ABSTRACT

Title of Thesis: ESTABLISHING NATIVE GRASSES ALONG MARYLAND ROADWAYS

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The use of native grasses and other meadow species in roadside rights-of-way is perceived as environmentally and economically beneficial. There is a need for more information about successful establishment procedures appropriate for the mid-Atlantic region. This study examined the use of companion species and weed control treatments for native grass establishment in three distinct regions of Maryland. A mixture of eight perennial native grasses planted included big bluestem (*Andropogon gerardii* Vitman), bluejoint (*Calamagrostis canadensis* (Michx.) Beauv.), broomsedge (*Andropogon virginicus* L.), deertongue (*Dichanthelium clandestinum* (L.) Gould), eastern gamagrass (*Tripsacum dactyloides* (L.) L.), indian grass (*Sorghastrum nutans* (L.) Nash), little bluestem (*Schizachyrium scoparium* (Michx.) Nash), and switchgrass (*Panicum virgatum* L.). A variety of annual and perennial non-native and native grasses and two legumes planted as companion species, as well as various weed control treatments (mowing and the herbicides imazapic ((±)-2-[4,5-

dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-methyl-3 pyridinecarboxylic acid) and triclopyr ([(3,5,6-trichloro-2-pyridinyl)Oxy] acetic acid) with 2,4-D (2,4-dichlorophenoxyacetic acid) were tested for their utility in aiding establishment of the native mixture. Companion and weed control treatments had variable effects, depending on individual species, site and climatic conditions.

ESTABLISHING NATIVE GRASSES ALONG MARYLAND ROADWAYS

by

Nancy Lee Adamson

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

FHWA Federal Highway Administration
LSD least significant difference
MS mean square
MSA Maryland Seeding Association
NRCS Natural Resource Conservation Service
PLS pure live seed
SHA Maryland State Highway Administration
USDA United States Department of Agriculture

Introduction

Economics and ecology in late twentieth century America created the scientific and popular impetus for reestablishing and introducing native grasses and their meadow companions along roadsides throughout the country. Concerns about broad scale losses in biodiversity associated with construction and pollution, along with attention given to the potential environmental and economic costs of turf maintenance, have led to support for research to develop roadside plantings that are ecologically beneficial and also meet the State Highway Administration's (SHA) needs of safety and beauty (Glenn 1999; Harper-Lore 1999a). Perceived as requiring less maintenance than conventional turfgrass landscapes, providing wildlife and long term soil stability benefits, as well as aesthetic appeal, roadside plantings of native grasses and other meadow species are also perceived as initially costly, difficult to establish, slow in providing adequate cover to prevent soil erosion and aesthetically less than acceptable during the first few years of establishment (Harrington 1991, Harper-Lore 1998a). In Maryland, limited seed availability, limited experience with native meadow species, weed competition and the often weedy appearance of young plantings have prompted the State and Federal Highway Administrations to sponsor research on effective native grass establishment procedures and appropriate seed mixtures (Harper-Lore 1998b).

Native grasses, particularly warm season grasses, and associated flowering plants are perceived as ecologically and economically beneficial, but slow to become established and, depending on the species, difficult to use. Germination needs vary widely and are not adequately understood (Swartz 1998; Young and Young 1986). Some species have very small or fluffy seeds requiring specialized equipment for planting (DeFeo 1998; Harrington 1991). However, because of the perceived benefits associated with their natural adaptation to the sometimes very harsh conditions found along roadsides, the State and Federal Highway Administrations are particularly interested in planting warm season grasses (Harper-Lore 1998a; Harper-Lore 1996).

State highway departments around the country have recently been experimenting with the use of native flora, particularly meadow species, which require little mowing or chemical treatment and can be beautiful. Since this project began in 1998, the Federal Highway Administration (FHWA) published *Roadside Use of Native Plants*, providing plant lists and summary discussions of roadside restoration and management issues, the first of its kind covering national use of native plants (Harper-Lore 1999a). In Maryland, interest in using native grasses has led to efforts to develop effective establishment procedures to address specific seeding constraints of the mid-Atlantic region (Meyer 1998; Proc. Native Grasses 1997; Englert 1998; Englert 1997). Major constraints include weed competition, inadequate knowledge of germination requirements, and limited availability of regionally native seed (Poole 1997).

Interest in using native grasses has grown tremendously in the past few decades due to efforts to create or enhance wildlife habitat and to lower landscape management costs (Center for Transportation and the Environment 1998; Richards et al. 1998). Aside from State and Federal Highway Administrations, many other governmental and private organizations are seeking information about appropriate native seeds and planting techniques throughout the region. Several incentive programs exist to encourage planting of native grasses by farmers, particularly in riparian zones (Reichert and Gagnon 1999; Tjaden and Weber 1998). Managers of parks, golf courses, mitigation, reforestation projects and landfill caps, as well as school groups and community organizations, are increasingly seeking native grasses and meadow species. Use of native grasses has also increased for agricultural and other environmental buffer zones (Birchall and Pinyan 1986; Felton 1998; Schnabel 1999; Suszkiw 1998). Regional growers have begun collecting, propagating, and keeping track of the origins of many grass and forb seeds, in response to growing demand and in anticipation of changing specifications. It will take time before supplies of regionally native seeds are adequately available and affordable compared with conventional turfgrass species or native species grown in the mid-west (Englert 1998; Englert and White 1997; Meyer 1997). Federal mandates and increasing interest from highway administrations is already leading to lower prices, which will also encourage broader use by private companies and organizations.

This research investigates the effects of companion species planting, mowing, herbicides, and planting times on the establishment of a mixture of grasses native to the mid-Atlantic in three regions of Maryland. Using a mixture of species helps ensure that germination will be successful across a spectrum of conditions. Since many native grasses can be relatively slow to become established, companion (nurse) species are used to quickly provide ground cover to prevent soil erosion and suppress weed competition (Sustainable Agriculture Network 1998). This study investigates the effectiveness of various companion species in aiding establishment of native (desirable) grasses by providing cover and suppressing weed competition. It also investigates the effectiveness of mowing and herbicides in aiding establishment of native grasses by suppressing weed competition. The project was designed to provide better understanding of effective establishment procedures for native grasses in the mid-Atlantic region.

Chapter I

Literature Review

Why plant natives?

Plants native to an area are those species that "arrived, established, and survived there without direct or indirect human assistance" (Morse et al. 1999, 12). They have evolved with a community of species, adapting to particular environmental conditions and interactions with other species over geologic time scales (Thompson 1999). They are "generally in reasonable ecological balance with their associates and competitors, and have pests, predators, or diseases that limit their abundance" (Morse et al. 1999, 12). Some non-native species do not have natural checks and can quickly spread and dominate areas they invade, pushing out native species and diminishing biodiversity (Harper-Lore 1999b). Largely due to concerns about loss in biodiversity, federally funded projects have been required to spend a small percentage of planting budgets on regionally native species and encouraged to use natives wherever practicable since 1987 when the Native Wildflower Planting Requirements were enacted (Schneider 1996). In 1994, President Clinton issued an Executive Memorandum on Environmentally and Economically Beneficial Landscaping supporting use of native plants (Clinton 1994). In February 1999, Clinton issued an Executive Order on Invasive Species that prohibits use of invasive species except where no reasonable alternative is available and mandates use of regionally native species wherever practicable (Harper-Lore 1999b). Regionally, federal agencies signed an agreement to enhance watershed and ecosystem management, including expanded use of conservation landscaping (Federal Agencies Agreement 1998). Although a species might be native throughout the United States, a regionally native, local ecotype, is generally defined as originating within 250 miles of a designated planting site (Meyer 1998).

Roadside use of native species

State and Federal Highway Administrations have been experimenting with the use of native plants along roadways for a variety of reasons -- aesthetic, economic, and ecological (Ahern et al. 1992; Byler et al. 1993; Charvat 1995; Coleman and Harris 1996; Corley 1995; Corley and Smith 1991; Dana et al. 1996; Harper-Lore 1996; Johnson 1995; Lyman 1990; Skroch et al. 1995; Stenlund et al. 1994; Tatman 1993). *Roadside Use of Native Plants*, published by the FHWA in 1999, provides an excellent summary of issues relating to use of native species along roadsides. Bonnie Harper-Lore describes the evolution and complexity of roadside seeding objectives:

> Since highway construction began, the engineering objective was to establish a green growing slope stabilizer. Because of NEPA [National Environmental Protection Act] and the Clean Water Act, the environmental objective changed to a quick green growing slope stabilizer. Because of beautification concerns, the esthetic objective was to establish a visually pleasing, quick, green growing slope stabilizer. Because of vegetation management issues, the maintenance objective is becoming, establish a noninvasive, visually pleasing, quick green growing slope stabilizer. Because of diminishing resources, a holistic objective must be to establish an affordable, noninvasive, visually pleasing, quick, green growing slope stabilizer. This growing

list of roadside objectives makes the seed mix solution complex, and one standard specification cannot meet all objectives (Harper-Lore 1999a, 10).

Use of native species chosen based on specific site conditions is viewed as an ecological approach to roadside vegetation management needed to replace use of species such as sweet clover, smooth brome and crown vetch, which were introduced as quick growing stabilizers, but have become weed problems (Jacobson 1999).

Using native species is also seen as an opportunity to "heighten the public's understanding and appreciation of the unique local or regional landscape" (Morrison 1999, 19). This educational aspect of planting native species has been adopted by Maryland's Department of Transportation in cooperation with the Bayscapes program of the Chesapeake Bay Field Office, U.S. Fish and Wildlife Service (Bayscapes 2000). Native landscaping with interactive signage is being installed at visitor centers to provide travelers a sense of Maryland's unique landscapes. The project also reflects the role of popular support for ecologically oriented landscaping. Butterfly gardening and wildlife habitat creation within home gardens, supported by programs like the National Wildlife Federation's Backyard Wildlife Habitat program have led to political pressure to use more native species and to mow less in public spaces (Backyard Wildlife Habitat 2000). Less running of mowers helps reduce pollution. Less mowing could also significantly reduce urban air pollution because hydrocarbons released from cut grass account for up to 10% of hydrocarbons reaching the atmosphere and causing smog (Anderson 1998).

Ecologically, using native plants is viewed as a way to protect and restore biological diversity, to enhance wildlife habitat and avoid invasive species problems (Center for Transportation and the Environment 1998; Pain 1997). Economic savings associated with native plantings depend on the particular species used, on what, if anything, is being replaced, and on the time frame examined. Most of the economic reasons for using native species stem from ecological reasons. Choice of appropriate species depends on local site conditions. In the mid-Atlantic, ecological conditions often include acidic soils and periodic drought. In the past, periodic fire due to lightening or Native Americans helped shape plant communities (Delcourt and Delcourt 1998a; Frost 1998). Whether native or not, plants chosen based on site conditions should require less maintenance. In replacing invasive species with non-invasive species, economic savings would include elimination of containment costs and potential agricultural losses. Where meadow species replace turfgrass, maintenance costs could be lowered with less watering, mowing, or chemical inputs. Under conditions of drought, planting meadow species may reduce replacement costs when compared with conventional non-native plants other than grasses. There are many other potential economic and ecological benefits associated with particular planting needs, such as transition areas or reforestation zones (DeFeo and Borders 1998; Packard and Mutel 1997; Sauer 1998).

Highway administrations are particularly interested in using native meadow species because they are adapted to open, dry, poor soil conditions (Harper-Lore 1996; Harper-Lore 1998b; Harper-Lore 1999a; Qi and Redmann 1993). Warm season grasses are the main components of natural meadows or prairies. Using the C4 photosynthetic pathway, they have optimum growth at higher temperatures than cool season species, which go dormant during hot summer months (Larcher 1995; Poole 1997). Relatively slow in establishing aboveground cover, they tolerate very droughty and poor nutrient conditions by developing large, fibrous root systems (Van Devender 1995). With their deep fibrous roots, warm season grasses also provide excellent long term soil stabilization (Jacobson 1999). When considering wildlife habitat value, these bunch grasses provide better nesting space for groundnesting birds than sod-forming grasses, a greater diversity of insects tend to inhabit them, and they are generally more nutritious than turfgrass species (Buchmann and Nabhan 1997; Duffey 1974; Martin et al. 1961; Maryland Partners in Flight 1998). Some turfgrass species left unmowed could provide wildlife benefits, as well. However, some tall fescues, those containing endophytes, are toxic to some herbivores and their growth habit is unsuitable for nesting (Washburn et al. 1999).

Several factors have limited the use of warm season native grasses and their meadow associates in roadside rights-of-way. In the east, high levels of precipitation make weed competition and invasion of woody species problematic for initial establishment and long term meadow maintenance. Very light, fluffy seeds of many species require specialized seeders or are simply perceived as difficult to plant and establish. This perception also relates to the lower germination rates and dormancy of many native grasses when compared with conventional turfgrass species. However, growers try to prevent potential problems associated with lower germination or dormancy by selling "pure live seed," a measure based on purity and the percent of seed expected to germinate the season purchased. Unlike most turfgrass seeds that are close to 100% pure with germination rates around 97%, some of the native grass seeds may have 25% inert material or only 80% expected germination rates. For example, for a 1 kg per ha seeding rate, a landscaper buying 1 kg of pure live seed (PLS) might receive 1 ½ kg of seed and would need to plant the full quantity to ensure the 1 kg rate. The Maryland Seeding Association (MSA) guideline specifications include helpful information on pure live seed calculations based on purity and expected germination (Maryland Seeding Association 1998).

In the mid-Atlantic, there is also limited experience using both warm season grasses and the specialized drills used for seeding, heightening fears of failure when attempting to establish native meadows. Planting light, fluffy seeds by broadcasting, drill seeding or hydroseeding requires more care than seeding smooth, heavy seeds. Government workers and contractors are steadily gaining experience with these seeds and the established plants (Cam MacLachlan, personal communication, 2000; Panciera 1999). New roadside, restoration and native plant journals are providing a more focused forum for exchanging relevant seeding and maintenance experience. These include *Greener Roadsides*, published by the Federal Highway Administration, *Native Plants Journal* (peer reviewed) and two journals from the Society for Ecological Restoration, *Restoration Ecology* (peer reviewed) and *Ecological Restoration*. The United States Golf Association, Maryland Seeding Association, and other professional landscape related associations are also providing information about appropriate seeds and methods for conservation or restoration plantings (Harker et al. 1993; Maryland Seeding Association 1999). Cost of some seed remains very high, particularly compared to turfgrass species, but prices are dropping steadily as demand and production increase. Also, most seed currently comes from mid-western sources because mid-Atlantic ecotypes are available for only a few species.

Local ecotypes of native seeds are currently being collected and propagated by private growers and the Department of Agriculture's Natural Resource Conservation Service (NRCS), but the process of collecting, selecting, and propagating adequate supplies takes time, approximately 5 to 10 years (Englert and White 1997). NRCS initiated a program to collect native warm season grass seeds within the mid-Atlantic region in 1995. A similar program for cool season grass collections began in 1997. Most of the collections, particularly of warm season grasses, have been made by Dr. Harry Jan Swartz of the University of Maryland's Department of Natural Resource Sciences and Landscape Architecture. In tandem with seed collection, he also began research to better understand germination rates and stratification requirements. Valerie Williams and Gwen Meyer, students of Dr. Swartz and Dr. Thomas R. Turner, also of the University of Maryland's Department of Natural Resource Sciences and Landscape Architecture, investigated germination rates, competition and establishment practices for various local ecotypes of warm season native grasses in the mid- to late-1990s (Meyer 1998; Swartz 1999).

Establishment issues

Weed competition may be the greatest obstacle to successful establishment of native meadow species in the mid-Atlantic region, so most establishment recommendations include methods for minimizing weed competition prior to and following planting. Recommendations include the use of herbicides, tillage or burning prior to planting, from a month up to three years prior to seeding, to reduce weed growth and weed seed banks (Diboll 1984; Packard and Mutel 1997; Prairie Moon Nursery 2000; Prairie Nursery 2000; Sauer 1998; Weaner 1996).

Research was conducted on the establishment of native warm season grass ecotypes in the coastal plain of Maryland in 1996 and 1997 (Meyer 1998). Planting dates (April and June), several weed control methods involving mowing and herbicides, and application of nitrogen fertilizer were tested. Meyer found that weed control practices and June planting significantly improved the density of native grasses, while nitrogen had no significant effect on native grass establishment. Differences between weed control methods, which included frequent and infrequent mowing over two seasons, frequent mowing in the first season followed with broadleaf herbicide application in the second season, and frequent mowing in the first season followed with a non-crop herbicide application in the second season, were not significant.

Frequent mowing during the first season of growth is recommended by Larry Weaner, a landscape designer who has been installing meadows in the mid-Atlantic region for more than fifteen years. He argues that deficient seed mixes and poor planning have led to "one-year success stories that end with a massive weed invasion" (Weaner 1996, 24). Mowing has also been found to be helpful as a tool for controlling cool season exotic grasses in prairie grass plantings in Wisconsin (Diboll 1984). Most meadow mixtures, like the wildflower mixtures used by Maryland's highway administration, contain a large number of annual species that provide wonderfully colorful landscapes within the first season of planting, but are not sustainable meadows because of weed invasions by the second or third season.

These areas must be replanted every few years. The United States Park Service has also generally used showy annuals to provide cover for initial year native meadow establishment. There is a trade-off between a showy first season and preventing longer term weed invasion problems, which may be lessened by use of companion species.

Along with first year mowing, a seed mixture based on the specific conditions of the planting site and a niche concept imitating a natural prairie is recommended by Weaner. In a natural prairie, different plants take up different spaces above and below ground and through time, filling every available ecological niche, and leaving little room for invasion by weed species. The dominant components of natural prairies are clump-forming grasses. However, like many of their perennial wildflower companions, the grasses are relatively slow in establishing aboveground cover. Therefore, a nursery or companion crop is used to prevent weed invasion and erosion during the first season. According to this view, a mixture of showy annual and perennial wildflowers without grasses does not take up enough of the available niche space above and, especially, below ground. A seed mixture based on the niche concept would include warm season grasses that flourish in summer and cool season species that grow primarily in spring and fall. Niches in time over several years would also be considered. The mixture would include plants that establish cover very quickly (within the first season, such as companion species), moderately quickly (by the second or third season, like most of the warm season grasses) and relatively slowly (forbs like blue false indigo, *Baptisia australis* (L.) R., or a grass like eastern gamagrass, *Tripsacum dactyloides* (L.) L., that establish substantial aboveground cover in three to four years). Weaner stresses that mowing the first season ensures longer term success than using a showy annual for first season bloom. When plantings are mowed no lower than 10 cm (4 in) and no higher than 30 cm (12 in) the first season, light reaches the young seedlings, which put more energy into roots (and take up more room underground). With mowing, weeds are kept from going to seed. Using this method, Weaner has seen a much fuller flush of growth in the second year and a tremendous reduction in weed problems in consecutive years (Weaner 1999).

Mycorrhizae have historically been used to improve establishment of non-native bush clovers, but relatively little research has investigated the use of mycorrhizae in establishing native meadow species (Charvat 1995; Smith et al. 1998). Big bluestem and little bluestem, for example, are known to depend on mycorrhizae in prairie soils (Anderson et al. 1994). The Plant Materials Center in Cape May, New Jersey found inoculating beach grass (*Ammophila breviligulata*) with arbuscular mycorrhizal fungi improved tiller and inflorescence growth (Gemma and Koske 1997). More research in this area of grass establishment is needed.

Companion species

Companion species are chosen to provide cover -- to shade out weeds and prevent soil erosion (Liebman and Janke 1990; Sustainable Agriculture Network 1998). Species commonly used are annual rye *(Lolium multiflorum* Lam.), oats (*Avena sativa* L.), and other annual species that germinate quickly, but ideally compete little by the second season of growth (Sustainable Agriculture Network 1998). Native wild ryes (*Elymus* spp.) are often used as cover crops for meadow plantings because they are native and germinate quickly, and seeds are relatively cheap (Packard and Mutel 1997; Prairie Moon Nursery 2000; Prairie Nursery 2000). Various native seed mixtures including companions have been tried across the country, but little scientific documentation exists. Most research on companion crops, also called cover or nurse crops, has been for agricultural uses or disturbed land revegetation (Bennett et al. 1972; Launchbaugh and Anderson 1963; Malhi 1993; Sustainable Agriculture Network 1998). Dr. Kenneth Lair, a plant ecologist, notes that cover crop type and amount is generally less important than other seeding factors such as seeding timing, moisture and seedbed preparation (Lair, personal communication 1999). Launchbaugh and Anderson (1963) found fewer differences between cover crop types or amounts used than planting times in native grass establishment. Bennett et al. (1972) found that rye, wheat and barley were beneficial for providing cover and mulch for perennial grass plantings on mine spoil in West Virginia.

Other benefits associated with cover crops in agriculture are related to soil quality. For example, legumes add nitrogen and the deep roots of annual rye loosen underlying soil layers, becoming excellent green manure when tilled in spring. Rye has also been used for its allelopathic suppression of weeds (Barnes and Putnam 1983). Decomposition of cover crop residues through microbial activity can immobilize nutrients (primarily nitrogen) or release toxic by-products that produce allelopathic-like symptoms (Lair, personal communication, 1999). Small grain stubble has been found to aid native grass establishment by improving cumulative water infiltration, decreasing temperature fluctuation, improving moisture storage at shallow soil depths, suppressing weeds, and lowering mulching costs (Greb et al.

1970; Munshower 1993; Schumann et al. 1980). Main objectives in agricultural cover cropping are that the cover compete less with desired species than weed species would, prevent intrusion of a noxious weed or a weed with seeds difficult to separate from the main crop, prevent soil erosion, either die out or be mowed, tilled or treated with a selective herbicide once it is no longer needed and cost little.

First season objectives in cover cropping for a meadow planting are similar to those in agriculture – prevent soil erosion, prevent intrusion of weed species and keep costs low – but long term objectives are somewhat different. The term companion tends to reflect this long term difference. A few additional criteria would need to be considered when seeking a suitable cover crop for a native meadow. Ideally, besides germinating quickly, it (or a mixture of species) would be a natural annual or perennial component of the local plant community, but not be too aggressive, such as the wild ryes, deertongue (*Dichanthelium clandestinum* (L.) Gould), or Florida paspalum (*Paspalum floridanum* Michx.). If not a native species, it would naturally die out within one season, like oats; weaken and eventually die out as it became shaded by desirable species, as may happen with some low-growing fine fescues (*Festuca* spp.); or be controlled easily with mowing that favored native species.

For agricultural crops, physical plant structures such as height and seed size are considered in relation to the growth habits or processing methods of the crop to be harvested. For a native meadow planting, physical plant structure could be important from a functional, aesthetic or wildlife perspective. Low-growing cool season grasses such as the fine fescues, if not planted too heavily, could prevent soil erosion, provide an attractive green cover if mowed in late fall, winter, or early spring until meadow species become established, yet create relatively little competition for light or moisture in spring and summer, the primary growth period of warm season native grasses. However, the structure of clump-forming grasses (that of most native warm season species), is considered important for wildlife like ground nesting birds and other wildlife. Clump-forming grasses provide cover, but also space for movement close to the ground (Maryland Partners in Flight 1998; Pain 1997). Although the ground may be bare close to the base of grasses, the fibrous roots systems of warm season species tightly hold the soil.

Although Meyer found that addition of nitrogen fertilizer did not improve warm season native grass establishment, tending instead to benefit weed species, it is not clear how legumes would affect establishment (Meyer 1998). Use of legumes for nutrient management is another consideration for cover crops, but use of native legumes has been limited because seeds are less available or very costly, or plants do not become established quickly enough. Many non-native legumes are very aggressive and, as mentioned earlier, can become weed problems in themselves. Crimson clover (*Trifolium incarnatum* L.) is an annual non-native legume with showy red flower heads that has been found to be an effective cover crop beneficial for soil nitrogen and not aggressive (Sustainable Agriculture Network 1998). Among native legumes, partridge pea (*Cassia fasciculata* Michx.) is probably the least costly. As a low growing, upright native annual, with bright yellow blossoms, naturally found on dry or sandy soils, it would potentially be an effective companion in native grass or meadow establishment. Bush clovers (*Lespedeza* spp.) are commonly used along roadsides, but currently only non-native species are used due to their low cost and current SHA seeding specifications. Native species such as round-headed bush clover (*Lespedeza capitata* Michx.) are spectacular perennials, but plants are relatively slow growing and seeds are presently very expensive and germinate at low rates unless mechanically scarified (with sandpaper, for example) (Harry Jan Swartz, personal communication, 2000). Some of the most common legumes in this region are tick-trefoils (*Desmodium* spp.) and also merit research. The NRCS is currently collecting, propagating and selecting native legumes, along with native grasses, for use in conservation planting and roadside rights-of-way, in response, to some extent, to the executive order on invasive species issued by President Clinton in 1999 and the need to find replacements for invasive legumes currently used.

Timing of planting and weed control

Time of planting is important to consider in choosing companion species, as well as in choosing the overall seed mixture. Warm season species generally need soil temperatures of at least 10°C (50°F) to germinate, with optimum air temperatures of 20 to 35°C (68 to 95°F), while cool season species will germinate at somewhat lower temperatures (Poole 1997; Smoliak and Johnston 1968). Established warm season grasses begin growth in late spring (late May or early June). Recommended seeding time for native grasses is generally spring or early summer so seedlings can mature before winter (Gaynor and Meyer 1999). A fall planting, or dormant seeding, can allow for germination of cool season companion species, prior to spring germination of warm season species, and prevent intrusion of cool season weeds. Gaynor and Meyer (1999) investigated planting times for Minnesota's Department of Transportation, testing a mixture of warm and cool season grasses, varying percent cool season to warm season species, planting every 2 to 4 weeks, and measuring effects during the first and second season of growth. They found that with adequate moisture, warm season species survived winter if planted by early August and cool season species survived winter if planted by early September. They suggest planting anytime before those dates, if areas are irrigated, and that vegetation managers need to weigh the chances for adequate moisture otherwise. Given the warmer conditions in the mid-Atlantic, one would expect those dates to be a little later in this region. Gaynor and Meyer (1999) also found that dormant seedings did not establish as well and that there were dramatic differences between the two years of the study. Rainfall and temperature directly affected establishment of native grasses and weed competition. Their results paralleled the work of Qi (1993) and Ries and Hofmann (1987), where pattern of rainfall was found to be more important than amount.

Fall plantings are sometimes required, however, due to circumstances unrelated to appropriate planting times. Research is needed to investigate the interaction of planting time with companion species and other weed control methods. If a fall planting is used, depending on the height of plants just prior to the germination period of warm season species, the area could be mowed or a selective herbicide applied to allow more sunlight to reach warm season seedlings, while still protecting soil from erosion. Thus, a relatively weed-free, but low-growing, ground cover would be retained while warm season species become established. A spring planting can be advantageous for the warm season species, but a companion to prevent growth of summer annual weeds could be helpful in preventing long term weed problems. Clearly, the success of a given planting will also depend on the specific site and weather conditions at the time of planting and throughout the growing season. Most research has been conducted in more westerly regions, such as Wisconsin and Minnesota, where prairie is a more prominent part of the natural landscape. More research is needed to investigate effects of planting time, use of companion species, and native species mixtures in the mid-Atlantic region.

Herbicides for weed control

Development of herbicides for use in native grass and forb establishment has increased in conjunction with expanded interest in conservation planting. Research has investigated the use of atrazine, metolachlor, 2,4-D, and, relatively recently, imazapic (or imidazolinone), all of which are labeled for use with grasses (Martin et al. 1982; Masters 1995; Masters et al. 1996; McKenna et al. 1991; Washburn et al. 1999; Washburn and Barnes 2000). Use of imazapic has been found to be effective in foliar and seedhead suppression of cool season grasses and other weed species, which can aid native warm season grass establishment. However, it is not labeled for use with panic grasses such as switchgrass and deertongue of the Paniceae (millet tribe of grasses) (American Cyanamid Company 1997; Clark and Pohl 1996). Indian grass, little bluestem and big bluestem, of the Andropogoneae (sorghum tribe of grasses) along with several native forb species, tolerate a range of imazapic application rates (Washburn and Barnes 2000; Clark and Pohl 1996). Pre-emergence application of imazapic at a 0.7 kg active ingredient per ha rate can significantly reduce weed cover and increase native grass density. Weed cover was reduced to less than 5% with preplanting imazapic application, compared with 95% weed cover without preplanting imazapic application (Washburn and Barnes 2000). Native grass density increased fourfold with preplanting imazapic application compared to densities without preplanting imazapic treatment (Washburn and Barnes 2000). However, post-emergence imazapic applications, despite noticeable reduction in weed cover, produced no significant increase in native grass densities (Washburn and Barnes 2000). In a separate study investigating establishment of native grasses in fields dominated by tall fescue, use of imazapic or imazapic with burning treatments also significantly improved native grass densities, which doubled to quadrupled compared to no treatment or burning only (Washburn et al. 1999).

Planting methods

A variety of planting methods have been used successfully for native grass and forb establishment, including broadcast seeding, raking and rolling; conventional tilling and seeding; no-till drill seeding; and hydroseeding (Ahern et al. 1992; Corley and Smith 1991; DeFeo and Borders 1998; John Krouse, personal communication, 1998; Meyer 1998; Cam MacLachlan, personal communication, 2000; Packard and Mutel 1997; Poole 1997; Prairie Moon Nursery 2000; Prairie Nursery 2000). Use of a no-till drill is considered advantageous because of less soil disturbance and less subsequent erosion. Recommended seeding rates are generally 20% lower for no-till drilling. Less seed is lost to wind and wildlife because of deeper planting depths and germination is higher due to improved seed to soil contact with no-till drill seeders. Rolling is recommended if seed is broadcast, and some practitioners also recommend it with drilled seedings (Robert Swain, personal communication, 1999). In restoration projects with children, use of a roller after broadcast seeding has been replaced with "rain dancing" by all those involved. Improving seed to soil contact of broadcast plantings with feet stomping may only be appropriate for relatively small-scale plantings, but has been found to be successful in not only establishing native prairies, but in improving children's understanding of and love for their natural surroundings (Grese 1998).

Native grass communities in Maryland

Native grasses can be found throughout the state of Maryland, but areas that remain dominated by native grass species are often sites inhospitable to many other plants because of thin, toxic or hydrated soils (Brown and Brown 1984; Norton 1930). Barrens with serpentinite soils, mountain balds, riverbed scours, marshes, sandy pinelands, dunes or other sites periodically disturbed by flooding, mowing, herbicides, or fire host many of Maryland's native grass or grass-associated species. Only cool season species like wild ryes, bottlebrush grasses (currently in the genus *Elymus*, though previously *Hystrix*), wild oats (*Chasmanthium* spp.), or woodreed (*Cinna* spp.) are found in richer woodland soils. Berdine (in progress) describes about 60 grassland communities in Maryland, some dominated by grasses, others dominated by sedges and rushes. Native grasses defining some relatively dry natural communities include big bluestem, bluejoint, broomsedge, indian grass, little bluestem, switchgrass, plumegrass (*Saccharum* spp.), and wild oats (Berdine, in progress).

The research of Delcourt and Delcourt (1997; 1998a; 1998b) and Frost (1998) indicates that fire historically shaped all but the wettest plant communities throughout the United States. For Maryland, Frost (1998) maps fire frequency as 4 to 6 years on the southern Eastern Shore, 7 to 12 years on the western and eastern coastal plains, and 13 to 25 years in western Maryland. Pine and oak communities with an understory dominated by little bluestem probably received the highest frequency of fires. Grasses are adapted to fire with their deep roots, meristematic tissue at every node, and perennial culms or tillers (Norton 1930). These adaptations allow grasses to regrow quickly, and, to some extent, create favorable conditions for other species (Nabhan 1997). These adaptations also help them survive certain herbicides. Powerline sites, where herbicides are sprayed on a regular basis, support diverse native plant communities.

In contrast, since the SHA decreased its use of herbicides along roadsides in the early 1990s, there has been a remarkable increase in the appearance of native grasses in those areas, particularly broomsedge, eastern gamagrass, indian grass, little bluestem, and Florida paspalum. Nevertheless, many areas remain dominated by non-native grasses, particularly western Maryland, where forage grasses have been widely planted and have spread into disturbed areas (frequently mowed areas) or been planted along roads. Southern Maryland and the Eastern Shore, where forage has been less important or where tobacco was historically a more important crop, retain wonderfully intact native plant communities that include indian grass, little bluestem, wild ryes, panic grasses, eastern gamagrass, plumegrasses, three-awn grasses (*Aristida* spp.) and a rich diversity of associated flowering plants.

Chapter 2

Research Objectives

The primary objective of this research is to develop best establishment procedures for native grasses to be planted in roadside rights-of-way in Maryland. Effective methods are needed to reduce weed competition and provide adequate ground cover until the relatively slow growing native perennial species become well established. Two separate studies were developed to examine 1) the effectiveness of companion species (companion species study) and 2) the use of mowing and herbicide treatments for weed control (weed control study) in aiding establishment of native grasses.

A mixture of native grasses was planted for both studies. The mixture included eight perennial species: big bluestem, bluejoint, broomsedge, deertongue, eastern gamagrass, indian grass, little bluestem, and switchgrass, all of which, with the exception of bluejoint, are warm season grasses. All of these are common throughout the mid-Atlantic. Of these, deertongue and switchgrass are currently the most reasonably priced and easiest to plant, with small, smooth, relatively heavy seeds with high germination rates. Broomsedge, indian grass, little bluestem and eastern gamagrass are very common species, but seeds are either slow germinators (eastern gamagrass) or difficult to handle because they are fluffy and light (broomsedge, indian grass, little bluestem), though good germinators. Bluejoint is more common in more northerly or cooler areas, and suited to moist soil conditions. There is some debate about how appropriate it is to plant big bluestem since in this region it is almost exclusively found in Serpentine soils or river scours. It also has a fluffy seed, but germinates well, and has been successfully planted in Maryland's Conservation Reserve Program.

Primarily warm season grasses were chosen because they are adapted to dry, exposed conditions, typical of roadsides. Most mid-Atlantic native cool season species are found in part-shade or moist soils. Since warm season species need warmer temperatures to germinate, a late spring planting could be advantageous. However, the use of companion species, mowing or herbicide with a fall planting might also aid establishment. Although commercial seed is pre-stratified, providing a period of cold wet stratification by planting in fall is believed to aid germination of certain native grass seeds (Swartz 1998). Also, companions could prevent germination of some cool season weeds. Close mowing with or without companions or herbicide application just prior to the germination period of warm season grasses could be helpful depending on how tall and thick vegetation is by late spring when warm season species begin active growth.

Weed control treatments for the companion and weed control studies were chosen based on the growth habits of warm season native grasses, the availability of selective herbicides promoted for use in native meadow establishment, and SHA practices. Following preplanting treatment of sites with glyphosate, late summer mowing (common highway vegetation management practice), application of selective herbicides during the prime growth period of warm season grasses, and second season mowing or herbicide application (just prior to the active growth period of warm season grasses) were tested.

Chapter 3

Native Grass Establishment -- Companion Species Study

Methods and Materials

Planting and management

Perennial grasses native to the mid-Atlantic region were planted along with companion species in a study replicated in three different regions of Maryland. A randomized complete block split plot experimental design was used, with three weed control treatments (control, mowing, and herbicide) as whole plots, and companion species in sub-plots (see Appendix A for the layout of each site). The study was also replicated in time, with spring and fall 1998 plantings.

Since companion species, weed competition and planting date effects on establishment could also vary greatly by location, three study sites were chosen to reflect different conditions across the state. The three sites were 1) a roadside area on the Eastern Shore, 2) agricultural land in Beltsville, and 3) a roadside area in western Maryland at Sideling Hill. The Eastern Shore planting was along Route 301 at the intersection of Route 405 in Queen Anne's county, within the eastern coastal plain physiographic province. Soil at this site is a sandy loam with pH ranging from 5.1 to 5.6. At the Beltsville site, in Prince George's county, plantings were on United States Department of Agriculture land previously cultivated with corn and soybeans.

Soil at this western coastal plain site is a silt loam with pH ranging from 6.1 to 6.6. At the third site, in western Maryland, plantings were located on fill from the Sideling Hill cut-through for Interstate 68, west of Hancock in Washington County. Soil at Sideling Hill is a silt loam ranging in pH from 6.8 to 7.5.

Sites were treated with a 2% solution of glyphosate herbicide (isopropylamine salt of N-(phosphonomethyl)glycine, product name Roundup), the standard rate for rough areas of mixed vegetation. Applications were made three to four weeks prior to planting to diminish weed competition and promote more uniform conditions over the test sites. No-till drill seeders designed to handle fluffy seeds were used to plant the background mixture of native grasses. A Tye wildflower no-till drill seeder was used for the spring planting and a Truax no-till drill seeder was used for the fall planting. Planting depth was approximately 1 cm (1/2 in) with 20 cm (8 in) spacing. Several passes were made in a crisscross pattern, so that overall seeding was as uniform as possible across plots. Various bulk materials were added to the fluffy and light seeds to improve movement through the seeders, including cocoa bean shells, kitty litter, and vermiculite. Although conventional tilling and seeding may be equally or more effective, the SHA was interested in drill seeding to minimize soil disturbance and subsequent erosion (John Krouse, personal communication, 1998; Packard and Mutel 1997; Prairie Moon Nursery 2000; Prairie Nursery 2000). Also, drill seeding helps minimize costs since recommended seeding rates are 20% lower compared to broadcast seeding. Companion species were broadcast seeded in 3.7 m x 3.7 m (12 ft x 12 ft) plots over the background mixture. Planting dates are shown in Table 3-1.

Table 3-1. Planting dates.

Site	Spring planting	Fall planting
Eastern Shore	June 1, 1998	December 17, 1998
Beltsville	May 22, 1998	December 15, 1998
Sideling Hill	June 2, 1998	December 21, 1998

The mixture of native grasses includes eight perennial species: big bluestem, bluejoint, broomsedge, deertongue, eastern gamagrass, indian grass, little bluestem and switchgrass, all of which, with the exception of bluejoint, are warm season grasses. Of these species, big bluestem, broomsedge, bluejoint, indian grass and little bluestem have very fluffy or light seeds, requiring a specialized seeder. All of these grasses are distributed throughout the mid-Atlantic and the mid-west (USDA, NRCS 1997). Dr. Harry Swartz, Elmina Hilsenrath, and Bonnie Harper-Lore (head of the vegetation management office of the Federal Highway Administration, FHWA), developed this species mixture, based upon 1) accessibility of seed, 2) FHWA experience with native grasses in the mid-west, and 3) research in the Department of Natural Resource Sciences and Landscape Architecture at the University of Maryland conducted by Dr. Swartz, Dr. Thomas Turner, and graduate students Gwen Meyer and Valerie Williams in the early 1990s.

The following grasses and forbs were planted as companion species to provide cover and control weed competition: annual rye (*Lolium multiflorum* Lam.), oats (*Avena sativa* L.), creeping red fescue (*Festuca rubra* L.), hard fescue (*Festuca trachyphylla* (Hack.) Krajina), tall fescue (*Festuca arundinacea* Schreb.), redtop (*Agrostis alba* L.), Canada wild rye (*Elymus canadensis* L.), Virginia wild rye (*Elymus virginicus* L.), Florida paspalum (*Paspalum floridanum* Michx.) (for the fall planting only), crimson clover (*Trifolium incarnatum* L.) and bush clover (*Lespedeza capitata* Michx.). Annual rye and oats are non-native annual grasses. Hard fescue, creeping red fescue, tall fescue and redtop are non-native perennial grasses. Canada wild rye, Virginia wild rye, and Florida paspalum are native perennial grasses. The native wild ryes are cool season grasses that are commonly perceived as relatively short-lived, while Florida paspalum is a warm season species known to germinate quickly, have a high germination rate, and tolerate mowing (Gaynor and Meyer 1999; Meyer 1998; Swartz 1999). However, Florida paspalum is not yet available commercially. All of the non-native companion grasses are cool season species commonly used by SHA. Crimson clover is a non-invasive non-native legume. Bush clover is a native legume. Treatments also included a control (no companion) and a treatment with a doubled rate of the background native grass mixture without a companion species.

Seeding rates, generally based on seed size and weight, are shown in Table 3-2 and Table 3-3. Seeding rates are based on recommendations by Dr. Turner, Dr. Swartz and John Krouse, of the University of Maryland Paintbranch Turfgrass Facility, and by Bonnie Harper-Lore. Suggested seeding rates for native grasses are much lower than those for turfgrass species. For native grass mixtures, the FHWA has found that between 8 to 22 kg ha^{-1} (7 to 20 lb $acre^{-1}$) is adequate, and that heavier seeding does not improve establishment (Harper-Lore 1998b). The overall rate for the background mixture was 10.6 kg ha^{-1} (9.5 lb $acre^{-1}$). As bunch-type grasses, each plant can develop a lot of bulk after a few years of growth, while initially providing little cover.

Table 3-2. Seeding rates of native grass mixture species in kg ha^{-1} and lb acre^{-1}.

	Pure live seed	
	kg ha^{-1}	lb acre^{-1}
Big bluestem (*Andropogon gerardii* Vitman)	1.1	1.0
Bluejoint (*Calamagrostis canadensis* (Michx.) Beauv.)	0.6	0.5
Broomsedge (*Andropogon virginicus* L.)	0.6	0.5
Deertongue (*Dichanthelium clandestinum* (L.) Gould)	2.2	2.0
Eastern gamagrass (*Tripsacum dactyloides* (L.) L.)	2.2	2.0
Indian grass (*Sorghastrum nutans* (L.) Nash)	2.2	2.0
Little bluestem (*Schizachyrium scoparium* (Michx.) Nash)	0.6	0.5
Switchgrass (*Panicum virgatum* L.)	1.1	1.0
Total	10.6	9.5

Table 3-3. Seeding rates of companion species.

	Pure live seed	
	kg ha^{-1}	lb acre^{-1}
Annual rye (*Lolium multiflorum* Lam.)	19.3	17.2
Oats (*Avena sativa* L.)	31.2	27.9
Creeping red fescue (*Festuca rubra* L.)	6.7	6.0
Hard fescue (*Festuca trachyphylla* (Hack.) Krajina)	6.4	5.7
Tall fescue (*Festuca arundinacea* Schreb.)	6.7	6.0
Redtop (*Agrostis alba* L.)	1.3	1.2
Canada wild rye (*Elymus canadensis* L.)	3.0	2.7
Virginia wild rye (*Elymus virginicus* L.)	2.7	2.4
Florida paspalum (*Paspalum floridanum* Michx.) *fall only*	1.1	1.0
Bush clover (*Lespedeza capitata* Michx.)	2.5	2.2
Crimson clover (*Trifolium incarnatum* L.)	1.3	1.2

The schedule of weed control treatments for the companion species study is shown in Table 3-4. Mowing and herbicide treatment times were determined based on rainfall and plant growth. Mowed plots were cut to a height of about 15 cm (6 in) using a rotary (bush-hog) mower. The herbicide treatment was imazapic ((±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-methyl-3 pyridinecarboxylic acid, product name Plateau®), a herbicide labeled for warm season grasses. Big bluestem, broomsedge, eastern gamagrass and indian grass are tolerant of imazapic application, while panic grasses such as switchgrass and deertongue are not (American Cyanamid Company 1997). It was applied at a rate of 1.2 L ha^{-1} (1 pint $acre^{-1}$), with 468 L ha^{-1} (50 gallons $acre^{-1}$) of water and 2.3 L ha^{-1} (2 pints $acre^{-1}$) of Triton non-ionic surfactant on the dates listed in Table 3-4.

Table 3-4. Schedule of weed control treatments for the companion species study.

Treatment	Eastern Shore	Beltsville	Sideling Hill
Mowing	August 14, 1998	August 3, 1998	August 20, 1998
	May 27, 1999	June 17, 1999	June 8, 1999
Herbicide	August 14, 1998	August 3, 1998	August 20, 1998
	May 27, 1999	June 17, 1999	June 8, 1999

Data collection

Grasses included in the native grass background mixture are referred to as desirable species to distinguish them from companion species, although native companions may also be considered desirable in the long term. Even with good germination of several of the desirable grasses, percent cover for the first season of growth was generally less than 1%. Therefore, counts of individual plants within a one square meter sample of each plot were taken at the end of the first and second growing season. By the end of the second growing season, percent cover for desirable species was generally greater than 1% and was therefore visually estimated for whole plots. Weed and companion species cover were also estimated. Destructive sampling to measure biomass of each species above and below ground would be useful for understanding the growth habits of different species through time, but plots were not large enough for destructive sampling. It was expected that changes in relative cover and individual species counts would provide adequate information about which treatments best support native grass establishment. For the spring planting, percent cover of weeds and companions for whole plots for all species that cover at least 5% of plots was measured toward the end of each growing season. General observations were recorded regarding plot appearance, height and flowering of desirable species, and the emergence of native species not planted.

Counts of desirable species per square meter and percent cover of desirable species per plot were analyzed using SAS PROC General Linear Model (GLM) procedures to determine the significant effects of companion species, weed control treatment, and their interactions. Least significant differences (LSD) were used to determine the highest number or greatest cover of native grass species (Littell et al. 1996). Desirable species counts were analyzed on a combined species basis, referred to in the text as total counts, and on an individual species basis. Significant differences were based on 0.05 probability levels. PROC UNIVARIATE procedures were used to examine the normality of residuals. Sources of variation for statistical models for the companion species study are shown in Appendix B.

Chapter 4

Native Grass Establishment – Companion Species Study

Results and Discussion

The summers of 1998 and 1999 were record drought years within the state of Maryland. Monthly deviance from 30 year average precipitation in 1998 and 1999 is shown in Table 4-1. Deviance from 30 year average temperatures is summarized in Table 4-2. Monthly precipitation and temperature in 1998 and 1999 versus 30 year average precipitation and temperature is in Appendices C to F. The spring planting received enough moisture prior to the onset of drought to allow for good germination of native warm season grass seeds. Companion species, however, did not germinate during the first season. For the fall planting, moisture was inadequate for warm season grass seed germination once temperatures were high enough for germination. Growth of desirable species in the fall planting was negligible at all three sites. Overall, due to the drought, there was very little growth, even of weed species, in fall planting plots. Therefore, results of the fall planting will not be examined. For the spring planting, along with good germination, several desirable species grew to maturity and flowered by the end of the first growing season. Plants from the spring planting grew well during both years, despite the droughts, and provided adequate numbers and cover (by the second year) for statistical analyses.

Table 4-1. Precipitation deviance from 30 year average precipitation (in cm and in) for 1998 and 1999 (from weather stations in Chestertown, Beltsville and Hagerstown) (Maryland State Climatologist 2000).

		Eastern Shore		Beltsville		Sideling Hill	
1998		cm	in	cm	in	cm	in
	January	6.4	2.5	5.6	2.2	9.4	3.7
	February	2.5	1	4.8	1.9	6.1	2.4
	March	6.1	2.4	7.4	2.9	7.6	3
	April	1.0	0.4	1.0	0.4	5.1	2
	May	2.3	0.9	2.8	1.1	4.8	1.9
	June	1.5	0.6	1.5	0.6	3.3	1.3
	July	-0.8	-0.3	-5.6	-2.2	-1.3	-0.5
	August	-2.3	-0.9	-9.1	-3.6	-2.5	-1
	September	-2.0	-0.8	-3.3	-1.3	-4.8	-1.9
	October	-5.3	-2.1	-6.4	-2.5	-4.1	-1.6
	November	-5.3	-2.1	-5.3	-2.1	-6.6	-2.6
	December	-4.8	-1.9	-5.1	-2	-6.1	-2.4
	Annual	-1.0	-0.4	-11.7	-4.6	10.9	4.3
1999		cm	in	cm	in	cm	in
	January	4.3	1.7	5.8	2.3	9.9	3.9
	February	1.0	0.4	-1.5	-0.6	0.5	0.2
	March	1.0	0.4	1.8	0.7	3.6	1.4
	April	-2.0	-0.8	-2.5	-1	1.5	0.6
	May	-7.4	-2.9	-6.6	-2.6	-6.6	-2.6
	June	-2.3	-0.9	-3.6	-1.4	-0.3	-0.1
	July	1.0	0.4	-7.6	-3	-5.6	-2.2
	August	0.3	0.1	0.3	0.1	-2.0	-0.8
	September	36.8	14.5	21.3	8.4	14.2	5.6
	October	0.0	0	-1.5	-0.6	-1.3	-0.5
	November	-3.0	-1.2	-3.3	-1.3	-5.3	-2.1
	December	-3.3	-1.3	no data	no data	-0.5	-0.2
	Annual	25.7	10.1			8.4	3.3

Overall site differences

Weed composition was very different at each site (see Table 4-3). Weed cover was recorded in September through October and therefore does not reflect the full extent of compositional change throughout the year.

Weed competition was greatest on the Eastern Shore. Prominent weed

Table 4-2. Temperature deviance from 30 year average temperature (in degrees Celsius and Fahrenheit) for 1998 and 1999 (from weather stations in Chestertown, Beltsville and Hagerstown) (Maryland State Climatologist 2000).

		Eastern Shore		Beltsville		Sideling Hill	
1998		° C	° F	° C	° F	° C	° F
	January	4.7	8.4	5.6	10.1	6.4	11.6
	February	3.8	6.7	4.7	8.4	5.1	9.2
	March	0.7	1.3	1.3	2.3	1.8	3.2
	April	1.4	2.4	2.3	4.1	2.5	4.5
	May	1.5	2.7	2.5	4.5	2.4	4.4
	June	-0.7	-1.2	0.6	1.0	-2.5	-4.4
	July	0.0	-0.1	0.7	1.2	0.2	0.3
	August	-0.1	-0.1	1.4	2.6	0.6	1.1
	September	1.1	2.0	3.6	6.4	3.2	5.7
	October	-0.6	-1.1	1.6	2.9	1.1	2.0
	November	-0.1	-0.1	0.5	0.8	1.3	2.4
	December	2.6	4.8	3.6	6.5	4.5	8.1
	Annual	1.2	2.1	2.4	4.3	2.2	4.0
1999		° C	° F	° C	° F	° C	° F
	January	2.6	4.7	3.4	6.1	2.6	4.6
	February	1.8	3.3	2.4	4.3	4.6	8.3
	March	-0.6	-1.0	-0.9	-1.5	-0.6	-1.1
	April	0.5	0.9	1.1	2.0	1.5	2.7
	May	0.8	1.5	1.2	2.2	0.3	0.5
	June	0.2	0.3	0.7	1.3	0.3	0.6
	July	2.1	3.7	2.3	4.1	2.4	4.4
	August	0.6	1.1	1.5	2.7	0.9	1.6
	September	0.2	0.4	0.8	1.5	-0.2	-0.4
	October	-1.1	-2.0	-0.4	-0.6	-0.6	-1.1
	November	2.1	3.7	3.1	5.6	3.4	6.2
	December	1.3	2.4	no data	no data	2.3	4.1
	Annual	0.9	1.6			1.4	2.5

competitors were non-native annual and perennial warm season grasses, chiefly foxtail (*Setaria* spp.) and bermudagrass (*Cynodon dactylon* (L.) Pers.), which made up approximately 50% and 15% of cover, respectively, on average across plots. However, the distribution of foxtail and bermudagrass was not uniform across plots.

Some plots had close to 100% foxtail cover, while plots without foxtail had a broader variety of cover. Oxalis (*Oxalis stricta* L.), knotweed (*Polygonum aviculare* L.), crownvetch (*Coronilla* L. spp.), pokeweed (*Phytolacca americana* (L.)), crabgrass (*Digitaria* spp.), and carpetweed (*Mollugo verticillata* L.) were fairly abundant at the Eastern Shore site.

Table 4-3. Primary weed competitors by site, average percent cover across plots.

Eastern Shore		Beltsville		Sideling Hill	
yellow foxtail	47	oxalis	8	birdsfoot-trefoil	14
bermudagrass	13	carpetweed	6	barnyard grass	6
oxalis	7	fall panicum	5	fall panicum	4
knotweed	5	lambsquarters	3	smartweed	2
crownvetch	3	amaranth	2	thistle	1
pokeweed	3	giant foxtail	2	giant foxtail	1
crabgrass	2	yellow foxtail	2	crabgrass	1
carpetweed	2	crabgrass	1	witchgrass	1

At Beltsville, the most abundant weed competitors were oxalis, carpetweed, fall panicum (*Panicum dichotomiflorum* Michx.) and lambsquarters (*Chenopodium album* L.). Other prominent, but less abundant, weed competitors were amaranth (*Amaranthus* spp.), foxtail and crabgrass. Average percent cover of even the most abundant weed species was less than 10% at Beltsville.

At Sideling Hill, birdsfoot-trefoil (*Lotus corniculatus* L.) was the dominant weed species, averaging 14% of cover within each plot. Barnyard grass (*Echinochloa crusgalli* (L.) Beauv.) and fall panicum were approximately 5% of cover, while thistle (*Cirsium* spp.), foxtail, crabgrass and witchgrass (*Panicum capillare* L.) averaged about 1% of cover.

Site and weather conditions varied considerably, with evident effects on desirable, companion and weed species at each site. Counts were taken for all desirable species other than bluejoint, which was not found. Desirable species establishment as measured by individual plant counts per square meter and percent cover per plot was significantly different by site, with highest means at Sideling Hill and lowest means on the Eastern Shore (see Table 4-4).

Table 4-4. Companion species study: Mean total desirable species counts per square meter and percent desirable species cover per plot by site at end of second season.

Desirable species	Eastern Shore		Beltsville		Sideling Hill		$LSD_{0.05}$
Plant counts/m^2	4(0.32)	c†	11(0.92b)	b	18(1.20)	a	(0.22)
Percent cover/plot	9	b	20	ab	29	a	12.0

†Percent means and log transformed means, in parentheses, within the same row with the same letter are not significantly different according to LSD at the 0.05 probability level.

Due to the large differences in size and quantity planted of individual species' seeds, only relative differences between species, such as the magnitude of change by site, are compared (see Table 4-5). Big bluestem, deertongue, indian grass, and little bluestem counts were significantly higher at Sideling Hill and Beltsville than on the Eastern Shore. Broomsedge and switchgrass counts were significantly higher at

Table 4-5. Companion species study: Mean individual desirable species per square meter by site in fall 1999.

	Mean individual desirable species/m^2						
Desirable species	Eastern Shore		Beltsville		Sideling Hill		$LSD_{0.05}$
Big bluestem	0.1	b†	1.3	a	0.8	a	0.53
Broomsedge	1.0	b	0.8	b	2.4	a	1.45
Deertongue	0.4	b	1.4	a	2.1	a	0.95
Eastern gamagrass	0.1	a	0.2	a	0.3	a	0.17
Indian grass	0.8	c	2.9	b	4.4	a	1.49
Little bluestem	0.2	b	1.4	a	1.9	a	0.60
Switchgrass	1.7	b	2.8	b	6.5	a	1.30

†Means within the same row with the same letter are not significantly different according to LSD at the 0.05 probability level.

Sideling Hill versus Beltsville.

Weed control effects

For total desirable species counts, significant differences between weed control treatments (control, mowing and herbicide) were found only for percent cover data at Beltsville and Sideling Hill (see Table 4-6 and 4-7). Mean percent cover of desirable species for control and herbicide plots at Beltsville was significantly higher than for mowed plots. At Sideling Hill, mean percent cover of control plots was significantly higher than mean percent cover for herbicide plots, but not significantly higher than mowed plots. On the Eastern Shore, despite the lack of significant difference in desirable species counts, use of imazapic had a noticeable

Table 4-6. Companion species study: Mean total desirable species per square meter by weed control treatment in fall 1999.

	Mean total desirable species/m^2		
Weed treatment	Eastern Shore	Beltsville	Sideling Hill
Control	5 a†	13 a	21 a
Mow	4 a	9 a	20 a
Herbicide	4 a	11 a	14 a
$LSD_{0.05}$	5.4	6.5	7.5

†Means within the same column with the same letter are not significantly different according to LSD at the 0.05 probability level.

Table 4-7. Companion species study: Mean percent total desirable species cover per plot by weed control treatment in fall 1999.

	Mean percent total desirable species cover/plot		
Weed treatment	Eastern Shore	Beltsville	Sideling Hill
Control	11 a†	24 a	39 a
Mow	9 a	11 b	33 ab
Herbicide	6 a	26 a	15 b
$LSD_{0.05}$	12.4	12.3	18

†Means within the same column with the same letter are not significantly different according to LSD at the 0.05 probability level.

stunting effect on foxtail and bermudagrass.

Significant differences between weed control treatment effects were greater for individual desirable species than the desirable species mixture as a whole (see Table 4-8). Indian grass and little bluestem counts were significantly higher with application of imazapic than with mowing or no treatment. For big bluestem, counts in imazapic treated plots were significantly higher than mowed plots, but not significantly different from no treatment. For deertongue, all treatments were significantly different, with highest counts with no treatment and lowest counts with imazapic treatment. Eastern gamagrass and switchgrass counts were also significantly lower with imazapic treatment, compared with both no treatment and mowing. The lower counts of switchgrass and deertongue with imazapic confirmed the herbicide's label.

Table 4-8. Companion species study: Mean individual species per square meter by weed control treatment in fall 1999.

	Mean individual species/m^2			
Desirable species	Control	Mowing	Imazapic	$LSD_{0.05}$
Big bluestem	0.7 ab†	0.5 b	1.0 a	0.45
Broomsedge	1.1 a	1.5 a	1.6 a	1.12
Deertongue	2.4 a	1.4 b	0.1 c	0.53
Eastern gamagrass	0.3 a	0.3 a	0.0 b	0.13
Indian grass	2.0 b	1.7 b	4.4 a	0.89
Little bluestem	0.8 b	0.6 b	2.1 a	0.69
Switchgrass	5.5 a	5.0 a	0.5 b	1.40

†Means within the same row with the same letter are not significantly different according to LSD at the 0.05 probability level.

Companion species effects

Overall mean desirable species counts per square meter by companion species are shown in Table 4-9. Data for total counts was log transformed, shown in

Table 4-9. Companion species study: Mean total desirable species per square meter across sites in fall 1999.

No.	Companion	Mean total desirable species/m^2	
12	doubled background mixture	14(0.96)	a†
2	oats	13(0.93)	ab
10	crimson clover	12(0.92)	abc
9	bush clover	13(0.90)	abc
7	Canada wild rye	11(0.89)	abc
6	redtop	10(0.82)	abc
11	no companion	12(0.82)	abc
5	hard fescue	12(0.77)	abc
1	annual rye	9(0.75)	bc
4	creeping red fescue	11(0.75)	bc
8	Virginia wild rye	10(0.74)	c
3	tall fescue	7(0.53)	d
$LSD_{0.05}$		3.6(0.192)	

†Log transformed means, in parentheses, with the same letter are not significantly different according to LSD at the 0.05 probability level.

parentheses following actual means. Differences discussed are based upon log transformed means and least significant differences. While there was a range in mean total desirable species per square meter from 14(0.96) to 7(0.53), there were few significant differences between companion treatments when examined across sites. Plots with a doubled background mixture seeding rate had the highest mean, but were not significantly different from plots with oats, crimson clover, bush clover, Canada wild rye, redtop, hard fescue, or no companion. Only tall fescue plots had significantly lower counts than all other companion species.

Few significant differences between companion species effects were found within each site. Mean total desirable species counts and percent cover for whole plots by companion treatment are shown in Tables 4-10 and 4-11. Graphs of highest to lowest means for count and percent cover data by companion at all three sites are shown in Figures 1 and 2.

Table 4-10. Companion species study: Mean total desirable species per square meter by companion species in fall 1999.

	Mean total desirable species/m^2		
Companion species	Eastern Shore	Beltsville	Sideling Hill
1 annual rye	5 abc†	11 a	12 c
2 oats	9 a	13 a	18 abc
3 tall fescue	5 abc	2 b	13 bc
4 creeping red fescue	3 bc	12 a	17 abc
5 hard fescue	2 c	12 a	24 a
6 redtop	3 bc	11 a	16 abc
7 Canada wild rye	4 abc	11 a	17 abc
8 Virginia wild rye	2 bc	9 a	17 abc
9 bush clover	8 ab	10 a	21 a
10 crimson clover	4 abc	13 a	20 ab
11 control	3 bc	11 a	22 a
12 doubled background mixture	4 abc	15 a	23 a
$LSD_{0.05}$	5.2	5.8	7.7

†Means in the same column with the same letter are not significantly different according to LSD at the 0.05 probability level.

Table 4-11. Companion species study: Mean percent total desirable species cover per plot by companion species in fall 1999.

	Mean percent total desirable species cover/plot		
Companion species	Eastern Shore	Beltsville	Sideling Hill
1 annual rye	11 ab†	18 a	8 c
2 oats	19 a	22 a	28 ab
3 tall fescue	11 ab	1 b	21 bc
4 creeping red fescue	5 b	18 a	28 ab
5 hard fescue	3 b	23 a	39 a
6 redtop	6 b	20 a	19 bc
7 Canada wild rye	8 ab	17 a	31 ab
8 Virginia wild rye	5 b	17 ab	28 ab
9 bush clover	15 ab	25 a	35 ab
10 crimson clover	6 ab	27 a	38 a
11 control	6 b	22 a	34 ab
12 doubled background mixture	10 ab	32 a	43 a
$LSD_{0.05}$	12.8	16.0	12.8

†Means within the same column with the same letter are not significantly different according to LSD at the 0.05 probability level.

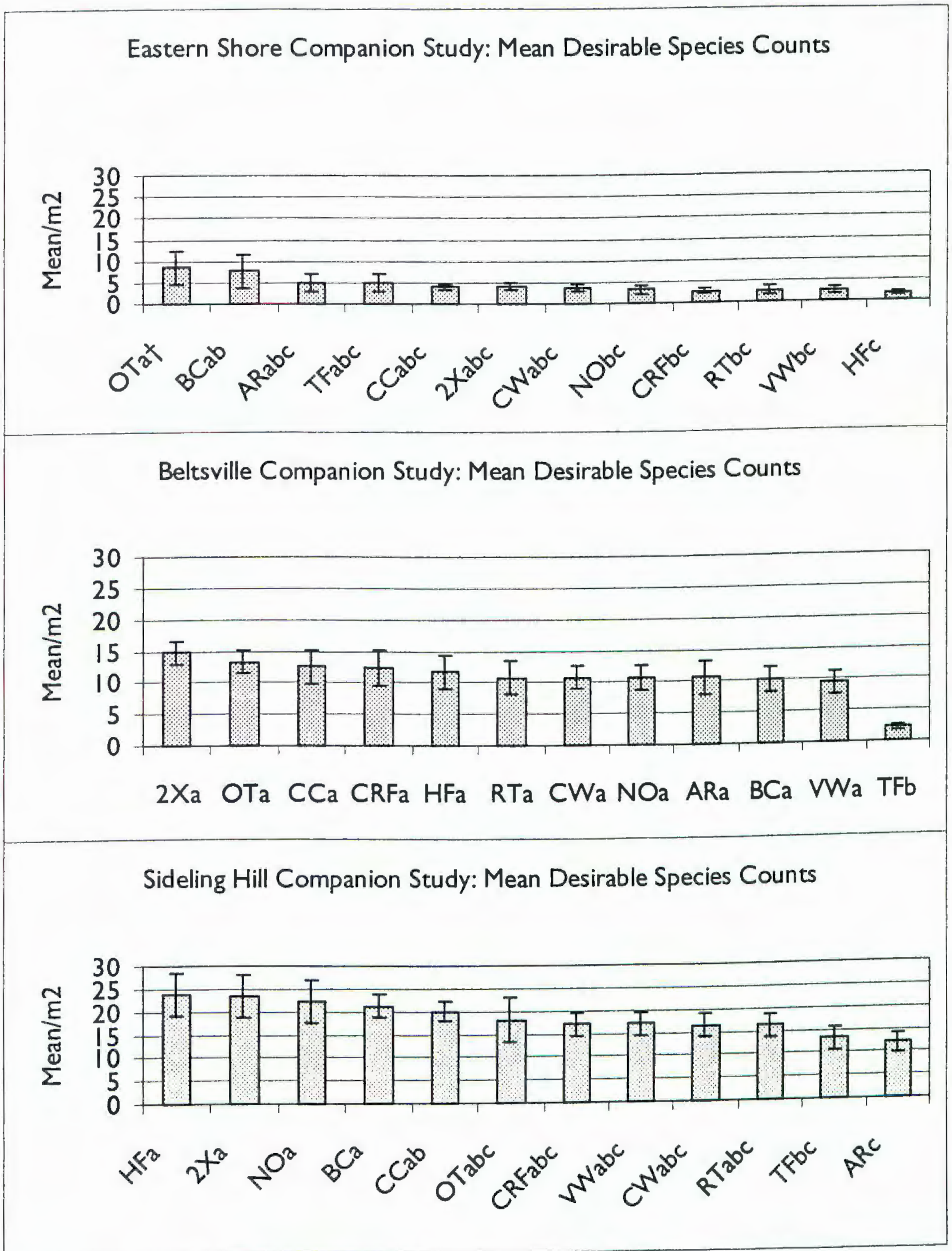


Figure 1. Companion species study: Mean total desirable species by companion species: annual rye AR, oats OA, tall fescue TF, creeping red fescue CRF, hard fescue HF, redtop RT, Canada wild rye CW, Virginia wild rye VW, bush clover BC, crimson clover CC, no companion NO and doubled background 2X.

†Means within the same site with the same letter are not significantly different according to LSD at the 0.05 probability level. Standard error bars shown.

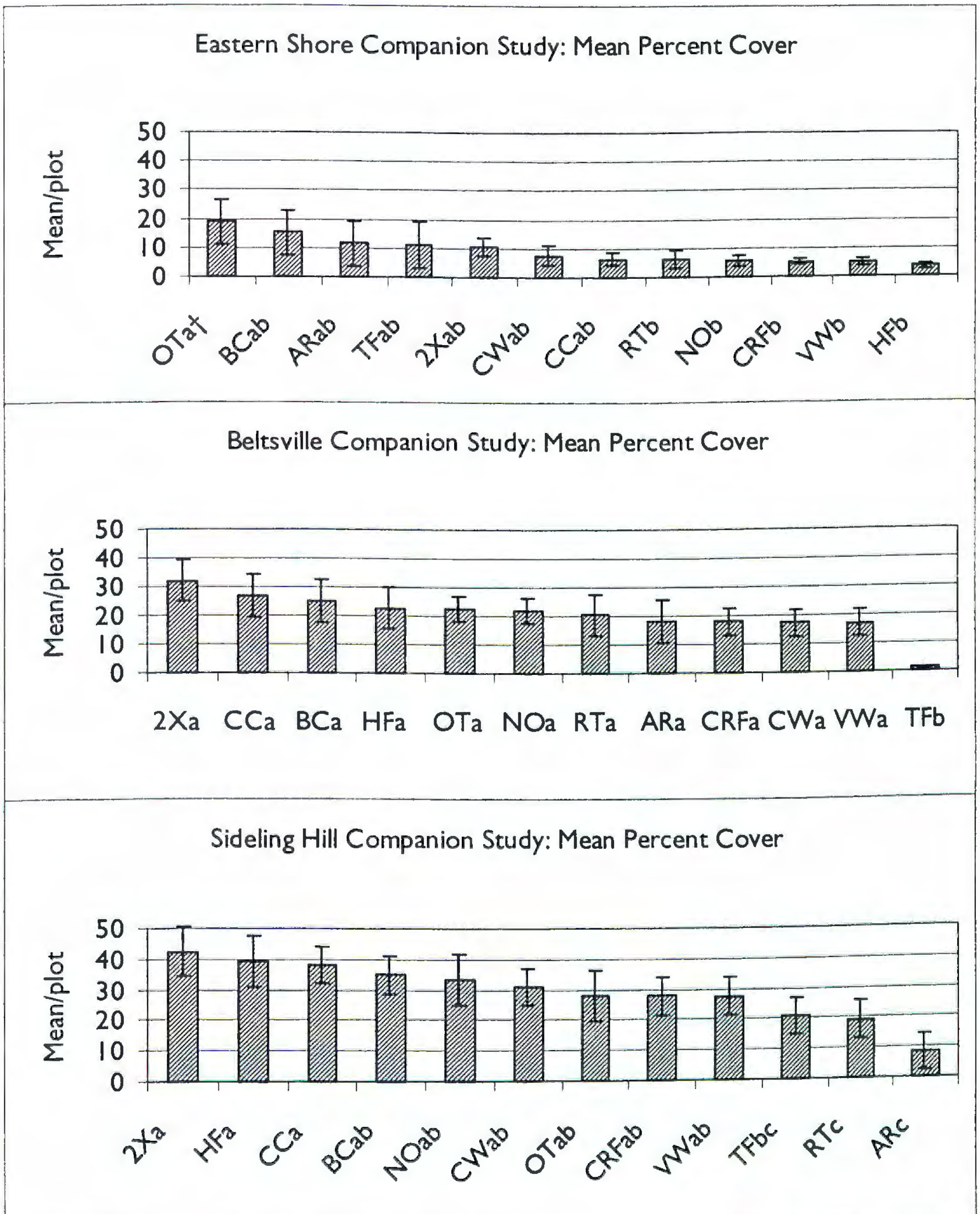


Figure 2. Companion species study: Mean percent total desirable species cover by companion species: annual rye AR, oats OA, tall fescue TF, creeping red fescue CRF, hard fescue HF, redtop RT, Canada wild rye CW, Virginia wild rye VW, bush clover BC, crimson clover CC, no companion NO and doubled background 2X.
†Means within the same site with the same letter are not significantly different according to LSD at the 0.05 probability level. Standard error bars shown.

On the Eastern Shore, hard fescue plots had the lowest mean total desirable species, but were only significantly lower than oats and bush clover plots. At Beltsville, only tall fescue plots had significantly lower desirable species counts than other plots. At Sideling Hill, plots with hard fescue, the doubled background mixture, no treatment and bush clover had the highest counts and were significantly higher than plots with annual rye and tall fescue, but were not significantly different from all other companions.

Changes from 1998 to 1999

Survival of plants from the first to second season of growth varied by species. The change in individual desirable species counts by site, weed control treatment and companion species are shown in Tables 4-12, 4-13, and 4-14. Because companion species germination was extremely low during the first season of growth, first year counts do not reflect effects of companion species, but changes in counts between the two seasons may reflect effects of companions. As mentioned previously, species counts do not represent absolute differences, since seed numbers varied considerably, with rates based in large part on seed size.

Overall, there was an increase in big bluestem, deertongue, eastern gamagrass and switchgrass at all three sites from the first to the second season. Broomsedge, indian grass and little bluestem generally decreased in numbers by the second season. While overall counts remained highest at Sideling Hill by the second season (see Tables 4-4 and 4-5), species losses were also greatest there, due primarily to losses in indian grass. Second season counts on the Eastern Shore averaged about 2 plants greater by the second season, increasing from the very low count of about 2 plants per plot in the first season.

Table 4-12. Companion species study: Average change in individual desirable species counts per square meter at the Eastern Shore, Beltsville, and Sideling Hill from 1998 to 1999.

	Average change in species counts/m^2			
	Eastern Shore	Beltsville	Sideling Hill	Cumulative change
Big bluestem	0.1	0.8	0.0	0.3
Broomsedge	0.1	-0.6	-0.2	-0.2
Deertongue	0.9	0.8	2.0	1.2
Eastern gamagrass	0.5	0.9	0.4	0.6
Indian grass	-0.2	-2.1	-15.4	-5.9
Little bluestem	0.3	-3.2	-8.0	-3.6
Switchgrass	0.1	0.2	0.3	0.2
Cumulative change	1.8	-3.2	-20.9	-7.5

Table 4-13. Companion species study: Average change in species counts per square meter from 1998 to 1999 by weed control treatment.

	Average change in species counts/m^2		
	Control	Mowing	Imazapic
Big bluestem	0.4	-0.1	0.4
Broomsedge	-0.4	-0.8	0.6
Deertongue	3.4	2.6	-2.4
Eastern gamagrass	0.3	-0.7	2.2
Indian grass	-3.6	-6.1	-8.0
Little bluestem	-2.9	-3.2	-4.8
Switchgrass	0.3	0.3	0.0
Cumulative change	-2.4	-8.0	-12.0

Greatest declines in species counts from season one to two came with application of imazapic, with an average loss of 12 plants per plot. Only deertongue and switchgrass showed increases under both of the other treatments. Big bluestem and eastern gamagrass counts increased with both imazapic and no treatment, and decreased only with mowing treatment. Little bluestem plant counts decreased across all treatments. Broomsedge decreased in both the control and mowing plots, while it increased under imazapic application. Indian grass decreases were nearly double with imazapic relative to the control. However, second year mean counts of indian grass were also greatest with imazapic, approximately double the counts in control and mowed plots (see Table 4-8).

Among companion species plots (see Table 4-14), fewest losses were found with annual rye overall, while greatest losses were found with tall fescue, redtop and Canada wild rye. However, at Sideling Hill, where overall desirable species counts were highest and losses were greatest, plots with annual rye had the lowest counts by the second season. Only switchgrass increased with every companion. Deertongue increased with every companion except tall fescue and redtop. Big bluestem increased under every treatment but tall fescue. Broomsedge increased

Table 4-14. Companion species study: Average change in individual desirable species counts per square meter from 1998 to 1999 by companion species.

	Average change in individual desirable species counts/m^2							
	Big bluestem	Broomsedge	Deertongue	E. gamagrass	Indian grass	L. bluestem	Switchgrass	Cumul. change
Annual rye	0.1	0.4	0.3	-0.3	-1.0	0.2	0.0	-0.2
Oats	0.3	0.4	1.9	1.3	-6.5	-1.9	0.1	-4.4
Tall fescue	-0.4	-0.6	-0.1	0.0	-8.8	-3.9	0.1	-13.8
Cr. red fescue	0.4	-0.5	0.3	0.9	-4.7	-3.4	0.3	-6.9
Hard fescue	0.4	0.0	0.7	1.1	-4.7	-3.9	0.4	-5.9
Redtop	0.1	-0.2	-0.4	0.1	-7.6	-5.8	0.0	-13.7
Can. wild rye	0.2	-0.5	1.4	-0.2	-5.8	-4.8	0.2	-9.6
Vir. wild rye	0.1	-0.4	1.9	0.6	-4.7	-2.7	0.2	-5.0
Bush clover	0.3	0.3	1.6	0.9	-6.6	-3.0	0.3	-6.2
Crim. clover	0.7	-0.5	2.3	0.6	-5.7	-2.6	0.2	-5.1
Control	0.3	-0.4	1.9	0.7	-5.1	-3.7	0.2	-6.1
Doubled mix	0.4	-0.1	2.5	1.6	-4.3	-4.3	0.5	-3.8

only with oats, annual rye, hard fescue and bush clover. Eastern gamagrass numbers were very low under all conditions. Indian grass and little bluestem decreased with every companion. Greatest losses for indian grass were seen with tall fescue. Greatest losses for little bluestem were seen with redtop.

General observations

Cocoa bean shells were found to be the most effective additive for use with the no-till drill seeders, having rough surfaces to which fluffy awns could become attached and enough weight to improve flow through the seeder.

By the time counts of desirable species were taken in late summer and early fall of the first season, virtually no companion species seeds (nearly all cool season species) had germinated, due to the drought. Therefore, counts at the end of the first season did not reflect companion species effects. All of the cool season grass companions – annual rye, oats, tall fescue, creeping red fescue, hard fescue, redtop, Canada wild rye and Virginia wild rye – as well as crimson clover, a cool season legume, germinated between fall of 1998 and spring of 1999. However, percent cover of companions was not measured until the end of the second growing season and, therefore, measurements did not reflect the cover of most species during their active growth periods. By late summer of 1999, other than tall fescue at all three sites and creeping red fescue, hard fescue, Canada wild rye and Virginia wild rye at Beltsville, very little companion species cover was found. Crimson clover cover was noted in early spring 1999, with plants about 13 cm (5 in) to 18 cm (7 in) across. Bush clover germination was very low and growth very slow. By the end of the second season, largest bush clover plants were about 10 cm (4 in) tall and 3 cm (1 in) across (full size plants are about 0.5 m to 0.75 m tall by mid-summer).

Germination of desirable species in the spring planting was followed by flowering of many species by the end of the first season at all three sites. Flowering was greatest at Sideling Hill and Beltsville, where numbers of plants were greatest, and was particularly noteworthy for big bluestem and indian grass, which grew to heights of 3 to 5 feet. Switchgrass, broomsedge, and little bluestem also flowered.

Other observations bearing note include the presence of broomsedge at Sideling Hill, and broomsedge and purpletop (*Tridens flavus* (L.) A.S.Hitchc.) on the Eastern Shore. These are naturally occurring warm season native grasses. Purpletop, in particular, did not appear to be hurt by mowing or application of imazapic. It would have been impossible to separate planted broomsedge from the native population. However, most seedlings in the first year were very small, no larger than plants known to be planted (in sites where no broomsedge occurred naturally). This indicated that herbicide treatment with glyphosate prior to planting likely killed existing broomsedge plants within plots.

Other native species appearing in plots included hairy thoroughwort (*Eupatorium pubescens* Muhl.), indian tobacco (*Lobelia inflata* L.), partridge pea (*Cassia fasciculata* Michx.) on the Eastern Shore; hairy thoroughwort, biennial gaura (*Gaura biennis* L.), and partridge pea at Beltsville; and sweet everlasting within plots at Sideling Hill (*Gnaphalium* sp.). Of note was the appearance, primarily in plots treated with herbicide, of legume species (partridge pea and tick-trefoil, *Desmodium* sp.) on the Eastern Shore and at Beltsville. Several other native forbs were present in the area surrounding the plots at Sideling Hill.

Discussion

These results reflect drought conditions during the growing seasons of 1998 and 1999 and do not reflect differences in planting times, since the germination of seeds in the fall planting was so low. Results of the companion species study indicate that preplanting treatment of sites may be the most important factor in improving establishment of native grasses in Maryland. Choice of companion species and weed control method had relatively little impact on overall establishment, although individual species response to mowing and herbicide application varied. Effects might change in time, and will be monitored for another 3 years.

Results indicate that establishment methods for native grasses in Maryland should not be uniform, but instead need to reflect differing site conditions, particularly weed competition. Choice of weed control methods should depend on the native species planted, since mowing and herbicide weed control treatments have variable effects depending upon the native grass species. Important establishment considerations include pre-existing weed competition at the site and individual desirable species responses to drought, herbicide, and mowing.

Site considerations

The extreme differences in desirable species counts between sites are most likely due to a combination of differences in site conditions, weed competition and precipitation. Undoubtedly, weed competition was the greatest impediment to desirable species growth on the Eastern Shore. It is unclear to what extent drought favored desirable species over weeds, but on the Eastern Shore, where precipitation was closest to 30 year average levels in 1998, desirable species counts were lowest. On the Eastern Shore, monthly deficits from June through August 1998 were less than 3 cm, while at Beltsville and Sideling Hill they were closer to 5 cm. In 1999, when drought conditions in May were more similar across sites (with approximately 8 cm deficits at all sites), species numbers on the Eastern Shore showed the greatest relative increases. Higher counts were found primarily in plots where broadleaf weeds shared a relatively high percentage of cover (where plots were less dominated by foxtail and Bermudagrass). Nearly all species counts were significantly higher at Sideling Hill compared with the Eastern Shore. Broomsedge, indian grass, and switchgrass were also significantly more abundant at Sideling Hill compared with Beltsville.

Weed composition was very different at each site. While foxtail species were present at every site, foxtail on the Eastern Shore averaged nearly 50% cover across plots (it was close to 100% on some plots), in tandem with Bermudagrass, which averaged 13% of cover. As annual and perennial warm season grasses, respectively, these species were probably not actively growing when glyphosate was applied a month prior to the spring plantings. At Beltsville and Sideling Hill, the broader variety of common weeds likely meant that a greater percent of dominant species were killed with the glyphosate preplanting treatment.

These results suggest that pre-treatment of sites, perhaps a full season ahead of expected planting dates, would be necessary wherever the predominant weed species include warm season annual or perennial grasses. Using a no-till drill can also help in establishment by preventing turning of the soil and exposure of weed seeds. Where annual grasses predominate, allowing weed seeds to germinate and then plowing them under before they go to seed, and repeating that process, is probably very effective, but may be impractical. It is not clear from this research if imazapic could be more effective for use on foxtail, partly due to the drought conditions during both years of growth. Recent research indicates that, for native grass establishment, imazapic is more effective when used in preplanting treatments than postplanting treatments (Washburn and Barnes 2000). The observed decreases in foxtail and Bermudagrass did not lead to increased desirable species counts, but different timing of application under different rainfall conditions might have borne very different results. If application of imazapic was effective under different environmental conditions in a postplanting treatment, choice of species for the native grass mixture would be somewhat restricted. Deertongue and switchgrass, the two cheapest and easiest to handle seeds, do not tolerate higher application rates of imazapic.

Weed control effects on desirable species mixture

Significant differences for all species combined between weed control treatments were found only for percent cover data at Beltsville and Sideling Hill. No significant differences were found for count data. At Beltsville, no treatment and herbicide treatment had significantly higher desirable species cover than mowing treatments. At Sideling Hill, herbicide treatment means were significantly lower than the control, but not significantly different from mowing. These differences may be due to differences in weed competition at Beltsville and Sideling Hill. Since differences were found only in percent cover data, mowing at a different time might have produced a very different result. The lower percent cover with imazapic at Sideling Hill reflects the negative effect of imazapic on deertongue and switchgrass. There is no clear cut explanation for these particular differences. The dry conditions present during most of both growing seasons severely limited potential times for mowing and application of herbicide. Different growing conditions and timing of mowing and herbicides would likely produce very different results.

Weed control effects on individual desirable species

Individual species responses to mowing and herbicide treatments varied. Imazapic applications favored big bluestem, broomsedge to some extent, indian grass and little bluestem. Deertongue, eastern gamagrass and switchgrass grew best with no weed control treatment or with mowing.

Individual species responses to weed control treatments indicate that choice of species and weed control methods should be integrated. For example, since deertongue is relatively cheap and plants are low-growing, they might be included in a mixture to provide quick cover in the first year. However, since deertongue does not tolerate imazapic applications, use of imazapic might be restricted to second season use to support establishment of other species if the mixture included big bluestem, broomsedge, indian grass or little bluestem. Where broomsedge or indian grass is a predominant component of a mixture, mowing might be restricted to very late winter or spring, just prior to the main growth period for warm season grasses since they do not tolerate mowing during their active growth period.

Companion species effects

Companion species effects on establishment of native grasses varied by site, with significant differences for only a few species at each site. On the Eastern Shore, due to the low counts and nature of variation for companion plots, no real differences are evident (see Figures 1 and 2). Clearly, tall fescue should not be recommended as a companion species. At both Beltsville and Sideling Hill, desirable species counts with tall fescue were significantly lower than desirable species counts with most other companion species. At Sideling Hill, counts of desirable species with annual rye as a companion, were even lower. Since many of the companion species were cool season species, it is likely that greater differences between treatments would have been seen between the spring and fall plantings, had precipitation and temperatures allowed for better germination and growth of the fall planting.

Seedling survival

Survival of species from the first to the second season indicates that individual species varied in their responses to site and weather conditions, weed control treatment and companion species. Switchgrass was the only species that increased under all conditions. Big bluestem and deertongue also increased under most conditions. Indian grass decreased under most conditions, but most of this decrease was found at Sideling Hill, where overall survival of indian grass was very good by the second season. Little bluestem also decreased under most conditions, but overall survival was still very high by the second season. The general increases in big bluestem, deertongue, eastern gamagraass and switchgrass could indicate greater drought tolerance. However, many broomsedge, indian grass and little bluestem plants flourished in both the first and second season, flowering and going to seed by the end of both seasons and forming relatively large clumps by the second season.

Chapter 5

Native Grass Establishment -- Weed Control Study

Methods and Materials

A second study investigated a greater variety of mowing and herbicide weed control treatments at each site. A randomized complete block experimental design was used (see Appendix A for the layout of each site). The study was also replicated in time, with spring and fall 1998 plantings. The same mixture of perennial grasses native to the mid-Atlantic region was planted in three different regions of Maryland at the same rate and time as described for the companion species study. Sites were the same for each study for Beltsville and Sideling Hill. The weed control study site on the Eastern Shore was at the intersection of Routes 301 and 213, about 10 miles from the companion study site, with silt loam soil ranging in pH from 5.9 to 6.1.

Herbicides chosen for the weed control study were imazapic and an herbicide containing triclopyr ([(3,5,6-trichloro-2-pyridinyl)Oxy] acetic acid) and 2,4-D (2,4-dichloro-phenoxyacetic acid), product name Crossbow™. Imazapic has been used for native grass establishment and the commercial product is labeled for "bermudagrass, bahiagrass, smooth bromegrass, wheatgrass, 'wildtype' common Kentucky bluegrass, native prairiegrass, wildflowers, crown vetch and certain legumes" (American Cyanamid 1997, 3). It controls a variety of broad-leaved weeds, grass weeds and sedges, including the panic grasses deertongue and switchgrass, tall fescue, annual rye and foxtail species. According to its manufacturer, Crossbow™ controls "woody weed species and broadleaf biennial and winter annual weeds, yet is easy on grasses" (Dow Agrosciences 1999, 1). Triclopyr is a selective systemic herbicide generally applied post emergence for controlling woody and broadleaf plants (Extension Technology Network 1998). 2,4-D is also generally applied post emergence, primarily in wheat and corn, for control of broadleaf weeds. 2,4-D is mixed with triclopyr to extend the utility range of the herbicides (Extension Toxicology Network 1998). Crossbow™ will be referred to as triclopyr+2,4-D throughout this text.

Treatments for the weed control study included: 1) mowing in late summer of the first season of growth and early spring of the second season, 2) mowing in early spring of the second season, 3) imazapic applied in late summer of the first season, 4) imazapic applied in spring of the second season, 5) triclopyr+2,4-D applied in spring of the second season, 6) imazapic combined with triclopyr+2,4-D applied in spring of the second season, and 7) a control (no treatment). Potential treatments were limited by the abnormally low levels of precipitation during both growing seasons.

Weed control treatments are shown in Table 5-1. Timing of mowing and herbicide treatments depended on rainfall and plant growth. Imazapic was applied at a rate of 1.2 L ha^{-1} (1 pint $acre^{-1}$) with 468 L ha^{-1} (50 gallons $acre^{-1}$) of water and 2.3 L ha^{-1} (2 pints $acre^{-1}$) of Triton non-ionic surfactant. Triclopyr+2,4-D was applied at a rate of 4.0 L ha^{-1} (3.4 pints $acre^{-1}$) with 468 L ha^{-1} (50 gallons $acre^{-1}$) of water. Tank mixtures of imazapic and triclopyr+2,4-D were made at these rates as well.

Table 5-1. Schedule of weed control study treatments.

Treatment		Eastern Shore	Beltsville	Sideling Hill
1	Mowing	August 14, 1998	August 3, 1998	August 20, 1998
		May 27, 1999	June 17, 1999	June 8, 1999
2	Mowing	May 27, 1999	June 17, 1999	June 8, 1999
3	Imazapic	August 14, 1998	August 3, 1998	August 20, 1998
4	Imazapic	May 27, 1999	June 17, 1999	June 8, 1999
5	Triclopyr+2,4D	May 27, 1999	June 17, 1999	June 8, 1999
6	Imaz.+triclopyr+2,4-D	May 27, 1999	June 17, 1999	June 8, 1999

Data collection

Data collection for the weed control study was generally the same as the companion study. Grasses included in the native grass background mixture are referred to as desirable species. Despite good germination of several of the desirable grasses, percent cover for the first season of growth was generally less than 1%. Counts of individual plants within a one square meter sample of each plot were taken at the end of the first and second growing season. By the end of the second growing season, percent cover for desirable species was generally greater than 1% and was therefore visually estimated for whole plots. Weed cover was also estimated. Destructive sampling to measure biomass of each species above and below ground would be useful for understanding the growth habits of different species through time, but plots were not large enough for destructive sampling. It was expected that changes in relative cover and individual species counts would provide adequate information about which treatments best support native grass establishment. For the spring planting, percent cover of weeds for whole plots for all species that cover at least 5% of plots was measured toward the end of each growing season. General observations were recorded regarding plot appearance, height and flowering of desirable species, and the emergence of native species not planted.

Counts of desirable species per square meter and percent cover of desirable species per plot were analyzed using SAS PROC GLM procedures to determine the significant effects of weed control treatments. Least significant differences were used to determine which weed control treatment supported the highest number or greatest cover of native grass species (Littell et al. 1996). Desirable species counts were analyzed on a combined species basis, referred to in the text as total counts, and on an individual species basis. Significant differences were based on 0.05 probability levels. PROC UNIVARIATE procedures were used to examine the normality of residuals. Sources of variation for statistical models are shown in Appendix G.

Chapter 6

Native Grass Establishment -- Weed Control Study

Results and Discussion

As with the companion species study, there was considerable variation between sites (see Tables 6-1 and 6-2). For overall counts and cover, Sideling Hill had significantly higher counts than the Eastern Shore and Beltsville. For overall counts and percent cover, significant differences between weed control treatments were found only at Sideling Hill. Figures 3 and 4 show mean desirable counts and cover by weed treatment, displayed with highest to lowest means and significant differences shown by letter group. Imazapic only and mowing in summer and spring

Table 6-1. Weed control study: Mean total desirable species per square meter by weed control treatment at the Eastern Shore, Beltsville and Sideling Hill in fall 1999.

	Mean total desirable species/m^2					
Weed control method	Eastern Shore		Beltsville		Sideling Hill	
1 mow summer '98 & spring '99	6	a†	20	a	22(0.71)	bc
2 mow spring '99	7	a	2	a	22(1.32)	ab
3 imazapic summer '98	10	a	10	a	3(0.48)	c
4 imazapic spring '99	19	a	10	a	5(0.65)	bc
5 triclopyr+2,4-D spring '99	9	a	2	a	49(1.65)	a
6 imaz.+ tricl.+2,4-D spring '99	6	a	6	a	12(1.05)	abc
7 control	13	a	4	a	42(1.61)	a
$LSD_{0.05}$	18.0		21.7		(0.80)	

†Means and log transformed means, in parentheses, within the same column with the same letter are not significantly different according to LSD at the 0.05 probability level.

Table 6-2. Weed control study: Mean percent total desirable species cover per plot by weed control treatment at the Eastern Shore, Beltsville, and Sideling Hill in fall 1999.

	Percent total desirable species cover/plot		
Weed control method	Eastern Shore	Beltsville	Sideling Hill
1 mow summer '98 & spring '99	4 a†	7 a	12 bc
2 mow spring '99	5 a	1 a	18 ab
3 imazapic summer '98	4 a	4 a	5 c
4 imazapic spring '99	9 a	5 a	7 c
5 triclopyr+2,4-D spring '99	6 a	2 a	25 a
6 imaz.+ tricl.+2,4-D spring '99	4 a	4 a	18 ab
7 control	8 a	4 a	22 ab
$LSD_{0.05}$	6.4	7.5	10.2

†Means within the same column with the same letter are not significantly different according to LSD at the 0.05 probability level.

treatments significantly reduced counts and cover at Sideling Hill compared to no treatment, spring mow and herbicide treatments without imazapic.

For individual species, deertongue and switchgrass were significantly more abundant at Sideling Hill than the Eastern Shore, and switchgrass counts at Sideling Hill were also significantly higher than Beltsville (see Table 6-3).

Table 6-3. Weed control study: Individual desirable species per square meter by site in the fall of 1999.

	Individual desirable species/m^2			
	Eastern Shore	Beltsville	Sideling Hill	$LSD_{0.05}$
Big bluestem	0.2 a†	0.7 a	0.3 a	0.79
Broomsedge	1.0 a	0.3 a	1.2 a	1.81
Deertongue	1.6 b	0.3 ab	4.8 a	3.93
Eastern gamagrass	0.2 a	0.1 a	0.2 a	0.31
Indian grass	1.9 a	1.3 a	1.6 a	2.35
Little bluestem	0.3 a	0.7 a	0.9 a	0.99
Switchgrass	0.9 b	0.9 b	6.9 a	2.63

†Means within the same row with the same letter are not significantly different according to LSD at the 0.05 probability level.

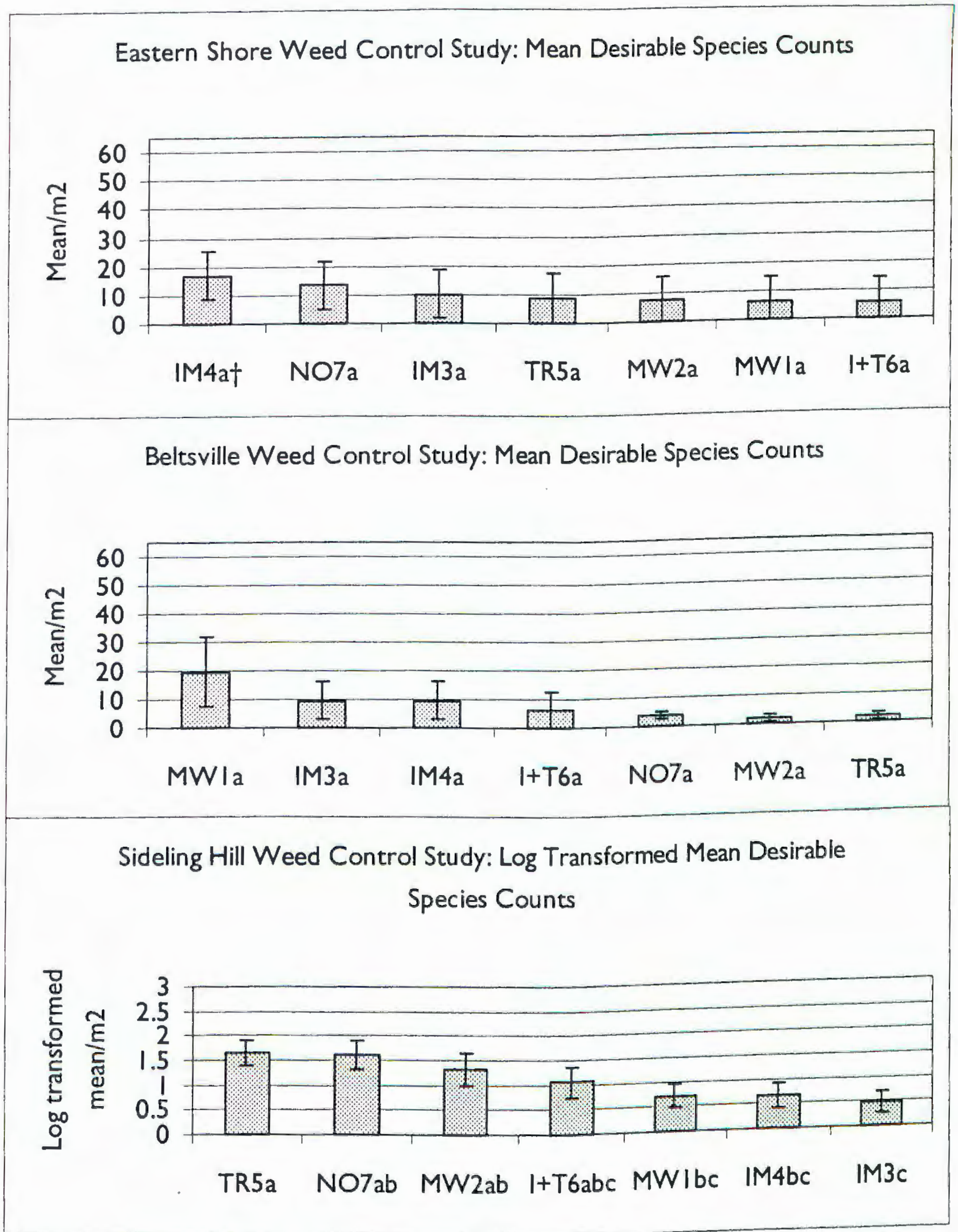


Figure 3. Weed control study: Mean total desirable species by weed control treatment: mowing in summer 1998 and spring 1999 (MW1), mowing in spring 1999 (MW2), imazapic in summer 1998 (IM3), imazapic in spring 1999 (IM4), triclopyr+2,4-D spring 1999 (TR5), imazapic+triclopyr+2,4-D (I+T6) and no treatment (NO7). †Means or log transformed means within the same site with the same letter are not significantly different according to LSD at the 0.05 probability level. Standard error bars shown.

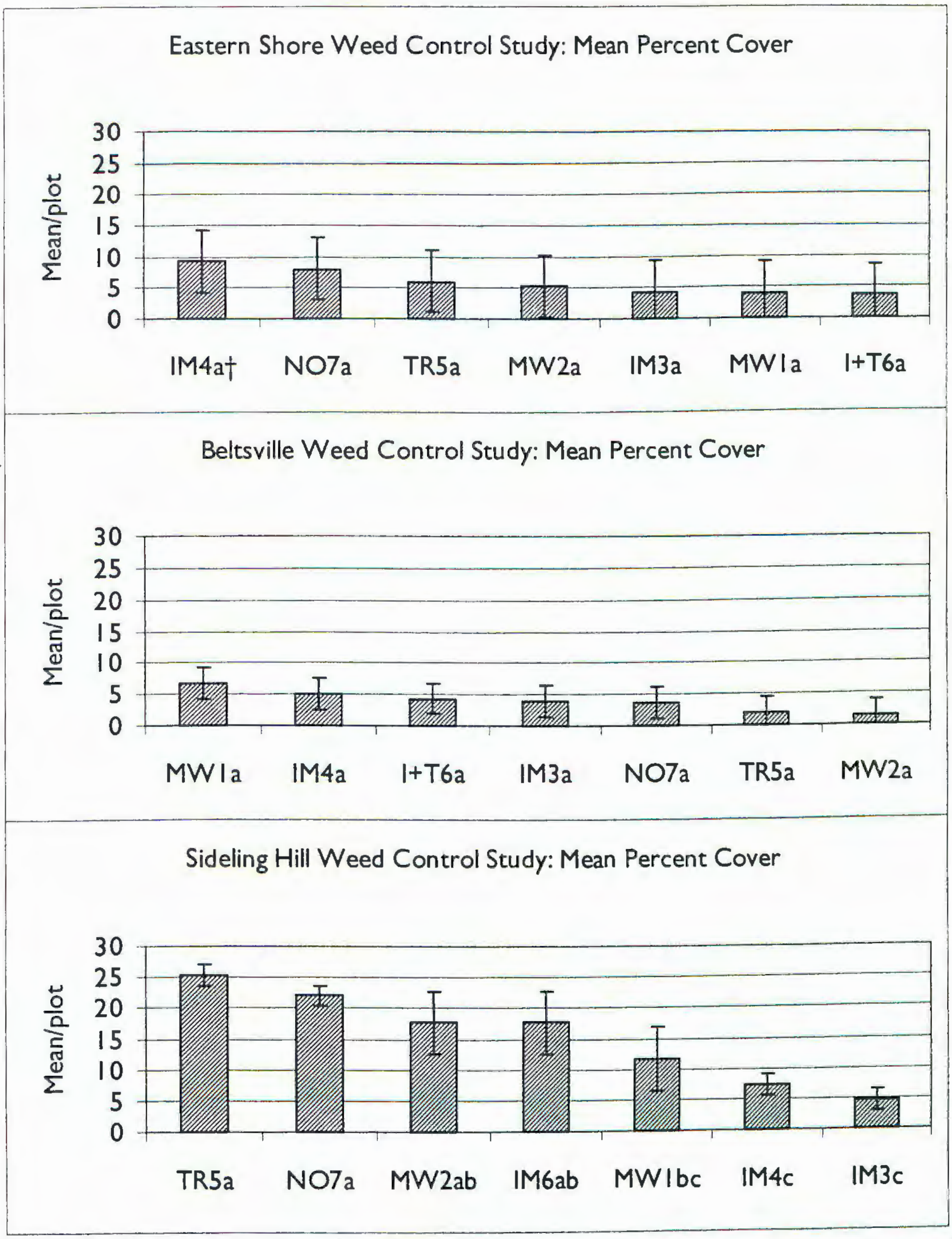


Figure 4. Weed control study: Mean percent total desirable species cover by weed control treatment: mowing in summer 1998 and spring 1999 (MW1), mowing in spring 1999 (MW2), imazapic in summer 1998 (IM3), imazapic in spring 1999 (IM4), triclopyr+2,4-D spring 1999 (TR5), imazapic+triclopyr+2,4-D (I+T6) and no treatment (NO7).

†Means within the same site with the same letter are not significantly different according to LSD at the 0.05 probability level. Standard error bars shown.

There were significant differences between weed control treatments at the species level for broomsedge, deertongue, eastern gamagrass, indian grass, and switchgrass (see Table 6-4). No significant differences between weed control treatments were found for other species. For broomsedge, counts were significantly higher with spring application of triclopyr+2,4-D than summer imazapic application or no treatment, but not significantly higher than other treatments. For deertongue, imazapic treatments and spring mowing had lowest counts, while no treatment and spring treatment with triclopyr+2,4-D had the highest counts. For indian grass, highest counts were with imazapic only treatments, but they were not significantly higher than no treatment, spring mowing or either treatment that included triclopyr+ 2,4-D. For switchgrass, no treatment, spring mowing and spring imazapic+triclopyr+ 2,4-D treatment had significantly higher counts than other treatments. For switchgrass, all herbicide treated plots had significantly lower counts than no treatment or spring mowing.

Table 6-4. Weed control study: Broomsedge, deertongue, eastern gamagrass, indian grass, and switchgrass plants per square meter by weed control treatment in the fall of 1999.

Treatment	Broom-sedge	Deer-tongue	Eastern gama.	Indian grass	Switch-grass
1 mow sum.'98 & spr.'99	0.9 ab†	2.6 abc	0.4 a	0.3 b	2.7 bc
2 mow spring'99	0.4 ab	1.0 bc	0.1 ab	1.9 ab	4.2 ab
3 imazapic summer '98	0.1 b	0.1 c	0.0 b	2.3 a	0.5 d
4 imazapic spring '99	1.3 ab	0.7 c	0.0 b	2.2 a	1.8 cd
5 triclopyr+2,4-D spr. '99	1.7 a	4.3 a	0.2 ab	1.6 ab	2.7 bc
6 imaz.+ tricl.+2,4-D spr. '99	1.1 ab	1.3 bc	0.2 ab	1.2 ab	3.2 abc
7 control	0.1 b	3.7 ab	0.3 ab	1.2 ab	4.9 a
$LSD_{0.05}$	1.5	2.76	0.34	1.57	1.72

†Means within the same column with the same letter are not significantly different according to LSD at the 0.05 probability level.

Survival of plants into the second season also varied by species. Tables 6-5 and 6-6 show the change in counts by species at each site and by treatment. Species counts at Sideling Hill decreased the most, due to decreases in deertongue, which also decreased in Beltsville and on the Eastern Shore. Big bluestem, eastern gamagrass, and switchgrass increased at all three sites. Broomsedge increased on the Eastern Shore, but decreased at both Beltsville and Sideling Hill. Indian grass and little bluestem increased on the Eastern Shore and at Beltsville, but decreased at Sideling Hill.

Table 6-5. Weed control study: Average change in individual desirable species per square meter at the Eastern Shore, Beltsville and Sideling Hill from 1998 to 1999.

	Average change in species counts/m^2			
	Eastern Shore	Beltsville	Sideling Hill	Cumulative change
Big bluestem	0.1	0.5	0.2	0.3
Broomsedge	0.1	-0.3	-1.0	-0.4
Deertongue	-0.9	-0.7	-19.0	-6.9
Eastern gamagrass	0.3	0.1	0.2	0.2
Indian grass	1.2	0.3	-0.4	0.4
Little bluestem	0.1	0.3	-0.1	0.1
Switchgrass	0.5	0.5	0.7	0.6
Cumulative change	1.4	0.8	-20.0	-5.9

Greater variation is seen in desirable species count changes when examined by weed treatment (see Table 6-6). Big bluestem and eastern gamagrass increased across all treatments from season one to two. Broomsedge increased with imazapic in spring 1999, as well as with triclopyr+2,4-D, but decreased with mowing in summer 1998 and spring 1999, mowing in spring 1999, imazapic in summer 1998, and no treatment. Deertongue decreased with all treatments, but lowest decreases were seen with imazapic in summer 1998. Indian grass increased with all treatments except mowing in summer 1998 and spring 1999. Little bluestem increased with all treatments that included imazapic, as well as with no treatment. Switchgrass increased with every treatment except imazapic in summer of 1998 and spring 1999.

Table 6-6. Weed control study: Average change in individual desirable species counts per square meter from 1998 to 1999 by weed control treatment. Treatments were 1) mowing summer 1998 and spring 1999, 2) mowing spring 1999, 3) imazapic summer 1998, 4) imazapic spring 1999, 5) triclopyr+2,4-D spring 1999, 6) imazapic +triclopyr+2,4-D spring 1999, and 7) control.

	Average change in species counts/m²						
	Mow		Imazapic		Tricl+ 2,4D	Tricl+ 2,4D +imaz	
	Summ. & spring	Spring	Summ.	Spring	Spring	Spring	Control
Big bluestem	0.2	0.2	0.0	0.8	0.3	0.4	0.2
Broomsedge	-0.1	-0.6	-2.1	0.8	0.4	0.0	-0.8
Deertongue	-6.2	-7.2	-1.7	-8.4	-5.6	-9.3	-8.9
E. gamagrass	0.4	0.1	0.0	0.0	0.2	0.2	0.3
Indian grass	-0.3	0.0	0.7	1.0	0.6	0.6	0.0
Lit. bluestem	-0.6	-0.2	0.6	0.0	-0.2	0.7	0.2
Switchgrass	0.1	2.2	0.0	-0.8	0.6	1.1	1.8
Cum. change	-6.4	-5.4	-2.6	-6.7	-3.7	-6.3	-7.1

Discussion

An understanding of how individual species respond to weed control methods could greatly improve initial establishment, as well as the long term management, of native grass plantings. Certain species varied in their response to timing of treatments, whether mowing or herbicide, and in their response to the various herbicide combinations. Switchgrass, deertongue and eastern gamagrass decreased with application of imazapic, while indian grass increased. Contrary to the companion species study, deertongue decreased least under summer 1998 imazapic application. This likely reflects the variability of response by some species to different application rates of imazapic. To some extent, these results parallel the results of Meyer (1998) and Washburn et al. (1999; 2000), who found post-planting weed control treatments resulted in few significant differences in native grass establishment. Washburn et al. (1999; 2000) found that preplanting treatment of plots with imazapic did have significant effects on native grass establishment, increasing plant density four-fold in some cases.

Chapter 7

Conclusions

The results of the companion species study and weed control study indicate that establishment methods for native grasses in Maryland must reflect specific site conditions, particularly existing weed composition. Results also indicate that weed control methods associated with establishment need to be based upon the individual native grass species in the seed mixture planted, due to the variability of individual species responses to mowing and herbicide treatments. Once established, all of the native grass species except bluejoint performed acceptably under the extreme drought conditions of 1998 and 1999, validating the perception that native grasses would likely be appropriate for the often droughty conditions in roadside rights-of-way. Weather conditions prevented successful germination of seeds planted in the fall and, therefore, no conclusions could be made about timing of planting and its effects upon desirable species or interactions between desirable and companion species.

Weed competition was often severe, particularly on the Eastern Shore. Results there indicate that where sites are dominated by non-native warm season grasses, more vigorous preplanting weed control treatment of the site would be needed. Where annual species predominate, allowing germination of annual weeds, then mowing or tilling prior to their going to seed, might be effective. Where perennial species predominate, use of cover crops in the season prior to planting, or preplanting application of selective herbicide might be necessary. As mentioned previously, research by Washburn et al. (1999; 2000) indicates that preplanting treatment of sites with imazapic can tremendously improve native grass establishment by reducing weed competition. However, their research was conducted in western Kentucky, and further investigation of preplanting use of imazapic within the mid-Atlantic region is needed. Dr. Harry Jan Swartz (personal communication, 1999) has found that responses to imazapic vary greatly with application rates, and further investigation of application rates, in combination with preplanting treatments, is needed.

Individual species response to mowing and herbicide applications varied and should be considered when seed mixture and weed control methods are being planned. Deertongue, eastern gamagrass and switchgrass did not tolerate application of imazapic well, while big bluestem, indian grass and little bluestem responded better to imazapic than to no treatment or mowing. These results confirm the labeling of imazapic, which indicates tolerance by big bluestem, indian grass and little bluestem, and intolerance by deertongue and switchgrass. Mowing treatments in summer did not aid establishment of any species, but this may simply reflect mowing damage due to the drought rather than mowing effects on plant growth. With the low cost and high germination rate of deertongue seeds, and the plant's low-growing habit, deertongue potentially provides the benefits of a companion species that is native. Canada and Virginia wild rye may have needed cooler temperatures or more moisture than the warm season native grasses to germinate. Therefore, if they are used in a mixture as companion species, it would be important to plant the mixture in fall or earlier in the spring. If they are included in a mixture to fill a cool season niche and other companion type species are used, a late spring planting would be appropriate in order to benefit warm season species in the mixture.

While this study investigated establishment of a grasses only mixture, a mixture of grasses and forbs would mostly likely benefit from a different approach to weed control. Based on research and discussions with individuals who install meadows in the mid-Atlantic region for a living, the method outlined by Weaner, using a mixture of grasses and forbs, with regular mowing the first season is the most successful in the long term (Packard and Mutel 1997; Prairie Moon Nursery 2000; Prairie Nursery 2000; Weaner 1996; Weaner 1999). Weaner's approach focuses on limiting not only initial weed problems, but creating a planting that minimizes the possibility of weed intrusion over a long period of time. This method potentially produces a very uniform appearance in the first season, and should be tested for use in public landscapes. Tests of this establishment method could be compared with preplanting treatments or a combination of preplanting and first season mowing treatments.

The use of native warm season grasses and wildflowers for steeply sloping areas, where mowing is impossible and reforestation ineffective due to lack of soil, also has practical application in roadside areas. Testing a variety of hydroseeding techniques in steeply sloped areas with a variety of soil conditions and planting times could provide very practical solutions for large areas of Maryland roadsides where successful establishment of vegetation has been problematic.

Results in this study were greatly affected by weather conditions. The benefits of fall planting, and the effects of cool season companion species within a fall planting, have yet to be examined. While this study found relatively few differences between companion treatments, it is likely that cool season companion species would have greater effects with a fall planting. Other native species such as partridge pea also merit study for use as companion plants. Partridge pea is a native annual legume, relatively inexpensive, with fine foliage and showy yellow blossoms.

Testing mixtures of native wildflowers and grasses for the SHA is currently underway at the University of Maryland and at the Natural Resource Conservation Service's Plant Materials Center, but other types of native plants would also be appropriate for roadside plantings. These include a tremendous variety of sedges adapted to dry conditions and woody plants such as shrubby St. John's wort (*Hypericum* spp.), also adapted to dry conditions. Many sedges have the added benefit of being evergreen.

The availability of native grass and forb seeds is rapidly increasing, and their cost is decreasing. While the SHA generally develops statewide planting specifications, specifications for native species planting should allow for choice of species to reflect the particular natural community of the area being planted. Species in the seed mixture used for this project are widely distributed, but species tend to be adapted to fairly specific environmental conditions. Since this research project began in 1998, SHA has sought the help of a broad range of individuals with experience in native plant use to develop appropriate seed mixtures and planting methodologies. Publication by the FHWA of *Roadside Use of Native Plants* has made appropriate species lists available for every state, but within each state, decisions still need to address specific site conditions (Harper-Lore 1999a). The Maryland Department of Natural Resources is currently developing a listing of plant communities within the state that will aid in developing appropriate planting mixtures (Berdine, in progress).

There is broad support for increased use of native plants throughout the country. States like Minnesota have been modifying roadside planting specifications to include only native species which are origin certified. Minnesota's Department of Transportation rejects seeds which have been selectively bred in any way. In this region, we have only recently realized the extent to which periodic fire historically shaped the landscape and periodically provided the perfect growing grounds for grasses (Frost 1998). Here, public interest in warm season grasses surged in response to the droughts of 1998 and 1999. Along with increased ecological awareness and demand for drought tolerant plants, interest in being able to see native grass species on display has grown. The Paintbranch Turfgrass facility at the University of Maryland and the Natural Resource Conservation Service's Plant Materials Center have recognized this interest and are currently installing display areas to educate not only individuals working in public land conservation or the landscape industry, but also private landowners. Maryland's Department of Transportation has recognized the use of native species as an opportunity to educate the public about Maryland landscapes. At the same time, SHA continues to support research with native species and to incorporate the advice of regional native plant specialists to ensure the success of native plantings along roadsides. In this climate of cooperation, the 21st century promises to be a time of positive growth for roadside native plant communities.

Appendix A. Plot plants of the Eastern Shore, Beltsville and Sideling Hill

control	1 annual rye	7 Canada wild rye	I rep I
mow	2 oats	8 Virginia wild rye	**II rep 2**
spray	3 tall fescue	9 bush clover	*III rep 3*
	4 cr. red fescue	10 crimson clover	
	5 hard fescue	11 none	
	6 redtop	12 2x native mixture	
		13 Florida paspalum	

Eastern Shore

Companion Species Study

spring planting

11	*2*	*5*	*9*	*3*	*8*										
3	*7*	*6*	*2*	*10*	*1*	*6*	*4*								
1	*9*	*2*	*11*	*8*	*12*	*10*	*7*								
								III							
12	**7**	**4**	**2**	**8**	*4*	*6*	*7*	*12*	*3*	*10*	*5*				
10	**5**	**1**	**11**	**3**	*8*	*12*	*9*	*1*	*4*	*5*	*11*				
II															
6	**8**	**4**	**12**	**6**	**1**	**9**	**11**	**3**	**10**	**7**	**2**	**5**	9	10	
9	**11**	**10**	**5**	**2**	**12**	**7**	**6**	**9**	**4**	**1**	**3**	**8**	11	12	
															I
1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
1	2	3	4	5	6	7	8	9	10	11	12	5	6	7	8

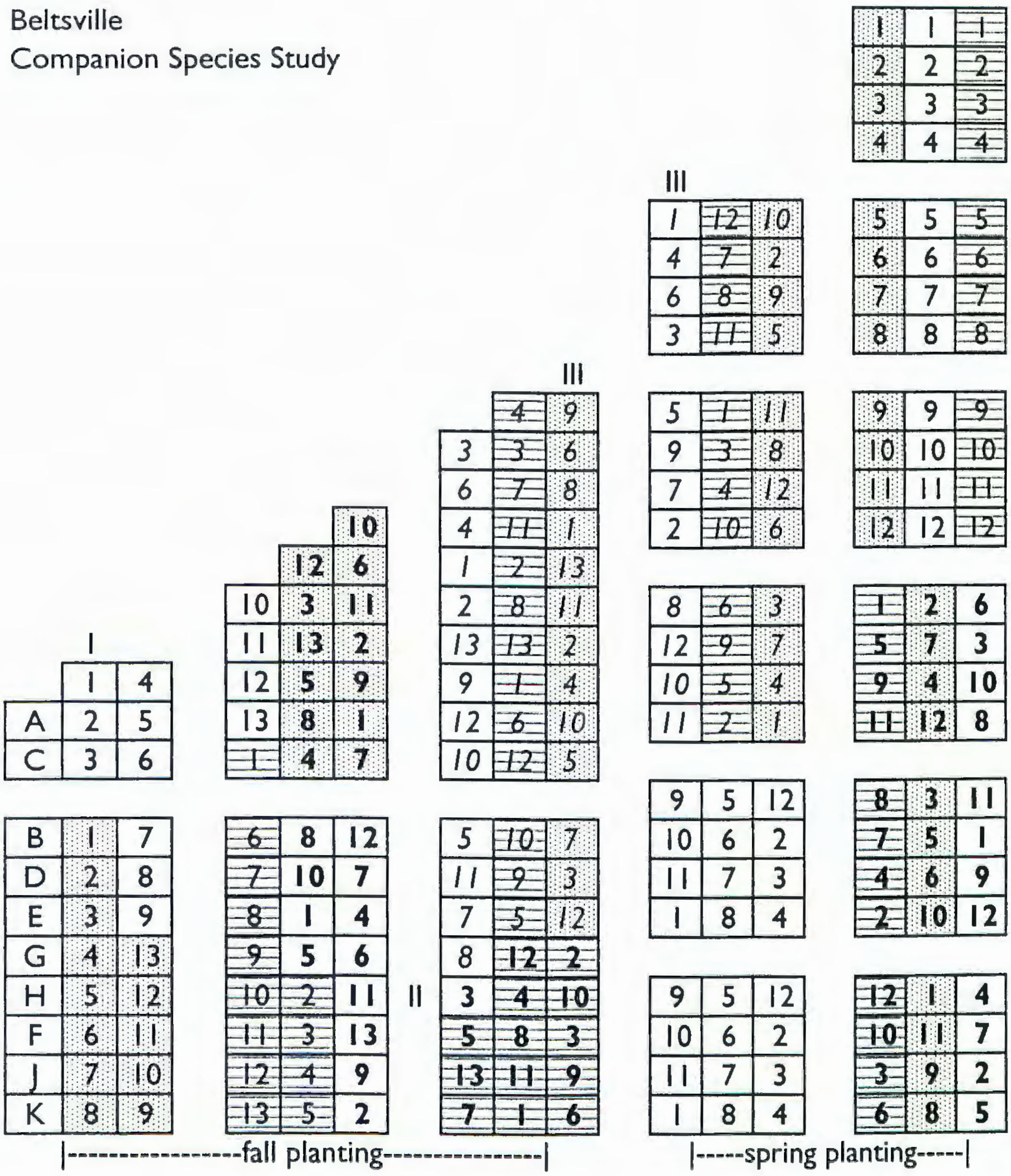
fall planting

I															
1	2	3	4	5	6	7	13	12	11	10	9	8	7	6	5
8	9	10	11	12	13	1	2	3	4	5	6	7	8	9	10
3	**11**	**9**	**12**	**1**	**5**	**13**	**8**	**7**	**11**	**12**	**13**	1	2	3	4
10	**4**	**6**	**2**	**12**	**7**	**3**	**4**	**5**	**1**	**8**	**10**	**2**	**13**	**9**	**11**
II															
6	*11*	*1*	*13*	*8*	*5*	*12*	*7*	*4*	*9*	*2*	*10*	*3*	*6*	*10*	*12*
2	**13**	**12**	**6**	**11**	*3*	*8*	*2*	*13*	*5*	*7*	*1*	*9*	*11*	*4*	*6*
										III					
7	**8**	**3**	**1**	**9**	**4**	**5**	**10**	*1*	*2*	*9*	*13*	*10*	*6*	*11*	*5*
A	B	C	D	E	F	G	H	I	J	K	*8*	*3*	*7*	*12*	*4*

Weed Control Study -- same layout for spring and fall plantings.

I									
5	1	4	3	9	7	2	6	10	8
II									
4	**6**	**2**	**9**	**3**	**1**	**5**	**8**	**10**	**7**
III									
1	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*10*

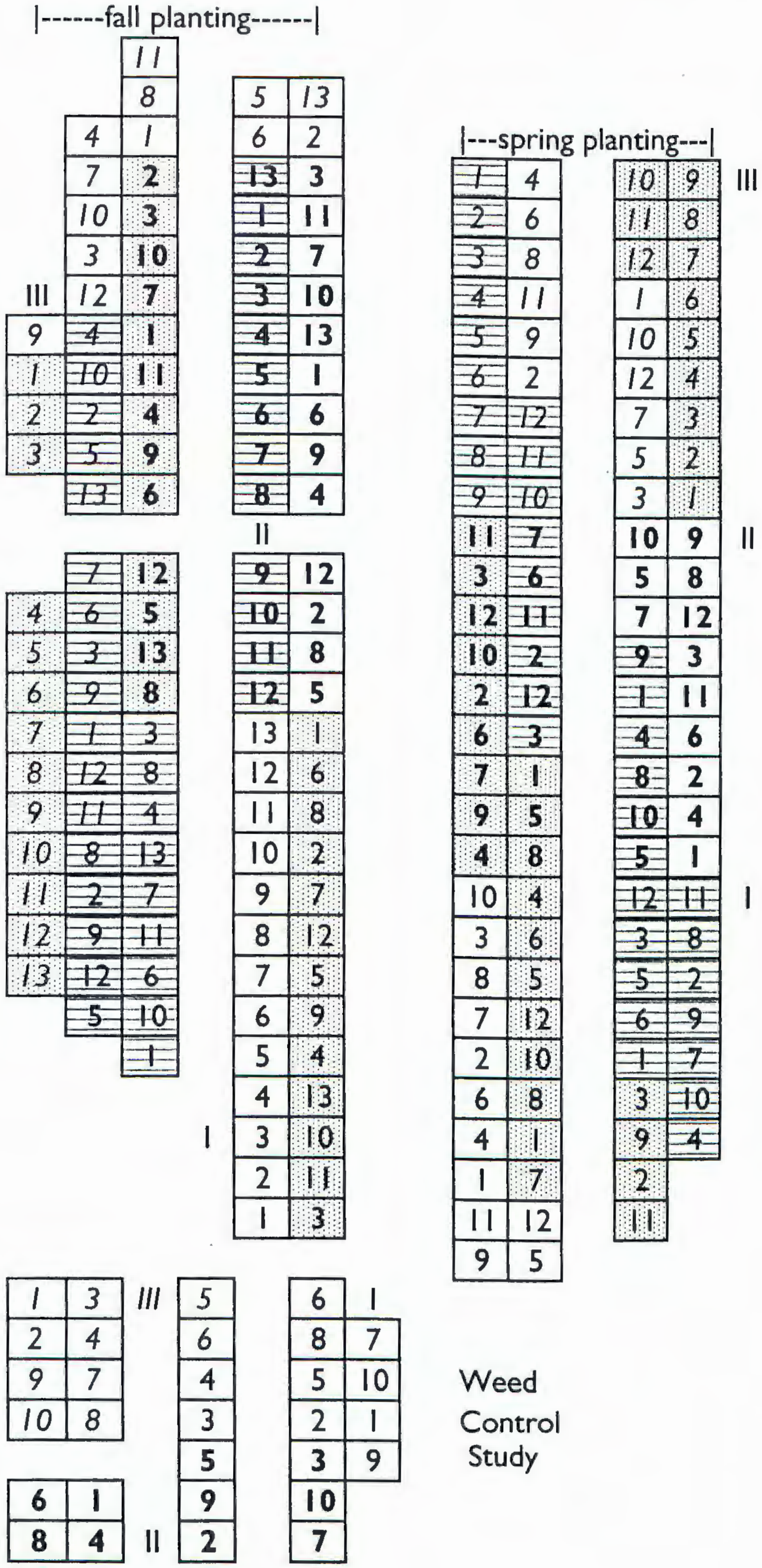
Beltsville
Companion Species Study



Weed Control Study -- same layout for spring and fall

I	II	III
1	**6**	*7*
2	**5**	*4*
3	**2**	*8*
4	**4**	*3*
5	**8**	*1*
6	**7**	*5*
7	**1**	*2*
8	**3**	*6*

Sideling Hill
Companion Species Study



Appendix B. Companion species study: Sources of variation (SOV) for GLM statistical models. REP=replication, TRT=weed treatment and COMP=companion species.

		Total counts†		Percent cover		Big bluestem	
SOV	df	MS	Pr>F	MS	Pr>F	MS	Pr>F
SITE	2	22.04	***	11273.89	***	39.39	***
Error a	6	0.59		1332.40		2.54	
TRT	2	1.46	***	2254.83	***	7.09	**
SITE*TRT	4	0.47	**	2927.70	***	3.15	*
Error b	12	0.53		493.12		2.34	
COMP	11	0.38	***	741.02	***	1.50	
SITE*COMP	22	0.28	**	401.30	*	1.42	
TRT*COMP	22	0.24	**	240.60		1.32	
SITE*TRT*COMP	44	0.20	*	247.09		1.15	
Error c	198	0.13		253.49		1.31	
		Broomsedge		**Deertongue**		**Eastern gamagrass**	
SOV	df	MS	Pr>F	MS	Pr>F	MS	Pr>F
SITE	2	87.05	***	77.51	***	0.88	**
Error a	6	19.03		8.05		0.26	
TRT	2	5.69		148.97	***	2.11	***
SITE*TRT	4	1.46		23.51	*	0.34	
Error b	12	14.31		3.19		0.18	
COMP	11	7.78		7.29		0.49	**
SITE*COMP	22	6.41		13.54	*	0.33	**
TRT*COMP	22	9.44	*	5.58		0.14	
SITE*TRT*COMP	44	4.76		8.61		0.23	
Error c	198	5.95		8.07		0.17	
		Indian grass		**Little bluestem**		**Switchgrass**	
SOV	df	MS	Pr>F	MS	Pr>F	MS	Pr>F
SITE	2	341.62	***	83.44	***	707.97	***
Error a	6	20.08		3.23		15.36	
TRT	2	231.21	***	75.05	***	837.55	***
SITE*TRT	4	33.57	***	19.56	***	181.98	***
Error b	12	9.08		5.45		22.51	
COMP	11	7.60		2.68		14.54	**
SITE*COMP	22	5.88		2.02		3.83	
TRT*COMP	22	5.98		1.92		7.39	
SITE*TRT*COMP	44	4.87		2.97		7.15	
Error c	198	5.97		2.09		5.52	

†Log transformed means.

*, **, *** indicate significance at the 0.05, 0.01 and 0.001 probability levels, respectively.

		Total counts by site					
		Eastern Shore		Beltsville		Sideling Hill	
SOV	df	MS	Pr>F	MS	Pr>F	MS	Pr>F
REP	2	90.29		154.19	*	192.15	
TRT	2	20.59		169.08	*	503.12	***
Error a	6	67.11		98.11		132.15	
COMP	4	39.07		86.51	*	129.403	*
TRT*COMP	4	34.39		27.39		88.28	
Error b	8	31.08		38.50		67.71	
		Percent cover by site					
		Eastern Shore		Beltsville		Sideling Hill	
SOV	df	MS	Pr>F	MS	Pr>F	MS	Pr>F
REP	2	568.95	*	1283.61	*	2144.67	***
TRT	2	179.62		2285.55	***	5647.06	***
Error a	6	357.15		355.25		766.96	
COMP	4	198.54		502.03		843.04	**
TRT*COMP	4	197.99		270.10		266.68	
Error b	8	185.54		290.00		284.93	

*, **, *** indicate significance at the 0.05, 0.01 and 0.001 probability levels, respectively.

Appendix C. Actual, 30 year average, and deviance from 30 year average monthly precipitation (in centimeters) at Chestertown, Beltsville and Hagerstown weather stations in 1998 and 1999 (MD State Climatologist 2000).

	Actual '98	Actual '99	Average	'98 - avg.	'99 - avg.
Chestertown					
January	14.5	12.2	8.1	6.4	4.1
February	10.2	8.9	7.9	2.3	1.0
March	15.2	10.2	9.4	5.8	0.8
April	9.4	6.1	8.1	1.3	-2.0
May	12.4	2.8	10.2	2.3	-7.4
June	12.4	8.6	11.2	1.3	-2.5
July	8.6	10.4	9.4	-0.8	1.0
August	7.6	10.2	10.2	-2.5	0.0
September	7.4	46.0	9.1	-1.8	36.8
October	2.8	7.9	7.9	-5.1	0.0
November	3.3	5.6	8.6	-5.3	-3.0
December	4.8	6.4	9.7	-4.8	-3.3
Annual	108.5	135.1	109.5	-1.0	25.7
Beltsville					
January	13.0	13.2	7.4	5.6	5.8
February	11.4	5.3	6.6	4.8	-1.3
March	15.7	9.9	8.4	7.4	1.5
April	9.4	5.8	8.4	1.0	-2.5
May	13.7	4.6	10.9	2.8	-6.4
June	10.4	5.3	8.9	1.5	-3.6
July	4.8	2.8	10.4	-5.6	-7.6
August	1.3	10.9	10.4	-9.1	0.5
September	6.1	30.7	9.4	-3.3	21.3
October	2.3	7.1	8.6	-6.4	-1.5
November	3.0	4.8	8.1	-5.1	-3.3
December	3.3	no data	8.6	-5.3	-
Annual	94.5	-	106.2	-11.7	-
Hagerstown					
January	8.9	6.1	6.6	2.3	-0.5
February	4.6	3.0	6.1	-1.5	-3.0
March	4.6	0.0	7.9	-3.3	-7.9
April	4.8	1.8	8.6	-3.8	-6.9
May	5.8	2.3	10.2	-4.3	-7.9
June	5.8	3.3	9.7	-3.8	-6.4
July	3.6	1.8	8.6	-5.1	-6.9
August	3.3	1.3	8.6	-5.3	-7.4
September	2.0	12.4	7.9	-5.8	4.6
October	3.6	1.8	8.4	-4.8	-6.6
November	0.8	1.0	8.4	-7.6	-7.4
December	2.0	4.1	7.1	-5.1	-3.0
Annual	49.8	39.1	98.0	-48.3	-58.9

Appendix D. Actual, 30 year average, and deviance from 30 year average monthly precipitation (in inches) at Chestertown, Beltsville and Hagerstown weather stations in 1998 and 1999 (MD State Climatologist 2000).

	Actual '98	Actual '99	Average	'98 - avg.	'99 - avg.
Chestertown					
January	5.7	4.8	3.2	2.5	1.7
February	4.0	3.5	3.1	1.0	0.4
March	6.0	4.0	3.7	2.4	0.4
April	3.7	2.4	3.2	0.4	-0.8
May	4.9	1.1	4.0	0.9	-2.9
June	4.9	3.4	4.4	0.6	-0.9
July	3.4	4.1	3.7	-0.3	0.4
August	3.0	4.0	4.0	-0.9	0.1
September	2.9	18.1	3.6	-0.8	14.5
October	1.1	3.1	3.1	-2.1	0.0
November	1.3	2.2	3.4	-2.1	-1.2
December	1.9	2.5	3.8	-1.9	-1.3
Annual	42.7	53.2	43.1	-0.4	10.1
Beltsville					
January	5.1	5.2	2.9	2.2	2.3
February	4.5	2.1	2.6	1.9	-0.6
March	6.2	3.9	3.3	2.9	0.7
April	3.7	2.3	3.3	0.4	-1.0
May	5.4	1.8	4.3	1.1	-2.6
June	4.1	2.1	3.5	0.6	-1.4
July	1.9	1.1	4.1	-2.2	-3.0
August	0.5	4.3	4.1	-3.6	0.1
September	2.4	12.1	3.7	-1.3	8.4
October	0.9	2.8	3.4	-2.5	-0.6
November	1.2	1.9	3.2	-2.1	-1.3
December	1.3	no data	3.4	-2.0	-
Annual	37.2	-	41.8	-4.6	-
Hagerstown					
January	3.5	2.4	2.6	0.9	-0.2
February	1.8	1.2	2.4	-0.6	-1.2
March	1.8	0.0	3.1	-1.3	-3.1
April	1.9	0.7	3.4	-1.5	-2.7
May	2.3	0.9	4.0	-1.7	-3.1
June	2.3	1.3	3.8	-1.5	-2.5
July	1.4	0.7	3.4	-2.0	-2.8
August	1.3	0.5	3.4	-2.1	-2.9
September	0.8	4.9	3.1	-2.3	1.9
October	1.4	0.7	3.3	-1.9	-2.6
November	0.3	0.4	3.3	-3.0	-2.9
December	0.8	1.6	2.8	-2.0	-1.2
Annual	19.6	15.4	38.6	-19.0	-23.2

Appendix E. Average daily maximum (Mx), minimum (Mi), mean (Mn), 30 year average (Avg), and deviance (Dv) from 30 year average monthly temperature (in degrees Celsius) in 1998 and 1999 at Chestertown, Beltsville and Hagerstown weather stations (Maryland State Climatologist 2000).

	Mx9	Mi98	Mn98	Dv98	Avg	Mx99	Mi99	Mn99	Dv99
Chestertown									
Jan	9.8	-0.3	4.7	4.7	0.1	8.1	-2.8	2.6	2.6
Feb	10.2	0.3	5.3	3.8	1.5	8.9	-2.2	3.3	1.8
Mar	13.1	1.6	7.3	0.7	6.6	11.8	0.3	6.1	-0.6
Apr	19.9	6.6	13.3	1.4	11.9	19.0	5.8	12.4	0.5
May	25.4	12.7	19.0	1.5	17.6	25.3	11.4	18.4	0.8
June	27.8	15.8	21.8	-0.7	22.5	28.6	16.7	22.7	0.2
July	31.3	18.4	24.9	0.0	24.9	33.0	20.9	26.9	2.1
Aug	31.2	17.1	24.2	-0.1	24.2	31.0	18.6	24.8	0.6
Sept	28.9	14.2	21.6	1.1	20.5	26.3	15.1	20.7	0.2
Oct	20.4	6.6	13.5	-0.6	14.2	19.9	6.3	13.1	-1.1
Nov	15.6	1.3	8.5	-0.1	8.6	16.6	4.7	10.6	2.1
Dec	10.8	0.0	5.4	2.6	2.8	9.4	-1.3	4.1	1.3
Annual	20.4	7.8	14.1	1.2	12.9	19.8	7.8	13.8	0.9
Beltsville									
Jan	9.4	0.2	4.8	5.6	-0.8	8.4	-3.3	2.6	3.4
Feb	9.7	1.1	5.4	4.7	0.7	8.6	-2.4	3.1	2.4
Mar	12.4	2.3	7.4	1.3	6.1	10.4	-0.1	5.2	-0.9
Apr	20.0	7.1	13.5	2.3	11.2	19.0	5.7	12.3	1.1
May	24.8	13.6	19.2	2.5	16.7	24.8	10.9	17.9	1.2
June	27.6	16.9	22.2	0.6	21.7	28.4	16.3	22.4	0.7
July	31.1	18.7	24.9	0.7	24.2	32.8	20.2	26.5	2.3
Aug	31.5	18.2	24.9	1.4	23.4	31.1	18.8	24.9	1.5
Sept	29.7	16.6	23.1	3.6	19.6	25.7	15.1	20.4	0.8
Oct	20.4	8.5	14.5	1.6	12.8	18.9	6.0	12.5	-0.4
Nov	14.9	1.5	8.2	0.5	7.7	16.8	4.8	10.8	3.1
Dec	11.2	0.3	5.8	3.6	2.1	--	--		
Annual	20.2	8.7	14.5	2.4	12.1				
Hagerstown									
Jan	8.4	0.7	4.6	6.4	-1.8	5.9	-4.5	0.7	2.6
Feb	9.1	0.1	4.6	5.1	-0.5	11.2	-3.0	4.1	4.6
Mar	12.6	2.1	7.3	1.8	5.6	11.9	-1.9	5.0	-0.6
Apr	20.2	6.8	13.5	2.5	11.0	19.5	5.4	12.5	1.5
May	25.3	13.4	19.4	2.4	16.9	24.4	10.1	17.2	0.3
June	24.3	13.8	19.0	-2.5	21.5	28.6	15.1	21.8	0.3
July	30.1	18.0	24.0	0.2	23.8	33.6	18.9	26.3	2.4
Aug	29.7	17.5	23.6	0.6	23.0	30.4	17.3	23.9	0.9
Sept	29.8	14.7	22.3	3.2	19.1	25.2	12.4	18.8	-0.2
Oct	19.8	7.8	13.8	1.1	12.7	18.8	5.4	12.1	-0.6
Nov	14.3	1.9	8.1	1.3	6.8	16.0	4.4	10.2	3.4
Dec	11.2	-0.2	5.5	4.5	1.0	8.7	-2.2	3.3	2.3
Annual	19.6	8.1	13.8	2.2	11.6	19.6	6.4	13.0	1.4

Appendix F. Average daily maximum (Mx), minimum (Mi), mean (Mn), 30 year average (Avg), and deviance (Dv) from 30 year average monthly temperature (in degrees Fahrenheit) in 1998 and 1999 at Chestertown, Beltsville and Hagerstown weather stations (Maryland State Climatologist 2000).

	Mx98	Mi98	Mn98	Dv98	Avg	Mx99	Mi99	Mn99	Dv99
Chestertown									
Jan	49.6	31.4	40.5	8.4	32.1	46.5	27.0	36.8	4.7
Feb	50.4	32.5	41.4	6.7	34.7	48.0	28.0	38.0	3.3
Mar	55.5	34.9	45.2	1.3	43.9	53.3	32.5	42.9	-1.0
Apr	67.9	43.8	55.8	2.4	53.4	66.2	42.5	54.3	0.9
May	77.7	54.8	66.3	2.7	63.6	77.6	52.5	65.1	1.5
June	82.1	60.5	71.3	-1.2	72.5	83.5	62.1	72.8	0.3
July	88.3	65.2	76.7	-0.1	76.8	91.4	69.6	80.5	3.7
Aug	88.2	62.8	75.5	-0.1	75.6	87.8	65.5	76.7	1.1
Sept	84.1	57.6	70.9	2.0	68.9	79.3	59.2	69.3	0.4
Oct	68.8	43.9	56.4	-1.1	57.5	67.8	43.3	55.5	-2.0
Nov	60.1	34.4	47.3	-0.1	47.4	61.8	40.5	51.1	3.7
Dec	51.5	32.0	41.8	4.8	37.0	49.0	29.7	39.4	2.4
Annual	68.7	46.1	57.4	2.1	55.3	67.7	46.0	56.9	1.6
Beltsville									
Jan	48.9	32.4	40.6	10.1	30.5	47.2	26.0	36.6	6.1
Feb	49.5	33.9	41.7	8.4	33.3	47.5	27.7	37.6	4.3
Mar	54.4	36.1	45.2	2.3	42.9	50.8	31.9	41.4	-1.5
Apr	68.0	44.7	56.3	4.1	52.2	66.2	42.2	54.2	2.0
May	76.6	56.4	66.5	4.5	62.0	76.6	51.7	64.2	2.2
June	81.6	62.4	72.0	1.0	71.0	83.2	61.3	72.3	1.3
July	87.9	65.7	76.8	1.2	75.6	91.1	68.3	79.7	4.1
Aug	88.7	64.8	76.8	2.6	74.2	87.9	65.8	76.9	2.7
Sept	85.4	61.8	73.6	6.4	67.2	78.2	59.2	68.7	1.5
Oct	68.8	47.3	58.0	2.9	55.1	66.1	42.8	54.5	-0.6
Nov	58.8	34.7	46.7	0.8	45.9	62.2	40.7	51.5	5.6
Dec	52.2	32.5	42.3	6.5	35.8	--	--		
Annual	68.4	47.7	58.1	4.3	53.8				
Hagerstown									
Jan	47.2	33.3	40.3	11.6	28.7	42.7	23.9	33.3	4.6
Feb	48.4	32.2	40.3	9.2	31.1	52.2	26.6	39.4	8.3
Mar	54.7	35.7	45.2	3.2	42.0	53.4	28.5	41.0	-1.1
Apr	68.3	44.2	56.3	4.5	51.8	67.1	41.8	54.5	2.7
May	77.6	56.2	66.9	4.4	62.5	75.9	50.1	63.0	0.5
June	75.7	56.8	66.3	-4.4	70.7	83.4	59.1	71.3	0.6
July	86.1	64.4	75.2	0.3	74.9	92.5	66.1	79.3	4.4
Aug	85.4	63.5	74.5	1.1	73.4	86.8	63.2	75.0	1.6
Sept	85.7	58.4	72.0	5.7	66.3	77.4	54.4	65.9	-0.4
Oct	67.7	46.0	56.9	2.0	54.9	65.9	41.7	53.8	-1.1
Nov	57.8	35.4	46.6	2.4	44.2	60.8	39.9	50.4	6.2
Dec	52.1	31.6	41.9	8.1	33.8	47.7	28.1	37.9	4.1
Annual	67.2		56.9	4.0	52.9	67.2	43.6	55.4	2.5

Appendix G. Weed control study: Sources of variation (SOV) for GLM statistical models. REP=replication and WTRT=weed control treatment.

		Total counts		Percent cover		Big bluestem	
SOV	df	MS	Pr>F	MS	Pr>F	MS	Pr>F
SITE	2	951.85	***	1448.12	***	1.56	
Error a	6	209.26		555.61		1.25	
WTRT	2	55.16	*	301.96		0.28	
SITE*WTRT	4	63.89	**	380.19	*	0.62	
Error b	12	21.80		157.38		0.71	
		Broomsedge		Deertongue		Eastern gamagrass	
SOV	df	MS	Pr>F	MS	Pr>F	MS	Pr>F
SITE	2	5.94		123.85	***	0.04	
Error a	6	6.54		30.97		0.19	
WTRT	2	2.85		25.47	**	0.26	
SITE*WTRT	4	2.49		18.41	*	0.10	
Error b	12	2.36		8.41		0.13	
		Indian grass		Little bluestem		Switchgrass	
SOV	df	MS	Pr>F	MS	Pr>F	MS	Pr>F
SITE	2	2.35		2.73		289.87	***
Error a	6	11.06		1.95		13.81	
WTRT	2	3.75		1.02		17.21	***
SITE*WTRT	4	3.38		0.61		14.64	***
Error b	12	2.73		1.00		3.28	

*, **, *** indicate significance at the 0.05, 0.01 and 0.001 probability levels, respectively.

		Total counts by site					
		Eastern Shore		Beltsville		Sideling Hill†	
SOV	df	MS	Pr>F	MS	Pr>F	MS	Pr>F
REP	2	1150.29	**	155.85		0.34	
WTRT	2	71.24		151.05		0.64	*
Error a	6	107.72		154.00		0.21	
		Percent cover by site					
		Eastern Shore		Beltsville		Sideling Hill	
SOV	df	MS	Pr>F	MS	Pr>F	MS	Pr>F
REP	2	486.12	***	20.04		121.63	
WTRT	2	12.67		10.57		159.71	**
Error a	6	183.08		18.23		34.10	

†Log transformed means.

*, **, *** indicate significance at the 0.05, 0.01 and 0.001 probability levels, respectively.

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