysis of covariance to determine the effects of ditch to plot distance and row position, which is on the row bed or in the row middle, on the distribution of population numbers. Only large crabgrass, which had a relationship between the populations in the ditch and the field based on correlation analyses, had population distributions affected by an interaction of ditch to plot distance by row position. The population of large crabgrass was highest in the ditch, decreased slightly, then increased as ditch to plot distance increased. While distance from the ditch seems to influence the population distribution of crabgrass within the field, the relationship between the ditch and field populations of crabgrass were not present based on ANOVA suggesting that the ditch populations are not influencing the field populations.

Three species [dodder spp., *Cuscut*a L. spp.; goosegrass, *Eleusine indica* (L.) Gaertn.; needleleaf rosette grass] did not have a relationship between ditch and field populations, but did have population distributions affected by an interaction of ditch to plot distance by row position. For all three species, occurrences were highest in the ditch, the plot nearest the ditch and on the row bed but did not change in a linear manner as ditch to plot distance increased. The data indicate that, while the ditch populations of these species are not influencing density and distribution of field populations, distribution of these species is affected by distance from the field edge.

Three species [broomsedge, *Andropogon virginicus* L.; Carolina jasmine, *Gelsemium sempervirens* (L.) W.T. Aiton; loblolly pine] had population distributions affected by ditch to plot distance. The populations of loblolly pine had a positive relationship between ditch and field population numbers according to ANOVA, while Carolina jasmine had a positive relationship based on the correlation analyses. There was no relationship between the field and ditch populations of broomsedge. For all three species, occurrences were highest in the ditch plots compared to the field plots, but did not change in a linear manner as distance into the field increased.

Three species had population distributions that were affected by row position (annual sedge, *Cyperus compressus* L.; American holly, *Ilex opaca* Aiton; greenbriar, *Smilax* L.

spp.). The annual sedge population was greatest in the row middles, whereas American holly and greenbriar populations were greatest on the row beds. The occurrence of annual sedge in the row middles may be due to increased moisture that is generally present in the low areas of the row middles. The occurrence of the woody perennials American holly and greenbriar on the row beds may be attributed to protection from the blueberry bushes. Greenbriar is an aggressive vine that uses blueberry bushes as supporting structures for growth and American holly is a small tree. Under and within the blueberry canopy, both species may be protected from herbicide or cultivation efforts.

Three species [Maryland meadowbeauty; red sorrel, *Rumex acetosella* L.; common toadflax, *Linaria canadensis* L. (Chaz.)] had positive relationships between the ditch and field populations according to both the correlation and ANOVA analyses as well as population distributions that were affected by an interaction of ditch to plot distance by row position. The species occurred in the highest numbers in plots that were placed in or near the ditch and had population numbers that generally decreased in a linear manner as ditch to plot increased. Population numbers for the species were generally higher on the row beds.

Overall, six of the 30 species populations (20%) analyzed with ANOVA had a positive relationship between ditch and field populations when factors such as sampling year and field were included in the analysis. Transects with higher ditch population counts also tended to have higher field population counts. The data indicate that changes in the ditch populations of these species may result in changes in the field populations. Thirteen species had a positive correlation between presence in the ditch and presence in the field. Because the correlation analysis did not take into account other factors, the analysis was considered exploratory and the ditch and field population correlations were no longer present for 10 of the 13 species when population numbers were analyzed using ANOVA.

A total of four species had population densities that were affected by an interaction of ditch to plot distance by row position. Three species had populations affected by ditch to plot distance or row position alone. Only three species that had a positive relationship between ditch and field population numbers according to both the correlation and ANOVA analysis also had population densities affected by an interaction of ditch to plot distance and row position. The cumulative analyses of these three species (Maryland meadowbeauty, red sorrel and common toadflax) indicates the existence of sink populations in the field that are potentially being supplied by source populations in the ditches and that population densities tend to decrease as ditch to plot distance increases. Maryland meadowbeauty has the potential to be the most aggressive of the three species because it is perennial and can reproduce both sexually and vegetatively (Craine 2002).

Based on the data, which indicates that only three of the 30 species (10%) had a positive relationship between ditch and field populations that was also affected by ditch to plot distance in the field, it appears that field drainage ditches are generally not serving as source populations for weed species occurring in the field interior. Consequently, it is possible that blueberry growers could benefit from decreasing the intensity of drainage ditch management without increasing weed populations in their fields. Moreover, allowing drainage ditches to go unmanaged may have other positive effects on native blueberry pollinators by providing increased habitat and foraging areas.

Sources of Materials

[1]SAS 9.1.3, SAS Institute Inc., Cary, NC. USA.

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Tables and Figures

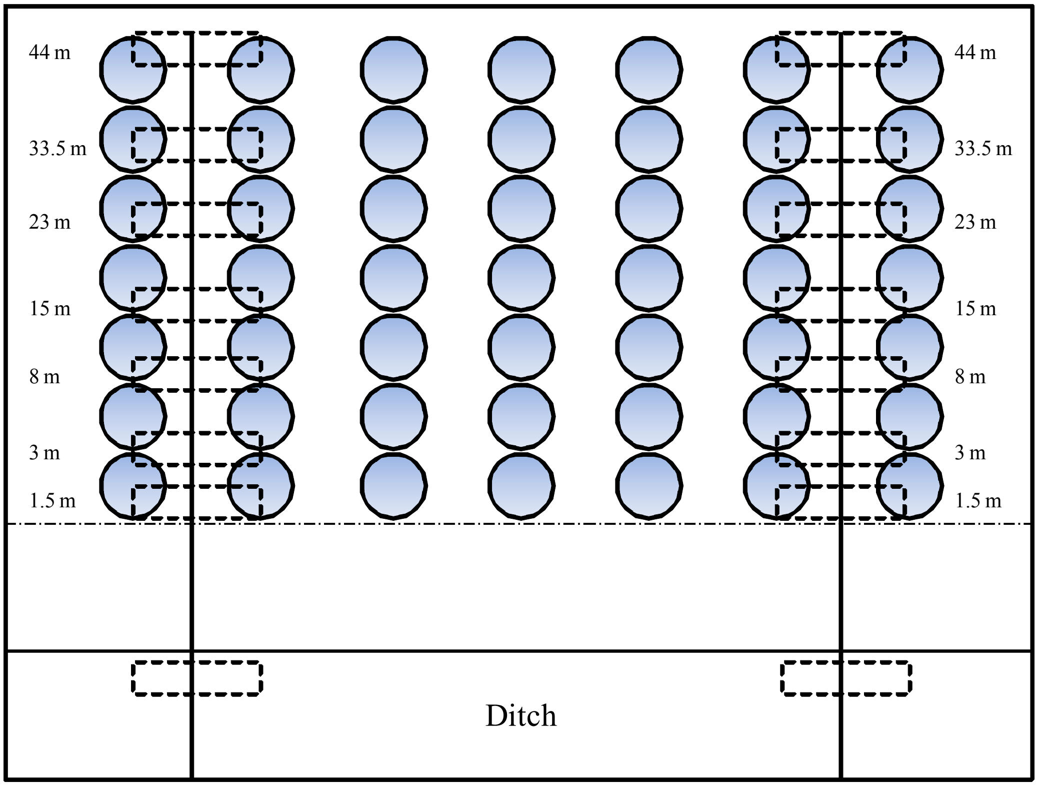

Figure 1.1. Map of the spatial layout of the transects and plots occurring on the ditch bank and in the field. Blueberry bushes are represented by circles. Blueberry rows are represented by rows of circles (blueberry plants). The ditch area is represented by the solid horizontal line. Plots are represented by dashed boxes.

Table 1.1. Biennial weed species sampled from 20 North Carolina blueberry fields in 2007 and 2008.

	Biennial weed species				
			Frequency[a]		
Common name	Scientific name	Nativity	Ditch	Field	Total
Carolina geranium	*Geranium carolinianum*	N	1	0	1
Cutleaf eveningprimrose	*Oenothera laciniata*	N	3	2	5

[a]Abbreviations: frequency, total number of times that each species occurred in a ditch or field plot during 2007 and 2008; nativity, defined at species that are native to the lower 48 states of the U.S.; N, indicates native status; I, indicates introduced status.

Table 1.2. Annual weed species sampled from 20 North Carolina blueberry fields in 2007 and 2008.

	Annual weed species				
			Frequency[a]		
Common name	Scientific name	Nativity	Ditch	Field	Total
Annual bluegrass	*Poa annua*	I	1	0	1
Annual sedge	*Cyperus compressus*	N	26	462	488
Bedstraw, catchleaf	*Galium aparine*	N	5	3	8
Broadleaf signalgrass	*Brachiaria platyphylla*	N	5	6	11
Carpetweed	*Mollugo verticillata*	N	0	2	2
Chickweed, common	*Stellaria media*	I	3	0	3
Corn spurry	*Spergula arvensis*	I	1	1	2
Crabgrass, large	*Digitaria sanguinalis*	N	36	550	586
Goosegrass	*Eleusine indica*	I	6	11	17
Horseweed	*Conyza canadensis*	N	3	0	3
Ladysthumb	*Polygonum persicaria*	I	7	15	22
Lespedeza	*Lespedeza* spp.	N/I	3	0	3
Morningglory, scarlet	*Ipomoea coccinea*	I	3	0	3
Pigweed spp.	*Amaranthus* spp.	N/I	0	2	2
Purslane, common	*Portulaca oleracea*	I	0	2	2
Rabbit tobacco	*Gnaphalium* spp.	N/I	16	36	52
Texas Panicum	*Panicum texanum*	N	2	2	4
Toadflax, common	*Linaria canadensis*	N	79	359	438
Vetch, common	*Vicia sativa*	I	1	0	1

[a]Abbreviations: frequency, total number of times that each species occurred in a ditch or field plot during 2007 and 2008; nativity, defined at species that are native to the lower 48 states of the U.S.; N, indicates native status; I, indicates introduced status; N/I, indicates a species with infra-taxa that are both native and introduced.

Table 1.3. Perennial weed species sampled from 20 North Carolina blueberry fields in 2007 and 2008.

	Perennial weed species				
			Frequency[a]		
Common name	Scientific name	Nativity	Ditch	Field	Total
American holly	*Ilex opaca*	N	1	78	79
Black cherry	*Prunus serotina*	N	90	7	97
Bramble spp.	*Rubus* spp.	N	22	11	33
Broomsedge	*Andropogon virginicus*	N	138	138	276
Cane spp.	*Arundinaria* spp.	N	32	22	54
Carolina jasmine	*Gelsemium sempervirens*	N	51	106	157
Carolina redroot	*Lachnanthes caroliana*	N	1	132	133
Cinnamon fern	*Osmunda cinnamomea*	N	18	2	20
Creeping blueberry	*Vaccinium crassifolium*	N	27	5	32
Dodder	*Cuscuta* spp.	N/I	3	19	22
Dogfennel	*Eupatorium capillifolium*	N	45	54	99
False dandelion	*Hypochoeris radicata*	I	25	8	33
Goldenrod	*Solidago canadensis*	N	56	8	64
Greenbriar	*Smilax* spp.	N	69	260	329
Horsenettle	*Solanum carolinense*	N	0	4	4
Horsetail	*Equisetum* spp.	N	1	0	1
Indian mock strawberry	*Duchesnea indica*	I	3	0	3
Johnsongrass	*Sorghum halepense*	I	1	1	2
Loblolly pine	*Pinus taeda*	N	18	64	82
Lycopods	*Lycopodium* spp.	N	1	5	6
Maryland meadowbeauty	*Rhexia mariana*	N	59	271	330
Milkweed, butterfly	*Asclepias tuberosa*	N	20	3	23
Needleleaf rosette grass	*Dichanthelium aciculare*	N	109	862	971

Table 1.3. Continued

Netted chain fern	*Woodwardia areolata*	N	31	0	31
Nutsedge, yellow	*Cyperus esculentus*	N/I	5	92	97
Oak	*Quercus* spp.	N	6	3	9
Poison ivy	*Toxicodendron radicans*	N	1	12	13
Pokeweed, common	*Phytolacca americana*	N	0	1	1
Prickly pear	*Opuntia humifusa*	N	0	17	17
Red maple	*Acer rubrum*	N	116	105	221
Red sorrel	*Rumex acetosella*	I	83	121	204
Rush	*Juncus* spp.	N	55	32	87
Sassafrass	*Sassafras albidum*	N	13	1	14
Sumac	*Rhus* spp.	N	44	52	96
Swamp rose	*Rosa setigera*	N	2	0	2
Sweetbay	*Magnolia virginiana*	N	22	7	29
Virginia creeper	*Parthenocissus quinquefolia*	N	1	0	1
Wild grape	*Vitis* spp.	N	7	2	9
Willow	*Salix* spp.	N	2	0	2
Woodsorrel, yellow	*Oxalis stricta*	N	0	1	1

[a]Abbreviations: frequency, total number of times that each species occurred in a ditch or field plot during 2007 and 2008; nativity, defined at species that are native to the lower 48 states of the U.S.; N, indicates native status; I, indicates introduced status; N/I, indicates a species with infra-taxa that are both native and introduced.

Table 1.4. Weed species with a positive relationship between population numbers in the ditch and the field interior in 2007 and 2008 according to correlation analysis.

	Weed species		
Common name	Scientific name	Duration[a]	p-value[b]
Annual sedge	*Cyperus compressus*	A	0.0042
Bramble	*Rubus spp.*	P	0.0308
Cane	*Arundinaria spp.*	P	0.0061
Carolina jasmine	*Gelsemium sempervirens*	P	0.006
Crabgrass, large	*Digitaria sanguinalis*	A	0.0001
Dogfennel	*Eupatorium capillifolium*	P	0.0001
Goldenrod	*Solidago canadensis*	P	0.0001
Maryland meadowbeauty	*Rhexia mariana*	P	0.0001
Nutsedge, yellow	*Cyperus esculentus*	P	0.0003
Rabbit tobacco	*Gnaphalium spp.*	A	0.0001
Red sorrel	*Rumex acetosella*	P	0.0058
Sumac	*Rhus spp.*	P	0.0127
Toadflax, common	*Linaria canadensis*	A	0.0004

[a]Abbreviations: A, annual weed species; P, perennial weed species.

[b]$\alpha=0.05$

Table 1.5. Weed species with a positive relationship between population numbers in the ditch and the field interior in 2007 and 2008 according to analysis of variance (ANOVA).

	Weed species			
Common name	Scientific name	Duration[a]	p-value[b]	R-square
Loblolly pine	*Pinus taeda*	P	0.0001	0.61
Maryland meadowbeauty	*Rhexia mariana*	P	0.0001	0.66
Rabbit tobacco	*Gnaphalium spp.*	A	0.0019	0.43
Red maple	*Acer rubrum*	P	0.0037	0.57
Red sorrel	*Rumex acetosella*	P	0.0001	0.63
Toadflax, common	*Linaria canadensis*	A	0.0001	0.75

[a]Abbreviations: A, annual weed species; P, perennial weed species.

[b]α=0.05

CHAPTER 2

Seed Biology of Maryland Meadowbeauty (*Rhexia mariana* L.) in Blueberry (*Vaccinium* spp.)

Abstract

Maryland meadowbeauty seed capsule density ranged from 1124/m^2 to 500/m^2. The number of meadowbeauty seeds per capsule was not different and was averaged across locations (74 seeds/ capsule). Meadowbeauty seeds germinated only in the 20/35C temperature regime, which represents the hottest month (August) of the growing season in southeastern NC. The total number of germinated seeds was different across locations and ranged from 30 to 57%. The percent of viable (66) and nonviable (26) meadowbeauty seeds was not different and was averaged across locations. Relative germination percentages and seed dormancy were calculated based on the number of viable seeds. The percent relative germination and seed dormancy were different across locations and ranged from 47 to 86% and 14 to 55% respectively. The data indicate that 90 days of stratification resulted in the highest amount of germination. A mean of 27 seedlings germinated in each sample of soil, which is equivalent to 989 seeds/m^2. The data indicate that the populations of meadowbeauty in blueberry fields have the potential to sexually reproduce and contribute $5x10^6$ to $1.1x10^7$ seed capsules/ha and $3.7x10^8$ to $8.3x10^8$ seeds/ha of infestation. Freshly mature seeds can germinate and contribute $1.79x10^8$ to $7.14x10^8$ seedlings/ha in the year the seeds are produced and $5.18x10^7$ to $4.4x10^8$ seeds/ha can be dormant and incorporated into the seed bank on an annual basis. Approximately $9.89x10^6$ seeds/ha are dormant and viable in the soil and have the potential to germinate following adequate stratification.

Introduction

North Carolina is the fifth largest producer of blueberries (*Vaccinium spp*.) in the U.S. with approximately 5,000 acres harvested in 2006 (USDA 2007a). Within the state, blueberries are the most lucrative fruit commodity with a value of $48 million (USDA 2007a). Although blueberry production is scattered across the state, the coastal plain of North Carolina accounts for approximately 55% of the state's growers and 96% of the state's total acreage (USDA 2007b). Within the coastal plain region, the southern coastal plain dominates production, accounting for 45% of the state's growers and 93% of the state's total acreage (USDA 2007b).

Weed communities most commonly observed in blueberry fields in the coastal plain are dominated by perennial species. Pine (*Pinus spp*.), holly (*Ilex spp*.), greenbriar (*Smilax spp.)*, small deciduous trees, and various species of herbaceous perennials consistently present weed control problems for growers. One of the most aggressive perennial weeds in blueberries in North Carolina is Maryland meadowbeauty [*Rhexia mariana* L. (Melastomataceae)]. Maryland meadowbeauty (hereafter called meadowbeauty) is a perennial herb that reproduces both sexually and vegetatively (Craine 2002). After a mature plant flowers in late summer, shoots with overlapping leaves and short internodes are produced from shallow rhizomes and remain small until growth resumes in the spring (James 1956). The ability to reproduce in such a way enables the species to grow in high densities and spread aggressively in some conditions (Craine 2002). Kral and Bostick (1969) found that large populations of meadowbeauty may be composed of only a few genetically distinct individuals.

The natural habitat of meadowbeauty is very similar to that of blueberries and it can be found in wet, open areas from Massachusetts to Florida, and as far west as southern Indiana, Missouri and Texas (Gleason and Cronquist 1991). In the Cape Cod area, meadowbeauty and the high bush blueberry (*Vaccinium corymbosum* L.) are commonly associated in natural communities that occur in acidic, nutrient-poor and wet soils. Meadowbeauty also depends on full sunlight for survival. In North Carolina, meadowbeauty is common in highly disturbed areas like roadside ditches, agricultural fields and forest edges. Observations of meadowbeauty becoming aggressive and invasive have been noted in both disturbed and non-disturbed areas in Florida (Craine 2002).

The contribution of sexually produced seeds to the population numbers of meadowbeauty in blueberry fields is not fully understood. The species produces seeds that are released from a capsule in an urn-shaped persistent hypanthium that is 9 to 11mm long at maturity (Craine 2002). Each seed is between 0.3 and 0.7mm long and cochleate with papillae occurring in longitudinal rows (James 1956). A seed bank study performed by Keddy and Reznicek (1982) found that the closely related *Rhexia virginica* L. contributed an estimated 900 seeds/m^2 in a lake shore seed bank.

The objectives of these studies were to define the seed biology of meadowbeauty at three North Carolina blueberry farms by determining temperature affects on germination, average number of seeds produced, seed presence in the seed bank, and seed dormancy.

Materials and Methods

Sexual Reproductive Potential. To determine the potential of meadowbeauty to reproduce sexually, meadowbeauty plants were collected from 1m^2 quadrats on three blueberry farms on August 13, 2008. All plants with stems occurring in the quadrat were harvested. Plant harvests were replicated six times at each location, and each replicate was stored individually. Seed capsules were removed from plants in each replicate and were counted.

To determine the mean number of seeds produced in each seed capsule, meadowbeauty seed capsules were collected from the same three locations on August 13, 2007. One sampling replicate included 10 randomly selected intact seed capsules, which were collected and stored individually. Sampling was replicated three times at each location. Each seed capsule was crushed and mature seeds were counted using a dissecting microscope. For the seed and capsule counts, an analysis of variance (ANOVA) and comparison of means by least significant difference tests (LSDs, P=0.05) (SAS Institute Inc. 2004[1]) were performed.

Temperature Effects on Seed Germination. Seeds were collected from three blueberry farms representative of the range of blueberry production in southeastern North Carolina. The farms were located in Harrells (34˚ 45’59” N, 78˚08’49” W), Rowan (34˚37’33” N, 78˚19’41” W) and Burgaw (34˚36’17” N, 77˚51’34” W). Intact, mature seed capsules were collected on August 13, 2007 and seeds were extracted by crushing the desiccated hypanthium. Seeds were separated from debris using sieves[2]. Sifted seeds were blown[3] using a set point of 6.5, which removed debris and empty or deformed seed.

Germinations were performed at the North Carolina Department of Agriculture and Consumer Services' Plant Industry Division Seed Lab in Raleigh, NC. Incubators were set at four temperature regimes that approximate minimum and maximum temperatures during the growing season in eastern North Carolina: 20° (March), 15°/25° (April/May), 20°/30° (June/July), 20°/35°C (August). Seeds were germinated in full light in plastic boxes on two sheets of filter paper (Baskin et al. 1999) saturated with either water or KNO_3. Potassium nitrate was used to reduce or overcome dormancy present in the seeds**.** A replicate consisted of 16 boxes each containing 100 seeds. There were four boxes (two water, two KNO_3) at each temperature. Seedling counts were taken beginning three wk after seeding and continued every seven d until counts were suspended following two consecutive wk without new germination. Only those seedlings that had grown to the cotyledon stage and fully shed the seed coat were considered germinated. Germinated seedlings were removed from the boxes once they were counted. Germinations were replicated three times for each site. Data were analyzed using an analysis of variance (ANOVA) and comparison of means by least significant difference tests (P=0.05) (SAS Institute Inc. 2004).

Determining Relative Germination and Dormancy. Tetrazolium testing of meadowbeauty seeds was performed at the North Carolina Department of Agriculture and Consumer Services Plant Industry Division Seed Lab in Raleigh, NC according to a protocol adapted from the Tetrazolium Testing Handbook from the Association of Official Seed Analysts (Peters 2000) to determine seed viability and calculate relative germination and dormancy. Seeds were imbibed for 18 hr inside a water saturated paper towel in an incubator set at 20°/30°C (low/high). Following imbibation, the funiculi-like structures that held the seeds to the ovary were removed from 100 seeds using a scalpel and a dissecting microscope. The seeds were placed in a 1% TZ solution for 18 hours in a 45˚C incubator and then drained and placed in a clearing solution of glycerol. Seeds were separated under a dissecting scope into viable, dead and empty seed. Tetrazolium testing was replicated three times for each site. An analysis of variance (ANOVA) and comparison of means by least significant difference tests (LSDs, P=0.05) (SAS Institute Inc. 2004) were performed.

The percent of dormant meadowbeauty seeds was determined by comparing the percent of germination at each location to the mean percent of viable seeds. Relative percent germination was calculated using the following equation (Equation 1).

$$\text{Total \% Germination/ Mean \% Viable Seeds} = \text{Relative \% Germination} \quad [1]$$

Percent dormancy was calculated by subtracting the relative percent germination from 100. Data were analyzed using an analysis of variance (ANOVA) and comparison of means by Fisher’s protected least significant difference (LSD α=0.05) (SAS Institute Inc. 2004).

Seed Presence in the Seed Bank. Soil was collected from a grower location in Rowan, NC (34˚37’33” N, 78˚19’41” W) having a history of severe meadowbeauty infestation. The top 2.54 cm of soil was collected from 50 randomly selected $1m^2$ quadrats. The soil collected from all quadrats was homogenized, sifted to remove large debris, and water was added to achieve an available soil moisture measurement of 5%. Soil was separated into 200g samples and placed in plastic trays[4]. A 200g-sample equates to 602 cm^3 of soil with a surface area of $273cm^2$. Two sheets of filter paper were placed in each tray prior to being filled with soil.

Experimental treatments included: germinate with no stratification,15 d of stratification (DOS), 30 DOS, 60 DOS, 90 DOS, and germinate after 90 d of room temperature. Treatments were replicated six times. Samples were stratified in a cooler at 3-4°C and germinated in reach-in C chambers with growing space of 0.91 by 1.22 m at the NC State University Phytotron. Lighting was provided with 1500 ma cool-white fluorescent and incandescent lamps. Samples were watered twice a d as needed to maintain soil moisture. The experiment was repeated in two chambers.

Samples were stirred every three wk following placement in the growth chamber. Seedling counts were taken every 7 d for 12 wk following placement in the chamber. Seedlings were only counted if they reached the cotyledon stage and shed the seed coat. Counted seedlings were removed from the trays. Data was analyzed using an analysis of variance (ANOVA) and comparison of means by least significant difference tests (LSD α=0.05) (SAS Institute Inc. 2004).

Results and Discussion

Sexual Reproductive Potential. Seed capsule counts were different across locations (p=0.0243). Seed capsule density ranged from 1124/m^2 at Burgaw to 500/m^2 at Rowan The number of meadowbeauty seeds per capsule was not different and was averaged across locations (74 seeds/ capsule). Meadowbeauty has a reproductive potential of $5x10^6$ to $1.1x10^7$ seed capsules/ha and $3.7x10^8$ to $8.3x10^8$ seeds/ha of infestation.

The Rowan location had the highest visual density of meadowbeauty mother plants compared to the other locations. The low density of seed capsules at the Rowan location may be attributed to the high density of mother plants because increased competition for space and resources at Rowan may have resulted in the production of fewer reproductive structures. This trade-off is viewed as a compromise of the allocation of the resources available to the species (Begon et al, 2006). If the meadowbeauty plants in the Rowan population are devoting resources to competition, those resources are unavailable for reproduction.

Temperature Effects on Germination. Meadowbeauty seeds germinated only in the 20/35C temperature regime, which represents the hottest month (August) of the growing season in southeastern NC. Thus, germination data is only presented for this regime. Germination occurred for three consecutive wk beginning seven d after seeding (DAS) and counts were suspended at five wk following two wk without germination. Seed counts at 7, 14, and 21 DAS were different across locations and these data are presented together (Table 2.1). While treatment did have an effect on germination at Rowan 21 DAS, treatment did not affect germination at any other time or location (data not shown). The total number of germinated seeds was different across locations (Table 2.2). Harrells and Burgaw had similar levels of total germination at 30 and 36% respectively. Rowan had the highest level of total germination at 57%.

The fact that germination only occurred in the temperature regime of 20/35˚C supports the research findings performed on the closely related species *R. mariana* var. *interior*, in which *R. mariana* var. *interior* germinated most successfully at the same temperature regime (Baskin et al. 1999). The germination rates of freshly matured meadowbeauty seeds from NC are higher than those observed in *R. mariana* var. *interior* collected from TN, which had a maximum 3 to 4% germination without stratification (Baskin et al. 1999). The difference in percent germination between the NC and TN seeds could be the result of climatic adaptations of meadowbeauty. Winter temperatures in the southeastern coastal plain of NC are generally more mild then those in TN where the seeds were collected. Meadowbeauty seeds from the NC coastal plain would not experience the same intensity and duration of temperatures required for stratification and may have adapted to have less seed dormancy in freshly mature seeds.

Determining Relative Germination and Dormancy. The percent of viable (66) and nonviable (26) meadowbeauty seeds was not different and was averaged across locations (data not shown). The percent of viable seeds provided information that allowed for the calculation of relative germination and dormancy of meadowbeauty seeds. Percent germinations were previously based on 100 seeds. If only 66 of those seeds were viable on average, then germination percentages must be calculated based on the number of viable seeds.

The percent relative germination and seed dormancy were different across locations (Table 2.3). The Rowan location had 86% germination and 14% dormancy compared to 47% and 55% germination and 53% and 45% dormancy at Harrells and Burgaw respectively. Germination may be higher at Rowan due to the decreased number of seed capsules. Fewer seed capsules means that there is less competition for pollination and this may have resulted in more viable seeds and greater germination in freshly matured seeds.

Seed Presence in the Seed Bank. Meadowbeauty seeds germinated in all treatments. Total mean germination of meadowbeauty seeds was highest in the 90 DOS treatment (Table 2.4) during wk two of counting (Table 2.5). The data indicate that 90 days of stratification resulted in the highest amount of germination, suggesting that the meadowbeauty seeds from NC blueberry farms experience dormancy that is overcome by exposure to cold temperature. Those seeds that experience dormancy may remain viable in the seed bank and contribute to future infestations of meadowbeauty.

Those counts that followed stirring of the soil samples (counts four, seven and ten) had the next highest levels of germination, providing further support that meadowbeauty seeds require exposure to light for germination (Baskin et al. 1999). Counts were different between treatments during wk two, three, four, five, seven, eight, and ten (Table 2.5). A mean of 27 seedlings germinated in each sample of soil, which is equivalent to 989 seeds/m^2. The number of meadowbeauty seeds that germinated from the soil collected in NC appears to be similar to the number of seeds of *Rhexia virginica*, a closely related species, that germinated in a lake shore seed bank study (Keddy and Reznicek 1982).

Overall, the data indicate that the populations of meadowbeauty in blueberry fields in southeastern NC have the potential to sexually reproduce and contribute $5x10^6$ to $1.1x10^7$ seed capsules/ha and $3.7x10^8$ to $8.3x10^8$ seeds/ha of infestation. Relative germination ranged from 47 to 86%, indicating that freshly mature seeds have the potential to germinate and contribute $1.79x10^8$ to $7.14x10^8$ seedlings/ha in the year the seeds are produced. Dormancy ranged from 14 to 53%, indicating that $5.18x10^7$ to $4.4x10^8$ seeds/ha can be incorporated into the seed bank on an annual basis to await natural stratification and future germination. The presence of 989 seeds/m^2 in the soil seed bank indicates that approximately $9.89x10^6$ seeds/ha are dormant and viable in the soil and have the potential to germinate following adequate stratification.

The ability of meadowbeauty to contribute large numbers of freshly mature and dormant viable seeds to the soil seed bank creates a challenge for growers attempting to control the species. Not only must weed management strategies target the herbaceous mother plants, but they must also target the seeds that may contribute indefinitely to future re-infestations of meadowbeauty in grower fields. Weed management measures could include mowing or application of herbicides to mother plants to prevent flowering or formation of seeds. Management of the soil seed bank could include the use of preemergent herbicides to prevent seed germination as well as shallow cultivation to bury the small meadowbeauty seeds, which cannot germinate in darkness.

Sources of Materials

[1]SAS 9.1.3, SAS Institute Inc., Cary, NC. USA.

[2]#40 425 micrometer and #50 300 micrometer sieve. Hoffman Manufacturing Inc., Jefferson, OR, USA.

[3]South Dakota Seed blower. Seedburo Equipment Co., Chicago, IL, USA.

[4]Com-Packs bedding plant containers #601, 7" x 5-1/4". Hummert International, St. Louis, MO. USA.

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Tables

Table 2.1. Germination % of meadowbeauty seeds from Harrells, Rowan and Burgaw 7, 14 and 21 d after seeding (DAS)[a] in 2007.

	Germination		
Location	7 DAS	14 DAS	21 DAS
	%		
Harrells	15	13	1
Rowan	13	21	23
Burgaw	25	10	1
LSD (0.05)	7	7	3

[a]Abbreviations: DAS, d after seeding.

Table 2.2. Total germination % of meadowbeauty seeds at Harrells, Rowan and Burgaw in 2007.

Location	Germination
	Total[a]
	%
Harrells	30
Rowan	57
Burgaw	36
LSD (0.05)	8

[a]Abbreviations: Total, total percent germination at each location.

Table 2.3. Relative germination % and dormancy % of meadowbeauty seeds at Harrells, Rowan and Burgaw in 2007.

	Meadowbeauty seeds	
	Relative germination	Dormancy
Location	%	
Harrells	47	53
Rowan	86	14
Burgaw	55	45
LSD (0.05)	13	13

Table 2.4. Mean germination of meadowbeauty seeds in the six soil stratification treatments.

	Meadowbeauty germination
Treatment[a]	Mean[b]
1	2
2	1
3	2
4	2
5	5
6	2
LSD (0.05)	2

[a]Treatments: 1, germinate immediately; 2, germinate following 15 d of stratification (DOS); 3, germinate following 30 DOS; 4, germinate following 60 DOS; 5, germinate following 90 DOS; 6, germinate following 90 d at room temperature.

[b]Abbreviations: DOS, days of stratification; mean, mean germination of meadowbeauty seeds averaged across both chambers and all replications of each treatment.

Table 2.5. Mean germination of meadowbeauty seeds at each count time separated by stratification treatment.

	Meadowbeauty germination											
	Count											
	1	2	3	4	5	6	7	8	9	10	11	12
Treatment[a]	Mean[b]											
1	0	1	1	2	6	0	2	1	1	1	2	2
2	1	1	0	0	0	1	1	0	1	3	1	2
3	8	0	0	2	1	1	0	0	1	8	0	0
4	1	2	0	0	4	2	5	0	1	7	1	3
5	4	17	11	11	0	0	15	0	0	0	0	2
6	0	9	0	3	0	1	6	0	0	0	1	4
LSD (0.05)	NS	9	3	4	6	NS	3	1	NS	4	NS	NS

[a]Treatments: 1, germinate immediately; 2, germinate following 15 d of stratification (DOS); 3, germinate following 30 DOS; 4, germinate following 60 DOS; 5, germinate following 90 DOS; 6, germinate following 90 d at room temperature.

[b]Abbreviations: mean, mean germination of meadowbeauty seeds averaged across chambers and replications for each count timing

CHAPTER 3

Response of Maryland Meadowbeauty (*Rhexia mariana* L.) and Blueberry

to Flumioxazin PRE

Abstract

A study was conducted to determine the response of Maryland meadowbeauty and blueberry to flumioxazin PRE. No visual injury to non-bearing or bearing blueberry from flumioxazin PRE was observed. For single applications of flumioxazin in bearing blueberry, yields ranged from 3150 kg/ha to 6065 kg/h. For the sequential application of flumioxazin in bearing blueberry, yields ranged from 3551 kg/ha to 5735 kg/ha. Flumioxazin applied PRE in a single or a sequential application did not have a negative effect on blueberry yield regardless of application rate. In non-bearing blueberry, control of meadowbeauty was greater than 97% at 90 DAT with the registered rate of 0.42 kg ai/ha flumioxazin. Control of meadowbeauty in bearing blueberry with a single application of flumioxazin at the registered rate of 0.42 kg ai/ha ranged from 79 to 88% at 90 DAT. Sequential applications of flumioxazin at 0.21 kg ai/ha per application resulted in control greater than 96% 30 d after the last of two applications.

Introduction

North Carolina is the fifth largest producer of blueberries (*Vaccinium spp*.) in the U.S. with approximately 5,000 acres harvested in 2006 (USDA 2007). Within the state, blueberries are the most lucrative fruit commodity with a value of $48 million (USDA 2007). Due to the high value of the crop, weed control and crop tolerance to herbicides are of great concern to blueberry producers. Weeds compete with the crop for nutrients and can serve as alternate hosts for pathogens and insects (Pritts and Hancock 1992). The shallow root systems of blueberry cause the crop to be particularly vulnerable to competition from weeds and exposure to herbicide. The roots of many weeds occupy the same soil zone as the root systems of blueberry, and young bushes less than three years old are especially vulnerable (Pritts and Hancock 1992). Additionally, the weed communities observed in blueberry fields are dominated by difficult to control perennial species such as pine (*Pinus spp*.), holly (*Ilex spp*.), greenbriar (*Smilax spp.)*, small deciduous trees, and various species of herbaceous perennials. These species can interfere with blueberry production and harvest.

One of the most aggressive perennial weeds in North Carolina blueberry fields is Maryland meadowbeauty [*Rhexia mariana* L. (Melastomataceae)]. Maryland Meadowbeauty (hereafter known as meadowbeauty) is an herbaceous perennial that reproduces both sexually and vegetatively (Craine 2002). After a bearing meadowbeauty plant flowers in late summer, shoots with overlapping leaves and short internodes are produced from shallow rhizomes and remain small until growth resumes in the spring (James 1956). The ability to reproduce in this way enables the species to grow in high densities and spread aggressively in some environments (Craine 2002).

The natural habitat of meadowbeauty is very similar to that of blueberries and this weed can be found in wet, open areas from Massachusetts to Florida, and as far west as southern Indiana, Missouri and Texas (Gleason and Cronquist 1991**)**. In the Cape Cod area, meadowbeauty and highbush blueberry (*Vaccinium corymbosum* L.) are commonly associated in natural communities that occur in acidic, nutrient-poor, wet soils. Meadowbeauty also depends on full sunlight for survival. In North Carolina, meadowbeauty is common in highly disturbed areas like roadside ditches, agricultural fields and forest edges. Meadowbeauty has invaded disturbed and undisturbed areas in Florida (Craine 2002).

Flumioxazin[1] was recently registered for use in blueberry (Anon. 2005). Flumioxazin is a N-phenylphthalimide herbicide that inhibits protoporphyrinogen oxidase in the chlorophyll biosynthetic pathway (Bigot et al. 2007; Scott et al. 2001) and results in light-induced lipid peroxidation and destruction of cellular membranes (Moreland 1999). When applied PRE, flumioxazin controls many annual broadleaf weed species including pigweeds (*Amaranthus* spp.), nightshades (*Solanum* spp.), common lambsquarters (*Chenopodium album*), and Florida pusley (*Richardia scabra*). In addition to blueberry, flumioxazin is registered for use in grape, fruit and nut trees, and strawberry (Anon. 2005).

Because flumioxazin controls many broadleaf weed species and certain fruit crops have shown tolerance to flumioxazin, the objective of this study was to determine the efficacy of flumioxazin on meadowbeauty and the tolerance of blueberry to flumioxazin PRE.

Materials and Methods

Field experiments were conducted in non-bearing (less than three years old) and bearing (older than three years) blueberry bushes in grower fields near the communities of Harrells (34˚36'58"N, 78˚20'15"W) and Burgaw (34˚36'12"N, 77˚51'13"W), NC in the southeastern coastal plain. The soil at Harrells was a Lynn Haven (sandy, siliceous, thermic Typic Alaquods) – Torhunta (coarse-loamy, siliceous, active, acid, thermic Typic Humaquepts) complex with CEC 10.7, pH 3.8, and 3.9% organic matter. The soil at Burgaw was Murville Muck (sandy, siliceous, thermic Umbric Endoaquods) with CEC 7.9, pH 4.7, and 4.1% organic matter. Treatments were applied with a CO_2 pressurized backpack sprayer equipped with flat-fan nozzles[2] delivering 187 L/ha at 289 kPa at a walking speed of 4.8 km/h. Each plot was 1.2 m wide by 5 m long and included four blueberry bushes. The experimental design was a randomized complete block with four replications.

Visual crop injury evaluations were taken 14 d after treatment (DAT) and weed control ratings were taken 30, 60, and 90 DAT using a scale of 0 (no crop injury or no control) to 100 (crop death or complete control). In experiments conducted in bearing blueberry bushes, ripe and unripe fruit were harvested from two bushes in each plot. Fruit was sorted into ripe and unripe fruit and weighed. The weight of unripe fruit was converted into ripe weight (Equation 1).

(average individual ripe berry weight/average individual unripe berry weight)
* total unripe fruit weight per plot [1]

Average individual ripe and green berry weights were determined by weighing 10 sets each of 250 ripe and unripe berries and then dividing by the total number to obtain the average. Total yield per plot was calculated by taking the sum of the ripe fruit weight and the converted unripe fruit weight. Analysis of variance (ANOVA) was conducted and means were separated using Fisher's protected LSD (p=0.05) (SAS Institute Inc. 2004[3]).

Non-bearing Blueberry. In 2008, two experiments were conducted in 'O'Neal' and 'Legacy' blueberry at Harrells and Burgaw, respectively. Treatments included flumioxazin PRE at 0, 0.21, 0.28, 0.35, 0.42, and 0.49 kg ai/ha. Glufosinate at 1.12 kg ai/ha was applied to all plots to control emerged weeds. Treatments were applied at Harrells on March 21, 2008 and at Burgaw on March 17, 2008. Analysis of variance (ANOVA) was conducted and means were separated using Fisher's protected LSD (p=0.05) (SAS Institute Inc. 2004). Regression was performed on those variables correlated with treatments.

Bearing Blueberry. *Single Applications of Flumioxazin.* Experiments were conducted in bearing blueberry bushes at Harrells and Burgaw in 2007 and 2008. Treatments included flumioxazin PRE at 0, 0.21, 0.28, 0.35, 0.42, 0.49, 0.56, 0.63, 0.7, and 0.76 kg ai/ha. In 2007, in order to remove emerged weeds, all plots were mowed and plant debris was removed prior to application of flumioxazin. In 2008, glufosinate at 1.12 kg ai/ha was applied to the entire test area when flumioxazin treatments were applied. In 2007, treatments were applied at Harrells and Burgaw on July 13. In 2008, treatments were applied at Harrells on March 31 and at Burgaw on March 12. Analysis of variance (ANOVA) was conducted and means were separated using Fisher's protected LSD (p=0.05) (SAS Institute Inc. 2004).

Sequential Applications of Flumioxazin. Experiments were conducted in 2008 at both grower locations in bearing bushes. Treatments were a factorial arrangement of flumioxazin rate by application timing. Treatments included flumioxazin applied at 0, 0.21, 0.28, 0.35, and 0.42 kg ai/ha applied as single treatments and as sequential treatments. Application timings included the initial application (Early PRE) and the sequential application applied approximately 60 d after the initial application (Late PRE). For comparison, the grower standard herbicide treatment of hexazinone at 0.75 and 1.5 kg ai/ ha was applied Early PRE. To control emerged weeds, glufosinate at 1.12 kg ai/ha was included with Early PRE treatments and paraquat at 0.84 kg ai/ha was included with all Late PRE treatments. Early PRE treatments and Late PRE treatments were applied at Harrells on March 31 and May 26, 2008, respectively. Early PRE and Late PRE treatments were applied at Burgaw on March 12 and May 15, 2008, respectively. Analysis of variance (ANOVA) was conducted and means were separated using Fisher's protected LSD (p=0.05) (SAS Institute Inc. 2004).

Results and Discussion

Meadowbeauty Control. In non-bearing blueberry, meadowbeauty was present at Harrells and Burgaw. At 30, 60 and 90 DAT, there was no difference among herbicide treatments, therefore treatments were averaged across locations (Table 3.1). Control of meadowbeauty in non-bearing blueberry with flumioxazin PRE ranged from 94 to 97% 30 DAT, 96 to 100% 60 DAT, and 92 to 97% 90 DAT.

Bearing Blueberry. In the single application flumioxazin trials, meadowbeauty was present at both locations in 2007 and 2008. No difference in meadowbeauty control occurred between locations, therefore treatments were separated by location and averaged across years (Table 3.2). At 30 DAT, no difference was observed in meadowbeauty control among herbicide treatments at both locations, and control ranged from 97 to 100%. At 60 DAT, herbicide treatments at the Harrells location were not different and control ranged from 77 to 94%. However, there was no difference between treatments at Burgaw 60 DAT and control ranged from 94 to 98%. Differences in control among herbicide treatments at both locations 90 DAT were observed, and control ranged from 46 to 93%. In general, meadowbeauty control was greater at the Burgaw location. This observation may be attributed to lower meadowbeauty pressure at the Burgaw location.

In blueberry, a single application of flumioxazin can be applied at the maximum registered rate of 0.42 kg ai/ha in a 12 month period (Anon. 2005). Control of meadowbeauty at the registered rate of 0.42 kg ai/ha 30 DAT ranged from 98 to 100% across both locations. Control 60 DAT was 87 to 91% and at 90 DAT control was 79 to 88% across locations.

Sequential Applications of Flumioxazin. A treatment by location interaction was present 30 and 60 DAT with the Early PRE application of flumioxazin and 30 DAT with the Late PRE application. Data for each evaluation are presented separately (Table 3.3). At 30 DAT with the Early PRE application, control of meadowbeauty was 97% or greater for all treatments at both Harrells and Burgaw. By 60 DAT with the early PRE application, control from flumioxazin was 76 to 88% at the Harrells location but remained 98% or greater at Burgaw. Thirty days after the Late PRE application of flumioxazin, control at Harrells and Burgaw was greater than 96% for all rates of flumioxazin applied sequentially. However, 30 DAT with the Late PRE application, those treatments of flumioxazin applied in a single application at the Early PRE timing was 34 to 81% at Harrells and 83 to 97% at Burgaw. The analysis indicates that sequential applications of flumioxazin may be necessary to obtain extended residual control of meadowbeauty. The grower standard herbicide hexazinone did not give acceptable control.

Sequential applications of flumioxazin can be applied at the maximum rate of 0.21 kg ai/ha per application not to exceed 0.42 kg ai/ha during a 12 month period. Control of meadowbeauty at the registered rate of 0.21 kg ai/ha 30 DAT with the Early PRE plus Late PRE applications was greater than 98% at Harrells and Burgaw (Table 3.3).

Overall, control of meadowbeauty with flumioxazin at Burgaw was generally greater than the control at Harrells. This result is true of the single application trials in non-bearing and bearing bushes as well as the sequential application trials. Differences in control between locations are possibly due to a greater density of meadowbeauty at Harrells. Additionally, PRE applications of flumioxazin require moisture to activate the herbicide on soil for residual weed control. The soil at Burgaw was generally wetter than that at Harrells, possibly resulting in more effective herbicide activation and greater residual control.

Visual Blueberry Injury. No visual crop injury from flumioxazin was observed in non-bearing or bearing blueberry (data not shown). These results are similar to conclusions reported in other experiments in peach (MacRae et al. 2002) and grape (W. Mitchem personal communication).

Blueberry Yield. The single and the sequential treatments of flumioxazin did not have an effect on blueberry yield. However, the mean yields were different between locations for the single and the sequential studies. For the single application study of flumioxazin in bearing blueberry, yields were 3150 kg/ha at Harrells and 6065 kg/ha at Burgaw (Table 3.4). For the sequential study application of flumioxazin in bearing blueberry, Harrells had a mean yield of 3551 kg/ha whereas Burgaw had a mean yield of 5735 kg/ha (Table 3.4).

In 2006, the mean yield per hectare for blueberries within North Carolina was 6086 kg/ha (USDA 2007). To compare the mean state yields with the yields from Harrells and Burgaw, an analysis of variance was conducted and means were separated using Fisher's protected LSD (p=0.05) (SAS Institute Inc. 2004). The mean yields from both the single and sequential application flumioxazin studies at Burgaw were statistically similar to the mean yields of the state of North Carolina. However, the mean yields from both the single and sequential application flumioxazin studies at Harrells were lower than those mean yields reported by the state (Table 3.5). The lower yields at Harrells may be attributed to variety-related yield reductions experienced by the grower.

The data suggest that flumioxazin does not injure blueberry when applied PRE. Flumioxazin applied PRE in a single or a sequential application does not have a negative effect on blueberry yield, even at rates that exceed the registered rate. In non-bearing blueberry, control of meadowbeauty was greater than 97% at 90 DAT with the registered rate of flumioxazin. Control of meadowbeauty in bearing blueberry with a single application of flumioxazin at the registered rate of 0.42 kg ai/ha ranged from 79 to 88% at 90 DAT. Sequential applications of flumioxazin at 0.21 kg ai/ha per application resulted in control greater than 96% 30 d after the sequential application. The level of meadowbeauty control with a single application of flumioxazin 90 DAT was considerably lower than the level of control achieved with a split application of flumioxazin 60 DAT with the final split application. Therefore, flumioxazin applied PRE at the registered rate of 0.21 kg ai/ha per two sequential applications in a 12 month period is an effective herbicide to control meadowbeauty.

Sources of Materials

[1] Chateau Herbicide WDG. Valent USA Corporation, Walnut Creek, CA, USA.

[2] DG8002 TeeJet Drift Guard Flat Spray Tip. TeeJet Technologies, Wheaton, IL, USA.

[3] SAS 9.1.3, SAS Institute Inc., Cary, NC, USA.

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[USDA] U.S. Department of Agriculture/ National Agricultural Statistics Service/ North Carolina Field Office. 2007. Agricultural Statistics- 2007 Annual Statistics Book. Raleigh, NC: North Carolina Department of Agriculture and Consumer Services Agricultural Statistics Division, p. 42.

Tables

Table 3. 6. Effect of flumioxazin on Maryland meadowbeauty control in non-bearing blueberry 30, 60 and 90 DAT averaged across locations at Harrells and Burgaw, NC in 2008.

	Maryland Meadowbeauty		
Rate	30 DAT[a]	60 DAT	90 DAT
kg ai/ha	% control		
0	0	0	0
0.21	97	96	92
0.28	94	96	92
0.35	96	97	93
0.42	94	98	97
0.49	97	100	97
LSD (0.05)	N.S.	N.S.	N.S.

[a]Abbreviations: DAT, days after treatment; N.S., not significant; Rate, rate of Flumioxazin PRE in kg ai/ha

Table 3.7. Effect of flumioxazin on Maryland meadowbeauty control in bearing blueberry 30, 60 and 90 DAT at Harrells and Burgaw, NC.

	Maryland Meadowbeauty					
	Harrells			Burgaw		
Rate	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
kg ai/ha	% control					
0	0	0	0	0	0	0
0.21	97	77	46	100	94	53
0.28	98	77	53	100	94	68
0.35	98	82	60	100	95	76
0.42	98	87	88	100	91	79
0.49	99	90	84	100	94	84
0.56	98	93	88	100	94	86
0.63	99	94	88	100	93	83
0.70	99	95	91	100	92	86
0.76	98	94	93	100	98	90
LSD	N.S.	6	20	N.S.	N.S.	8

[a]Abbreviations: DAT, days after treatment; N.S., not significant; Rate, rate of Flumioxazin PRE in kg ai/ha

Table 3.3. Meadowbearuty control by flumioxazin applied Early PRE or Early PRE followed by Late PRE (60 DAT) at Harrells and Burgaw, NC in 2008.

			Maryland Meadowbeauty					
			Harrells			Burgaw		
Herbicide	Rate	Timing[a]	30 DATa[b]	60 DATa	30 DATa+b	30 DATa	60 DATa	30 DATa+b
	kg ai/ha		% control					
Nontreated	0		0	0	0	0	0	0
Flumioxazin	0.21	a	98	77	34	100	99	97
Flumioxazin	0.28	a	100	79	49	100	99	92
Flumioxazin	0.35	a	99	86	63	100	99	83
Flumioxazin	0.42	a	99	88	81	100	99	92
Flumioxazin	0.21	a + b	98	76	98	100	99	99
Flumioxazin	0.28	a + b	97	76	96	100	99	99
Flumioxazin	0.35	a + b	100	86	100	100	99	99
Flumioxazin	0.42	a + b	100	88	99	100	99	99
Hexazinone	4.73	a	21	11	22	100	98	76
Hexazinone	9.46	a	25	19	13	100	99	90
LSD (0.05)			7	15	22	0	1	9

[a] Timing: a, single application applied Early PRE; a+b, sequential application of Early PRE followed by Late PRE (60 DAT).

[b] Abbreviations: DATa, days after Early PRE application; DATa+b, days after Late PRE application; PRE, pre-emergence.

Table 3.4. Blueberry yield averaged across treatments for flumioxazin applied Early PRE or Early PRE followed by Late PRE (60 DAT) at Burgaw and Harrells, NC in 2008.

Location	Blueberry yield	
	Early PRE[a]	Early PRE fb
	kg/ha	
Harrells	3150	3551
Burgaw	6065	5735
LSD (0.05)	788	828

[a] Abbreviations: Early PRE, single PRE application of flumioxazin; Early PRE fb Late, sequential applications of flumioxazin Early and Late PRE.

Table 3.5. Comparison of blueberry yield of the flumioxazin applied Early PRE or Early PRE followed by Late PRE (60 DAT) treatments at Burgaw and Harrells, NC with mean yield reported by the state of North Carolina.

Location	Blueberry yield	
	Single[a]	Sequential
	kg/ha	
Harrells	3150	3551
Burgaw	6065	5735
State	6086	6086
LSD (0.05)	673	673

[a] Abbreviations: Early PRE, single PRE application of flumioxazin; Early PRE fb Late, sequential applications of flumioxazin Early and Late PRE; State, mean yield in kg/ha for blueberries produced in North Carolina in 2006.

Chapter 4

Utilizing a Grower Survey to Assess Weed Management Practices in North Carolina Blueberries

Abstract

The majority of the growers (41.5%) participating in the survey grew rabbiteye blueberries. Of the responding growers, only 1% are certified organic producers while majority of survey respondents (65%) do not produce blueberries organically. The variety 'Croatan' was the most frequently planted highbush variety in total ha as well as the most frequently planted variety by year. The variety 'Premier' was the most frequently planted rabbiteye variety in total ha and from 1981 to 2003. Growers most commonly scout their blueberries for weeds, diseases, and insects at least once a week (40%). While approximately 50% of growers keep a written or electronic record of chemical applications to their crop, only 4% keep a written or electronic record of scouting events and data in their crop. Organic (plant-based) mulch is applied by 43% of growers as a method of weed suppression with only 6% reporting the use of polyethylene mulch. Pine bark is the most popular type of organic mulch (39%) and 75% of growers using organic mulch obtain it from a source outside their farm. Of those growers who responded that certain weed species are no longer causing problems, 22% reported that goldenrod is the most common species to have decreased in severity. Among those species that have become a problem, 19% of growers responded that greenbriar species (Smilax spp.) are increasing in severity. Of the weed families that growers believe cause the greatest loss in blueberry yield, 41% reported annual and perennial grasses, 31% reported annual and perennial sedges, 20% reported broadleaf weeds, and 7% reported woody perennials. Twelve growers (21%) reported using mechanical cultivation to control weeds at an average cost of $445/ha. Thirty growers (52%) reported using hand removal as a method of weed control at an average cost of $2431/ha. Thirty growers (52%) reported utilizing herbicides to

control weeds at an average cost of $3037/ha. The most commonly applied herbicide in non-bearing blueberries is sethoxydim, which accounts for approximately 324 ha or 24% of total ha treated with herbicides as reported in the survey. Hexazinone is the most commonly applied herbicide in bearing bushes and is applied to 513 ha or 39% of the total ha treated with herbicides. Glyphosate was the second most common herbicide applied to both non-bearing and bearing bushes, for a total of 17% of the non-bearing ha and 31% of the bearing ha.

Introduction

North Carolina is the fifth largest producer of blueberries in the U.S. with approximately 5,000 ha harvested in 2006 (USDA 2007a). Within the state, blueberries are the most lucrative fruit commodity with a value of $48 million in 2006 (USDA 2007a). Although the coastal plain of North Carolina accounts for 55% of the state's growers and 96% of the state's total ha, growers are scattered throughout the state and occur in both the piedmont and mountain regions as well as the coastal plain (USDA 2007b). The production of highbush blueberry is centered in the southeastern coastal plain and makes up 95% of the state's total commercial ha (USDA 2007b). The production of rabbiteye blueberries is scattered across the state because this blueberry type is more tolerant of a wider range of growing conditions than highbush. Rabbiteye blueberry accounts for the remainder of commercial production.

Due to the high value of the crop, weed control and crop safety are of great concern to blueberry producers. The shallow root systems of mature blueberry may cause the bushes to be vulnerable to herbicide exposure or damage by cultivation (Pritts and Hancock 1992). Young, non-bearing bushes (less than 3 years old) are especially vulnerable to herbicide injury as well as competition from weed species. Additionally, the weed communities observed in blueberry fields are unique and dominated by perennial species. Pine (*Pinus spp*.), holly (*Ilex spp*.), greenbriar (*Smilax spp.)*, small deciduous trees, and various species of herbaceous perennials consistently present weed control problems for growers. Several of these species interfere with crop management and harvest.

Many weed management options exist for blueberry producers, but it is unclear as to which methods are most frequently employed. Chemical weed control options exist, and currently there are 16 herbicide formulations approved for use in blueberry in North Carolina (Mitchem et al. 2008). Manual removal of weeds by hand, hoeing or mowing is also used (Pritts and Hancock 1992). In younger bushes, mulching with polyethylene mulch or organic materials is sometimes used to suppress weed growth. Organic mulch can also be used to suppress weeds in older plantings, but must be replaced at a rate of 2.5 cm depth per year (Pritts and Hancock 1992).

Growers surveys have been used by weed scientists to obtain various types of information including: farmer perceptions of weeds and weed management practices (Gibson 2005), problem weeds (Webster and MacDonald 2001), areas of grower need (Norsworthy 2003), and the presence of herbicide resistant weeds (Shaw et. al. 2008; Scott and VanGessel 2006). Obtaining information from North Carolina blueberry growers concerning their weed management problems and strategies, herbicide use patterns, general production practices, and emerging weed problems will allow for the development of a comprehensive weed management plan tailored to the requirements of blueberry production within the state. Understanding the practices currently employed by blueberry growers in general will also assist in making applicable weed management recommendations to growers on an individual basis. Additionally, information from North Carolina blueberry growers would allow for possible development of registrations of herbicides through the national IR-4 program. The objective of the survey was to determine the weed management practices used by blueberry producers in North Carolina.

Materials and Methods

A 41 question survey (Table 4.1) was designed by the authors and was mailed to 301 blueberry growers in North Carolina in February 2008. The mailing list was compiled with assistance from the North Carolina Blueberry Council, Inc. Additional grower contact information was obtained from the publicly accessible Appalachian Sustainable Agriculture Project Local Food Guide and North Carolina Department of Agriculture and Consumer Services General Store online grower lists (ASAP 2008; NCDA & CS 2008). Blueberry growers on the mailing list represent the majority of commercial blueberry ha in the southeastern part of the state as well as the smaller ha operations throughout North Carolina. A second mailing of the survey was completed in April 2008. Of the total surveys mailed, 42 were returned unread due to invalid addresses and 18 were returned without being opened, reducing the number of mailed surveys to 241. Completed surveys were considered valid only if growers reported that they currently grew blueberries. A total of 58 valid responses were returned and were entered into the data set. Respondents represent 24% of the 241 surveys successfully mailed and 19% of the total original survey population.

The survey was divided into six sections that included general farm information, scouting and record keeping, education information, fertilizer information, weed history, and current weed management practices (Table 4.1). Due to the effects of the Easter freeze on blueberries in 2007, all questions in the survey refer to yields and production methods in 2006. Questions were designed as multiple choice with numerically coded answers or as short answer. The responses to short answer questions were grouped by similarity. Respondents were asked to fill in tables with information on blueberry varieties, fertilizer applications, weed removal strategies, weed management costs, and herbicide applications. Unless otherwise stated, data were analyzed by determining answer frequencies relative to the total number of responses (SAS Institute Inc. 2004[1]).

Results and Discussion

General Farm Information. The majority of the growers (41.5%) participating in the survey grew rabbiteye blueberries. Growers producing a combination of highbush and rabbiteye types were second most common (38%), while those growers producing solely highbush blueberries were in the minority (21%). Approximately 44% produce blueberries in a sandy or sandy loam soil, while 42% of the growers produce blueberries in a clay loam soil. Fewer than 10% produce fruit in clay or loam soil. Of the responding growers, only 1% are certified organic producers, while 9% are planning to become certified. Roughly 24% of the respondents claim that they produce organic blueberries but are neither certified nor plan to become so. The majority of survey respondents (65%) do not produce blueberries organically.

Growers were asked to provide information regarding the ha of each blueberry variety they produce and the year in which the bushes were planted (Tables 4.2 and 4.3). The variety 'Croatan' was the most frequently planted highbush variety in total ha as well as the most frequently planted variety by year. The variety 'Premier' was the most frequently planted rabbiteye variety in total ha and from 1981 to 2003. From 2004 to 2007, 'Powderblue' was the most frequently planted rabbiteye variety and 'Tifblue' was the most frequently planted rabbiteye variety planted before 1981. The total combined ha of highbush and rabbiteye varieties reported was 1663 ha and accounts for approximately 32% of the total ha of blueberry reported by the state (USDA 2007b). The highbush variety 'Croatan' and the rabbiteye variety 'Premier' are also the most commonly planted varieties reported by the state of North Carolina (USDA 2007b).

Twenty-nine different row spacing dimensions were provided by responding growers. Survey results indicate that blueberries are most commonly planted (11%) on a spacing of 2 m (in row) by 4 m (between row). Row spacing of 1.5 m by 3 m, 2 m by 3 m, and 1 m by 3 m, each accounting for approximately 9%, are the next most common. All additional row spacing dimensions were only reported by a single producer (data not shown).

There were eight beginning harvest dates indicated by growers, and they ranged from the third week of May to the third week of July. In 2006, the third week of June was the most common time reported as the beginning date of harvest (31%). The third week of May (19%) and the first week of July (14%) were the second and third most common starting times for harvest respectively. Number of harvested ha ranged from 0.04 to 182 ha and averaged 15 ha per grower. Of the 42 growers who provided harvest information, 76% harvested fewer than

4 ha, 12% harvested between 4 and 40 ha, and 14% harvested greater than 40 ha. Total yield was provided by 38 growers. Reported yields ranged from 13 to 9191 kg/ha and averaged 3123 kg/ha. Approximately 14% of responding growers harvested less than 560 kg/ha, 34% harvested 1121-3362 kg/ha, and 36% harvested greater than 3362 kg/ha. The average yield/ha by the state of North Carolina in 2006 was 6086 kg/ha (USDA 2007a).

Scouting and Record Keeping. Growers most commonly scout their blueberries for weeds, diseases, and insects at least once a week (40%). An additional 40% of growers scout their fields at least once a month. Growers most commonly scout their fields themselves and 87% report that scouting is performed by them or a family member.

While approximately 50% of growers keep a written or electronic record of chemical applications to their crop, only 4% keep a written or electronic record of scouting events and data in their crop. If growers adopted the practice of scouting and keeping records for each of their fields, this would allow them to tailor their weed management specifically for each field. Also, a historic documentation of weed species would allow growers to detect changes in weed populations and any new species that may occur, including resistant weeds.

Educational Information. Growers most frequently obtain educational information from extension agents (38%). Other common sources of educational information include grower meetings (29%) and the internet (18%). Approximately 70% of growers say that they use the internet and 52% use it daily. Seventy-six percent of growers say that they would use the internet to access educational material. Thus, the internet may be one tool for delivery of timely information on weed management strategies.

Fertilizer Information. Eighty-four percent of growers apply fertilizer to their crop. The most commonly applied fertilizer is 10:10:10 (10% nitrogen, 10% phosphorus, 10% potassium), which is used by 31% of responding growers. Fifty-five percent of growers apply fertilizer to their blueberries only once in a growing season. An additional 40% of growers apply fertilizer two or three times in a growing season. Growers reported fertilizing a total of 915 ha.

Weed History. Organic (plant-based) mulch is applied by 43% of growers as a method of weed suppression with only 6% reporting the use of polyethylene mulch. Pine bark is the most popular type of organic mulch (39%) and 75% of growers using organic mulch obtain it from a source outside their farm. Importing organic materials like mulch from outside their farms has the potential to introduce new weed species as well as disease and insect pests.

Thirty-five percent of growers indicated that there are weed species that used to be problems but are no longer causing issues. Of those growers who responded that certain weed species are no longer causing problems (Table 4.4), 22% reported that goldenrod is the most common species to have decreased in severity. Conversely, 57% of growers reported that there are weed species that have become problem species in recent years (Table 4.5). Among those species that have become a problem, 19% of growers responded that greenbriar species (*Smilax* spp.) are increasing in severity.

Fifty-nine percent of responding growers reported that their fields are not bordered by drainage ditches. Of the 41% who reported drainage ditches bordering their fields, 52% reported having fields bordered on one or two sides by ditches and 34% reported ditches bordering their fields on three or four sides. Drainage ditches are believed to be a possible source of weed species on blueberry farms and an increased number of drainage ditches may correlate with increased weed severity and diversity. Approximately 13% of growers indicated that they have drainage ponds located on their farms and do not use ditches for drainage.

Weed Management. Of the weed families that growers believe cause the greatest loss in blueberry yield, 41% reported annual and perennial grasses, 31% reported annual and perennial sedges, 20% reported broadleaf weeds, and 7% reported woody perennials. Eleven percent of growers named greenbriar spp. as the most difficult weeds to manage (Table 4.6) and 39% reported that they interfere the most with harvest (Table 4.7).

Twelve growers (21%) reported using mechanical cultivation to control weeds at an average cost of $445/ha. Sixty-two percent of those growers employ cultivation one time during the growing season, most frequently in the month of August (27%). Thirty growers (52%) reported using hand removal as a method of weed control at an average cost of $2431/ha. Hand removal is most commonly performed twice in a growing season (35%) in the months of April, June or July, each month representing 14% of responding growers. Thirty growers (52%) reported utilizing herbicides to control weeds at an average cost of $3037/ha. Thirty-seven percent of growers using herbicides usually apply them twice in a growing season during the months of April (22%), May (13%) or June (13%).

Of those growers who use hand removal as a weed management strategy, 33% indicated that the pulled weeds are left in the row middle. Twenty-seven percent reported that they removed the weeds from the field, while 20% removed the weeds from the rows but left them in the field. Twenty percent removed the weeds from the field and destroyed them through burning or composting. Leaving weed debris in the field may contribute to future weed infestations. If there are seeds present in the hand removed weeds, or the weed species are capable of reproducing vegetatively from tissue fragments, leaving the weeds in the rows may be equivalent to planting them intentionally.

Seventy-seven percent of responding growers reported that they do not employ any sanitation strategies to prevent weed movement. Of the 23% who employ sanitation strategies, 52% indicated that they wash tools before using them in a field, 29% indicated that they washed machinery before entering a field, and 18% indicated that employees are required to wash boots before entering a field. Increasing the implementation of sanitation strategies by blueberry growers may be an effective way to prevent weed movement within and between farms. Sanitation also has the potential to reduce disease and insect pests.

The most commonly applied herbicide in non-bearing blueberries is sethoxydim, which accounts for approximately 324 ha or 24% of total ha treated with herbicides as reported in the survey (Table 4.8). Hexazinone is the most commonly applied herbicide in bearing bushes and is applied to 513 ha or 39% of the total ha treated with herbicides. Glyphosate was the second most common herbicide applied to both non-bearing and bearing bushes, for a total of 17% of the non-bearing ha and 31% of the bearing ha. The seemingly heavy use of hexazinone and glyphosate implied by grower responses may lead to development of resistant weed species. If resistance does not occur, repeated use of the same herbicide formulations has the potential to result in weed population shifts where certain difficult to control species can become dominant.

Twenty-nine percent of growers indicated that they have noticed weed species that are not being killed by registered rates and applications of herbicide recommended for that species. The species most commonly not controlled by recommended rates of herbicide is greenbriar (25%) (Table 4.9). Forty-four percent of growers responded that glyphosate at recommended rates is not controlling several species including pokeweed, greenbriar and sedges. Twenty-six percent of growers reported that hexazinone is not controlling sumac and crabgrass at the recommended rate. It is possible that the herbicides are not efficacious on these weed species or that the control of these weed species is not lasting through the growing season.

When asked about their greatest concern in weed control, 24% of blueberry growers responded that crop safety from herbicides is their most pressing concern. Eleven percent mentioned weed control cost as the greatest concern, while 11% indicated that control of a specific weed species was their biggest issue.

The grower responses indicate that North Carolina blueberry farmers are producing a wide variety of blueberries on various sized operations in a range of environmental conditions. It appears that there is not a single production model being used uniformly across the state, but rather growers are utilizing various crop spacings and different crop management strategies in their production models. From these surveys, it is evident that blueberry growers are implementing various management strategies (cultivation, hand removal, herbicides, mulching) to manage a wide variety of annual and perennial weed species. However, it was also apparent that many growers need further information on certain weed management strategies including scouting, keeping up-to-date records of scouting events specific to each field, implementing sanitation strategies, and integrating various chemical formulations to avoid problems with resistance and species population shifts. Utilizing resources such as the internet, extension personnel and grower meetings to disseminate educational information may assist in the improved implementation of certain weed management strategies.

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Tables

Table 4.8. Complete instrument for the North Carolina blueberry grower survey conducted in 2008 to determine weed management strategies employed by growers.

I. General Information

1) Did you grow blueberries in 2007? (Circle one)
Yes- Please continue
No- Please return the survey

2) Do you grow?
1- Highbush
2- Rabbiteye
3- Both Highbush and Rabbiteye

3) Field Soil Type (Circle One):
1- Sandy
2- Sandy loam
3- Loam
4- Clay loam
5- Clay

4) Do you grow organically produced blueberries that are (Circle One):
1- Currently certified
2- Planning to become certified
3- Not certified
4- Do not grow organically produced blueberries

5) Please complete the following tables. Include the blueberry varieties, the acreage of each variety by planting year and total acreage of each variety in production.

Highbush Varieties	Acres Planted 2004-2007	Acres Planted 1994-2003	Acres Planted 1981-1993	Acres Planted Before 1981	Total Acres in Production

Rabbitye Varieties	Acres Planted 2004-2007	Acres Planted 1994-2003	Acres Planted 1981-1993	Acres Planted Before 1981	Total Acres in Production

6) What is your row spacing and plant spacing?

Table 4.1. Continued

7) What was the beginning date of your harvest in 2006? If you cannot remember a specific date, just provide a month and a week (i.e. the third week of June)

8) What was your total number of harvested acres in 2006?

9) What was your total yield in 2006 in pounds/acre?

II. Scouting and Record Keeping

10) In 2006, how often were your blueberry fields scouted for weeds, diseases and insects? (Check one)
1- ___ At least once a week
2- ___ Every 2 weeks
3- ___ About once a month
4- ___ Less than once a month
5- ___ Did not scout field

11) In 2006, who scouted your fields? (Check all that apply)
1- ___ Yourself or a family member
2- ___ Employee
3- ___ Independent crop consultant
4- ___ Pesticide/ herbicide dealer
5- ___ Other person (please specify):

12) Do you keep a written or electronic (computer) record of chemical applications to your crop? (Circle one)
1- Yes
2- No

13) Do you keep a written or electronic record of scouting for weeds in your crop? (Circle one)
1- Yes
2- No

III. Education Information

14) Where do you get your pest management information? (Check all that apply)
1- ___ Internet
2- ___ Extension agent
3- ___ Independent crop consultant
4- ___ Pesticide/ herbicide dealer
5- ___ Grower meetings
6- ___ Other (Please specify):____________________

15) Do you use the internet? (Circle one)
1- Yes
2- No

Table 4.1. Continued

16) How often do you use the internet? (Check one)
1- ___ Daily
2- ___ Weekly
3- ___ Every other week
4- ___ I do not use the internet

17) Would you use the internet to access educational material? (Circle one)
1- Yes
2- No

IV. Fertilizer Information

18) Do you fertilize your blueberry fields? (Circle one)
1- Yes
2- No

19) Please indicate the type of fertilizer you use, the number of acres treated and the average number of treatments per season:

Fertilizer	Acres Treated	Average Number of Applications
______________________	__________	______________________
______________________	__________	______________________
______________________	__________	______________________

V. Weed History

20) When you planted your blueberries, did you use mulch or plastic sheeting to suppress weeds around new plantings? (Circle one)
1- Yes plastic
2- Yes mulch
3- Yes both
4- Neither

21) If you used non-plastic mulch, what type did you use?

22) Did the mulch come from a source outside your farm? (Circle one)
1- Yes
2- No

23) In the past 10 years, have there been weeds that *used to be problems* but currently are no longer causing issues? (Circle one)
1- Yes
2- No

Table 4.1. Continued

24) If yes to question 23, please name these weeds. Feel free to use common plant names:

25) In the past 10 years, have there been weeds that *were previously not problems* but are becoming troublesome? (Circle one)
1- Yes
2- No

26) If yes to question 25, please name these weeds. Feel free to use common names:

27) Are your blueberry fields bordered by drainage ditches? (Circle one)
1- Yes
2- No

28) If your fields are bordered by ditches, on average would you say your fields are (Check one):
1- ___ Bordered on all sides by ditches
2- ___ Bordered on at least 3 sides by ditches
3- ___ Bordered on at least 2 sides by ditches
4- ___ Bordered on 1 side by ditches
5- ___ Other (Please specify):_________________

VI. Weed Management

29) Which of the following do you believe cause the greatest loss in blueberry yield, Please label each line starting with 1- cause the greatest yield loss and ending with 4- cause the least yield loss
1- ___ Broadleaf weeds (including but not limited to Maryland meadowbeauty, pigweed etc)
2- ___ Grasses (including but not limited to panic grass, Johnsongrass, crabgrass etc.)
3- ___ Sedges (yellow nutsedge, purple nutsedge, annual sedge etc.)
4- ___ Woody Perennials (including but not limited to cat briar, greenbriar, hollies, pines, small trees etc.)

30) Please name the weeds that you feel are currently causing you the largest problem in terms of management and yield loss. Feel free to use common names:

31) Please name the weeds that you feel interfere with harvest. Feel free to use common names:

32) In 2007, did you use the following weed management strategies? Please indicate the date as mm/yy (08/06):

Practice	Acres Treated	Average Number of Treatments	Dates of Treatments
Cultivation	_________	_____________	_____________________________
Hand weeding	_________	_____________	_____________________________
Herbicides	_________	_____________	_____________________________

Table 4.1. Continued

33) Please indicate the approximate annual expense for you to use the following weed management strategies.

Practice	Annual Cost per Acre
Cultivation	___________________________
Hand weeding	___________________________
Herbicides	___________________________

34) If you used hand weeding, were the pulled weeds (Please check all that apply):
1- ___ Removed from the field
2- ___ Left in the row/ row middle
3- ___ Removed from the rows but left in the field
4- ___ Destroyed (burned, composted etc.)
___ Other (please specify):

35) Do you employ any sanitation strategies (washing machinery and tools, removing soil from boots etc.) to prevent weed movement within or between your fields? (Circle one)
1- Yes
2- No

36) If you employ sanitation strategies, which of the following do you use on your farm? (Check all that apply)
1- ___ Wash machinery before entering/leaving a field
2- ___ Wash implements (hoes, clippers, shovels etc) before using them in a field
3- ___ Employees wash boots before entering/leaving a field
4- ___ Other (please specify):

37) In 2006, which of the following herbicides were applied to your blueberry bushes **not in production (non-bearing)**?

Herbicide	Acres Treated	Number of Applications
Glyphosate	_______________	_______________
Devrinol	_______________	_______________
Oryzalin	_______________	_______________
Karmex	_______________	_______________
Surflan	_______________	_______________
Princep	_______________	_______________
Sinbar	_______________	_______________
Velpar	_______________	_______________
Kerb	_______________	_______________
Casoron	_______________	_______________
Rely		_______________

Table 4.1. Continued

Gramoxone	______	______
Select	______	______
Fusilade	______	______
Poast	______	______
Solicam	______	______
Other:	______	______

38) In 2006, which of the following herbicides were applied to your blueberry bushes **in production (fruit bearing)**?

Herbicide	**Acres Treated**	**Number of Applications**
Glyphosate	______	______
Devrinol	______	______
Oryzalin	______	______
Karmex	______	______
Surflan	______	______
Princep	______	______
Sinbar	______	______
Velpar	______	______
Kerb	______	______
Casoron	______	______
Rely	______	______
Gramoxone	______	______
Select	______	______
Fusilade	______	______
Poast	______	______
Solicam	______	______
Other:	______	______

Table 4.1. Continued

39) Have you noticed any weed species that are not being killed by normal rates and applications of herbicide recommended for that species? (Circle one)
 1- Yes
 2- No

40) If yes to question 39, will you please name those weed species that are not responding to normal rates of herbicide. Feel free to use common names. **In your answer, please indicate which herbicides are not working for each species** (i.e. Pigweed- glyphosate).

41) What is your greatest concern in weed control?

Table 4.9. Highbush blueberry hectares by variety and year planted.

Variety	Blueberry variety				
	Planting interval				
	2004-2007	1994-2003	1981-1993	Before 1981	Total
	ha				
Angola	0	0.61	0	0	1
Bladen	2	0.40	0	0	3
Bluechip	0	0	2	0	2
Bluecrop	0.05	0.32	0.34	0.13	1
Bluejay	0	0.20	0.20	0	0
Blueray	0.16	0.22	0.30	0.13	1
Blueridge	2	2	0	0	3
Carteret	2	2	0	0	4
Coville	0	0.20	0.20	0	0
Croatan	38	45	106	125	315
Duke	18	12	0	0	30
Earlyblue	0.03	0	0	0	0
Elliot	0.03	0.12	0.04	0	0
Jersey	0.05	14	0.10	0.13	14
Jubilee	1	0	0	0	1
Legacy	17	1	0	0	18
Murphy	0	24	2	0	25
New Hanover	1	0	0	0	1
O'Neal	34	0.30	5	0	40
Patriot	0.03	1	0.24	0	1
Pender	0	0	0	0	0
Reveille	4	47	8	0	58
Sampson	2	1	0	0	3
Sierra	0	0	0	0	0
Spartan	0	0	0	0	0
Star	0	0	0	0	0
Total	122	149	124	126	521

Table 4.10. Rabbiteye blueberry hectares by variety and year planted.

Variety	Blueberry variety				
	Planting interval				
	2004-2007	1994-2003	1981-1993	Before 1981	Total
	ha				
Baldwin	0	0.32	0	0	0
Brightwell	0.45	0.04	0	0.10	1
Centurion	0	0	0.40	0	0
Climax	2	6	6	0	14
Columbus	0.40	1	0.40	0	2
Delight	0	0	0.40	0	0
Gardenblue	0.10	0	0.06	0.06	0
Mendito	0	0	0.04	0	0
Onslow	1	1	0.40	0	3
Powderblue	2	9	5	0.10	17
Premier	5	25	26	2	59
Robinson	0.20	0	0	0	0
Southland	0.10	0	0.20	0	0
Tifblue	2	1	3	41	47
Woodard	0	0	1	0	1
Total	14	44	42	44	144

Table 4.11. Weed species that have decreased in severity over the past decade.

	Weed species			
Common Name	Scientific Name	Duration	Frequency	%
Brambles	*Rubus* spp.	Perennial	3	13
Broomsedge	*Andropogon virginicus*	Perennial	2	9
Crabgrass, large	*Digitaria sanquinalis*	Annual	3	13
Dodder	*Cuscuta* spp.	Perennial	1	4
Dogfennel	*Eupatorium capillifolium*	Perennial	1	4
Goldenrod, Canada	*Solidago canadensis*	Perennial	5	22
Grasses		Annual/Perennial	1	4
Greenbriar	*Smilax* spp.	Perennial	2	9
Horseweed	*Conyza canadensis*	Annual	1	4
Pigweed	*Amaranthus* spp.	Annual	1	4
Pokeweed	*Phytolaca americana*	Perennial	2	9
Sandbur	*Cenchrus* spp.	Perennial	1	4

Table 4.12. Weed species that have increased in severity over the past decade.

Common Name	Weed species			
	Scientific Name	Duration	Frequency	%
Bermudagrass	*Cynodon dactylon*	Perennial	1	2
Bittersweet	*Celastrus* spp.	Perennial	3	7
Brambles	*Rubus* spp.	Perennial	1	2
Cane	*Arundinaria* spp.	Perennial	1	2
Chickweed, common	*Stellaria media*	Annual	3	7
Crabgrass, large	*Digitaria sanguinalis*	Annual	1	2
Fescue	*Festuca* spp.	Perennial	1	2
Greenbriar	*Smilax* spp.	Perennial	8	19
Henbit	*Lamium amplexicaule*	Annual	1	2
Honeysuckle	*Lonicera spp.*	Perennial	1	2
Johnsongrass	*Sorghum halepense*	Perennial	1	2
Maryland meadowbeauty	*Rhexia mariana*	Perennial	1	2
Maypops	*Passiflora* spp.	Perennial	1	2
Miscanthus	*Miscanthus* spp.	Perennial	1	2
Morningglory	*Ipomoea* spp.	Annual	1	2
Nutsedge	*Cyperus* spp.	Perennial	3	7
Pine	*Pinus* spp.	Perennial	1	2
Poison ivy	*Toxicodendron radicans*	Perennial	2	5
Pokeweed	*Phtyolaca americana*	Perennial	3	7
Sicklepod	*Cassia obtusifolius*	Annual	1	2
Sumac	*Rhus* spp.	Perennial	3	7
Virginia creeper	*Parthenocissus quinquefolia*	Perennial	2	5
Water oak	*Quercus nigra*	Perennial	1	2
Wild garlic	*Allium vineale*	Perennial	1	2

Table 4.13. Weed species listed as being the most difficult to manage.

Common Name	Weed species			
	Scientific Name	Duration	Frequency	%
Bermudagrass	*Cynodon dactylon*	Perennial	3	5
Bittersweet	*Celastrus* spp.	Perennial	2	3
Brambles	*Rubus* spp.	Perennial	3	5
Chickweed, common	*Stellaria media*	Annual	2	3
Crabgrass, large	*Digitaria sanguinalis*	Annual	6	9
Fern sp.		Perennial	1	2
Fescue	*Festuca* spp.	Perennial	3	5
Goldenrod, Canada	*Solidago canadensis*	Perennial	1	2
Grape	*Vitis* spp.	Perennial	1	2
Grasses		Annual/Perennial	5	8
Greenbriar	*Smilax* spp.	Perennial	7	11
Honeysuckle	*Lonicera* spp.	Perennial	4	6
Johnsongrass	*Sorghum halepense*	Perennial	4	6
Maryland meadowbeauty	*Rhexia mariana*	Perennial	1	2
Maypops	*Passiflora* spp.	Perennial	1	2
Morningglory	*Ipomoea* spp.	Annual	2	3
Nutsedge	*Cyperus* spp.	Perennial	3	5
Oak	*Quercus* spp.	Perennial	1	2
Pigweed	*Amaranthus* spp.	Annual	1	2
Pine	*Pinus* spp.	Perennial	1	2
Pokeweed	*Phtyolaca americana*	Perennial	3	5
Privet	*Ligustrum* spp.	Perennial	1	2
Sicklepod	*Cassia obtusifolius*	Annual	1	2
Virginia creeper	*Parthenocissus quinquefolia*	Perennial	2	3
Water oak	*Quercus nigra*	Perennial	1	2
White clover	*Trifolium repens*	Perennial	1	2

Table 4.14. Weed species that interfere most with blueberry harvest.

	Weed species			
Common Name	Scientific Name	Duration	Frequency	%
Bermudagrass	*Cynodon dactylon*	Perennial	1	3
Bittersweet	*Celastrus* spp.	Perennial	1	3
Brambles	*Rubus* spp.	Perennial	3	10
Dandelion	*Taraxacum officinale*	Perennial	1	3
Fern sp.		Perennial	1	3
Fescue	*Festuca* spp.	Perennial	1	3
Grasses		Annual/Perennial	1	3
Greenbriar	*Smilax* spp.	Perennial	12	39
Maypops	*Passiflora* spp.	Perennial	1	3
Morningglory	*Ipomoea* spp.	Annual	1	3
Multiflora rose	*Rosa multiflora*	Perennial	1	3
Plantain	*Plantago* spp.	Perennial	1	3
Poison ivy	*Toxicodendron radicans*	Perennial	2	6
Virginia creeper	*Parthenocissus quinquefolia*	Perennial	1	3

Table 4.15. Average number of hectares to which registered herbicides are applied and average number of applications in bearing and non-bearing blueberry in North Carolina in 2007.

	Herbicide					
	Bearing			Non-bearing		
Chemical Name	ha[a]	% ha	Applications	ha	% ha	Applications
Bentazon	4	0.3	2	0	0	0
Clethodim	1	0.05	2	0.08	0.01	2
Dichlobenil	0	0	0	0	0	0
Diuron	2	0.15	1	0.40	0.03	1
Fluazifop	0	0	0	0.40	0.03	1
Glufosinate	134	10	1	132	10	2
Glyphosate	407	31	2	229	17	2
Hexazinone	513	39	1	277	20	1
Napropamide	0	0	0	0	0	0
Norflurazon	0	0	0	0	0	0
Oryzalin	4	0.3	2	168	12	1
Paraquat	59	4	2	1	0.06	3
Pronamide	0	0	0	0	0	0
Sethoxydim	197	15	1	323	24	1
Simazine	2	0.15	2	0	0	0
Terbacil	4	0.3	2	225	17	2
Acetic acid	0	0	0	0.40	0.03	2
Total	1327	100		1356	100	

[a]Abbreviations: ha, total number of ha to which each herbicide was applied according to grower responses; % ha, percent of the total reported ha to which each herbicide was applied; applications, number of applications in a growing season averaged over grower responses for each herbicide.

Table 4.16. Species that are not being controlled by registered herbicide rates.

	Weed Species				
Common Name	Scientific name	Duration	Herbicide	Frequency	%
Bindweed, field	*Convolvulus arvensis*	Perennial	Glyphosate	1	13
Crabgrass, large	*Digitaria sanguinalis*	Annual	Hexazinone	1	13
Greenbriar	*Smilax* spp.	Perennial	Glyphosate	2	25
Honeysuckle	*Lonicera* spp.	Perennial	Diuron	1	13
Nutsedge	*Cyperus* spp.	Perennial	Bentazon	1	13
Pokeweed	*Phytolaca americana*	Perennial	Glyphosate	1	13
Sumac	*Rhus* spp.	Perennial	Hexazinone	1	13