Native Roadside Wildflowers in Rural Areas: Developing Best Management Practices for Establishment of Plantings by Seed and Enhancement of Naturally-Occurring Populations

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Final Report

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Metric Conversion Table

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
^oC	Celsius	1.8C+32	Fahrenheit	^oF

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc

cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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16. Abstract

This main goal of this study was to determine the effects of competition and mowing on native wildflower establishment on roadside right-of-ways (ROWs) dominated by bahiagrass (*Paspalum notatum*). The species were Florida ecotypes of *Coreopsis lanceolata*, *C. leavenworthii*, *Gaillardia pulchella*, and *Ipomopsis rubra*. Bahiagrass competition was the main factor limiting establishment of wildflowers under simulated ROW conditions. The optimal establishment method was to spray sites twice with glyphosate in the fall (2 weeks apart, with final application 2 weeks before seeding), mow the site a few days prior to seeding, and remove excessive thatch and clippings. Short-term sustainability was not affected by mowing two to six times per year, when timed to avoid flowering and seed set. Frequent mowing (12-24 times per year) that did not account for flowering and seed set reduced the fitness and growth of *C. lanceolata* and *C. leavenworthii*. Based on costs, aesthetics, safety, and management practices, establishing new plantings of Florida ecotype native wildflowers by seed is cost-effective for rural ROWs that require mowing by small to medium-sized mowers or string trimmers. However, preserving existing stands of native wildflower plantings is also an economically justified method of establishing new native wildflower plantings on all ROWS. Results of our study suggest that aesthetically appealing stands of *Flaveria linearis* in south Florida can be established provided that *F. linearis* covers at least 20% of the ROW site, and mowing frequency is substantially reduced and timed to maximize natural reseeding.

17. Key Word	18. Distribution Statement
Native wildflower, native forb, establishment, bahiagrass, *Paspalum notatum*, sustainable, weed competition, site preparation	No restrictions

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Preface

Much of the research for this grant project was completed by Anne Frances as part of a Ph.D. dissertation. The dissertation research was advised by the co-principle investigators Jeff Norcini, Sandy Wilson, and Debbie Miller, as well as the three other members of Anne Frances' Ph.D. committee, Carrie Reinhardt Adams, Doria Gordon, and Bijan Dehgan. Jeff Norcini and Carrie Reinhardt Adams served as co-chairs of the committee. This final report is a concise version of the major findings published in Dr. Frances' dissertation, which is used with her permission.

Executive Summary

Establishing native wildflowers into areas dominated by bahiagrass (*Paspalum notatum*) is a common goal of roadside management and ecological restoration. Yet, there is limited information on establishment and management practices for Florida ecotypes. The main emphasis of this study was to determine the effects of competition and mowing on native wildflower establishment (via seeds) on roadside right-of-ways (ROWs) dominated by bahiagrass. The four species included in this portion of the study were Florida ecotypes of *Coreopsis lanceolata* (lanceleaf tickseed), *Coreopsis leavenworthii* (Leavenworth's tickseed), *Gaillardia pulchella* (blanketflower), and *Ipomopsis rubra* (standing cypress).

Bahiagrass competition was the main factor limiting establishment of Florida ecotypes of native wildflowers under conditions that simulated roadside ROWs dominated by bahiagrass. Spraying with glyphosate prior to planting in the fall reduced the competitive advantage of bahiagrass and improved establishment. Within a few days prior to seeding, glyphosate-treated sites were mowed, and excessive thatch and clippings removed to ensure soil-to-seed contact. While bahiagrass competition limited wildflower establishment and growth, aboveground competition from bahiagrass did not account for the total reduction in wildflower growth. Other abiotic and biotic factors may be involved. While bahiagrass did not limit germination and emergence of wildflowers, bahiagrass did limit subsequent growth and flowering of wildflowers. Moreover, *C. lanceolata* can become established in sites dominated by sparse to moderately dense bahiagrass when *C. lanceolata* seeds are sown in the fall into bahiagrass that has been mowed. However, *C. lanceolata* establishment in glyphosate-treated plots was more successful than in plots that were not treated with glyphosate.

Seeding rates can greatly influence wildflower establishment. In this study, seeding rates were explicitly tested for *C. lanceolata*. The optimal seeding rate was 7 lb pure live seed (PLS) per acre. Seeding at too low of a rate (1.2 lb PLS per acre) resulted in poor establishment but seeding at too high of a rate (13 lb PLS per acre) provided limited additional benefit compared to 7 lb PLS per acre, especially when seed cost is considered. Although PLS rates account for differences in seed viability, seed mass varies among species and even seed lots of the same species resulting in widely varying seeding rates per unit area (i.e., number of viable seeds per square foot). Developing species specific seeding rates for Florida ecotype seeds will help to decrease costs.

Short-term sustainability was not affected by mowing two to six times per year, when timed to avoid flowering and seed set of each species. Frequent mowing (12 to 24 times per year), however, that did not account for flowering and seed set reduced the fitness and growth of *C. lanceolata* and *C. leavenworthii*. Hence, wildflower plantings can be mowed as little as twice per year provided flowering and seed set are considered.

A secondary objective of this study was to investigate management (i.e., mowing) practices that would preserve and enhance existing stands of native wildflowers in south Florida. The results of our study suggest that existing stands of *Flaveria linearis* (narrowleaf yellowtops) that cover at least 20% of the site seem to be suitable for developing into aesthetically appealing

stands of wildflowers in south Florida. Sites with less than 20% cover of a single wildflower but with the majority of cover represented by a suite of native species may be preserved as native habitat. However, avoid sites that are covered by more than a small percentage of aggressive weeds like *Panicum repens* (torpedograss). Mow suitable sites at least once per year, after seed set of *F. linearis*, and avoid the use of any supplemental fertilizer

The third objective of this study was to analyze costs of establishing new plantings of Florida ecotypes of native wildflowers by seeds. Based on costs as of fall 2008 (including mowing contracts) as well as aesthetics, current safety issues, and management practices for turf and native wildflower plantings, the establishment of new wildflower plantings is most cost-effective and appropriate for rural ROWs requiring mowing by small to medium-sized mowers or string trimmers. However, preserving existing stands of native wildflower plantings is also an economically justified method of designating new native wildflower plantings on all roadside ROWS.

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CHAPTER ONE: INTRODUCTION

The Florida Department of Transportation's (FDOT) roadside right-of-way (ROW) wildflower program began in 1963 (FDOT, 1994). In addition to the aesthetic attributes, FDOT noted that wildflower plantings would increase driver alertness and lower maintenance costs. The economic benefit is even more relevant today because maintenance expenses are driven by higher fuel, labor and equipment costs.

The economic value of using native wildflowers in ROWs, especially native wildflowers adapted to Florida's environment (often referred to as Florida ecotypes) began to be recognized in the 1980s (FDOT, 1994). Today, the ecological value and sustainability of using native wildflowers adapted to specific regions of the country is widely acknowledged (Harper-Lore and Wilson, 1999). When plantings of these types of wildflowers are established and managed appropriately, maintenance costs are minimized as is the need to replant.

Increasing the use of native wildflower seeds of Florida ecotypes produced in Florida is consistent with ecosystem management goals of FDOT and has the potential for reducing maintenance costs. The 1994 publication, "Wildflowers in Florida" published by the Environmental Management Office, states that FDOT "…desires to purchase and plant native harvested and native Florida grown wildflower seed in 1998 for planting in November of that year" based on Florida Statute 334.044(25) (FDOT, 1994). It was hoped that by 2003 "…100% of [FDOT's] seed order [would] be certified, native Florida wildflower seed."   Moreover, one of the new policies of FDOT's recently revised Wildflower Program (FDOT, 2004) goes one step further: "The Department, to the extent quality seed is available, will purchase and plant native wildflower seed from Florida sources. Planting programs will, to the extent practicable, be developed based on the use of available native seeds."

FDOT began purchasing Florida ecotype seed in 2002. However, the nature of this seed makes it relatively expensive compared to that from out-of-state commercial suppliers. While plantings of Florida ecotypes of native wildflowers are expected to be sustainable for several years, or more (given proper management practices), scientific evidence is needed to show that these populations are indeed sustainable when established and managed using appropriate practices.   Current recommendations for establishment and maintenance of roadside wildflower plantings are based mainly on FDOT's experiences with seeds purchased from out-of-state suppliers, i.e., seeds that are derived from plants that are not adapted to Florida's climate.

In addition to planting wildflowers on ROWs, preserving and maintaining wildflower populations that naturally occur on ROWs contributes to the number of FDOT designated wildflower sites (that is, sites created or managed for their aesthetic appeal). This approach is consistent with FDOT's 2004 wildflower policy that includes the need for best management practices "… to identify and protect naturally occurring wildflower stands, and to promote natural regeneration and dispersal of native wildflowers" (FDOT, 2004). Preserving natural wildflower stands has the advantage of using plants that are already adapted to the specific conditions at that site. Moreover, the cost of establishing new wildflowers sites in this manner is substantially less expensive that establishing a wildflower site by direct seeding, since there are no site preparation costs and seeds do not have to be purchased.

With increases in land development across Florida, there is a corresponding increase in the number of roads and a decrease in natural habitat for native species. A common practice in Florida is to plant roadsides with bahiagrass (*Paspalum notatum*). This helps prevent erosion and damage to the road. There is, however, growing awareness of some problems with bahiagrass. Because bahiagrass is a fast-growing grass, it can be expensive to mow and maintain, especially with increased fuel costs. Bahiagrass is also a non-native grass from Brazil, which, while meeting the goals of roadside stability, is less favorable to natives that could perform these functions, especially beyond the area immediately adjacent to the paved surface. To address these issues, it is becoming more common to preserve naturally occurring wildflower populations and plant roadsides with native wildflower seeds.

Objectives/Tasks

1. Evaluate stand establishment and performance over a 2-year period for plantings of Florida ecotypes of native wildflowers under simulated roadside conditions.

2. Evaluate management methods that will result in preservation and spread of naturally occurring roadside wildflower populations in south Florida.

3. Individual Best Management Practices (BMPs) will be written based on information obtained in objectives one and two.

4. Economics – Inputs associated with establishment and maintenance will be used to estimate the costs needed to implement the BMPs defined in objective three.

CHAPTER TWO: LITERATURE REVIEW

The ecotype concept was introduced in the 1920's describing variation within a species. It essentially stated that a population of a species (on a local or regional scale) will adapt to a particular set of environmental conditions over time through a process of natural selection (Turesson, 1922). Since then evidence has mounted about the ecological and economic benefits of using locally or regionally adapted species resulting in an increasing demand for ecotypes (especially seeds) for use in restoration and along roadside ROWs (Harper-Lore and Wilson, 1999; Houseal and Smith, 2000; Burton and Burton, 2002) The expectation is that plantings established with such seeds will be more sustainable and less expensive over the long term compared with plantings established with wildflowers derived from nonlocal or nonregional sources. The expected increased sustainability of these plantings would be due not only to adaptation to the local environment but because of the relatively high level of genotypic and phenotypic diversity characteristic of many ecotypes, for example a central Florida ecotype of *Coreopsis leavenworthii* (Leavenworth's tickseed) (Czarneki et al., 2007, 2008).

Genotype refers to the set of genes, commonly referred to as the 'genetic fingerprint', in a particular plant. Seeds of many ecotypes are derived from plants that are often vastly genetically different, a characteristic that is retained during seed production. In contrast, cultivated varieties of plants, such as bedding plants and many agronomic crops, represent the other extreme in that all plants are genetically identical. **Phenotype** refers to the appearance of the plant (height, width, flower color, etc.) as well as performance (flowering season, survival, physiological activity, etc.). The phenotype of a plant is affected by the genetic makeup of the plant as well as the environment. For example, plants with the same genotype would probably look and perform differently if grown in full sun or shade. Hence, because many ecotypes are genetically diverse, the expectation is that their appearance and performance would be diverse as well. One of the main advantages of this phenotypic diversity is the increased level of sustainability of a planting. For example, in a genetically diverse, and therefore phenotypically diverse, planting, some plants might die as a result of a particular genotype being susceptible to drought. However, the planting is sustained because most plants live. In contrast, in a planting comprised of a cultivated variety, which typically has no or very limited genetic diversity, many or all plants would die if plant with a particular genotype was susceptible to drought.

In Florida, it has been shown that seed origin can affect flowering, growth, and or survival of several native wildflower species that occur and/or are planted on roadsides (Norcini et al., 1998, 2001; Marois and Norcini, 2003; Norcini and Aldrich, 2003). For example, a northern Florida ecotype of *Coreopsis lanceolata* (lanceleaf tickseed) was found to bloom earlier and have higher survivorship than non-local ecotypes (Norcini et al., 2001).

Direct seeding is often more economical than other revegetation methods (Pfaff and Gonter, 1999). However, it is necessary to ensure that the site meets the requirements for germination, emergence and survival of the seedlings – adequate moisture, seed-to-soil contact, and limited competition from weeds and turf. Hence, when direct seeding, it is important to plant when there will be sufficient rain or by supplying supplemental irrigation and to suppress or remove competing vegetation (Harper-Lore and Wilson, 2000; Cox et al., 2004). Plant establishment is said to be limited by the availability of seeds, of areas suitable for emergence and growth, or of both (Stampfli and Zeiter, 1999; Turnbull et al., 2000Zobel et al. 2000; Holzel 2005). To overcome seed limitation, a species specific seeding rate can be determined. Frequently, though, seeding rates are similar among wildflower species because research into appropriate species specific seeding rates is limited or nonexistent, especially for Florida ecotypes (see Markwardt [2005] for species specific seeding rates used in Texas). As a result, seeding rates could be excessive. While seeding at an excessively high rate may result in higher emergence and density (Orrock et al., *in press*), sometimes doubling the seed rate may have no effect on overall density of mature plants (Harkess and Lyons, 1998).

Bahiagrass, which is commonly planted on Florida's roadside ROWs, is very competitive. There is some evidence that that the failure of some wildflower plantings is due to bahiagrass outcompeting the wildflowers (Uridel, 1994; Violi, 2000).

Competition can take place both above ground for light (Lepik et al., 2005) and below ground for water and nutrients (Tilman, 1994). The order in which a plant arrives at a site can also influence its competitive advantage (Ejrnaes et al., 2006). This may be an important consideration for wildflower establishment in bahiagrass because when a plant has been established at a site for several years, its competitive advantage may increase (Hely and Roxburgh, 2005). Another important influence on competition is the season of planting. Bahiagrass becomes dormant in the fall and winter (Marousky and Blondon, 1995) and therefore should be less competitive during those seasons. Hence, planting wildflowers in fall would seem to be a reasonable time to plant seeds. Another method of reducing the competitive advantage of bahiagrass is by mowing or spraying with an herbicide.

Nearly all natural ecosystems depend on disturbance in some form. Both species richness and diversity benefit, in many cases, from moderate disturbances at an intermediate frequency (Dayton, 1971; Lepš, 1999; Connell, 1978). Some ecosystems depend on frequent disturbance to maintain their diversity. These include longleaf pine ecosystems and most Florida wildflower habitats (Taylor, 1998). On roadsides, however, natural disturbances tend to be suppressed and are replaced by mowing or applying herbicides (Forman et al., 2003).

Herbicide treatment can be an effective tool for removing or reducing existing vegetation. There are two main categories of herbicides: nonselective and selective. Nonselective herbicides theoretically suppress or kill all plant species, while selective herbicides only suppress or kill specific types of plants. A common nonselective herbicide is glyphosate (e.g., Roundup®). It has been shown to increase native wildflower establishment in bahiagrass, but it should only be applied prior to seeding (Gordon et al., 2000; Uridel, 1994). An example of a selective herbicide is sethoxydim (e.g., Poast®, Vantage®), which is a graminicide, that is, it only targets grasses. Theoretically, a graminicide can be applied over-the-top of broadleaf, wildflower species without injuring them. Another selective herbicide is imazapic (e.g., Plateau®). Wildflowers greatly vary in their sensitivity to imazapic, and are generally more tolerant when applied within a day of seeding (BASF Corporation, 2003; Norcini and Aldrich, 2003). Glyphosate, sethoxydim, and imazapic have all been shown to effectively control bahiagrass (Baker et al., 1999), therefore, it is likely that these herbicides would benefit wildflower establishment as long as the wildflowers are not negatively affected by these herbicides.

Mechanical disturbance is the other primary method for removing or suppressing competitive species prior to seeding desirable species; it includes tilling, disking, mowing, and topsoil removal. Topsoil removal has been shown to be particularly effective in the restoration of abandoned agricultural land because not only is the existing vegetation removed but also high levels of agricultural nutrients like nitrogen that generally favor non-native species (Holzel, 2005). Violi (2000) found that mechanical sod removal following herbicide treatment can control bahiagrass.

Mowing is another effective mechanical treatment. Mowing is a very common management practice along roadsides and is used for maintaining driver visibility and reducing woody plants along roadsides. Mowing can also have a dramatic effect on species composition depending on frequency, height, and timing. While grasses generally thrive in mowed areas (Forman et al., 2003), mowing can increase species diversity in some habitats (Parr and Way, 1988; Collins et al., 1998). Parr and Way (1998) found in a study that a roadside area that was mowed twice a year had greater diversity than plots mowed once a year or not at all, the latter having the least diversity. Mowing and litter removal can also increase seed germination and establishment (Jensen and Meyer, 2001; Jutila and Grace, 2002). Timing of mowing is important especially with regards to seed set (Brys et al., 2004). A population will likely have significantly increased sustainability if mowing occurs after seed have matured.

Because of the increasingly common practice of planting roadsides with native wildflowers, it is important to understand differences between wildflower species. Species vary in their response to environmental factors such as water, disturbance, and competition from bahiagrass. Many times there are tradeoffs involved with different survival strategies. For example, plants that are good colonizers (e.g., many of our native wildflowers) do not typically have traits for long-term competition survival (Coomes and Grubb, 2000). Species also differ in the types of habitats best suited for them. In this study, we examined the species specific responses of four Florida native wildflowers to establishment and management practices. These wildflowers were: *Coreopsis lanceolata* (lanceleaf tickseed), *Coreopsis leavenworthii* (Leavenworth's tickseed), *Gaillardia pulchella* (blanket flower, firewheel), and *Ipomopsis rubra* (standing cypress). Standing cypress is an annual to be biennial that occurs in north and central Florida on sandhills and dunes (Wunderlin and Hansen, 2003). Blanketflower is an annual or short-lived perennial that commonly grows on disturbed uplands throughout Florida (Wunderlin and Hansen, 2003). Lanceleaf tickseed is a semi-evergreen to evergreen, short-lived perennial and occurs in north and north-central Florida in sandhills and disturbed habitats (Wunderlin and Hansen, 2003). Leavenworth's tickseed is an annual to short-lived perennial, facultative wetland species (Wunderlin and Hansen, 2003). It occurs in a variety of habitats throughout Florida including depression marshes, disturbed wetland, marl prairie, pine rockland, wet flatwoods, wet prairie habitats (Gann et al., 2008). All four species naturally occur along on Florida's roadside ROWs, with Leavenworth's tickseed mostly limited to moist areas like roadside ditches and swales.

Establishing new native wildflower sites by direct seeding on roadside ROWs is not the only means of establishing new plantings of native wildflowers. Preserving and maintaining wildflower populations that naturally occur on ROWs is another approach. Moreover, this approach is consistent with FDOT's 2004 wildflower policy, which includes the need for best management practices "… to identify and protect naturally occurring wildflower stands, and to promote natural regeneration and dispersal of native wildflowers" (FDOT, 2004). Not only is this approach much less expensive than direct seeding, but it is an approach for establishing designated sites of native wildflowers when Florida ecotype seeds are not available, or quantities are too limited for commercial scale seeding operations. In Texas, such an approach was initiated in 1934 (Markwardt, 2005).

A classic example of using appropriate cultural practices to preserve and enhance an existing stand of native wildflowers has been the highly successful recovery of *Harperocallis flava* (Harper's beauty) on the roadside ROW of State Route 65 in the Florida panhandle (USFWS, 1983). *Harperocallis flava* is an endangered species found only in the Florida panhandle (Wunderlin and Hansen, 2008b). Only 100 plants existed on the SR 65 ROW in 1979. In 1980, FDOT modified their mowing schedule to "allow the plants to flower and seed" (USFWS, 1983); herbicide applications were also restricted. As a result of the modified management practices, the number of plants along SR 65 increased to about 6000 in 1983 (USFWS, 1983).

While we have noted the aesthetic and ecological attributes of native wildflower plantings on Florida's roadside ROWs, the cost of establishing and maintaining these plantings must be considered. There is some evidence that such plantings provide an economic benefit. Researchers at Purdue University, in cooperation with the Indiana DOT and the FHWA concluded that while use of local/regional ecotype seeds of native wildflowers were about 1.6 times more expensive to establish compared to garden wildflowers, estimated maintenance costs were more than 10 times less for plantings established with ecotype seeds (Dana et al., 1996). Part of the maintenance cost for plantings of garden wildflowers was reseeding every 3 years; ecotype plantings required no reseeding. Researchers noted that while garden wildflowers would likely be less expensive, other benefits of using ecotype seeds need to be considered, especially erosion control. Erosion is less likely to be a problem in ecotype plantings because of their sustainability. This sustainability also makes such plantings less susceptible to infestation by invasive, exotic species. In Texas, Markwardt (2005) noted that native wildflower plantings required less mowing, thereby reducing maintenance costs about 25% (~ $8 million).

CHAPTER THREE: METHODOLOGY

Objective One: Stand Establishment

Establishment and Performance of Direct-Seeded and Transplants Plots Over 2 Years

Wildflower experiments under simulated roadside conditions were conducted at two University of Florida/IFAS Research & Education Centers—North Florida REC, Quincy and Indian River REC, Ft. Pierce—and at the University of Florida/IFAS Plant Science Unit in Citra, Florida. Experiments at these sites included research plots of wildflower species established by direct seeding as well as by transplanting seedlings (Tables 1, 2). In the direct-seeded and transplant plots, two mowing regimes and three establishment methods were evaluated in a split plot design. The two mowing regimes represented the main plot treatment and differed in the number of times each plot was mowed per year (Tables 3, 4). The three establishment methods represented the subplot treatments and varied between the direct-seeded and transplant plots. In the direct-seeded plots, the establishment methods evaluated were the use of herbicides: 1) glyphosate (Roundup®, Monsanto) at 2.3 L ai/ha applied approximately 4 and 2 weeks before seeding; 2) imazapic (Plateau®, BASF) applied at 0.07 kg ai/ha within 1 day of seeding; and 3) an untreated control (= 'mow only'). All plots were mowed to 5 cm within 1 week before seeding; thatch and clippings were removed prior to seeding. Because bahiagrass was especially dense in Fort Pierce, vegetation was scarified with a conservation planter before seeding.

Experiments with direct-seeded plots were established in early October 2005 at Quincy, Citra, and Ft. Pierce (Table 1). Treatment effects were assessed separately for each species and there were four replicates per site. Replicate plots were 12 m^2 (3 x 4 m) with 1-m perimeter buffers within each plot, 1-m alleys between each plot, and a 10-m buffer strip between each experiment. The seeding rate (pure live seed [PLS]) varied by species: *Coreopsis leavenworthii* – 3.1 kg/ha (2.7 lb/A); *Coreopsis lanceolata* – 6.2 kg/ha (5.5 lb/A); *Gaillardia pulchella* – 1.9 kg/ha (1.7 lb/A); *Ipomopsis rubra* – 6.5 kg/ha (5.7 lb/A). After seeding, plots were rolled with a turf roller to increase seed-to-soil contact and overhead irrigated for approximately 2 weeks to facilitate germination and emergence.

Experiments with transplants were established in spring 2005 at Quincy and Ft. Pierce (Table 2). In the transplant plots, the three establishment methods evaluated were the use of glyphosate (applied as described previously, a prescribed burn the day before transplanting, and an untreated control ['mow only']) (Table 2). Seedlings were produced in cell packs; the root ball of each well-rooted seedling was about 2.5 cm in diameter. Seedlings were transplanted approximately 46 cm on-center. Each replicate plot was 12 m^2 (3 x 4 m) with 1-m alleys between each plot. There was a 10-m buffer strip between each experiment.

In the Ft. Pierce transplant experiment, the research plots were mowed and sprayed with imazapic during the summer of 2005 in order to control a *Cyperus rotundus* (purple nutsedge) infestation. The imazapic application negatively affected the *C. leavenworthii* growing in these plots. While some *C. leavenworthii* seedlings emerged after the herbicide application, by May 2006 the density and percent cover of *C. leavenworthii* were minimal. Therefore, the August evaluation was not conducted and research in these plots was terminated. Results presented for the transplant plots only include those from research plots in Quincy.

Plots were evaluated at all three sites in November/ December, April/ May, and August/September of each year during the project. The final data collection for all sites was November/ December 2007. Density and percent cover were evaluated in the center square meter of each plot. Density counts were for all individuals (adults and seedlings) of the wildflower species. Percent cover was visually estimated by the same observer at each data collection to minimize observer bias (Korb et al., 2003). Percent cover categories included the wildflower species, forbs (broadleaf species, excluding the wildflower species), graminoids (grasses/sedges), bare ground, and standing dead (brown plant material).

An additional study was conducted to obtain information about the number of native wildflower seeds in the seed bank 1 year after seeding. "In fall 2006, eight soil cores (6 cm diameter by 5 cm deep, 141 cm^3) were randomly sampled from each plot (excluding the center square meter), aggregated, and a subsample (282 cm^3) was selected for the seed bank study. Soil samples were spread evenly, to no more than 2 cm deep, over a soilless medium (Fafard #2 Mix, Conrad Fafard, Inc.) in pots (18 cm diameter by 11 cm high). Initially, soil was misted until saturated and subsequently irrigated by drip lines placed underneath the top 2 cm of soil. Pots were arranged in a randomized complete block design in a greenhouse at the University of Florida in Gainesville. A control pot filled only with a soilless medium was included within each block. After 2 months, emerged seedlings were removed from each pot and counted into groups of wildflower species, forbs, and graminoids. The surface soil was stirred in the pots and irrigated. After another 2 months, all emerged seedlings were counted again. The first and second data collections were combined for analysis" (Frances, 2008).

"Aboveground vegetation data [were analyzed] using mixed models with restricted maximum likelihood methodology (PROC MIXED, version 9.1; SAS Institute, Cary, [NC]). Preliminary results indicated significant differences among seasons of data collection; therefore, each season was analyzed separately. Within each season, the fixed factors were mowing regime, establishment method, site, and year of data collection. Random factors were block (from split plot design), block by mowing regime, and block by site. To identify changes in wildflower percent cover and density over time, a repeated measures analysis was added to the model. Density data were log $(x + 1)$ transformed and percent cover data were arcsine square root transformed to meet assumptions of normality and homogeneity of variance. Treatment effects on the seed bank (emerged seedlings) were determined as above, but without the repeated measures analysis. Counts of emerged seedlings were converted from cm^3 to m^2 (McBurney 2005), and log $(x + 1)$ transformed to meet assumptions of normality and homogeneity of variance. Means were separated using least squares means (with PDIFF option) as part of the mixed models analyses; P values were adjusted using the Bonferroni method" (Frances, 2008).

Table 1. Direct-seeded experiments.

Site	**Species**	**Planting date**
Quincy	*Coreopsis lanceolata* *Coreopsis leavenworthii* *Gaillardia pulchella*	Oct. 7, 2005
Citra	*Coreopsis lanceolata* *Coreopsis leavenworthii* *Gaillardia pulchella* *Ipomopsis rubra*	Oct. 5, 2005
Ft. Pierce	*Coreopsis leavenworthii*	Oct. 4, 2005

Table 2. Establishment of *Coreopsis leavenworthii* with transplants.

Site	**Species**	**Planting date**
Quincy	*Coreopsis leavenworthii*	Mar. 31, 2005
Ft. Pierce	*Coreopsis leavenworthii*	Mar.-Apr. 2005

Table 3. Mowing frequency. The timing of mowing treatments was adjusted to allow for flowering and seed set of each wildflower species. Mowing dates were adjusted slightly for *Coreopsis leavenworthii* in Fort Pierce because of earlier flowering due to the warmer climate.

	Species Site			
Mowing Treatment Year	*Gaillardia pulchella* Quincy & Citra	*Coreopsis lanceolata* Quincy & Citra	*Coreopsis leavenworthii* Quincy & Citra	*Coreopsis leavenworthii* Fort Pierce
Mow 2 times/ year				
2006	Mar 15 Oct 15	Mar 1 Oct 15	Apr 1 Oct 15	Mar 1 Oct 1
2007	Mar 15 Oct 15	Mar 1 Oct 15	Apr 1 Oct 15	Mar 1 Oct 1
Mow 6 times/ year				
2005	Dec 1		Nov 15	Nov 15
2006	Jan 1 Feb 15 Mar 15 Jul 1 Oct 15 Nov 15 Dec 15	Jan 1 Mar 1 May 15 Jul 15 Sep 1 Oct 15	Jan 1 Mar 1 Apr 1 Aug 1 Oct 15 Dec 1	Jan 1 Mar 1 Jul 15 Aug 21 Oct 1 Dec 1
2007	Feb 15 Mar 15 Jul 1 Oct 15	Jan 1 Mar 1 May 15 Jul 1 Sep 1 Oct 15	Jan 1 Mar 1 Apr 1 Aug 1 Oct 15	Jan 1 Mar 1 July 15 Aug 21 Oct 1

Table 4. Dates of mowing treatments used in Citra, FL for *Ipomopsis rubra*. The timing of mowing treatments was adjusted to allow for flowering and seeding.

Mowing Treatment Year	*Ipomopsis rubra*
Mow 2 times / year	
2006	Apr 15
	Oct 15
2007	Apr 15
	Oct 15
Mow 6 times / year	
2005	Dec 15
2006	Feb 15
	Mar 15
	Apr 15
	Sep 1
	Oct 15
	Dec 15
2007	Feb 15
	Mar 15
	Apr 15
	Sep 1
	Oct 15

Factors Affecting Establishment of Coreopsis Lanceolata

Factors affecting *C. lanceolata* establishment under simulated roadside conditions within 1 year of planting were investigated. We examined the effects of seed and microsite availability on *C. lanceolata* establishment with and without competition from bahiagrass. Specifically, we wanted to determine whether low levels of wildflower establishment in bahiagrass result from lack of seed availability or from lack of suitable microsites for germination and seedling survival. The study was conducted at the University of Florida/IFAS Plant Science Unit in Citra.

To test for seed availability, plots were seeded on November 6, 2006 at 100 (low), 600 (mid), and 1100 (high) pure live seeds (PLS) per meter squared (1.2, 7, and 12.8 lb PLS per acre, respectively) with a hydraulic seed drill. To test for microsite availability, two factors were examined: irrigation and disturbance of existing vegetation. The three irrigation treatments were: no irrigation (none), a pre-seeding soak (pre), and pre and post-seeding irrigation (full). For the pre-seeding soak treatment, plots were irrigated to approximately 5 cm immediately before seeding. The pre and post-seeding irrigation included the same pre-seeding soak plus 2.5 cm irrigation twice/week for 6 weeks following seeding. The four disturbance treatments were: glyphosate, sethoxydim, scraped, and a nontreated control in which the bahiagrass was not disturbed. The sethoxydim treatment was Poast® applied at 2.6 L/ha (with a surfactant of 83% paraffin base petroleum oil at 2.3 L/ha) at 23 and 30 weeks after seeding (May 2007) when bahiagrass was actively growing. The glyphosate treatment was Roundup Original Max® applied 4 and 2 weeks prior to seeding at 2.3 L/ha, after which the vegetation was mowed to 5 cm (2 days prior to seeding). The scraped treatment was intended to mimic a newly constructed roadside and consisted of removing approximately the top 13 cm of vegetation and soil. This was done 1 week prior to seeding. The coarse removal of soil was done with a motor grader attachment; the soil was then leveled with a box blade attachment. The soil was compacted with a turf roller a few days before planting.

The experiment was arranged in a split-plot design with irrigation as the main plot treatment and seeding rate and disturbance regime as factorial sub plots. The experiment was conducted in two adjacent fields and replicated three times in each field. Each replicate plot was 25 m^2 (5 x 5 m) with at least a 1 m alley between each plot. Percent cover and density data were recorded at 10, 20, 39 and 46 weeks after seeding (WAS). Three 1-m^2 subsamples were randomly placed within each plot to estimate percent cover. Density data were collected in 0.25 x 0.25 m subsamples nested within the 1 m^2 cover subsamples. Percent cover categories were *C. lanceolata*, bahiagrass, forbs (broadleaves, excluding *C. lanceolata*), and graminoids (grasses and sedges, excluding bahiagrass), standing dead, bare ground, and an estimate of the cover occupied by *C. lanceolata* flowers.

"[Data were] analyzed using mixed models with restricted maximum likelihood methodology (PROC MIXED, version 9.1; SAS Institute, Cary, [NC]). The fixed effects were seeding rate (low, medium, high), irrigation (none, pre, full), disturbance (control, sethoxydim, glyphosate, scraped), and the interactions among them. The random effects were block (for field), main plots within blocks, and main plot by sub plot within blocks. Degrees of freedom were approximated with Kenward-Roger's method. Response variables included density, percent cover, and biomass as explained above. To identify changes in percent cover and density over time, a repeated measures analysis was added to the model with an exponential spatial covariance structure (SP(EXP)). Means were separated using least squares means (with PDIFF option) as part of the mixed models analyses; *P* values were adjusted using the Bonferroni method. Percent cover and density data were averaged by subplot for the repeated measures analysis and biomass data were averaged by subplot and converted to a per meter squared basis before analysis. Density data were log $(x + 1)$ transformed, percent cover data were arcsine square root transformed and biomass of *P. notatum*, forbs, and graminoids were square root transformed to meet assumptions of normality and homogeneity of variance" (Frances, 2008).

Effects of Disturbance on the Competition between Bahiagrass and Coreopsis

To complement the field studies, a study was conducted under more controlled conditions to determine the effects of bahiagrass competition on *C. leavenworthii* and *C. lanceolata*. We hypothesized that bahiagrass would be the more competitive species, and that an intermediate frequency of disturbance (i.e., mowing, which was simulated by hand clipping, hereafter referred to as cutting) would result in the highest likelihood of species coexistence. To examine differences in competition based on seasonality, the experiment was planted in fall 2006 and repeated in spring 2007. However, due to high mortality in spring-established *Coreopsis*, only results from fall-established plants will be presented here (see Frances, 2008 for details).

Coreopsis seedlings were transplanted into 27-liter pots in a low density monoculture (one seedling/pot), high density monoculture (seven seedlings/pot), or in a mixture (a single *Coreopsis* seedling surrounded by six bahiagrass seedlings). The *Coreopsis* in the center of the pot was termed the target *Coreopsis*, while the six *Coreopsis* or bahiagrass seedlings surrounding the target *Coreopsis* were termed neighbors. Pots were filled with a soilless medium (Fafard #2 Mix, Conrad Fafard, Inc.). The diameter of the pot was 34 cm and propagules in mixtures and high density monocultures were planted 10.5 cm apart. To focus on effects of cutting, fertilizer and supplemental irrigation were applied so that nutrients and water would not limit growth. Pots were fertilized 8 to 10 weeks after planting (WAP) with one-half the low label rate of Osmocote® 18-6-12 (Scotts Miracle-Gro Company) for 27-liter pots. Supplemental irrigation was provided as needed through pressure-compensated dribble rings so that the amount and distribution of water among and within pots was uniform. Pots were watered until saturated. Pesticides were used to control disease and insect problems as they arose. To simulate disturbance, shoots taller than 10 cm were cut throughout the study, beginning at 17 WAP, every 2 weeks (frequent), every 4 weeks (intermediate), or never (none). Cutting treatments continued until 27 to 28 WAP and were terminated 6 to 8 weeks before plants were harvested for biomass. Cutting treatments were initiated when the majority of plants reached a height >10 cm. The experiment was initiated November 9, 2006. Plants were grown outdoors in full sun in Gainesville.

Biomass from all plants was harvested 8 months after planting. Shoots and roots were separated at the soil line, washed, and dried at 60 to 70^{o}C for 1 week. Belowground growth that could not be separated to species comprised less than 4% of total belowground biomass and was therefore not included in the analysis. *Coreopsis* fitness was assessed by the number of flowers. In the high density monoculture, the number of flowers for the target *Coreopsis* (the plant in the center of the pot) was estimated by counting all flowers in the pot and dividing by the total number of plants present. Flowers were counted 26 and 29 WAP for *C. leavenworthii* and 21 and 29 WAP for *C. lanceolata*.

The experiment was a factorial in a completely randomized design and replicated 10 times. The four treatments were season (fall, spring), species (*C. leavenworthii*, *C. lanceolata*), cutting frequency (none, moderate, high), and planting treatments (two monocultures and four mixtures). "[Data were analyzed] using mixed models with restricted maximum likelihood methodology (PROC MIXED, version 9.1; SAS Institute, Cary, [NC]). The fixed effects were season, species, planting treatment, cutting frequency, and their interactions. Since this was a completely randomized design, there were no random effects in the model. Biomass results of the target *Coreopsis* (above- and belowground) were square root transformed and *Coreopsis* flower counts were log (x + 1) transformed to meet assumptions of normality and homogeneity of variance. Means were separated using least squares means (with PDIFF option) as part of the mixed models analyses; *P* values were adjusted using the Bonferroni method" (Frances, 2008).

Objective 2: Facilitating Spread of Naturally Occurring Wildflowers in South Florida

Three sites with naturally occurring wildflower populations on the Florida Turnpike were located in December 2004. All sites were in northern Miami-Dade County in close proximity to each other (Table 5). *Flaveria linearis* (narrowleaf yellowtops) occurred on two sites and *Coreopsis leavenworthii* occurred on the third site. *Flaveria linearis* is a facultative wetland perennial mainly found in coastal counties of peninsular Florida, with the only documented populations in north Florida in Wakulla and Taylor County (Wunderlin and Hansen, 2008a).

In December 2004, areas with dense concentrations of the targeted wildflower species were delineated with flagging tape to prevent future mowing. The sites were evaluated seven times: March, May, August, and December 2005, and March, May, and September 2006. Sampling plots were established at each site by imposing a 6 x 60 m grid and randomly selecting 15 plots to sample within the grid. Within each plot, vegetation was sampled in an area of 1 m^2 by estimating the percent cover of the wildflower species (either *F. linearis* or *C. leavenworthii*) as well as forbs (broadleaf species), graminoids (grasses, sedges, and rushes), bare ground, and standing dead (brown plant material. During the August 2005 site evaluations, a plant species list was compiled (Tables 6, 7; see pages 31-32).

Due to the infeasibility of excluding mowing at these sites, only one mowing regime was evaluated. The mowing regime reduced mowing from approximately 12 times per year to 2 to 4 times per year. Mowing was excluded from the two *F. linearis* sites from December 2004 to August 2005. The area was mowed from September to December 2005, after the wildflowers had flowered and produced seed. Mowing was excluded again in December 2005 but did not resume again until January 2007, even though the flags to exclude mowing were removed in September 2006.

At the *C. leavenworthii* site, mowing was excluded from December 2004 to August 2005 but did not resume again until early 2006, even though the flags to exclude mowing were removed. Mowing was probably hindered due to high water levels and the presence of large debris left by the hurricanes. By February 2006, the large debris had been removed and the tall, woody shrubs had been cut back. Also, the *Panicum repens* (torpedograss) that was invading part of the site had been sprayed with an herbicide. The encroachment of tall, woody vegetation in addition to the herbicide application seems to have reduced this wildflower population. In May 2006, *C. leavenworthii* occurred in only one-third of the research plots compared to over two-thirds when the project started. Therefore, research at this site was terminated in September 2006 and results are not presented here.

Objective 3: Best Management Practice Publications

See Results and Discussion, p. 33

Table 5. Locations and species of south Florida sites with naturally occurring wildflower populations.

Location (Florida Turnpike)	Species
Approximately MM 40.7, Southbound	*Flaveria linearis*
Approximately MM 38.9, Southbound at I-75 interchange	*Flaveria linearis*
Okeechobee Entrance Ramp, Northbound	*Coreopsis leavenworthii*

Objective 4: Economics

The economics of establishing native wildflower plantings is based on information gleaned from a complementary grant project* conducted in cooperation with Les Harrison, an agricultural economist with the Leon County Extension Service. Cost estimates were based on information obtained from FDOT and county personnel. Since the final report for cost analyses has not been submitted to the USDA, only conclusions and recommendations will be presented here.

***** *The Economics of Marketing Localized Eco-Type Native Wildflower Seed to State Departments of Transportation*; funded by The Federal State Market Improvement Program, Agricultural Marketing Service, United States Department of Agriculture.

CHAPTER FOUR: RESULTS AND DISCUSSION

Objective One: Stand Establishment

Establishment and Performance of Direct-Seeded and Transplants Plots Over 2 Years

*Direct-seeded plots***.** The preparation of planting sites in early fall with two applications of glyphosate to bahiagrass followed by mowing and thatch/clippings removal within 1 week of seeding clearly increased establishment of all wildflower species compared to the 'mow only' (control) and imazapic treatments (Fig. 1). However, overall wildflower establishment varied by species. While *Coreopsis lanceolata* cover in the glyphosate-treated plots was high throughout the study and with few seasonal fluctuations, *C. lanceolata* also became relatively well-established in the 'mow only' treatment.

In contrast, *C. leavenworthii* establishment varied by site and over time, with overall cover gradually declining regardless of site (Fig. 1). The overall decline was likely due to site conditions and the short-lived nature of this species. *Coreopsis leavenworthii* is a facultative wetland species. While wetland conditions are not an absolute requirement, *C. leavenworthii* is more likely to be most competitive and exhibit long-term sustainability in moist sites. For example, a population of *C. leavenworthii* in a periodically flooded swale at the Quincy research center not only has sustained itself for several years but has expanded. None of the sites in this study, however, would be considered wetland sites. For example, in Citra, which is part of an upland, xeric habitat, establishment was lower than in Quincy and Fort Pierce.   Additionally, *C. leavenworthii* is an annual to short-lived perennial that often dies after flowering. The seasonal mortality of this species may have created gaps that were colonized by bahiagrass and broadleaf species from the seed bank. These species, in turn, likely limited the growth (and increase in cover) of *C. leavenworthii* seedlings.

For *Gaillardia pulchella*, the glyphosate treatment increased cover but establishment of this species was lower than that of the other wildflower species (Fig. 1). Cover of *G. pulchella* remained below 25% throughout the study. This may have been caused by seeding at a lower seeding rate than the other species. Although the *G. pulchella* population was small, it did not appear to decrease over time, aside from seasonal fluctuations in cover.

The trend of the positive effect of glyphosate on wildflower establishment was also demonstrated for *Ipomopsis rubra* in Citra (Fig. 2). While there was no clear advantage of the glyphosate treatment within the first 6 months after seeding, the glyphosate effect was evident by August 2006, about 10 months after seeding, mostly likely because *I. rubra* blooms in late summer and increases in cover are most apparent during full bloom. Percent cover of this

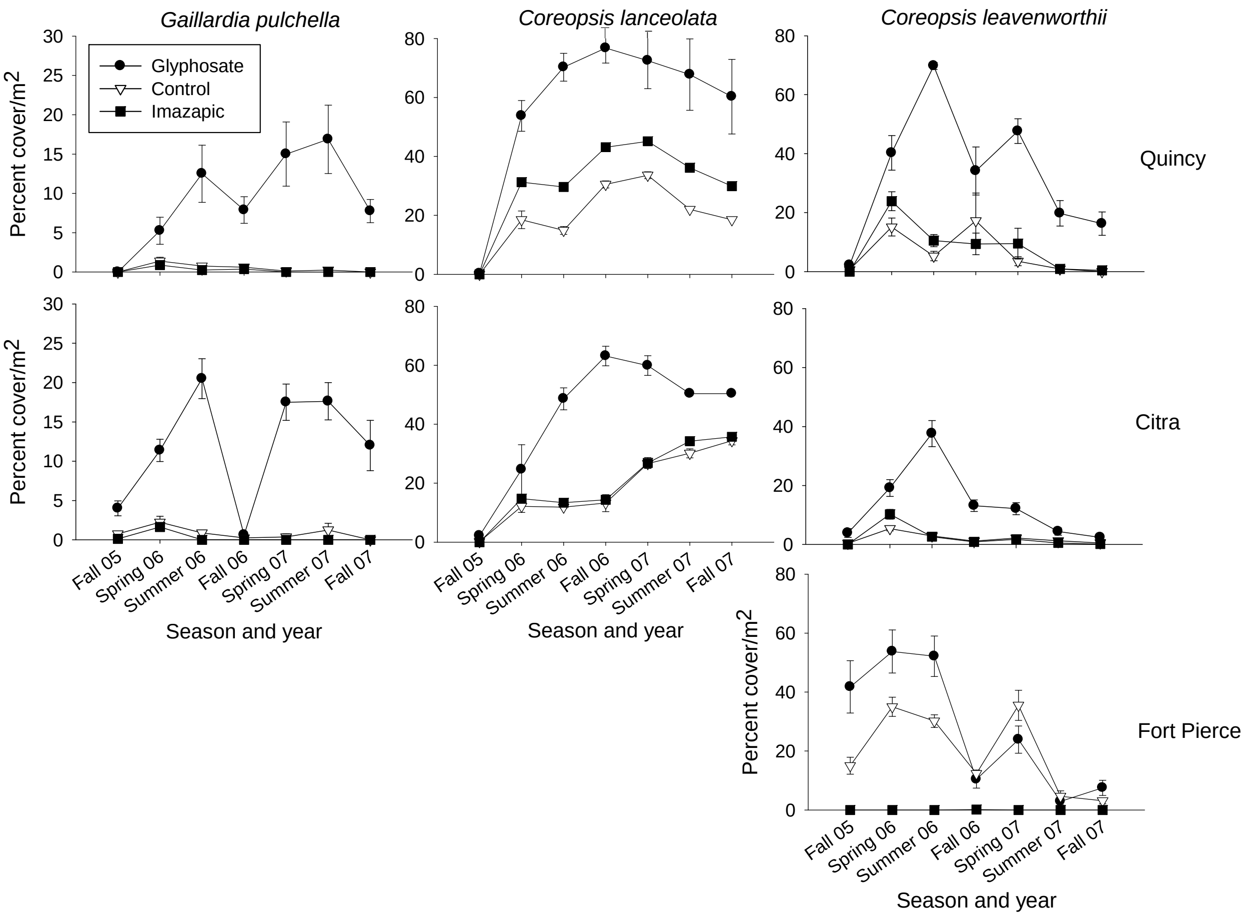

Figure 1. Effects of establishment treatment (pre-seeding herbicide: control, glyphosate, and imazapic) on mean (± 1 SE) percent cover of direct-seeded *Gaillardia pulchella*, *Coreopsis lanceolata*, and *C. leavenworthii* by site, season, and year. Copyright 2008, Anne Frances. Used with permission.

narrowly upright species was over 30% while coverage in the 'mow only' and imazapic plots was about 5% or less. Percent cover in the glyphosate plots gradually declined to about 15% by fall 2007; coverage in the other plots remained at 5% or less. The lower coverage of this upland species compared to *C. lanceolata* was likely due to its narrow, upright nature. Because *I. rubra* is a biennial rather than a perennial, about half the population died back after flowering, leaving empty space that bahiagrass and other species could colonize.

Mowing did not affect cover, density, or number of seedlings emerging from the seed bank of any of the wildflower species in this study (results not shown; Frances, 2008). Hence, mowing twice per season was adequate to maintain wildflower populations. The species specific mowing schedules that were adjusted for the flowering and seed set of each wildflower species (Tables 3, 4) was the likely reason for the lack of any significant effects of mowing. Appropriate timing of mowing is especially critical for annual and short-lived perennial species such as the ones in this

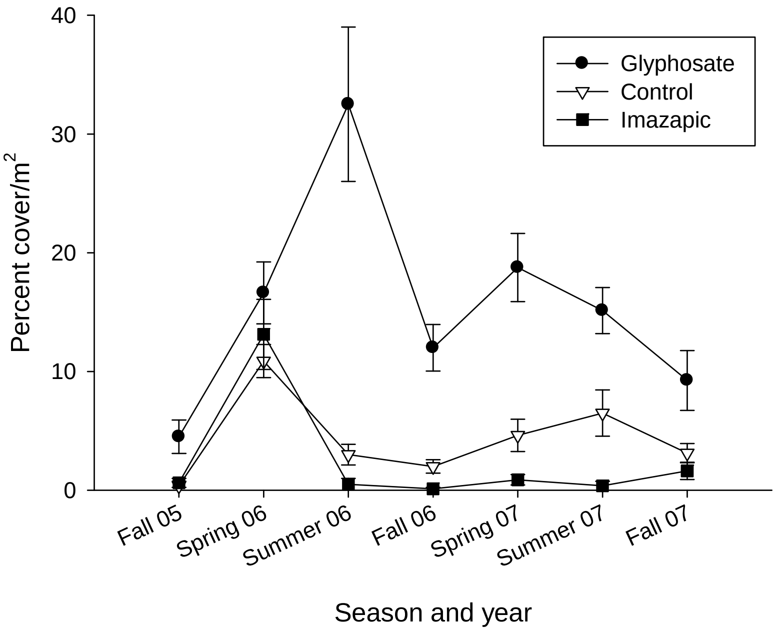

Figure 2. Effects of establishment treatment (pre-seeding herbicide: control, glyphosate, and imazapic) on mean (± 1 SE) percent cover of direct-seeded *Ipomopsis rubra* in Citra.

study. Such species rely on seedling recruitment derived from viable seeds in the seed bank for the population to sustain itself (Rees, 1997; Norcini et al., 2003).

Given the importance of wildflowers banking seeds in order to sustain the population, results of the seed bank study were interesting in that the aboveground vegetation differed markedly from the seed bank composition, an effect which varied by species. One year after the initial seeding, *C. leavenworthii* seeds dominated the seed bank in the glyphosate treatment (Fig. 3). However, this was not expressed in aboveground growth for *C. leavenworthii* in Fort Pierce or Citra. Conversely, in glyphosate treated plots, *C. lanceolata* was the dominant species aboveground but did not comprise the majority of seeds in the seed bank (Fig. 4). *Gaillardia pulchella* neither dominated the seed bank community nor the aboveground vegetation (Fig. 5). Studies on the establishment of perennial native forbs in grass-dominated communities also found differential effects by species (Fenner, 1978; Brown and Bugg, 2001). The number of *I. rubra* seedlings emerging from the soil seed bank in fall 2006 was also greater in the glyphosate treatment than the control and imazapic treatments, but there was no difference in *I. rubra* seed bank density between the imazapic and control treatments (Fig. 6).

The small proportion of graminoids (grasses/sedges) in the seed bank suggests that regeneration of grasses and sedges, particularly bahiagrass, after glyphosate treatment, occurs vegetatively rather than through seeds. Forbs (broadleaves) occupied the majority of the seed bank, reinforcing the benefits of a no-till system on roadsides or simulated roadsides. While tilling would decrease bahiagrass competition, it would also increase competition from

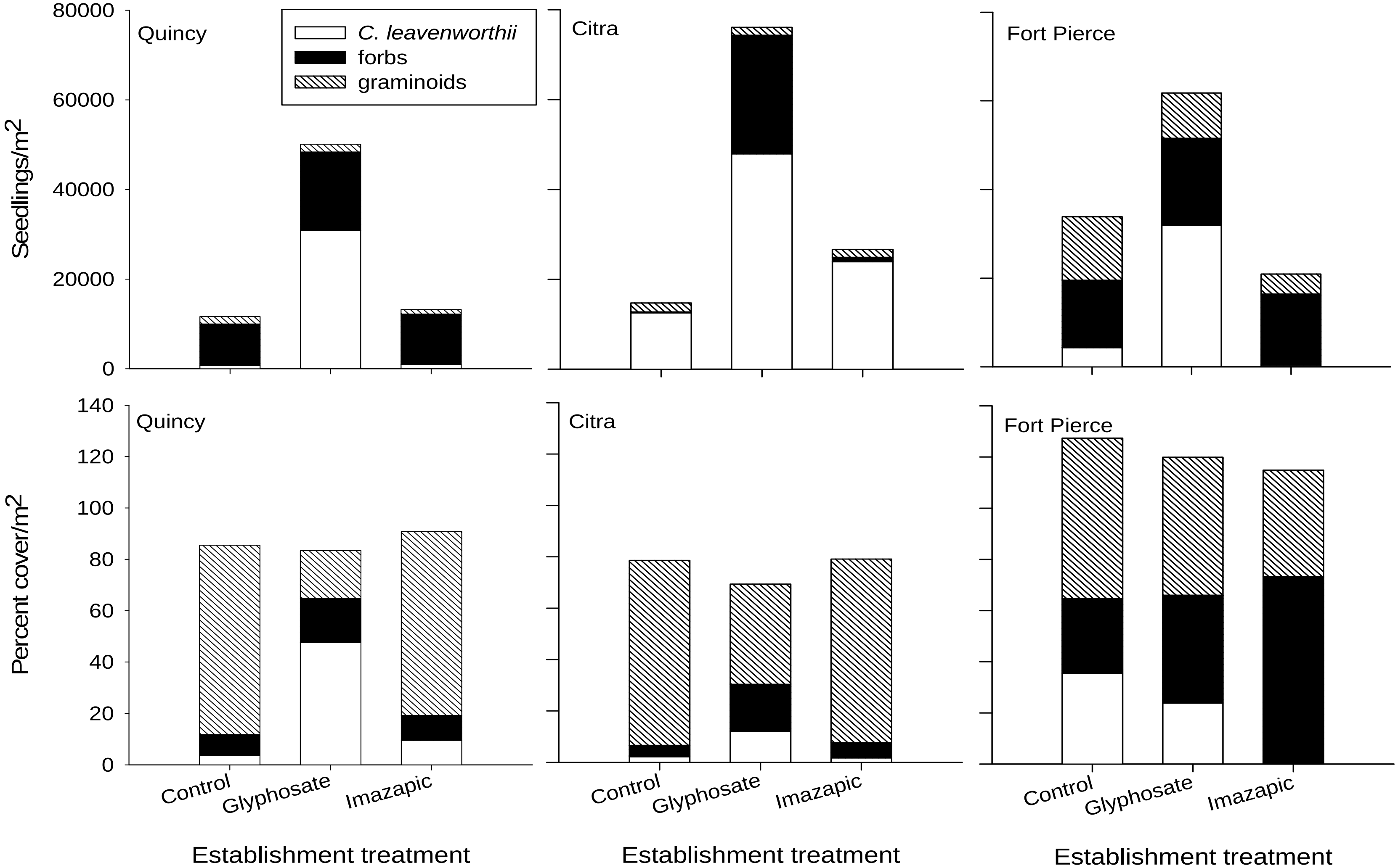

Figure 3. Composition of *Coreopsis leavenworthii*, forbs, and graminoids in the seed bank in fall 2006 (emerged seedlings/m^2, top graphs) and as aboveground vegetation in spring 2007 (percent cover/m^2, bottom graphs) in Quincy, Citra, and Fort Pierce. Copyright 2008, Anne Frances. Used with permission.

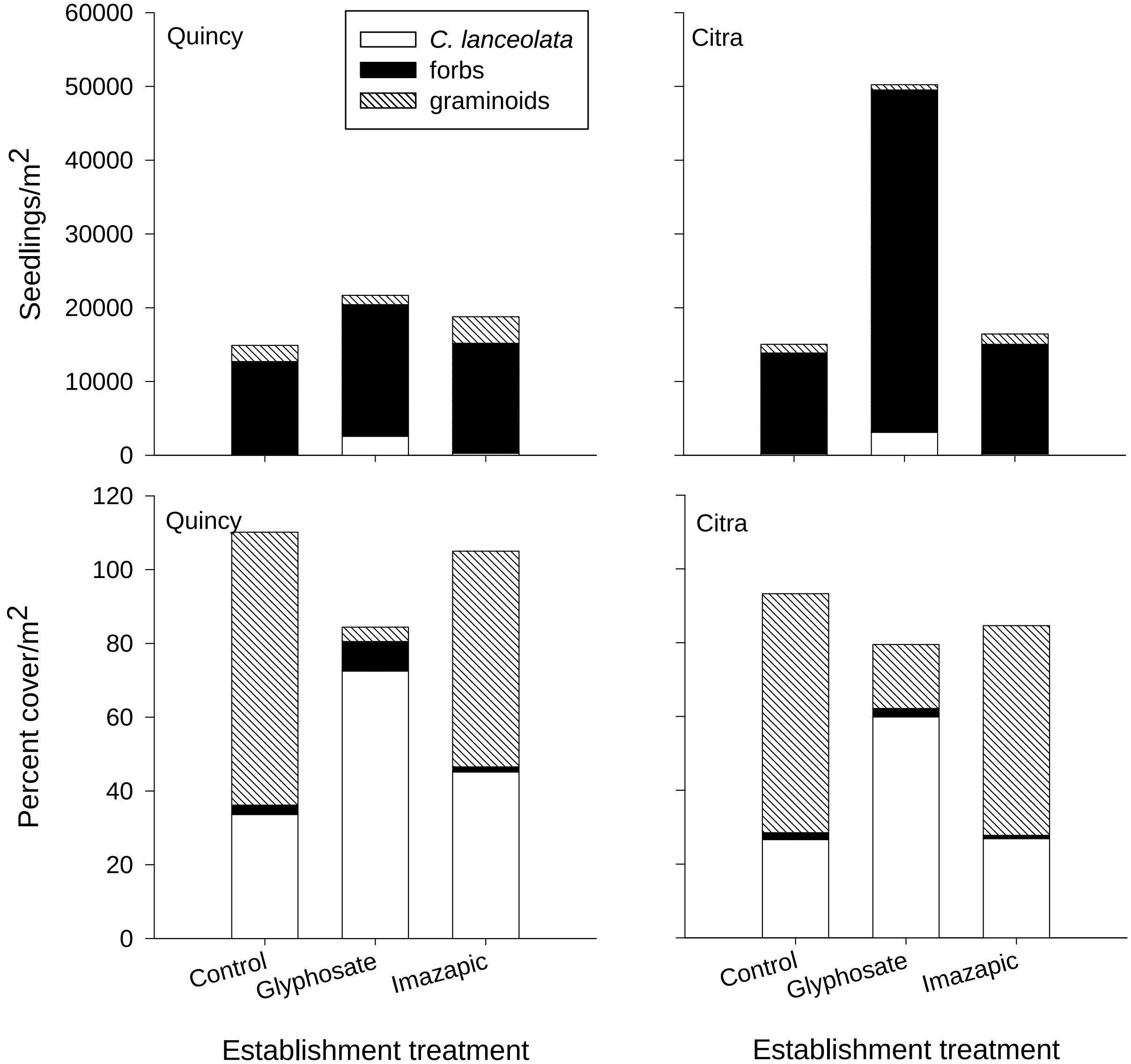

Figure 4. Composition of *Coreopsis lanceolata*, forbs, and graminoids in the seed bank in fall 2006 (emerged seedlings/m^2, top graphs) and as aboveground vegetation in spring 2007 (percent cover/m^2, bottom graphs) in Quincy and Citra. Copyright 2008, Anne Frances. Used with permission.

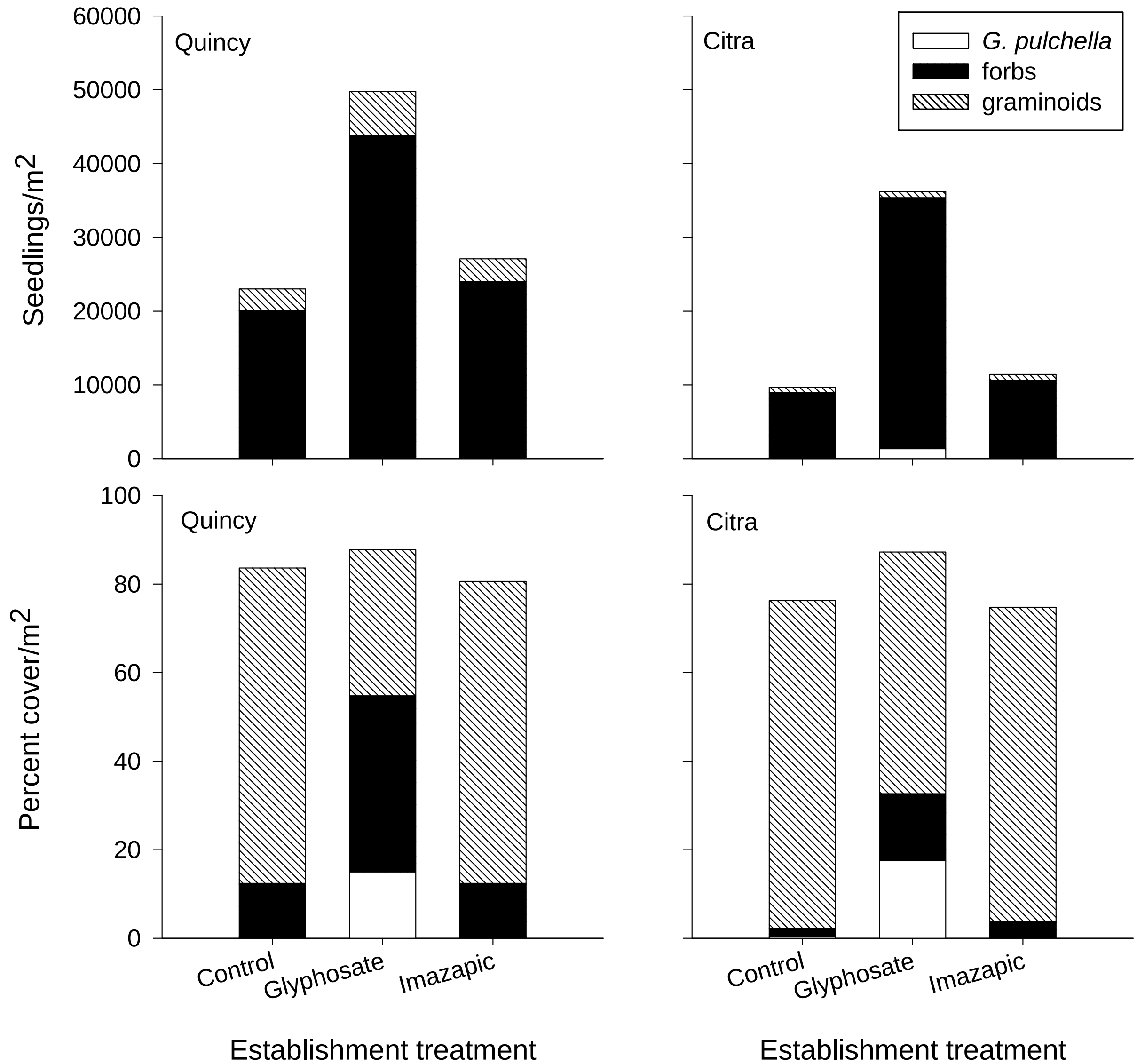

Figure 5. Composition of *Gaillardia pulchella*, forbs, and graminoids in the seed bank in fall 2006 (emerged seedlings/m^2, top graphs) and as aboveground vegetation in spring 2007 (percent cover/m^2, bottom graphs) in Quincy and Citra. Copyright 2008, Anne Frances. Used with permission.

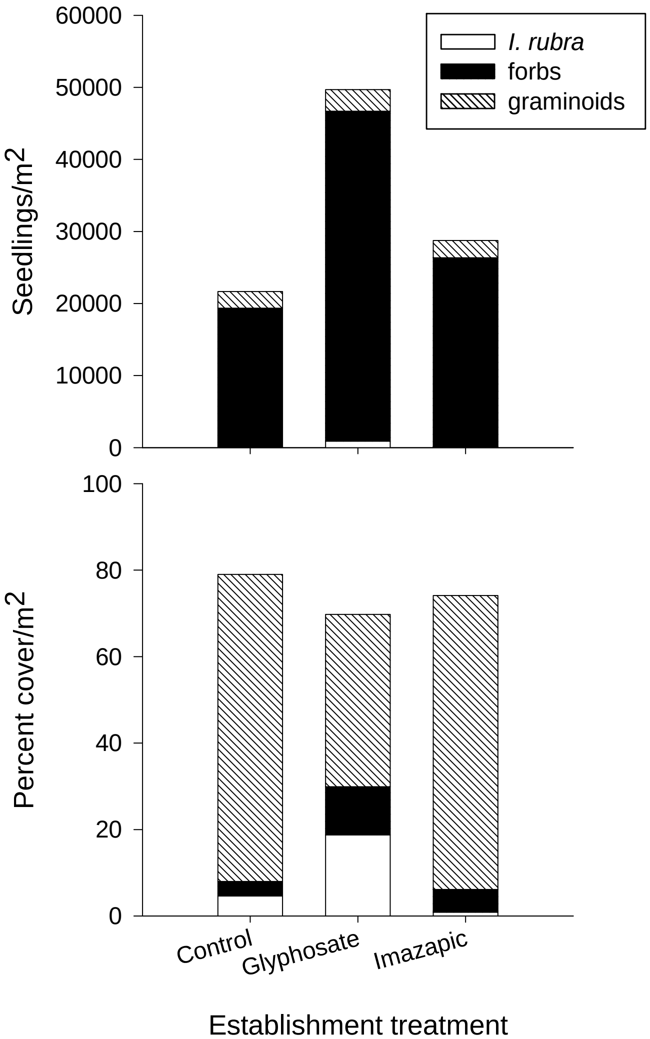

Figure 6. Composition of *Ipomopsis rubra*, forbs, and graminoids in the seed bank in fall 2006 (emerged seedlings/m^2, top graphs) and as aboveground vegetation in spring 2007 (percent cover/m^2, bottom graphs) in Citra.

broadleaf weeds emerging from the seed bank.

Transplant plots. At Quincy**,** percent cover of *Coreopsis leavenworthii* in transplant plots generally appeared to be higher in the glyphosate treated plots than in the prescribed burn and control plots (based on visual estimations, Fig. 7). However, percent cover gradually declined over time as with the direct-seeded plots. After *C. leavenworthii* flowered and above-ground vegetation decreased, grasses and other vegetation had filled in much of the area in the glyphosate treated plots (results not shown), perhaps limiting growth of *C. leavenworthii* through competition.

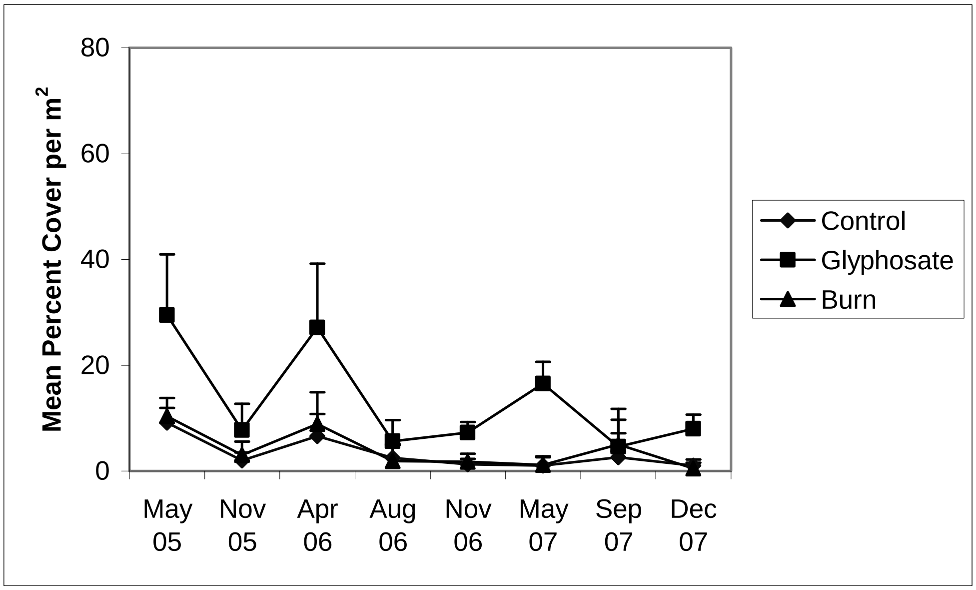

Figure 7. Mean percent cover (+ 1 SD) of transplanted *Coreopsis leavenworthii* by establishment (herbicide or burn) treatment from spring 2005 through fall 2007 in Quincy. In general, glyphosate resulted in the greatest wildflower cover.

Factors Affecting Establishment of Coreopsis Lanceolata

As occurred in the previous field study, the best establishment of *C. lanceolata* was with the glyphosate treatment regardless of seeding rate or irrigation treatment (Fig. 8). Density was greater in glyphosate-treated plots than in scraped plots but equal to that of bahiagrass and sethoxydim-treated plots. Density changed little from 10 to 20 weeks, while percent cover was greater in most treatments at 20 than at 10 weeks. This indicates that most germination of *C. lanceolata* occurred within the first 10 weeks of seeding and that subsequent increases in percent cover can be attributed to the existing seedlings increasing in size. However, while *C. lanceolata* germinated in dormant, unmowed bahiagrass, the resulting seedlings were much smaller than those in the glyphosate-treated plots. There were no differences in density between the bahiagrass and glyphosate-treated plots at 10 and 20 weeks after seeding but by the end of the study, density was greater in glyphosate-treated plots than in all other treatments.

Removing the topsoil resulted in the lowest density of *C. lanceolata* but not the lowest cover (Fig. 8). Moreover, while this site preparation treatment increased *C. lanceolata* cover somewhat compared to the control, removing topsoil also increased the colonization by broadleaf weeds. Since removing topsoil likely removed most, if not all, of the weed seed bank, weeds that emerged were likely to have blown in from adjacent agricultural fields. The majority of broadleaf weeds were agricultural weeds like *Rumex* sp. (dock) and *Indigofera hirsuta* (roughhairy indigo). Most of the broadleaf weeds that colonized the scraped plots occurred in nearby agricultural fields. Removing topsoil created large patches of bare ground where

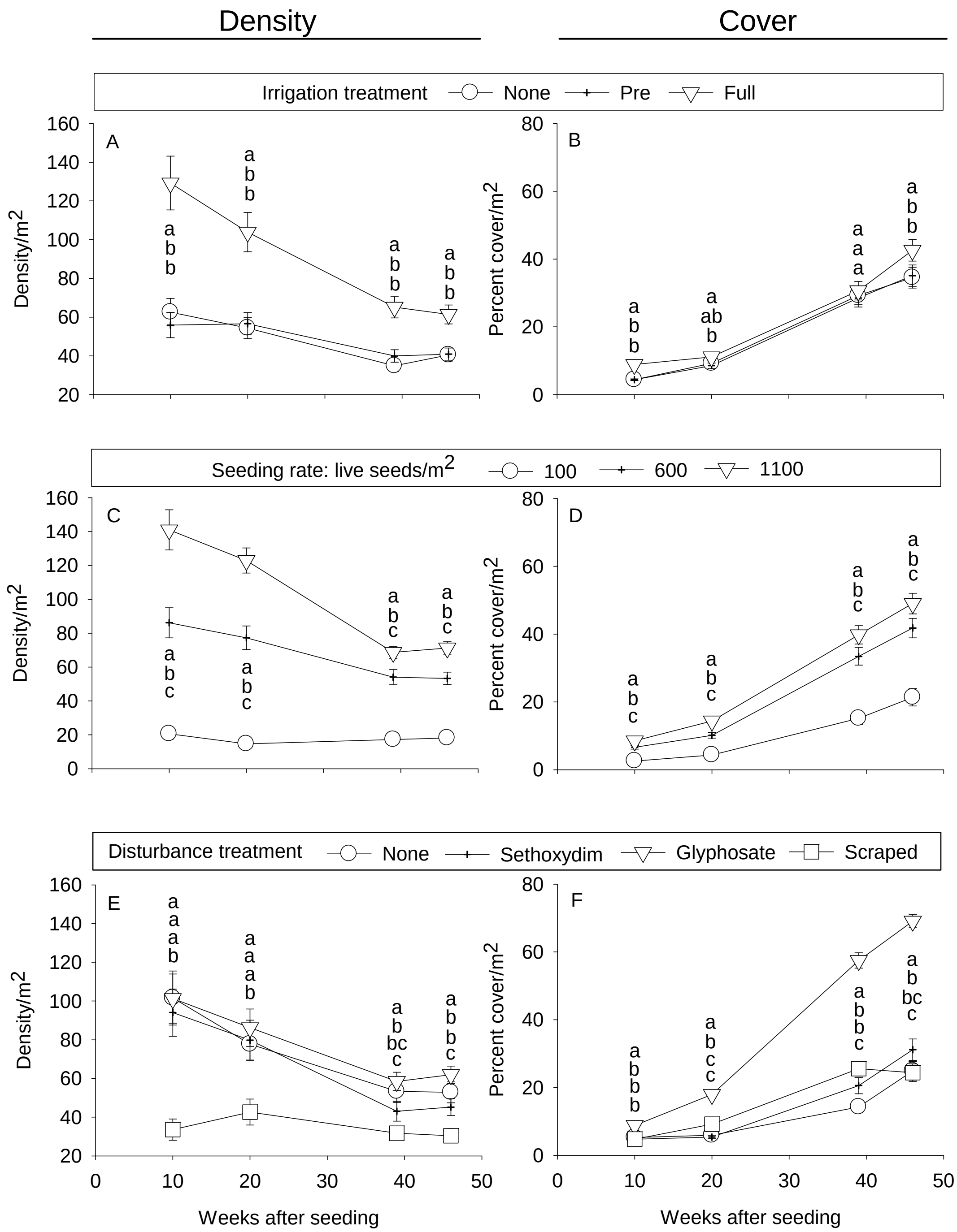

Figure 8. Effects of irrigation (graphs A and B), seeding rate (graphs C and D), and disturbance (graphs E and F) treatments on mean (± SE) *Coreopsis lanceolata* density (individuals/m^2; graphs A, C, E) and percent cover (graphs B, D, F). Different letters within each column indicate significant differences ($P < 0.05$; Bonferroni correction). Analysis was performed on log (x + 1) transformed density data and arcsine square root cover data; untransformed means are presented here. Means are presented separately for each main effect because there were no significant interactions by the end of the study. Copyright 2008, Anne Frances. Used with permission.

colonizing plants (i.e., weeds) established more quickly than *C. lanceolata.*

Density was greater will the full irrigation treatment throughout the study; however, cover was greater with the full irrigation treatment only at the beginning and at the end of the study (Fig. 8). There was no difference between the pre and no irrigation treatments for *C. lanceolata* density or cover (Fig. 8).

Coreopsis lanceolata establishment was limited when seeded at 100 live seeds/m^2 (1.2 lb PLS/acre); an acceptable, showy stand resulted from seeding at 600 live seeds/m^2 (7 lb PLS/acre) (Fig. 8). Seeding at 1100 live seeds/m^2 (12.8 lb PLS/acre) provided little additional benefits to overall *C. lanceolata* establishment**.** However, increasing the seeding rate decreased cover of bahiagrass, forbs (broadleaf weeds), and graminoids (grasses/sedges) (results not shown).

Applying sethoxydim surprisingly provided limited long-term benefit to establishment **–** coverage of *C. lanceolata* was greater compared to the control at 39 WAS but by the end of the study coverage was the same as the control treatment.

In summary, treatment differences in *C. lanceolata* density and percent cover throughout the study suggest that 1) requirements for seedling emergence are less stringent than those for plant establishment, 2) seeding of *C. lanceolata* at 7 lb PLS/acre resulted in an acceptable, showy stand, and 3) seeding at 12.8 lb PLS/acre had limited increased benefit compared with seeding at 7 lb PLS. In addition, grasses and sedges, other than bahiagrass, comprised only a small percentage of the vegetation found in these plots and were mostly represented by common sedges (*Cyperus* spp.); native grasses were nearly absent. These results suggest that while introducing a single native wildflower species may be a short term solution in converting a bahiagrass dominated ROW to native habitat, seed introductions of a suite of native grasses and wildflowers probably would be necessary to develop ROWs into a species rich native community.

Effects of Disturbance on Competition between Bahiagrass and Coreopsis

Competition from bahiagrass reduced biomass of both *Coreopsis* species established in the fall but, interestingly, not as much as competition from other *Coreopsis* plants (Fig. 9). In addition, survival of *C. lanceolata* (~83%) was greater than that of *C. leavenworthii* (~67%), even though *C. leavenworthii* biomass was greater than that of *C. lanceolata* (Fig. 9). Cutting frequency affected competitive interactions between species. For both *Coreopsis* species, shoot biomass was greatest when target plants were not cut (Fig. 10). The same trend was observed for root biomass of *C. lanceolata*, but *C. leavenworthii* root biomass was not affected by cutting frequency. Neighbor plants, however, were not affected by cutting. They likely compensated for loss in height due to cutting by width increases as they were able to extend growth beyond the perimeter of the pot. Shoot and root biomass of bahiagrass were not affected by cutting frequency when grown with *C. leavenworthii*. However when grown with *C. lanceolata*,

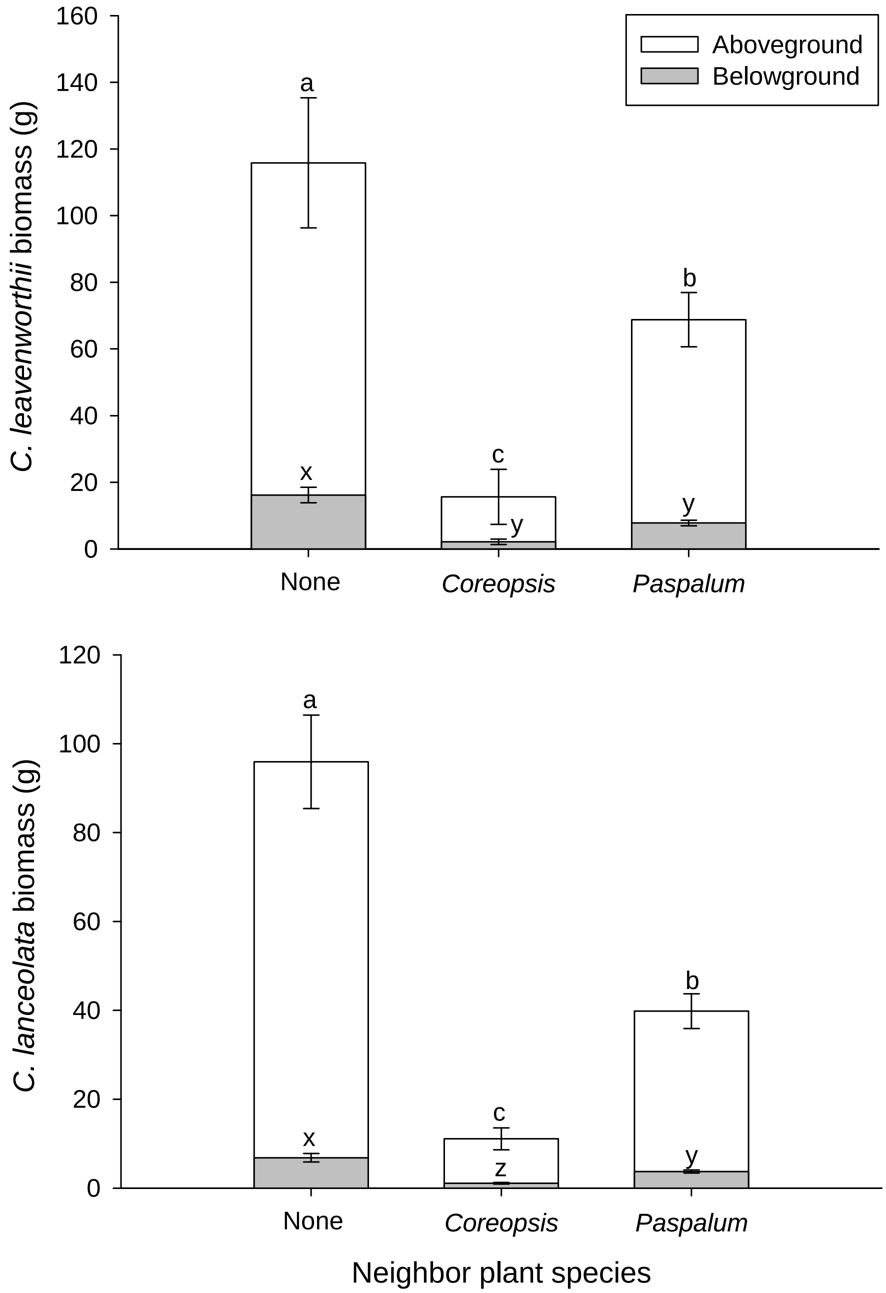

Figure 9. Effects of neighbor plant species (none, conspecific *Coreopsis*, or *Paspalum*) on above- and belowground biomass of the target (center) *Coreopsis* in fall-established plants growing in containers. Means (± 1 SE) with different letters within a graph (target species) and above- and belowground biomass differ significantly ($P < 0.05$, Bonferroni correction). Above- and belowground biomass of the target *Coreopsis* were square root transformed for analysis; untransformed means are presented here. Means were averaged across cutting treatments. Copyright 2008, Anne Frances. Used with permission.

bahiagrass shoot biomass was greatest when bahiagrass was cut once per month. Much of the bahiagrass biomass is stored in the rhizomes, which were not affected by cutting frequency. In addition, cutting was stopped 6 to 8 weeks before bahiagrass was harvested, a time which corresponded with increased growth and flowering. Hence, bahiagrass may have been able to compensate for loss of biomass due to cutting.

For flowering (results not shown), which is an indicator of potential seed production and overall plant fitness, mean number of *C. leavenworthii* flowers was greater than that of *C. lanceolata*. Bahiagrass neighbors reduced flowering of the target *C. leavenworthii*; however, *C. leavenworthii* neighbors did not reduce target *C. leavenworthii* flowers compared to plants grown alone. The presence of *Coreopsis* and bahiagrass neighbors reduced *C. lanceolata* flowers compared to plants grown alone. Cutting once or twice per month reduced the mean number of *C. leavenworthii* flowers compared to no cutting (averaged across planting treatments). For *C. lanceolata*, cutting twice per month decreased the number of flowers compared to no cutting or cutting once per month.

In summary, bahiagrass is a strong competitor with *C. lanceolata* and *C. leavenworthii*. While competition of the neighbor *Coreopsis* species reduced biomass of the target *Coreopsis* equally or more so than by competition from bahiagrass, fitness of the population was reduced more by bahiagrass neighbors than by *Coreopsis* neighbors. Competition from bahiagrass affected the two *Coreopsis* species differently. For example, *C. lanceolata* survivorship was greater than that of *C. leavenworthii*, while biomass of *C. leavenworthii* was greater than that of *C. lanceolata*. Additionally, *C. leavenworthii* produced more flowers than *C. lanceolata*. Disturbance (cutting), which can reduce competition for light in some circumstances (Lepš 1999), did not increase the ability of *Coreopsis* species to coexist with bahiagrass, at least under the conditions and time limits of this study. Cutting in this study occurred once or twice per month, perhaps too frequent to foster species coexistence. Frequent cutting may have promoted bahiagrass growth due to bahiagrass' ability to regrow from a stem at ground level.

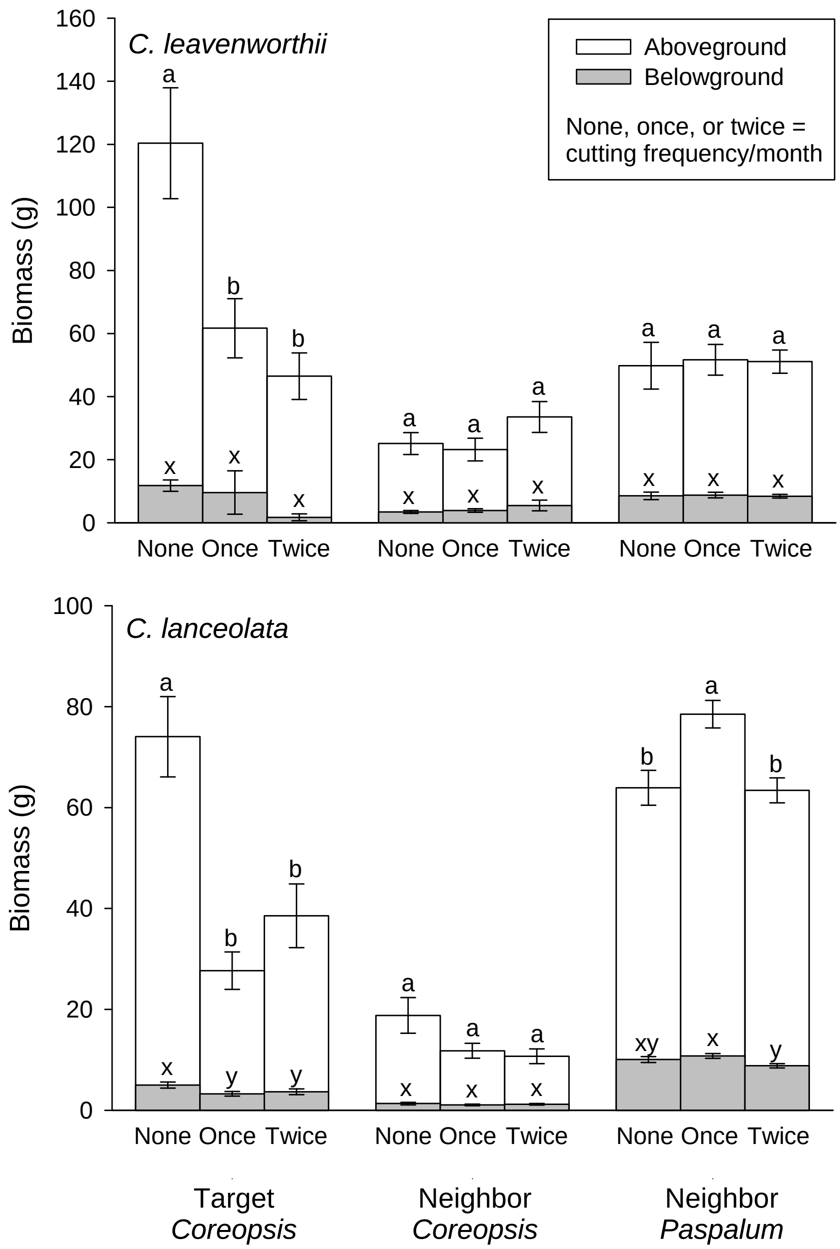

Figure 10. Effects of cutting frequency on above- and belowground biomass of the target (center) *Coreopsis*, neighboring *Coreopsis*, and neighboring *Paspalum* in fall-established plants growing in containers. *Coreopsis* indicates *C. leavenworthii* in the top graph and *C. lanceolata* in the bottom graph. Means (± 1 SE) with different letters within a group (target, neighbor *Coreopsis*, or neighbor *Paspalum*) and above- and belowground biomass differ significantly ($P < 0.05$, Bonferroni correction). Above- and belowground biomass of the target *Coreopsis* were square root transformed for analysis; untransformed means are presented here. Total neighbor biomass per pot was divided by number of neighbors (generally six) to compare with target biomass on a per plant basis. Means for cutting frequencies were averaged across planting treatments. Copyright 2008, Anne Frances. Used with permission.

Objective 2: Facilitating Spread of Naturally Occurring Wildflowers in South Florida

While the effect of reduced mowing on *Flaveria linearis* was similar at both sites, density and percent cover of *F. linearis* were much greater at the I75 site than at the MM 40 site (Fig. 11). Based on these results, the I75 site would be suitable to be a FDOT designated wildflower site. Although the *F. linearis* population was small at the MM 40 site, it is part of a habitat occupied by mostly native wetland species. The regular mowing regime for this area (12 to 15 times per year) did not allow the majority of the plants to flower and produce seed. Therefore, the site at MM 40 would be suitable to be designated a native wetland conservation area, with reduced mowing.

Results of the study suggest that the number of mature *F. linearis* increased from 2005 to 2006, while percent cover was consistent from 2005 to 2006 (Fig. 11). Seasonal fluctuations in percent cover reflected the mowing cycle, with a decrease in cover in December after mowing occurred from September through December. The increase in density from 2005 to 2006 likely reflected new plants, which resulted from the seeds produced while mowing was excluded in 2005. Although the long-term effects of reduced mowing on *F. linearis* cannot be inferred from this study, excluding mowing from January to August/September allowed the *F. linearis* to flower and set seed in both 2005 and 2006.

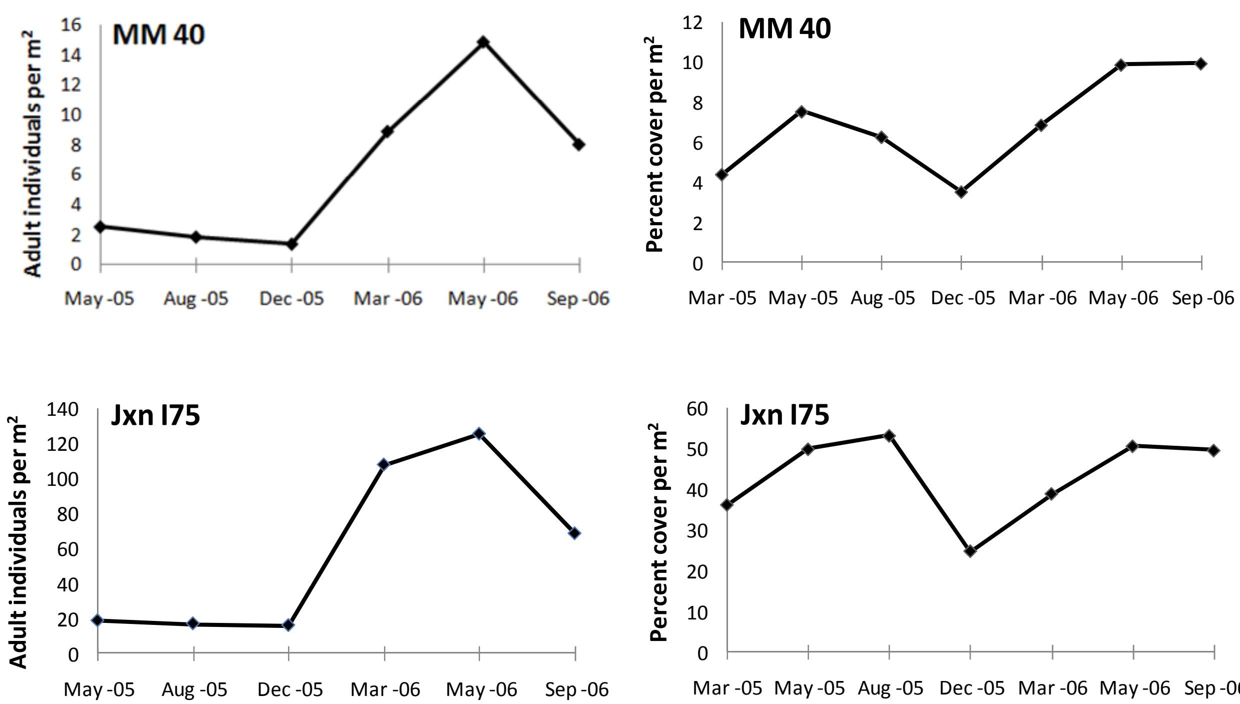

Figure 11. Changes in density (left) and coverage (right) of naturally occurring *Flaveria linearis* at two sites (near the junction of I75 and near mile marker (MM) 40) southbound on the Florida Turnpike in north Miami-Dade County. Sites were not mowed from January to August in 2005 and January to September in 2006. Note the differences in the y-axis scales.

In areas adjacent to the study site with continuous mowing, flowering and seed set of *F. linearis* individuals was very limited.

Based on the results of this study, mowing of naturally occurring stands of *F. linearis* should be timed to maximize natural reseeding, that is, when the majority of *F. linearis* flowers have turned brown. Although peak flowering typically is summer to fall, *F. linearis* can bloom throughout the year. Additionally, the flowering season and duration may be altered by mowing. Sites should be mowed at least once per year to maintain conditions that will favor sustainability and spread of *F. linearis*. Mowing less frequently, or delaying mowing for too long, could result in decline of the *F. linearis* stand due to competition from successional species (for example, woody plants) or aggressive weed species. Since *F. linearis* often occurs in or near wetlands with soft soil, mowing should be done carefully to avoid scalping the soil. Scalping damages or removes any vegetation present and may facilitate the spread of faster growing non-native species like torpedograss (*Panicum repens*).

In both study sites, *F. linearis* did not occur in areas that were planted with bahiagrass (Tables 5 and 6). However, *F. linearis* did co-occur with native grasses such as bushy bluestem (*Andropogon glomeratus var. pumilus*), arrowfeather threeawn (*Aristida purpurascens*), Elliot's lovegrass (*Eragrostis elliottii*), and pinewoods fingergrass (*Eustachys petraea*). *Flaveria linearis* also grew alongside wildflowers such as blue mistflower (*Conoclinium coelestinum*), pineland heliotrope (*Heliotropium polyphyllum*), and beggarticks (*Bidens alba*), and sedges such as starrush whitetop (*Rhynchospora colorata*) and spreading beaksedge (*Rhynchospora divergens*).

Native plant communities that have high densities of *F. linearis* and low densities of aggressive weeds will likely not need to be managed for competing vegetation (other than mowing once per year as described above). However, during periods when normal mowing (6 to 8 inches) is excluded, the existing vegetation may grow taller than acceptable according to FDOT guidelines. The tall vegetation may be managed without affecting *F. linearis* by mowing at a height of 10 to 12 inches.

The results of our study suggest that existing stands of *F. linearis* that cover at least 20% of the site seem to be suitable for developing into aesthetically appealing stands of wildflowers in south Florida. Sites with less than 20% *F. linearis* cover but with a majority of native species may be preserved as native habitat. However, avoid sites that are covered by more than a small percentage of aggressive weeds. Mow suitable sites at least once per year, after seed set of *F. linearis*, and avoid the use of any supplemental fertilizer.

Table 6. Species present at Southbound Turnpike HEFT Mile Marker 40.7.

Native Species	**Native species, cont'd.**
Andropogon glomeratus var. *pumilus*	*Sacciolepis striata*
Aristida purpurascens	*Sagittaria lanceolata*
Axonopis fissifolius	*Scleria verticillata*
Bacopa caroliniana	*Setaria parviflora*
Bacopa monnieri	*Sida acuta*
Bidens alba var. radiata	*Stylosanthes hamata*
Boehmeria cylindrica	
Buchnera americana	**Non-Native Species**
Centella asiatica	*Caperonia palustris*
Conoclinium coelestinum	*Cuphea carthagenensis*
Croton glandulosus var. *glandulosus*	*Fimbristylis cymosa*
Cyperus haspan	*Phyllanthus urinaria*
Cyperus polystachyos	*Panicum repens*
Desmodium incanum	*Richardia grandiflora*
Dichanthelium dichotomum	*Sacciolepis indica*
Eleocharis geniculata	*Spermacoce verticillata*
Eragrostis elliottii	
Eustachys petrae	
Flaveria linearis	
Fuirena breviseta	
Heliotropium polyphyllum	
Hydrocotyle umbellata	
Juncus megacephalus	
Leersia hexandra	
Ludwigia microcarpa	
Ludwigia octovalvis	
Ludwigia repens	
Mecardonia procumbens	
Mikonia scandens	
Mitreola petiolata	
Mitriola sessilifolia	
Panicum rigidulum	
Paspalum cespetosum	
Passiflora suberosa	
Phyla nodiflora	
Phyllanthus caroliniensis ssp. *saxicola*	
Pluchea rosea	
Poinsettia cyathophora	
Polygonum hydropiperoides	
Polygonum punctatum	
Pontedaria cordata	
Proserpinaca palustris	
Rhynchospora colorata	
Rhynchospora divergens	
Rhynchospora microcarpa	
Rhynchospora odorata	

Table 7. Species present at Turnpike and I-75 in northern Miami-Dade County.

Native Species	**Non-Native Species**
Andropogon glomeratus var. *pumilis*	*Blechum pyramidatum*
Aristida purpurascens	*Cuphea carthagenensis*
Symphyotrichum dumosum	*Eremochloa ophiuroides*
Axonopus furcatus	*Fimbristylis cymosa*
Bidens alba var. *radiata*	*Melaleuca quinquenervia*
Centella asiatica	*Panicum repens*
Chamaesyce hypericifolia	*Sida rhombifolia*
Desmodium incanum	*Spermacoce verticillata*
Dichanthelium dichotomum	
Eleocharis geniculata	
Eragrostis elliottii	
Eustachys petrae	
Flaveria linearis	
Fuirena breviseta	
Heliotropium polyphyllum	
Ipomoea triloba	
Ludwigia microcarpa	
Mecardonia aculinata ssp. *peninsularis*	
Mitreola petiolata	
Mitriola sessilifolia	
Paspalum cespetosum	
Paspalum setaceum	
Phyla nodiflora	
Phyllanthus caroliniensis ssp. *saxicola*	
Physalis walteri	
Pluchea rosea	
Poinsettia heterophylla	
Polygala grandiflora	
Rhynchospora colorata	
Rhynchospora divergens	
Roystonea regia	
Scleria verticillata	
Setaria parviflora	
Waltheria indica	

Objective Three: Best Management Practices Publications

Based on the results of Objectives 1 and 2, BMPs for *Coreopsis lanceolata* and *C. leavenworthii* are being published as IFAS extension publications (EDIS: http://edis.ifas.ufl.edu). Both of these IFAS extension publications have been internally reviewed and submitted to the EDIS editor.

A *Gaillardia pulchella* BMP is also included; however, at this time it will not be published as an IFAS extension publication because Florida ecotype seeds are not available (except in very small quantities) and are not currently being produced because seeds cannot be cleaned economically.

A BMP publication is also attached about appropriate practices for managing naturally occurring *Flaveria linearis* populations in south Florida.

Training sessions were held in 2008 for FDOT roadside maintenance personnel on September 22 (Gainesville), 23 (Turnpike Admin Bldg., Turkey Lake), and 24 (Tallahassee). Tim Allen of the FDOT Maintenance Office coordinated all three sessions. At each 3-hour session, the topics below were presented as PowerPoint (PPT) presentations by Jeff Norcini. Attendees received hard copies of each presentation as well as the IFAS Extension Publication "Native Plants: An Overview".

- Right-of-Way Native Wildflowers: Seed Origin Matters
- Establishment of Lanceleaf Tickseed on Roadside Right-of-Ways
- Establishment of Leavenworth's Tickseed on Roadside Right-of-Ways
- Native Wildflowers as an Alternative Groundcover: Economics

No presentation was made about *G. pulchella* for the reasons noted above.

All four BMP publications and the *C. lanceolata and C. leavenworthii* PPTs are included in the Final Report as individual attachments. To maximize accessibility, the PPTs are formatted as PPT version 2003 and as PDF files.

Objective Four: Economics

The economics of establishing native wildflower plantings was based on information gleaned from a complementary grant project conducted in cooperation with Les Harrison, an agricultural economist with the Leon County Extension Service: *The Economics of Marketing Localized Eco-Type Native Wildflower Seed to State Departments of Transportation*; funded by The Federal State Market Improvement Program, Agricultural Marketing Service, United States Department of Agriculture. Information presented here is a summary of information obtained in that project that is pertinent to the FDOT project. Results should be considered preliminary because of the limited response we had in obtaining cost data from FDOT personnel.

One of the reasons for establishing native wildflower stands along roadside ROWs is to reduce maintenance costs. However, results of this study provided preliminary evidence that the cost of establishing and maintaining a native wildflower planting is economically justified only in sites that are mowed with small- and medium-size mowers, and string trimmers (see below). Native wildflower establishment costs were based on the recommendation that site preparation includes two applications of glyphosate and mowing (plus thatch/clippings removal) prior to drill seeding. As detailed in the current report, these establishment methods have proven to be very effective. Moreover, the effectiveness of these methods has been independently confirmed under roadside ROWs on the Florida turnpike system (Chris Grossenbacher, personal communication.).

Considering costs as of fall 2008 (including mowing contracts) and aesthetics as well as current safety issues and practices used to manage turf and native wildflower plantings, establishing new plantings of Florida ecotypes of native wildflowers by seed is appropriate for:

- Rural area ROWs requiring mowing by small to medium-sized mowers, and/or string trimmers
- Rest areas and welcome centers
- Steep slopes
- Moist infields that are too wet to mow (Leavenworth's tickseed only)

However, an economically justified method of designating new native wildflower plantings on <u>ALL roadside ROWS</u> is to preserve existing stands of native wildflowers. Existing wildflower populations can be designated as wildflower sites by using appropriate mowing practices to maintain these populations and facilitate their spread. The main costs of establishing and maintaining a native wildflower planting are the establishment costs, and most of the cost is for site preparation and drill seeding. While Florida ecotype seed is relatively expensive, seed costs are only a small fraction of the establishment cost. Preserving existing stands of native wildflowers eliminates the cost of site preparation and sowing seed. Substantial cost savings are then realized because the need for mowing is substantially reduced.

CHAPTER FIVE: CONCLUSIONS

Bahiagrass competition is the main factor limiting establishment of Florida ecotypes of native wildflowers on roadside ROWs dominated by bahiagrass. Spraying with glyphosate prior to planting in the fall reduces the competitive advantage of bahiagrass and improves establishment. The other two tested herbicides, imazapic and sethoxydim, provided little to no benefit to establishment in most cases. However, imazapic did increase *Coreopsis lanceolata* compared to the control at one site in the study. Imazapic was applied to dormant bahiagrass in the fall within 1 day of seeding while sethoxydim was applied in mid-spring to actively growing bahiagrass. Short-term sustainability was not affected by mowing two to six times per year, when timed to avoid flowering and seed set of each species. Frequent mowing (12 to 24 times per year), however, that did not account for flowering and seed set, reduced the fitness and growth of *C.* and *C. leavenworthii*. Hence, wildflower plantings can be mowed as little as twice per year provided that mowing is avoided during flowering (including when flower stems exceed 6 inches in height) and seed set.

While bahiagrass competition limited wildflower establishment and growth, aboveground competition did not account for the total reduction in wildflower growth. Bahiagrass competition was reduced or eliminated with glyphosate or by removing the turf and underlying topsoil. However, *C. lanceolata* cover or density were not similar between these two treatments, which suggests that microsite requirements are more complex than simply providing adequate space. For example, there was probably less moisture at the soil surface of plots in which top soil was removed than in glyphosate-treated plots. However, the need to reduce or eliminate bahiagrass competition cannot be overstated. As was observed with *C. lanceolata*, increasing the seeding rate and providing supplemental irrigation could not overcome the effects of bahiagrass competition. Interestingly though, bahiagrass did not limit germination and emergence of *C. lanceolata* and *C. leavenworthii*, but did limit subsequent growth and flowering. Moreover, *C. lanceolata* can become established in sites dominated by sparse to moderately dense bahiagrass, provided that *C. lanceolata* seed are sown in the fall, bahiagrass has been mowed, and bare soil is present. However, *C. lanceolata* populations were smaller and established more slowly than when bahiagrass was treated with glyphosate.

It should also be noted that in bahiagrass dominated sites, forbs (broadleaf species) typically dominated the seed bank. When bahiagrass was eliminated or its growth substantially suppressed by glyphosate, which permitted successful establishment of wildflowers, broadleaf species, including undesirable weeds species, were also released. This potential release of broadleaf weeds, some of which could be natives, needs to be considered in the site selection process. For example, the presence of a moderate density of broadleaf plants or noxious weed species could indicate the presence of a substantial seed bank of those species. Those undesirable species could be released after applying glyphosate resulting in poor establishment of wildflowers. Hence, scouting for undesirable species should be an important part of wildflower planting site selection.

Another consideration for eliminating or suppressing glyphosate competition is season of application. The effectiveness of the glyphosate treatment may have been related to seasonal differences in bahiagrass physiology. However, it is important to note that we did not specifically evaluate the seasonal sensitivity of bahiagrass to glyphosate. To be effective, glyphosate must be absorbed through green tissue, which typically is the foliage. Moreover, rapidly growing plants are the most sensitive (Monaco et al., 2002). However, the timing of glyphosate application can affect its efficacy(Adams and Galatowitsch, 2006). Although rapidly growing plants are the most sensitive, better control of perennial plants like bahiagrass may be achieved when plants are not rapidly growing. Many perennial plants, including bahiagrass, often store carbohydrates in roots or rhizomes. For this reason, perennial plants are often able to resprout the season following glyphosate application if the glyphosate was not translocated into the roots and rhizomes. Because movement of carbohydrates into the roots and rhizomes often follows a seasonal pattern, applying glyphosate when plants are moving carbohydrates to the roots and rhizomes s may help to increase movement of glyphosate into the roots and rhizomes (Adams and Galatowitsch, 2006). This may improve the effectiveness of glyphosate in controlling perennial plants like bahiagrass over the long-term.

Seeding rates can greatly influence wildflower establishment, although in this study seeding rates were only explicitly tested for *C. lanceolata*. Seeding at too low of a rate resulted in poor establishment but seeding at too high of a rate provided limited additional benefit compared to seeding at a moderate rate, especially when seed cost is considered. Pure live seed (PLS) rates are often expressed as seed mass per unit area seeded (e.g., lb/acre). Although PLS rates account for differences in seed viability, seed mass varies among species, and even seed lots of the same species, resulting in widely varying seeding rates per unit area (i.e., number of viable seeds per square foot). For example, because the mass of *C. leavenworthii* seeds is much less than *C. lanceolata*, seeding at the same rate of PLS per acre will result in substantially more seeds of *C. leavenworthii* being sown compared to *C. lanceolata*. Developing species specific seeding rates for Florida ecotype seeds will help to decrease costs.

Although this study was limited to establishment of four wildflower species in bahiagrass, results suggest that evergreen, perennial wildflower species may be stronger competitors with bahiagrass than annual species or perennials with seasonal growth fluctuations. For example, *C. lanceolata*, which is evergreen and a short-lived perennial, seemed to be very competitive with bahiagrass. Individual plants grew larger in the winter which allowed them to be more competitive once bahiagrass growth resumed in the spring. Another benefit of active cool season growth was that *C. lanceolata* covered bare soil that would otherwise be susceptible to invasion by cool season weeds.

Based on the results of this study, recommendations for establishing and managing new native wildflower plantings include: 1) limiting bahiagrass establishment and occurrence to areas where erosion control is absolutely necessary, like areas closest to the road, 2) removing bahiagrass where it is not necessary or beneficial, with two glyphosate applications in the fall, and 3) carefully timing roadside mowing or other post-planting disturbance to avoid flowering and seed set of each wildflower species. Recommendations for managing existing stands of *Flaveria linearis* include reducing mowing frequency to twice per year, designating stands that cover at least 20% of the site as wildflower sites, and sites with less than 20% *F. linearis* cover but with a majority of native species being preserved as native habitat.

We also recommend that establishing new plantings of Florida ecotypes of native wildflowers by seeds is appropriate for rural area ROWs requiring mowing by small to medium-sized mowers, or string trimmers, and preserving existing stands of native wildflower plantings is an economically justified method of establishing new native wildflower plantings on all roadside ROWS. In addition, recommendations for future research include: 1) studies on native wildflowers that can compete with aggressive grasses including evergreen perennials and/or species that bloom in early spring, 2) species specific seeding rates based on the number of viable seeds per unit area as well as species life history traits, 3) continued research on native grasses appropriate for roadsides and restoration, 4) restoration approaches to roadside vegetation management, and 5) studies that include long-term results of establishment and management methods.

While our conclusions are based on work with *Coreopsis lanceolata, C. leavenworthii*, *Gaillardia pulchella*, *Ipomopsis rubra*, and *Flaveria linearis*, the general concepts dealing with site preparation, sowing seeds, and mowing are applicable to the use of other native wildflower species on Florida's roadside ROWs. Although overall effects of establishment and management were similar among the wildflower species, some species specific differences were noteworthy and may help to guide future research.

CHAPTER SIX: LITERATURE CITED

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