BIOLOGY AND MANAGEMENT OF CUT-LEAVED TEASEL (*Dipsacus laciniatus* L.)
IN CENTRAL MISSOURI.

A Thesis presented to
the Faculty of the Graduated School
University of Missouri- Columbia.

In Partial Fulfillment of
the Requirements for the Degree

Master of Science

By

DIEGO JAVIER BENTIVEGNA

Dr. Reid J. Smeda, Thesis Supervisor

AUGUST 2006

The undersigned, appointed by the Dean of the Graduated School, have examined the thesis entitled:

BIOLOGY AND MANAGEMENT OF CUT-LEAVED TEASEL *(Dipsacus laciniatus* L.)
IN CENTRAL MISSOURI.

Presented by Diego Javier Bentivegna

A candidate of the degree of Master of Science

And hereby certify that in their opinion it is worthy of acceptance

Mayor Professor:

Dr. Reid Smeda
Associate Professor

Thesis Committee:

Dr. Robert J Kremer
Adjunct Professor

Dr. Kelly Nelson
Professor, Research Assistant

To ELVIRA and LUIS
MY LOVE PARENTS

ACKNOWLEDGEMENTS

I would like to thank Dr. Reid J. Smeda for his willingness to take me on as graduate student in his weed science program. Thanks for the advice, support, knowledge and experience that you gave to me in the past years.

I would like to thank to Dr. Brent Sellers, Dr. Kelly Nelson and Dr. Robert Kremer for providing input into this thesis. I would like to thanks Dr. Mark Ellersieck for his statistical assistance. A special thanks to Jianmei Li and Jimmy Wait for your friendship and technical assistance throughout the research. Special grateful is to Nancy Price who put the better of her knowledge to improve significantly my English skills. To Romina Guelli, Chad Smith, Chris Zwiener, Justin Pollard, Nicolas Monning, Johnathan Dieking and all undergraduated students that assisted with this project, I would like to thank specially. Thank you all for living in United States a wonderful experience.

Finally, I would like to thank all of my family and friends who have supported me in attaining this new degree.

.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDIX TABLES

BIOLOGY AND MANGEMENT OF CUT-LEAVED TEASEL (*Dipsacus laciniatus* L.) IN CENTRAL MISSOURI

Diego J Bentivegna

Dr. Reid J Smeda, Thesis Supervisor

ABSTRACT

Cut-leaved teasel is a biennial invasive weed that grows along roadsides and low disturbed areas. This research was to determine growth characteristics, herbicide efficacy, and seed production of teasel. Growth characteristics were evaluated at two locations by measuring plant dry weight and leaf area. Herbicide efficacy experiments were conducted with four modes of action: amino acid biosynthesis inhibitors, growth regulators, acetolactate synthase (ALS) inhibitors, and cell membrane disrupters. Total seedheads, seeds per primary seedhead and plant were estimated under two levels of intraspecific competition.

Plant rosettes stored resources in the taproot and produced larger and fewer leaves compared with reproductive stage plants. Most of the herbicides were highly effective for teasel control (>90%), but ALS inhibitors such as sulfosulfuron and sulfometuron-methyl were ineffective (less 80%). Seed production reached 33,500 in plants growing alone and was affected by location, year and growth habit. Primary seedheads produced more than 1000 seeds.

CHAPTER I

Literature Review

RESEARCH JUSTIFICACION

Teasel is a species in the *Dipsacaceae* family (sometimes spelled teasle, teasel or teazle). All species in this family are categorized as exotic, invasive weeds. Dipsacus is an Old World genus comprised of 15 species, whose center of origin is Eastern Europe and western Russia (Bobrov 1957). Endemic in Europe, teasel was introduced in the 1700's in North America. Initially, this plant was used in the textile industry to "tease" out the knots and separate strands in wool prior to spinning (hence the name teasel). In Canada, common teasel (*Dipsacus sativus*) was first collected in 1877 at the Niagara Falls (Werner 1975c). John Snook saw potential in the plant as a crop, and his firm started an industry (Rodale 1984). *Dipsacus* is derived from the Greek word 'dipsakos', which means thirst (Werner 1975c). Apparently, the link between 'thirst' and the plant is based on the water that can accumulate at the base of the oppositely arranged and jointed leaves.

Different species of the genus *Dipsacus* (*laciniatus, fullonum and sylvestris*) are present in the U.S., with each of them increasing in geographic distribution. The lack of natural enemies (insect, diseases, and animals) was thought to facilitate the spread over a broad geographical area (Glass 1991; INHS 1990). More than 40 states have reported the presence of teasel. Cut-leaved teasel (*Dipsacus laciniatus* L.) is increasingly common along roadsides and other areas throughout much of the central U.S., including Missouri. Whereas *D. laciniatus* is present in 19 states, especially in the northeast part of the country, *D. fullonum* is spread throughout 40 states (USDA 2006). The species *Dipsacus fullonum* L, also called common teasel or Fuller's teasel, has two subspecies including *D. fullonum* L. *spp. silvestris* (common teasel*)* and *D. fullonum* L. *spp. fullonum*, and their distributions are different (USDA 2006).

Common teasel has been used for *Dipsacus fullonum L* the cultivated teasel (Ferguson and Brizicky 1965) and for *Dipsacus sylvestris* Huds the wild teasel (Mullins 1951; Ryder 1996; Werner 1975c). The scales between florets are sharply hooked (*D. fullonum*) instead of being merely spiny (*D. sylvestris*) was the special feature used for the textile industry to separate them (Mullins 1951). Ferguson and Brizicky (1965) and USDA (2006) showed *D. sylvestris* as subspecies of *D. fullonum*. *Dipsacus sativus*, called Indian Teasel (USDA 2006) Fullers' teasel (Ryder 1996) is also considered subspecies of *D. fullonum* (Ferguson 1965b; Ryder 1996). Cut-leaved teasel (*Dipsacus laciniatus* L.) is separated for the previous species by the deeply lobed or laciniate leaves, white flowers and short involucral bracts (Solecki 1993), and is more aggressive than common teasel (Glass 1991). In reproductive stage, cut-leaved teasel is larger, more robust plant and deeper taproot than common teasel (Solecki 1993).

Teasel typically colonizes habitats along roadsides, and this relatively unmanaged area could be one of the mechanisms that contribute to the rapid spread of this weed. Also, plants thrive in undisturbed areas such as pastures, cemeteries, railroads, open meadows, forest edges, and undisturbed areas. The stark beauty of the seedhead has made teasel popular in dried flower arrangements. New infestations around homes or cemeteries are due to human activities (Werner 1977; Missouri Vegetation Management Manual 1997). On April 17, 2000, *D. fullonum* and *D. laciniatus* were declared noxious weeds in Missouri.

Teasel is an invasive weed which negatively impacts infested areas. Teasel can reduce species diversification in natural areas, leading to less available food sources for wildlife. Cut-leaved teasel has been reported to present considerable problems for conservation in natural areas such as the suppression or elimination of native species which alters nutrient and hydrological cycles (Huenneke and Thomson 1994; Solecki 1993; Werner 1977). The taproot can alter soil moisture levels by reducing infiltration and increasing runoff (Lacey et al. 1989). Along roadsides, mature plants can grow up to 2.1 meters tall, reducing traffic visibility (Rand Swanigan, personal communication [1]).

BIOLOGY

Teasel is categorized as a biennial, with seedling establishment in both fall and spring. Seedlings form a strong rosette during the first summer followed by a tall flowering stalk during the second summer. Mature plants die soon after seed maturation. Spread of teasel is only by seed (Jurica 1921; Caswell and Werner 1978).

The dispersal pattern of seed contributes to teasel growing in patches or communities, where an aggressive growth habit allows teasel to interfere with native vegetation. The establishment of a population in a new site depends upon successful seed germination and seedling survival. Werner (1975d, 1977) observed that teasel seeds required “open spots” at ground level for germination. Where established grasses have formed a thick stand, teasel seeds fail to germinate. In limited studies, ungerminated teasel seeds live more than 7 years in the ground (Werner 1977). Although seeds are dispersed in late summer and fall, few seedlings are established until the following spring (Werner 1975c; Caswell and Werner

[1] Rand Swanigan Head of Roadside Management and Maintenance of Missouri State

1978). Up to 95% of common teasel seeds germinate within three days of establishment in laboratory trials, and a number of tests revealed that no stratification or period of light or dark is required (Werner 1975a,d). However, under a variety of field conditions, the previous percentage of germination decreases by 28 to 86% (Werner 1975c).

Established rosettes can extensively cover an area, and reduce available space for other plants with large taproot that reaches 5 cm in diameter and 45-75 cm long (Werner 1975c). This deep taproot allows plants to extract nutrients from deficient soils and withstand drought. Also, the root systems store photosynthates, enabling plants to rapidly re-grow following mowing, or quickly become established in early spring when conditions are favorable for growth.

Leaves are lanceolate to oblanceolate, entire or undulate, with rigid spines along the mid-rib on the adaxial surface. Smaller spines are set upon papillate bases on the surface of rosette leaves. Leaves on the flowering stem are opposite, prickly, basally connate, forming a "cup" which may hold rainwater (Jurica 1921; Maguire 1959). Cut-leaved teasel is distinguished by deeply lobed or laciniate leaves as the name implies (Solecki 1993). Rosettes are comprised of several layers of leaves which limit the amount of light reaching the soil surface.

Seedheads flower continuously between July and early September in Michigan, and in Missouri can extend until October (Werner 1975b). The minimum size for rosettes to initiate reproduction is approximately 30 cm in diameter (Werner 1975b). Although many plants reach the minimum size necessary for flowering within the second growing season, some plants under conditions of interspecific competition (Werner 1972) or high plant density (Harper and White, 1974), may not reach this critical size for several growing seasons

(Werner 1975b). Werner (1975b) found that in fields dominated by herbaceous perennials, no flowers were produced on teasel until the fourth year in southwestern Michigan. Following vernalization at the proper growth stage, stems elongate with opposite branches that arise from leaf axils. A capitulum (2 to 10 cm long) is borne at the end of each stem (Szabó 1923; Werner 1975b). The number of capitulums for each teasel plant can vary widely from 1 to 35 (Werner 1975c). Flowers are 10 to 15 mm in length, and packed in dense and oval shaped heads. The fruit is an achene of 4 to 5 mm in length. Each capitulum is subtended by stiff bracts, which pose an effective deterrent to herbivore feeding (Solecki 1993). The erect, spiny, flowering stem is 0.5 to 2.5 m in height. The stalks of mature plants persist throughout the winter, and sometimes for two or three years (Werner 1975c).

The number of seeds per inflorescence varies directly with the size of the capitulum, but data indicate the average number of potential seeds per inflorescence is up to 855 (Werner 1975c). A roadside population of *D. sylvestris* in Michigan had a mean of 3.9 inflorescences per plant; therefore, a single teasel plant might be expected to produce approximately 3,333 seeds (Werner 1975c). The number of inflorescences per plant also varies with size of the plant with three to nine commonly reported. In fact, plants that are taller and more vigorous are likely to have larger seedheads (Hedberg and Hedberg 1977). Glass (1991) reported that a single plant can produce up to 3,000 seeds, and up to 30-70 % of these seeds were viable. Solecki(1989) reported limited seed viability which, following mowing of immature flowers, indicates the time for seed maturation may be short.

Neither teasel plants nor the seeds possess morphological characteristics for dispersal by wind or animals (Werner 1972). Werner (1975a) reported that more than 99% of the seeds released fall less than 1.5 meters from parent plants. However, Neubert and Caswell (2000) illustrated with one population that plants moved an average of 27 km/year from Ontario, Canada to the east coast of North America (650 km) in only 13 years. Neubert and Caswell (2000) concluded that there could be some mechanism facilitating transport. Teasel seed could be spread by water. Long-distance dispersion could depend upon the seeds's ability to float on water (Werner 1975c). Also, mechanical control along roadsides could facilitate dispersion. Populations readily spread along the interstate highway system where mowing is common (Solecki 1993). Moderate winds exhibited an impact on the direction of seed dispersal, but little effect on distance (Werner 1974c).

MANAGEMENT

Management of invasive weeds begins with a thorough understanding of their biology. This allows proper identification of optimum management techniques. For teasel, management strategies must concentrate on eliminating the number of plants established as well as preventing the dispersal of viable seeds. Because teasel is not a common weed in pastures and agronomic crops, there are few reports of the effectiveness of management techniques. In addition, teasel is an exotic, invasive species with few known natural enemies, precluding the availability of biological methods (Missouri Vegetation Management Manual 1997).

Mechanical methods such as hand roguing, cutting, burning and herbicide treatment are used frequently as management techniques (Glass 1991; Solecki 1993). In small isolated patches, removing plants using hand labor appears successful. When infestation levels are considerably higher, expensive and time-consuming control techniques are needed (Solecki 1989).

Mowing is a common practice for vegetation management along roadsides. However, according to the Illinois Department of Transportation, “Mowing doesn’t eradicate your vegetation problems, it delays or hides them” (Caylor 1998). When teasel plants were mowed prior to flowering, Glass (1991) found that new shoots emerged flowered, produced viable seeds. To date, there are no reports on the effectiveness of repeated mowing in one particular growth stage. However, Cheesman (1998) stated that mowing was effective at reducing the incidence of seed production in the United Kingdom, if practiced prior to plant flowering. Mowing teasel in late June to July, up to one month prior to flowering, reduced seed production by 78 to 94% in Cambridgeshire, United Kingdom. Mowing when flowering was initiated eliminated seed production (Cheesman 1998). However, Glass (1991) documented that following removal of initial flowering stalks, regrowth of additional seed heads produced viable seeds.

In some situations, controlled burning of dead vegetation on roadsides has been attempted to control teasel. However, once an area is densely covered with rosettes, there is not enough vegetative fuel to spread fire throughout the infested area. Prescribed burning likely works best in conjunction with other methods such as mowing or herbicides (Solecki 1993).

The most effective and recommended technique for teasel management is selective application of herbicides (Caylor 1998; Missouri Vegetation Management Manual 1997). Only three herbicides are labeled currently for teasel control, sulfometuron-methyl, metsulfuron methyl, chlorsulfuron, triclopyr + clopyralid, aminopyralid (Crop Protection Reference 2006). However, a number of herbicides have shown promise for control of teasel including: triclopyr, 2,4-D, glyphosate, and dicamba (Crop Protection Reference 2006; Glass 1991; Missouri Vegetation Management Manual 1997).

Triclopyr and 2,4-D are both growth hormone-mimicking herbicides, and selectively remove teasel as well as other broadleaf plants (Glass 1991). Application of triclopyr is recommended during the growing season, but preferably before the plant has bolted (Missouri Vegetation Management Manual 1997). However, 2,4-D amine should be applied in early spring on young rosettes (Solecki 1993). Treating rosettes late into the fall or winter, provided actively growing green vegetation is present, prevents harm to other sensitive, desirable species (Missouri Vegetation Management Manual 1997).

Glyphosate is a systemic herbicide with activity on a broad range of species, including teasel (Missouri Vegetation Management Manual 1997; Solecki 1993). Glyphosate is most effective during periods of active plant growth. For teasel, this includes late fall and early spring (Solecki 1993). Application when teasel is not photosynthetically active has led to inconsistent results (Missouri Vegetation Management Manual 1997).

PURPOSE OF STUDY

Teasel was introduced into eastern North America from France in the 1700's for use in the textile industry and rapidly became a weed. Lacking natural enemies and adapted to growing conditions in the United States, this plant began infesting natural settings in undisturbed areas. As a weed, it can cause numerous problems such us the reduction in diversity in natural areas, reduced water infiltration (increasing erosion), and poor visibility along roads. Teasel is categorized as a biennial and develops a large taproot and rosette in its first year of growth followed by a tall blooming stalk in the second year. This growth habit enables teasel to form tight communities that crowd out native species.

Little information is available on teasel growth and reproduction. Studies are necessary that can lead to new management strategies. Determining the growth rate for above and below ground biomass for the life cycle of teasel can identify optimum periods for implementation of control strategies. Research is also needed to identify chemical management systems that provide control of emerged plants as well as residual control for suppressing establishment of new populations.

The thesis research is divided into three parts:

A) Biology

Objective: Determine the growth of teasel by periodic estimation of above and below ground tissue.

B) Herbicide efficacy

Objective: To determine the efficacy of herbicides on emerged teasel as well as residual affects.

C) Seed production

Objective: To determine the total amount of seeds produce by one plant

LITERATURE CITED

Bobrov, E. G. 1957. Genus 1411. *Dispasacus L. in* B.K. Shihkin and E. G. Bobrov, eds. Flora of the USSR, Vol XXIV. Izdaterl'stvo Akademii Nauk SSSR. Moskva-Leningrad. 16-20 pp.

Caswell, H. and P. A. Werner. 1978. Transient behavior and life history analysis of teasel (*Dipsacus sylvestris* Huds.). *Ecology* 59(1):53-66.

Caylor, P. 1998. Herbicides help Illinois DOT control roadside weeds. American City and Country 113:17-18.

Cheesman, O.D. 1998. The impact of some field boundary management practices on the development of *Dipsacus Fullonum* L. flowering stems, and implication for conservation. Agriculture, Ecosystems and Environment 68: 41-49.

Crop Protection Reference. 2006. C& O press. 302 5th Avenue. New York, NY. 10117-1058. 2395 pp

Ferguson, I.K and G.K.Brizicky. 1965. Nomenclatural notes on *Dipsacus fullonum* and *Dispacus sativus*. Journal of the Arnold Arboretum 46:362-365.

Glass, W.D. 1991. Vegetation management guideline: cut-leaved teasel (*Dipsacus lacinatus* L.) and common teasel (*Dipsacus sylvestris* Huds.). Natural Areas Journal 11:213-214.

Harper J.L. and White, J. 1974. The demography of plants. Annual Review of Ecology and Systematics. 5:419-463.

Hedberg, I and Hedberg, O. 1977. The genus *Dipsacus* in tropical Africa. *Botaniska notiser* 129: 383-389.

Huenneke, L. F. and J.K. Thomson. 1994. Potential interference between a threatened endemic thistle and an invasive nonnative plant. Conservation Biology 9 (2):416-425.

INHS. Illinois Natural History Survey. 1990. Vegetation Management Guidelines. Cut-leaved teasel (*Dipsacus laciniatus* L.) and Common teasel (*Dipsacus sylvestris* Huds.). In Vegetation Management Manual Ed. Illinois Nature Preserve Commission. 1: 24.

Jurica, H.S. 1921. Development of head and flower of Dipsacus sylvestris. Botanical Gazette 71 (2):138-145.

Lacey, J. R., C.B. Marlow, and J.R. Lane. 1989. Influence of spotted knapweed (*Centaurea maculosa*) on surface runoff and sediment yield. Weed Technology 3(4):627-631.

Maguire, B.Jr. 1959. Aquatic biotas of teasel waters. Ecology 40:506.

Missouri Vegetation Management Manual. 1997. Ed. Tim E. Smith. Missouri Department of Conservation. P.O. Box 180. Jefferson City. MO. 65102. 44-49 pp.

Neubert M.G. and H. Caswell. 2000. Demography and Dispersal: calculation and sensitivity analysis of invasion speed for structured population. Ecology 81(6): 1613-1628.

Rodale, R. 1984. Teasel in Our Lawn. Organic Gardening 31(11)22-25.

Ryder M.L. 1996. " Is the Fuller's Teasel (*Dipsacus sativus*) really a distinct species?" . The Linnean: newsetter and proceedings of the Linnean Society of London 11 (4):21-27.

Solecki, M.K. 1989. The viability of cut-leaved teasel (*Dipsacus laciniatus* L.) seed harvested from flowering stems: management implications. Natural Areas Journal 9:102-105.

Solecki, M.K. 1993. Cut-leaved and common teasel (*Dipsacus laciniatus* L and *D. sylvestris* Huds.): profile of two invasive aliens. *In* McKnight, B.N. (Ed), Biological Pollution: The control and impact of invasive exotic species. Indiana Academic of Science, Indianapolis. 85-92 pp.

Szabó ,Z. 1923. The development of the flower of the dipsacaceae. Annals of Botany 37 (146): 325-337.

USDA. 2006. The PLANTS Database, Version 3.5 (http://plants.usda.gov). National Plant Data Center, Baton Rouge, LA 70874-4490 USA. Access January 20, 2006

Werner, P.A. 1972. The effect of the invasion of *Dipsacus sylvestris* on plant communities in early old field succession. Ph. D. thesis. Michigan Sate University. University Microfilms, Ann Arbor. 140 pp.

Werner, P.A. 1975a. A seed trap for determining patterns of seed deposition in terrestrial plant. Canadian Journal of Botany 53:810-813.

Werner, P.A. 1975b. Predictions of fate from rosette size in teasel (*Dipsacus fullonum* L.). *Oecologia* 20:197-201.

Werner, P.A. 1975c. The biology of Canadian weeds 12. *Dipsacus sylvestris* Huds. Canadian Journal Plant Science 55:783-794.

Werner, P.A. 1975d. The effects of plant litter on germination in teasel, *Dipsacus sylvestris* Huds. The American Midland Naturalist 94(2) 470-476.

Werner, P.A. 1977. Colonization success of a "Biennial" plant species: experimental field studies of species cohabitation and replacement. Ecology 58:840-849.

CHAPTER II

Growth and Development of Cut-leaved Teasel (*Dipsacus laciniatus* L.) [1]

DIEGO J. BENTIVEGNA, REID J. SMEDA [2], AND BRENT A. SELLERS[3]

Abstract: Cut-leaved teasel is a biennial plant commonly found along roadsides in Missouri. Plants grow as rosette during the first year, then bolt and produce seeds in the second year. Field studies were conducted in 2004 and 2005 to determine the growth characteristics as well as resource allocation from emergence to seedset. Seedlings were established in polypropylene pots in April 2004 at two field locations in central Missouri. Ten plants were harvested every fifteen days during the first 2 months, and every month thereafter throughout the life cycle of the plant. For each plant harvested, variables measured included: rosette diameter, leaf area, length and width of leaves, stem length, as well as length and diameter of taproot. In addition, the dry weight of leaves, stem, seedhead, taproot and secondary roots were measured. Leaf area index, absolute (AGR) and relative (RGR) growth rates were calculated. Teasel had two peaks of leaf area, with a maximum value of 15,050 cm^2. While the first peak had fewer (<100) and larger size of leaf (44.3 cm), the second peak had bigger amount (189) and smallest leaf (11.2 cm). Leaf area index was highest in July with values of 2.9-3.0. Maximum stem length was 205 cm. Taproot increased in length and weight in the first year reaching a maximum of 79 cm and 73 grams, respectively. Secondary roots were around 10% of the weight the taproot. Maximum AGR aboveground biomass was 4.8 g day^{-1} and below ground biomass was 1.3 g day^{-1}. Movement of resources to the taproot was in November in both locations, but the inverse occurred in the reproductive phase.

[2] Graduated Research Assistant and Associate Professor, Division Plant Science, University of Missouri. Columbia, MO 65211.
[3] Assistant Professor. University of Florida-IFAS Range Cattle Research and Education Center. ONA,FL.33865-9706

Nomenclature: teasel, *Dipsacus laciniatus*, invasive, Dipsacus, roadside, noxiuos.
Abbreviations: AGR, absolute growth rate; RGR, relative growth rate; LA, leaf area; LAI, leaf area index.

INTRODUCTION

Teasel (*Dispsacus sp*.) species are included in the *Dipsacaceae* family, whose center of origin is southern Europe or western Asia (Bobrov 1957; Ryder 1996). Teasel was introduced into the USA for the textile industry with the intended purpose of disentangling and aligning wool fibers prior to spinning (Mullins 1951; Ryder 1996; Smith 1976). Although it is no longer used for this purpose, teasel dispersal has likely been facilitated by the construction of the highway system (Solecky 1993). The habitat in this system is low in maintenance and comprised of perennials, that thrive in low fertility soils. Today, teasel has spread throughout most states (USDA 2006). All species in this family are categorized as exotic, invasive weeds (Bobrov 1957; Rector 2004). Additionally, teasel has been declared noxious in several states including Colorado, Iowa, New Mexico, Oregon, and Missouri (Rector 2004; USDA 2006).

There are 12 species of teasel in the center of origin, but only three of them, *Dipsacus fullonum, D. laciniatus, and D. sativus* were introduced into North America (Ferguson 1965; WSSA 2006). However, the classification of teasel species is somewhat ambiguous, because individual species have few morphological differences. Unique features used in the identification of species include differences in characteristics of leaves, inflorescences, and involucral bracts (Ferguson 1965). Common teasel (*Dipsacus fullonum* L.) is known as the cultivated teasel (Ferguson and Brizicky 1965), while *Dipsacus sylvestris* Huds. is considered the wild teasel (Mullins 1951; Ryder 1996; Werner 1975c). *Dipsacus sativus,* called Indian teasel (USDA 2006) or Fullers' teasel (Ryder 1996) and wild teasel are considered sub-species of *D. fullonum* (Ferguson and Brizicky 1965). Cut-leaved teasel (*Dipsacus laciniatus* L.) is distinguishable from these species by the deeply lobed or laciniate leaves, white flowers, and short involucral bracts (Solecki 1993). Its growth habit is also more aggressive than common teasel (Glass 1991). In the reproductive stage, cut-leaved teasel is a larger, more robust plant with a deeper taproot than common teasel (Solecki 1993).

Cut-leaved teasel typically colonizes undisturbed habitats along roadsides, cemeteries, railroads, open meadows, forest edges, and pastures (Werner 1975c). Invasion of teasel into such areas has been shown to cause ecological and/or economic harm. For example, teasel establishment leads to suppression or elimination of desirable species while altering nutrient and hydrological cycles in natural areas (Huenneke and Thomson 1994; Solecki 1993; Werner 1977). Additionally, the taproot can alter soil moisture levels by reducing water infiltration and increasing runoff (Lacey et al. 1989). Furthermore, mature plants can grow up to 2.1 meters tall, reducing traffic visibility along highways and intersections, ultimately contributing to automotive collisions (Rand Swanigan, personal communication[4]).

Teasel is categorized as a biennial which grows in patches or communities, with seeds germinating in both fall and spring (Werner 1975d, 1977). Because seed-rain usually occurs near the parent plant, and seedling establishment is facilitated by older plants, dense patches of teasel are typical (Glass 1991; Werner 1975a). Seedlings form a large rosette during the first summer after establishment. After the rosette reaches 30 cm in diameter, the plant is mature and can flower and set seed following cold vernalization (Werner 1975b). Mature plants die after seed maturation.

[4] Rand Swanigan. Missouri Department of Transportation. Roadside Management Specialist.

Spread of teasel occurs only by seed (Jurica 1921; Werner and Caswell 1977). Several attributes such as a large taproot, spines on leaves and stems, and growth late in fall and early spring allow teasel to be successful in colonization (Solecki 1993). While native, herbaceous perennials require cold stratification prior to germination, teasel germination can occur without scarification, cold treatment, or light/dark treatment (Solecki 1989; Solecki 1993). In past years, optimal growing conditions and inappropriate management have contributed to the spread of teasel along roadsides. At this time, there is limited information regarding the biology of cut-leaved teasel that could potentially elucidate why this species is successful as an invasive weed. Rapid control of invasive weeds without biology studies can be achieved only where invasion is recent; however, where invasion is widespread such as with teasel, eradication or sustainable management requires intensive biological studies (Simberloff 2003). To date, few studies have characterized the growth of teasel over a life cycle in a natural setting. The objective of this study was to determine the growth characteristics as well as resource allocation from emergence to seed set for cut-leaved teasel in central Missouri.

MATERIAL AND METHODS

Teasel seeds were germinated in a greenhouse using professional potting mix[5] in polypropylene trays. In April 2004, three seedlings with one set of true leaves were transplanted into polypropylene pots containing field soil at the Bradford Research and Extension Center near Columbia, MO and Horticulture and Agroforestry Center near New

[5] Premier Pro-Mix"BX", Hummert International, Earth City, MO 63045.

Franklin, MO. Pots width and depth size were 10 x 18 cm for the first two months of harvest (1413 cm^3 of capacity) and 28 x 61 cm for the remain harvests (30280 cm^3). Pots were buried fifteen days before to start the experiment to establish the soil. The soil type at Columbia was a Mexico silt loam with soil pH of 5.9 and 2.9% organic matter; in New Franklin the soil type was Menfro Silt Loam with soil pH of 5.4 and 2.6% organic matter. Undesirable plant species were hand removed inside the pot and paraquat at 1.17 kg ai. ha^{-1} was applied to remove weeds between pots. Environmental conditions over the course of the study are shown in Figure 2.1.

Plants were harvested every fifteen days following establishment to record rapid early season growth during the first two months and monthly thereafter. At each harvest, two individual plants from five pots were harvested and one was discarded at random from each location. The diameter of the rosette was recorded and leaf area was measured with a LI-COR LI-3000A portable area meter[6]. Leaf area index (LAI) was calculated as total leaf area foliar divide by the total land area covered by the rosette. Leaf, stem, and seedhead dry weight was recorded after samples were placed into an electric dryer for 4 days at 60 C. For root measurements, the taproot and fibrous roots were separated prior to biomass measurements. Total taproot length and weight, as well as diameter of the taproot at one centimeter below the soil surface were measured.

The absolute growth rate (AGR), expressed in grams of dry weight per day, for above and below ground biomass was calculated as the difference of weight between two successive harvests divided by the time period (in days) between measurements.

$$AGR = \frac{W_1 - W_0}{t_1 - t_0} \qquad [1]$$

[6] LI-COR, Inc. 4421 Superior Street, Lincoln, NE. 68504.

Where W_1 and W_0 is the dry weight tissue between successive harvests, and $t_1 - t_0$ = time elapse between two successive harvests in days.

The relative growth rate (RGR) in grams of dry weight per day and per grams of plant of above and below ground biomass was calculated according the follow equation: (Hunt 1981)

$$RGR = \frac{LnW_1 - LnW_0}{t_1 - t_0} \qquad [2]$$

Where W_1 and W_0 is the dry weight between two successive harvests, $t_1 - t_0$ is the difference between harvests time in days, and Ln is natural logarithm of the parameter.

All data were combined over locations and harvest time and were subjected to analysis of variance using PROC GLM procedure of SAS (SAS 2003). Normality and residual tests were performed using PROC UNIVARIATE (SAS 2003) with a probability ≤ 0.05. All data were transformed by logarithm to ensure homogeneity of variance. The interaction between location and harvest was significant; therefore the analysis was not combined over location. Means of significant main effects were separated using Fisher's Protected LSD at $P \leq 0.05$. (SAS 2003).

RESULTS AND DISCUSSION

Teasel planted in May, 2004 completed their life cycle by August 2005 at Columbia and New Franklin (17 months). Rosettes reached a minimum diameter size of 30 cm by August 2004 (Table 2.1), which has been shown to be the minimum size necessary to bolt the following year (Werner 1975b). In other studies, the rosette growth stage persisted for longer than one year, depending on the available environmental resources such as competition with grasses (Missouri Vegetation Management Manual 1997; Solecki 1993; Werner 1975b).

There was an interaction between location and harvest time for leaf area (LA) and leaf biomass. Consequently, data were analyzed and presented separately for each location. Leaf area increased gradually during the initial stages of growth until after August, when leaf area was greater than 14,000 cm^2 in September 2004 at Columbia (Figure 2.2). Leaf area at New Franklin was greater than 10,800 cm^2 in October, 2004. After peaking, leaf area declined in leaf area until March 2005. A second leaf area peak was recorded in June 2005 at both locations, with a LA of 15,050 and 13,280 cm^2 at Columbia and New Franklin, respectively. These two peaks occurred during with high levels of radiation and temperature.

During the rosette growth stage, LAI was greatest in July at both locations, with values of 2.9 and 3.1 at Columbia and New Franklin, respectively (Table 2.1). Blackman and Black (1959) determined that an LAI value of 2 to 3 indicated an ability to intercept 95% of the available light in various plant mixtures. Large values of LAI prevent light from protruding into the plant canopy, reducing the photosynthetic capacity of understory vegetation. In the rosette growth stage, individual teasel plants form dense, wide, horizontally-oriented leaves that exclude other species (Huenneke and Thomson 1994; Werner 1975c). Caswell and Werner (1978) showed that rosette area is related to the occupation and defense of a given site as an adaptation to one location. Another invasive weed, kudzu (*Pueraria Montana* Lour.), can absorb all solar radiation with a maximum LAI of 8 (Fujita et al. 1993). Consequently, interception of the reduced solar radiation available in the fall (Figure 2.2) may be one of the mechanisms teasel utilizes to invade various plant communities. In the spring of the second year, plants had only LAI of 2 (Table 2.1) which was not enough to intercept all the available radiation. Similarly, Werner (1977) showed that the increase in LAI values when teasel flowered only served to increase their own production, but not reduce the growth of previously established grasses. The internodal space on the flowering stem allows the light to reach understory vegetation, allowing growth of established grasses or new teasel seedlings and rosettes (Werner 1977)

Leaf number and size were different when LA was the greatest during the rosette versus the bolting growth stages (Table 2.1). During the rosette growth stage, plants had larger, but fewer leaves compared to the bolting growth stage (Table 2.1). This small size of the leaves and the distribution around the stem allow teasel intercept great quantities of light, and growth with high photosynthetic rate in the reproductive stage.

The trend in leaf biomass was similar to leaf area over the life cycle of teasel plants (Figure 2.3). At Columbia, leaf biomass (994 g $plant^{-1}$) was greatest in September 2005, while leaf biomass (916 g $plant^{-1}$) was greatest in October 2005 at New Franklin. Leaf biomass decreased during the winter months before increasing prior to and during the bolting growth stage.

The reproductive phase was characterized by and increase in the total weight of the plant. There was no interaction between location and harvest time, and location was not significant with regards to stem weight and length, and seedhead weight (Table 2.2). This infers that photosynthates are transported to these structures similarly regardless of location. Stem weight increased the second year from May to August by an average of 43%. Seedhead weight increased from June to July by an average of 36%. Maximum stem length was approximately 2 meters (Table 2.2), which is similar to that reported by others (Cheesman 1998; Jurica 1921; Missouri Vegetation Management Manual 1997).

There was no interaction for the length and weight of the taproot between location and harvest time, and location was not significant (Figure 2.4). During the rosette growth stage, the taproot increased in both weight and length until November 2004. Maximum dry weight and length was 56.6 grams and 59 cm, respectively. The taproot provides a storage organ for water and carbohydrates during vegetative growth (Solecki 1993, Werner 1977). Although not significant, two periods of reductions in taproot weight occurred while over-wintering and in the reproductive stage. This suggests that plants utilized root resources to sustain plants over-winter. Maximum taproot length was 79 cm and 75 cm for Columbia and New Franklin, respectively, and was similar to that reported by others (Missouri Vegetation Management Manual 1997, Solecki 1993). The diameter of the taproot increased similarly compared to length (Appendix 1). Maximum secondary root values of 10.4 grams $plant^{-1}$ in Columbia and 6.5 grams $plant^{-1}$ in New Franklin were registered in May 2005, and were smaller than the overall taproot weight. Additionally, a significant reduction in secondary root weight during the reproductive stage (Appendix 1) suggests that teasel plants use resources stored in this root system.

For teasel, relative and absolute growth rate values revealed two important facts. In November, 2004, above-ground growth rate of rosettes was negative, but below-ground growth rate (root system) was positive (Table 2.3). This could suggest that the plant was allocating resources from the taproot. In the second year, the inverse situation was registered in the reproductive stage. Plants required enormous resources which results from mobilized storage carbohydrates from the root system to reproductive structures (Table 2.3). Caswell and Werner (1978) reported that resources have to be stored in the taproot, prior to flowering, and also that reproduction decreases in direct proportion to decreases in the total energy available.

In summary, plants growing under natural conditions in patches have different sizes and growth stages during the year. Basically, teasel had two peaks of growth during its life-cycle. The first one was in the rosette stage at the end of the summer, with large leaf area, taproot and growth rate. The second peak occurred during the reproductive stage, while growing at a high rate and transporting resources from the taproot to the aboveground biomass. In addition to growing all summer and at the onset of fall with this elevated growth rate, it has been reported that teasel can also grow late in the fall and early in the spring (Solecki 1993). Thus, cut-leaved teasel growth occurs throughout the year, reducing the available resources in the site and restricting the growth and establishment of desirable and/or native species.

LITERATURE CITED

Blackman, G.E. and J.N. Black. 1959. Physiological and ecological studies in the analysis of plant environment. XII. The role of the light factor in limiting growth. Annals of Botany 23:131-145.

Bobrov, E.G. 1957. Genus 1411. *Dispasacus* L.. In B.K. Shihkin and E. G. Bobrov, Eds. Flora of the USSR, Vol XXIV. Izdaterl'stvo Akademii Nauk SSSR. Moskva-Leningrad. 16-20 pp.

Caswell, H. and P. A. Werner. 1978. Transient behavior and life history analysis of teasel (*Dipsacus sylvestris* Huds.). Ecology 59(1):53-66.

Cheesman, O.D. 1998. The impact of some field boundary management practices on the development of Dipsacus Fullonum L. flowering stems, and implication for conservation. Agriculture, Ecosystems and Environment 68: 41-49.

Ferguson, I.K. 1965. The genera of Valerianaceae and Dipsacaceae in the southeastern United States. Journal of Arnold Arboretum 46:218-231

Ferguson I.K and G.K. Brizicky. 1965. Nomenclatural notes on Dipsacus fullonum and Dispacus sativus. Journal of the Arnold Arboretum 46:362-365.

Fujita, K., K. Matsumoto, B.G.K. Ofuso, and S. Ogata. 1993. Effect of shading on growth and dinitrogen fixation of kudzu and tropical pasture legumes. Soil Science Plant Nutrition 39:113-140.

Glass, W.D. 1991. Vegetation management guideline: cut-leaved teasel (*Dipsacus lacinatus* L.) and common teasel (*Dipsacus sylvestris* Huds.). Natural Areas Journal 11:213-214.

Huenneke, L. F. and J.K. Thomson. 1994. Potential interference between a threatened endemic thistle and an invasive nonnative plant. *Conservation Biology* 9 (2):416-425.

Hunt, R. 1981. Plant growth analysis. Studies. In Biology Nº 96. Ed. Edward Arnold. Printed in Great Britain 67 pp.

Jurica, H.S. 1921. Development of head and flower of *Dipsacus sylvestris*. Botanical Gazette 71 (2):138-145.

Lacey, J. R., C.B. Marlow, and J.R. Lane. 1989. Influence of spotted knapweed (*Centaurea maculosa*) on surface runoff and sediment yield. Weed Technology 3(4):627-631.

Missouri Vegetation Management Manual. 1997. Ed. Tim E. Smith. Missouri Department of Conservation, P.O. Box 180, Jefferson City, MO 65102, 44-49 pp.

Mullins, D. 1951. Teasel growing- An ancient practice. World Crops. April. 146-147 pp.

Rector, B. 2004. Prospects for biological control of teasel in the Midwest. IOBC- NRS Newsletter (International Organization for Biological Control – Nearctic Regional Section) 26 (2):1-2.

Ryder, M.L. 1996. " Is the Fuller's Teasel (*Dipsacus sativus*) really a distinct species?" The Linnean: newsetter and proceedings of the Linnean Society of London 11 (4):21-27.

SAS. 2003. Statistical Analysis Systems. SAS/STAT User's Guide. Release 9.1 Software version 8e. Cary, NC: Statistical Analysis Systems Institute.

Simberloff, D. 2003. How much information on population biology is needed to manage introduced species? Conservation Biology 17 (1):83-92.

Smith, L. 1976. Teasels. Pacific discovery 29 (6):24-25.

Solecki, M.K. 1989. The viability of cut-leaved teasel (*Dipsacus laciniatus* L.) seed harvested from flowering stems: management implications. Natural Areas Journal 9:102-105.

Solecki, M.K. 1993. Cut-leaved and common teasel (*Dipsacus laciniatus* L and *D. sylvestris* Huds.): profile of two invasive aliens. In McKnight, B.N. (Ed), Biological Pollution: The control and impact of invasive exotic species. Indiana Academic of Science, Indianapolis. 85-92 pp.

USDA. 2006. The PLANTS Database, Version 3.5 (http://plants.usda.gov). National Plant Data Center, Baton Rouge, LA 70874-4490 USA. Access January 20, 2006.

Werner, P.A. 1975a. A seed trap for determining patterns of seed deposition in terrestrial plant. Canadian Journal of Botany 53:810-813.

Werner, P.A. 1975b. Predictions of fate from rosette size in teasel (*Dipsacus fullonum* L.). Oecologia 20:197-201.

Werner, P.A. 1975c. The biology of Canadian weeds 12. *Dipsacus sylvestris* Huds. *Canadian* Journal Plant Science 55:783-794.

Werner, P.A. 1975d. The effects of plant litter on germination in teasel, *Dipsacus sylvestris* Huds. The American Midland Naturalist 94(2):470-476.

Werner, P.A. 1977. Colonization success of a "Biennial" plant species: experimental field studies of species cohabitation and replacement. Ecology 58:840-849.

Werner, P.A and H. Caswell. 1977. Population growth rates and age vs. size-distribution models for Teasel (*Dipsacus sylvestris* Huds.). Ecology 58:1101-1111.

WSSA. 2006. Weed Science Society of America. Common and Latin names index. http://www.wssa.net/CLNAMES/namesearch.asp. Access January 20, 2006

Table 2.1. Mean rosette diameter, leaf characteristic (number, length and width), and leaf area index for teasel at Columbia and New Franklin, Missouri.[a]

Harvest Date	Columbia Diameter of Rosette	Columbia Leaf length	Columbia Leaf width	Columbia Leaf Area Index	Columbia Number of leaves	New Franklin Diameter of Rosette	New Franklin Leaf length	New Franklin Leaf width	New Franklin Leaf Area Index	New Franklin Number of leaves
	(cm)	(cm)	(cm)		No.plant	(cm)	(cm)	(cm)		No.plant
7- May -04	2.9 g	2.2 h	0.5 g	0.57 fe	4 h	4 e	2.9 i	0.3 g	0.97 ab	4 ef
20-May	7.2 fg	10.3 g	0.3 f	0.92 def	6 g	6.1 e	8.8 gh	0.5 fg	0.93 de	7 ef
4 Jun	10.9 f	13.5 f	0.8 e	0.36 f	6 g	16.2 f	12.2 d	1.1 f	0.56 e	8 e
17 June	11.7 f	18.6 e	1.2 e	2.24 b	10 f	13.7 f	20.1 e	1.4 e	1.94 bc	10 d
July	25.2 e	26.2 d	2.9 bc	2.91 a	16 e	22.7 e	23.9 b	2.6 b	3.10 a	17 bcd
August	95.3 c	37.5 b	3.3 b	0.60 fe	32 d	113.6 a	41.2 ab	3.3 ab	0.58 e	36 b
September	117.3 a	44.5 a	2.8 bc	1.19 cd	96 bc	109.3 c	44.5 ab	3.5 a	0.99 cde	51 b
October	117.3 a	44.3 a	2.7 bc	0.90 def	73 c	109.3 c	46.2 a	3.8 a	1.14 cde	61 b
November	103.8 b	33.3 bc	1.7 c	0.82 def	71 c	109.8 b	32.8 c	2.9 b	0.52 e	47 c
March-05	30.4 e	12.5 fg	2.9 d	1.07 cde	34 d	20.1 e	7.8 gh	1.5 de	1.23 cde	34 ab
April	80 d	32 c	2.9 bc	1.54 c	74 c	78 d	31.6 c	2.6 bc	1.40 cde	90 abc
May	77.8 d	33.7 bc	3.9 a	2.23 b	81 bc	77.8 d	29.8 c	3.5 a	1.77 bcd	71 abc
June	Bolting	24.7 de	4 a	Bolting	106 ab	Bolting	20.5 de	3.6 a	Bolting	146 a
July	↓	11.2 fg	2.9 bc	↓	140 a	↓	11.2 fg	2.1 cd	↓	189 a
August	↓	10.6 fg	1.8 cd	↓	34 d	↓	4.1 hi	0.7 f	↓	8 g

[a] Means followed by the same letter within columns are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$.

Table 2.2. Stem length (cm) and weight (g) as well as capitulum weight (g) combined over locations (Columbia and New Franklin) in Missouri.[a]

Harvest Date	Stem weight	Stem length	Capitulum weight
	(g/plant)	(cm/plant)	(g/capitulum)
May-05	41.3 d	41.9 c	-
Jun-05	142.4 c	149.3 b	9.6 b
Jul-05	216.8 b	200.5 a	78.2 a
Aug-05	240.7 a	204.7 a	90.3 a

[a] Means followed by the same letter within columns are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$.

Table 2.3. Absolute growth rate (AGR) in grams day^{-1} plant^{-1} and relative growth rate (RGR) in grams day^{-1} grams of plant^{-1} of the total above and below biomass of cut-leaved teasel at Columbia and New Franklin, Missouri.

	Columbia				New Franklin			
	Above-ground biomass		Below-ground biomass		Above-ground biomass		Below-ground biomass	
Date	AGR	RGR	AGR	RGR	AGR	RGR	AGR	RGR
May- 04	0.007	0.152	0.003	0.113	0.005	0.112	0.002	0.059
Jun	0.005	0.037	0.000	0.009	0.018	0.094	0.003	0.044
Jun	0.078	0.143	0.017	0.123	0.080	0.104	0.014	0.093
Jul	0.392	0.081	0.078	0.077	0.305	0.068	0.073	0.076
Aug	1.292	0.045	0.195	0.038	1.866	0.059	0.300	0.050
Sep	4.783	0.043	0.985	0.049	2.211	0.022	0.692	0.033
Oct	-0.233	-0.001	0.549	0.012	1.165	0.008	0.535	0.013
Nov	-0.757	-0.004	0.210	0.004	-1.631	-0.012	0.266	0.005
Mar-05	-0.883	-0.009	0.122	-0.002	-0.592	-0.009	0.029	0.000
Apr	1.038	0.014	0.265	0.005	1.520	0.026	0.011	0.000
May	3.570	0.027	1.324	0.018	2.326	0.020	0.344	0.005
Jun	3.189	0.013	-1.098	-0.015	4.794	0.022	0.095	0.001
Jul	2.167	0.007	0.427	0.007	2.387	0.007	-0.358	-0.005
Aug	-1.171	-0.003	0.239	0.003	-1.279	-0.003	0.303	0.004

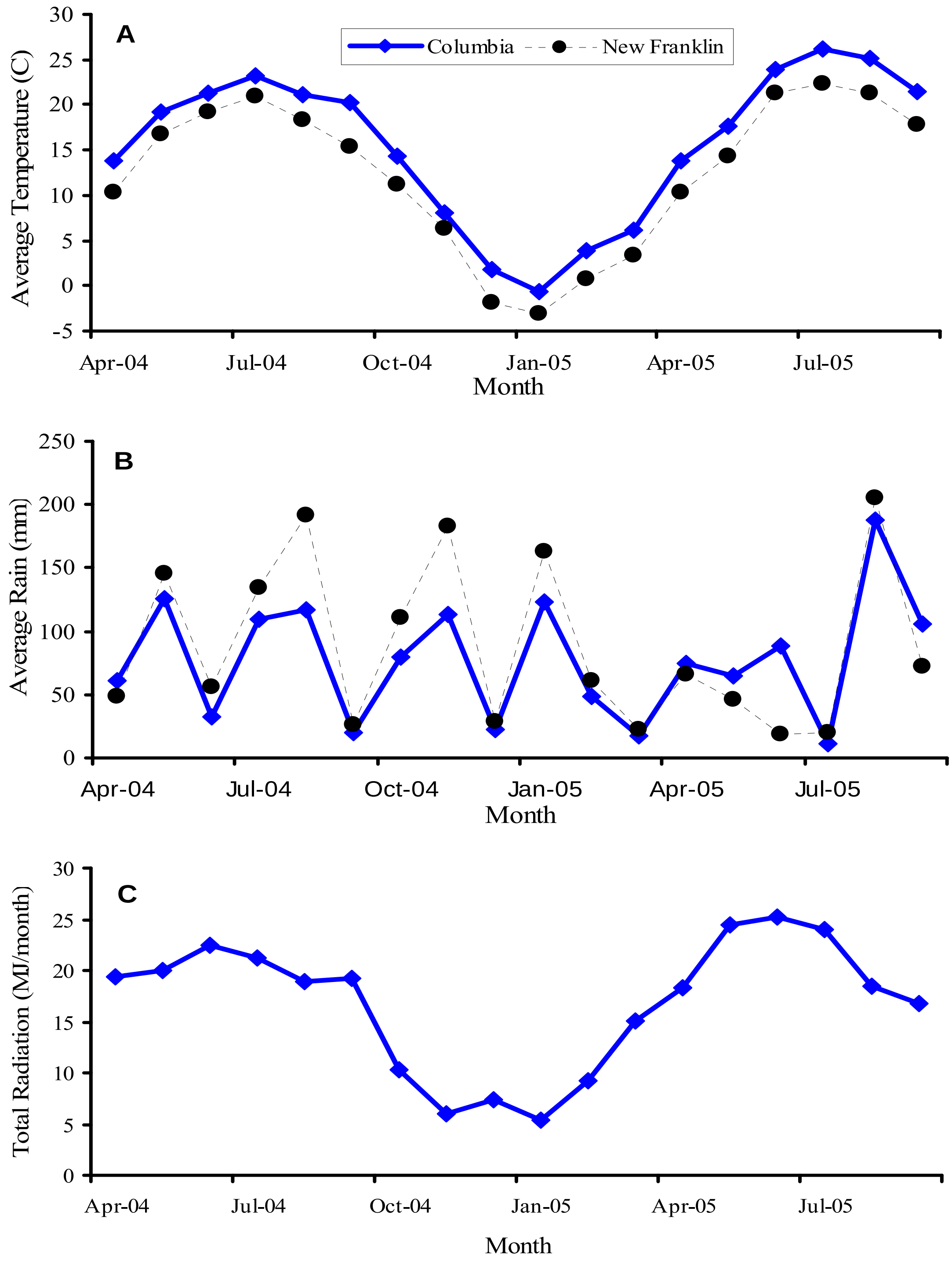

Figure 2.1. Monthly average of air temperature (A), total precipitation (B) and total solar radiation (C) during the period of teasel growth at Columbia and New Franklin. Data were recorded for Columbia in Boone County and New Franklin in Howard County, Missouri.

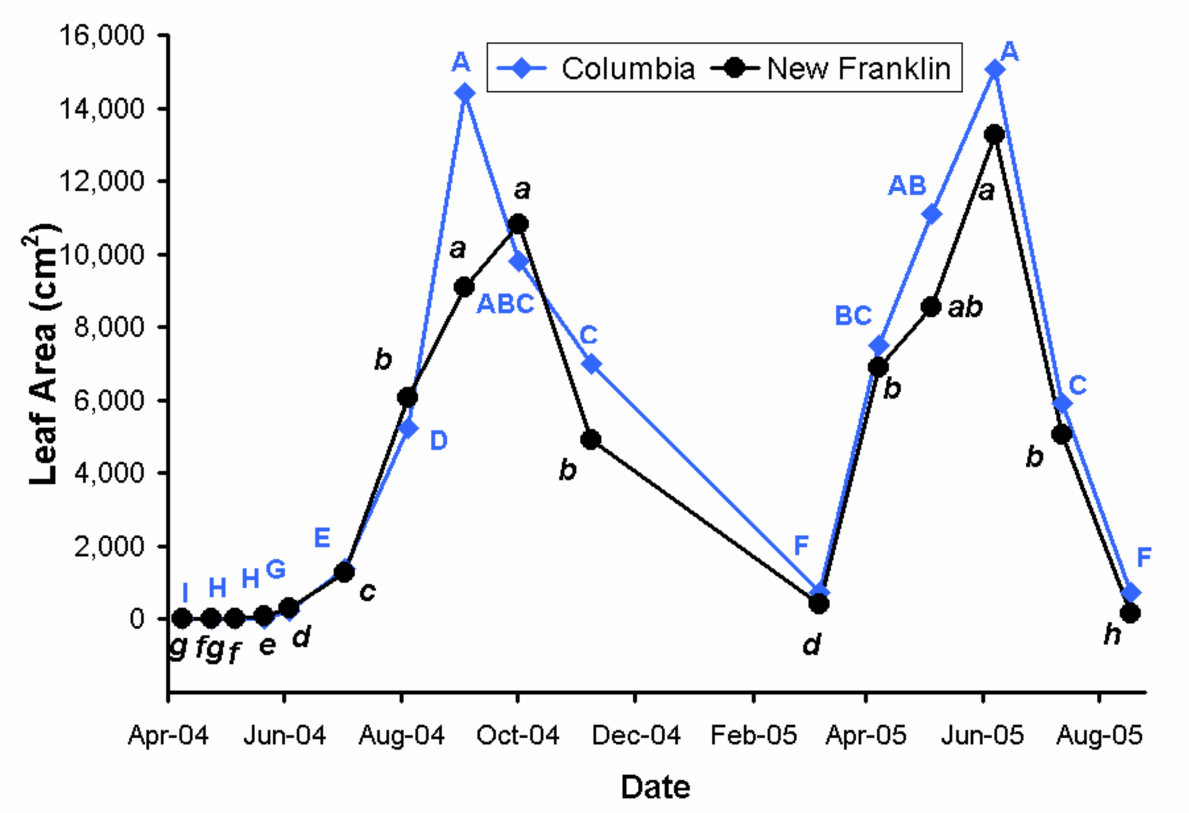

Figure 2.2. Means of total leaf area per plant throughout the growth cycle for cut-leaved teasel at two mid-Missouri locations (Columbia and New Franklin).

Means followed by the same letter within locations (capital letter = Columbia; small letter = New Franklin) are not significantly different according to Fisher's Protected LSD at p≤0.05.

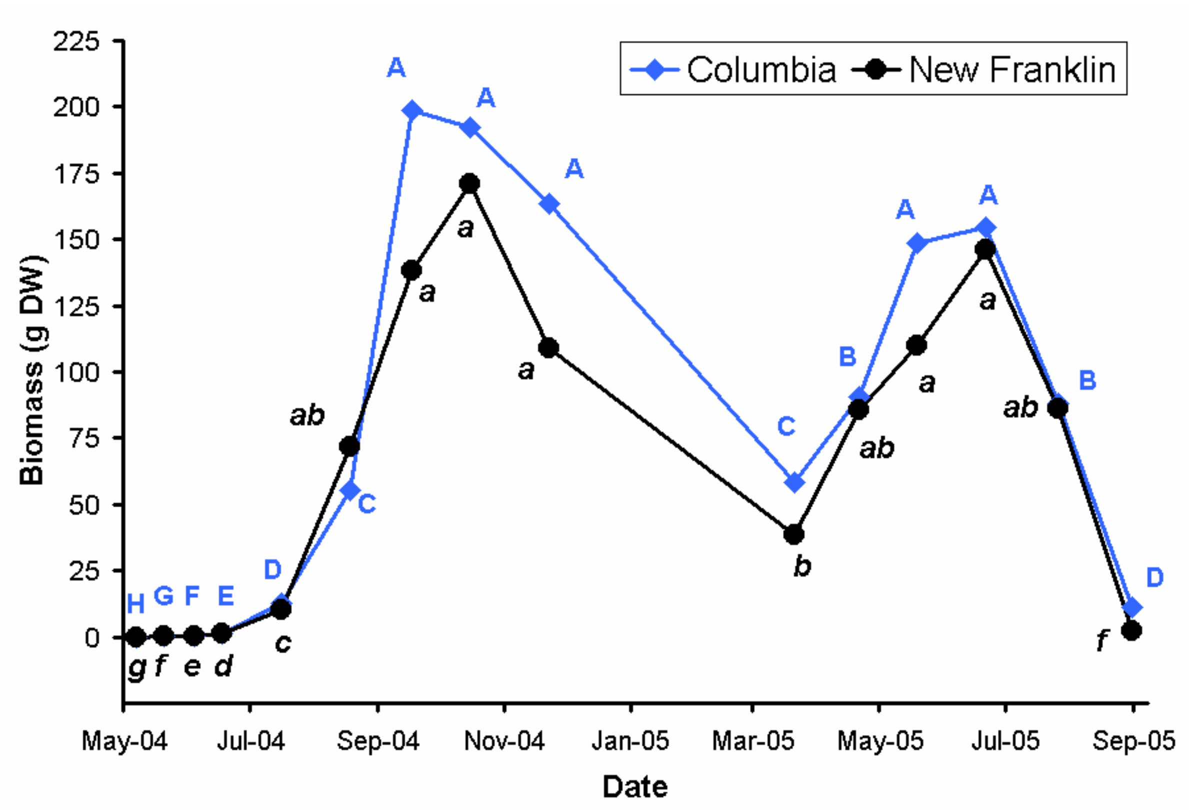

Figure 2.3. Means of the total dry weight (g) of leaves per plant throughout the growth cycle for cut-leaved teasel at two mid-Missouri locations (Columbia and New Franklin). Means followed by the same letter within locations (capital letter = Columbia; small letter = New Franklin) are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$.

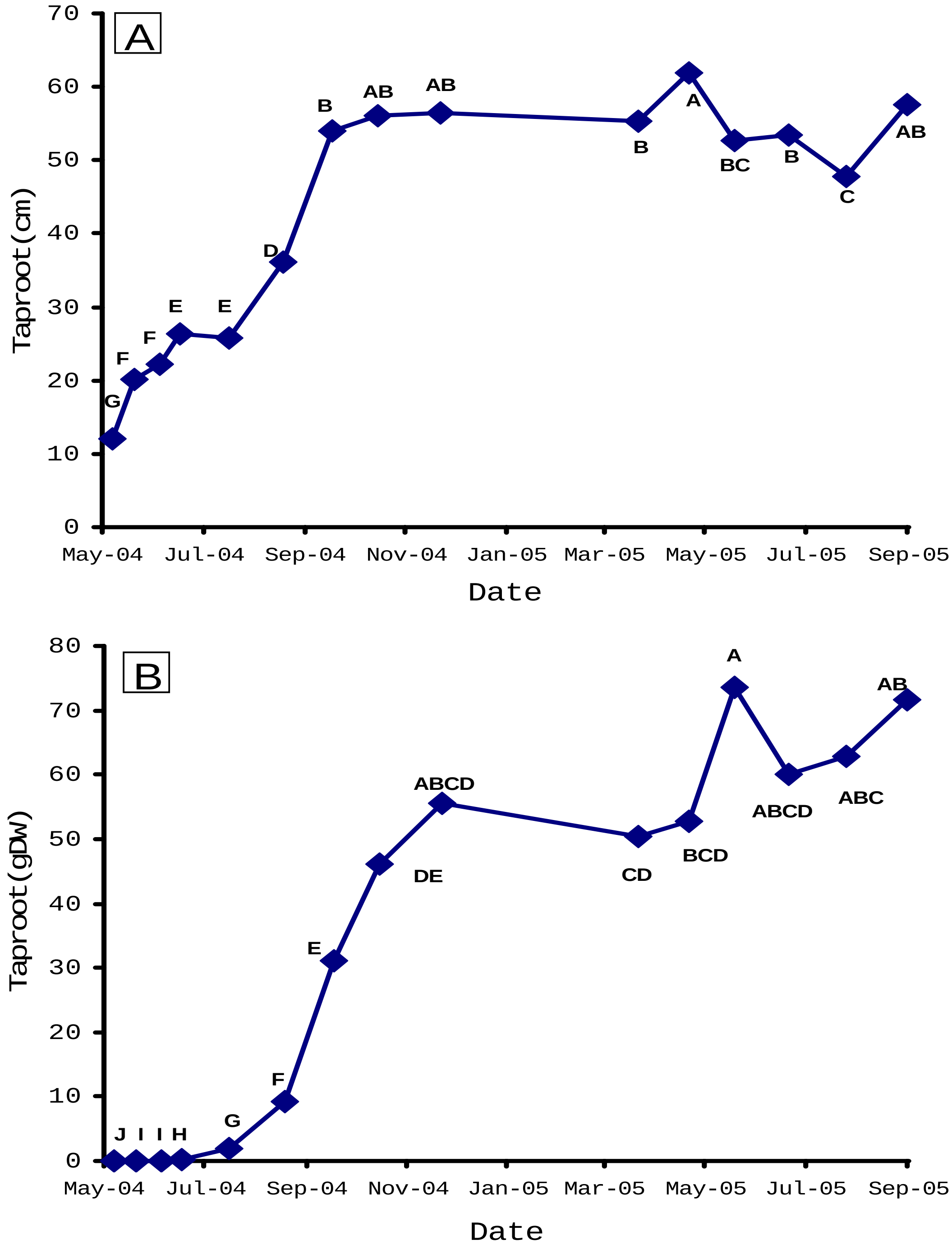

Figure 2.4. Means teasel taproot length (cm) (A) and taproot weight (grams) (B) for cut-leaved teasel over time and locations for each harvest in Missouri. Means followed by the same letter are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$.

CHAPTER III

Chemical Management of Teasel (*Dipsacus laciniatus* L.) in Central Missouri[1]

DIEGO J. BENTIVEGNA AND REID J. SMEDA [2]

Abstract: Cut-leaved teasel (*Dipsacus laciniatus* L.) is a biennial invasive weed, growing vegetatively as a rosette one growing season and flowering during the second year. Herbicides were evaluated for efficacy on rosette plant as well as residual activity for suppressing seedling emergence. Dicamba + diflufenzopyr, glyphosate, metsulfuron-methyl, sulfusolfuron, sulfometuron-methyl, paraquat, imazapyr, and a combination of 2,4-D with triclopyr, picloram or clopyralid were applied on established teasel in a randomized completed block design at two locations in central Missouri in fall 2003 and spring 2004, and again in fall 2004 and spring 2005. Teasel rosettes were visually evaluated for injury at 2, 4, and 8 weeks following application. New emergence was evaluated by counting individual seedlings in selected treatments 210 days after application. At 2 weeks after treatment, paraquat resulted in the best control (>85%). At 4 weeks, dicamba + diflufenzopyr provided the most consistent control at 75%. At 8 weeks, most of the herbicides resulted in more than 90% control. Sulfosulfuron and sulfometuron-methyl had less than 80% control. Combinations of triclopyr, picloram or clopyralid plus 2,4-D did not increase control over 2,4-D alone. Imazapyr was the only herbicide in 2005 that reduced the emergence of teasel. A number of herbicides were effective in managing emerged plants; but re-infestation of treated sites is likely, even with the residual herbicides used in this research.

Nomenclature: Teasel, *Dipsacus laciniatus* L.

---

[1] Received for publication on _________and in revised form on__________

[2] Graduated Research Assistant and Associate Professor, Division Plant Science, University of Missouri. Columbia, MO 65211.

Additional index words:, cut-leaved, herbicide, invasive, roadside

INTRODUCTION

Cut-leaved teasel (*Dipsacus laciniatus* L.) is an invasive weed introduced into the United States from Europe in the 1700's (Hoffman and Kearns 1997; Missouri Vegetation Management Manual 1997). Cut-leaved as well as common teasel (*Dipsacus silvestris* Huds.) may have been introduced with cultivated teasel (*Dipsacus fullonum* L.) (Solecki 1993). Lacking natural enemies and quickly adapting to low maintenance areas along highway medians, teasel has become widespread in many states in the last 10 to 30 years (Missouri Vegetation Management Manual, 1997; Solecki 1993). Rapid spread was likely assisted by the construction of the interstate highway system, which acted as a dispersal corridor (Solecki 1993). Today, cut-leaved teasel is distributed principally in the central and northeastern United States. Teasel is a noxious weed in Colorado, Iowa, New Mexico, Oregon, and Missouri (Rector et al. 2006; USDA 2003).

Teasel is characterized as a biennial with establishment as a basal rosette in the first year and reproduction during the second year (Jurica 1921). In the rosette stage, plants can store sufficient resources in the taproot prior for over wintering and flowering (Werner 1975a). Reproduction is only by seed, and one plant can produce more than 3,000 seeds (Werner 1975b). Seed dispersal is predominantly within 1.5 meters around the parent plant (Werner 1975a). Teasel typically colonizes habitats along roadsides, natural conservation areas, pastures, cemeteries, railroads, open meadows, forest edges, and other low maintenance areas (Missouri Vegetation Management Manual 1997; Werner 1977). Once established, teasel reduces plant diversity in natural conservation areas (Huenneke and Thomson 1994; Missouri

Vegetation Management Manual 1997; Solecki 1993), reduces water infiltration into the soil (Lacey et al. 1989), and reduces visibility along roadways and railroad crossings (Rand Swanigan, personal communication[3]).

Management strategies for teasel should focus on eliminating established plants and on preventing the dispersal of viable seeds (Solecki 1993). Mechanical methods such as hand roguing, mowing, and herbicides are frequently used as management techniques (Glass 1991; Solecki 1993). Rosettes can be extracted using mechanical equipment, but only in small areas (Glass 1991; Solecki 1993). Mowing is a common practice for vegetation management along roadsides; however, mowing equipment can increase seed dispersion from senescing plants (Hoffman and Kearns 1997). In addition, resources in large root systems can support regrowth of mowed plants; resulting in additional flowering (Cheesman 1998; Glass 1991). Typical management of teasel involves application of herbicides (Caylor 1998; Missouri Vegetation Management Manual 1997). However, there are few herbicides labeled for teasel control: triclopyr, 2,4-D + glyphosate, dicamba, clopyralid, and chlorsulfuron (Crop Protection Reference 2006; Glass 1991). Glyphosate, dicamba, 2,4-D, sulfometuron-methyl, metsulfuron-methyl as well as combinations of 2,4-D with picloram and clopyralid, are herbicides recommended for managing other biennial plants that have strong taproots and a rosette growth habit such as Cirsium vulgare (Savi) and Verbascum thapsus (L.) (Bradley and Kending 2004; Crop Protection Reference 2006; Nordby and Hager 2004). Despite label recommendations, published data on the effectiveness of different herbicides on cut-leaved teasel are lacking.

[3] Rand Swanigan. Missouri Department of Transportation. Roadside Management specialist.

According to the Missouri Department of Transportation, the incidence of cut-leaved teasel has increased rapidly over the past ten years (Rand Swanigan, personal communication). To date, present management techniques have failed to control or reduce the spread of this invasive plant. The objectives of this study were to identify herbicides for control of cut-leaved teasel and identify herbicides with residual activity for suppressing cut-leaved teasel emergence.

MATERIAL AND METHODS

This study was carried out in 2003-2005 along Highway 63 roadside as well as on the property of Boone County fairground in central Missouri. The habit for the Highway 63 was tall fescue (*Festuca arundinacea* Schreb.) with infrequent mowing. The habit at the fairground was a poorly drained area with weak stand of tall fescue. In 2004-2005, experiments were conducted on the property of Memorial Gardens (cemetery) near Moberly in Randolph County and at the Bradford Research and Extension Center in Boone County, Missouri. The habit at Moberly consisted of a dominant stand of teasel in an abandoned field, at the Bradford location, the habitat was an abandoned pasture with mixed tall fescue and weedy species. At each location, fifteen treatments were established in 3 by 6 m plots in a randomized completed block design with four replications. The list of treatments, rates, and application times are shown in Table 3.1. The 2,4-D was applied at the same rate (1.68 kg ai ha^{-1}) in single treatments or was combined with other herbicides. Herbicide treatments were applied in either the fall or following spring, with fall applications timed to follow some period after a night air temperature of 0 C. Treatments were applied with a CO_2-pressurized backpack sprayer equipped with XR 8002 VS Teejet nozzles[4], calibrated to deliver a spray volume of 147 L ha^{-1}, with an application velocity of 4.8 km hr^{-1}. Application dates and weather conditions at the time of the treatment are shown in Table 3.2. Weather conditions were registered by a Kestrel® 3000[5] Pocket Weather Station. Soil temperature was recorded by a temperature portable thermometer. Soil pH ranged from 5.9 to 7.5 and soil organic matter ranged from 1.8 to 2.9%. Soil texture at both locations was a clay loam in 2003-2004, a silt loam at Bradford, and silty clay loam at Moberly. All herbicide rates were selected based upon levels recommendations for control of biennial weeds in non-crop systems, because many herbicides lacked a recommended rate for teasel.

Teasel plants were visually evaluated for injury 2, 4 and 12 weeks following application,. A scale of 0 to 100% was used, where zero was no visible effect and 100% was defined as plant death. For fall applications, treatments were evaluated twice in the fall and once the following April. Due to snow in central Missouri in December 2004, evaluation at thirty days after fall treatments was not possible.

Residual activity for herbicides was evaluated throughout the year following for dicamba + diflufenzopyr (fall-spring), 2,4-dichlorophenoxyacetic acid + picloram, imazapyr, metsulfuron-methyl, and paraquat. Teasel emergence in the untreated check was recorded for comparison. In each replicate of designated treatments, cotyledon-stage teasel was counted until November in two 0.3 by 0.3m quadrates from each replicate, and were fixed throughout the study. After counting, paraquat was applied broadcast at 1.17 kg ai. ha^{-1} to remove seedlings. Cumulative emergence was calculated by sum of the monthly emergence in each location and treatment.

---

[4] TeeJet XR Spraying Systems CO., North Ave., Wheaton, IL 60188.
[5] Kestrel® 3000. Forestry Suppliers, INC. 205 West Rankin Street Jackson, Mississippi, 39201.

All data were subjected to analysis of variance using SAS statistical software (SAS 2001). There was no interaction over location for new seedling emergence; thus, emergence data were pooled. The test for normality of Shapiro Wilk and analysis of residual for equal variance were used with PROC UNIVARIATE of SAS with a probability ≤ 0.05 (SAS 2003). Variance analyses were combined over years and locations and performed using the PROC MIXED procedure of SAS (Little et al. 1996). Treatment means were separated using Fisher's Protected LSD at P ≤ 0.05 (Steel and Torrie 1980).

RESULTS AND DISCUSSION

There were significant three and two-way interactions among locations, treatments, and time of evaluation. Therefore, each treatment was analyzed within each evaluation time and location

Two weeks after treatment, control of teasel with paraquat ranged from 86 to 95%. All other treatments controlled teasel less than655 except spring applied glyphosate at the fairground site. Sulfosulfurom and 2,4-D (fall) had less effect on teasel control. Herbicides applied in spring controlled teasel equal or greater level than fall treatment (Table 3.4). For example, activity of the 2,4-D in fall was slower than spring application.

Four weeks after application, growth regulators such as dicamba + diflufenzopyr (spring) and 2,4-D + picloram resulted in the maximum level of control at in most of the locations (Table 3.4). Similarly, paraquat had a range of 68 to 93% of control. Using the same concentration of 2,4-D, the combination of 2,4-D + picloram had better control than 2,4-D + triclopyr, 2,4-D + clopyralid and 2,4-D alone. Glyphosate, dicamba + diflufenzopyr, and 2,4-D applications made in the spring had better or similar effects than fall treatments 30 days after treatments.

Most of the treatments resulted in greater than 90% control of teasel eight weeks after application. Sulfometuron-methyl control reached only 80%, and control with sulfosulfuron was very poor (< 33%). Dicamba + diflufenzopyr and glyphosate resulted similar control for fall and spring applications (Table 3.5). However, efficacy of 2,4-D application in the fall of 2004 was 19% lower compared to early fall 2003 or spring applications. Combinations of 2,4-D with other active ingredients versus 2,4-D alone resulted in similar control. Even though triclopyr is an auxinic herbicide recommended for control of teasel (Caylor 1998, Czarapata 2005, Hoffman and Kearns 1997, Glass 1991, Missouri Vegetation Management Manual 1997), the addition to 2,4-D did not increase the control of teasel. Glyphosate and 2,4-D are two herbicides labeled for control of teasel (Czarapata 2005; Glass 1991; INHS 1990; Missouri Vegetation Management Manual 1997; Solecki 1993). Combinations of 2,4-D + glyphosate is recommended at 0.59 kg ai ha^{-1} of 2,4-D and 0.42 kg ai ha^{-1}, respectively. Thus, both herbicides at low rates can reduce teasel without damage to the present grasses (Crop Protection Reference 2006).

Significant interactions among treatment and locations were observed for seedling emergence. Therefore, data were analyzed separately within each location. Cumulativ seedling emergence from June to November is shown in Figure 3.1. Teasel required open space to emerge (Werner 1975c, 1977); however, few seedlings emerged in untreated plots at Bradford and Moberly in 2005. Because teasel take advantage of the open spot created after one plant die, emergence in treated plots was higher compared with untreated plot. In 2004, paraquat reduced of seedlings emergence when compared to other chemical treatments. In

2005, imazapyr resulted in a significant reduction of teasel emergence compared with other treatments. Residual activity of imazapyr ranged from 3 to 24 months depending on the application rate (WWSA 2002). Emergence was also different between years (Fig 3.1). Population density at the Highway and Fairground locations along with better environmental conditions in 2004 could be the source for emergence differences between years.

In summary, several herbicides adequately controlled emerged teasel. Fall applications were similar in effectiveness to spring application for dicamba plus diflufenzopyr and glyphosate. Only imazapyr suppressed sequential emergence of teasel up to 71.1% at 210 days after treatments. Herbicides are an important tool in the management of emerged teasel, but long term control may include other techniques such as mowing and establishment of acceptable species.

LITERATURE CITED

Bradley, K.W. and J.A. Kending. 2004. Weed and brush control guide for forage, pastures and noncropland. Technical report MP581. Ed. University of Missouri Extension. 32 pp.

Caylor, P. 1998. Herbicides help Illinois DOT control roadside weeds. American City & County 113:17-18.

Cheesman, O.D. 1998. The impact of some field boundary management practices on the development of *Dipsacus fullonum* L. flowering stems, and implication for conservation. Agriculture, Ecosystems and Environment 68:41-49.

Crop Protection Reference. 2006. C & O press. 302 5th Avenue New York, NY 10117-1058. 2395 pp.

Czarapata, E.J. 2005. Invasive plant of the upper Midwest. Ed. University of Wisconsin press. WI. 215 pp.

Glass, W.D. 1991. Vegetation management guideline: cut-leaved teasel (*Dipsacus lacinatus* L.) and common teasel (*Dipsacus sylvestris* Huds.). Natural Areas Journal 11:213-214.

Hoffman, R. and K. Kearns. 1997. Wisconsin Manual of Control. Recommendation for ecologically invasive plants. Wisconsin Department of natural Resources, Madison, WI. 102 pp.

Huenneke, L. F. and J.K. Thomson. 1994. Potential interference between a threatened endemic thistle and an invasive nonnative plant. Conservation Biology 9(2):416-426.

INHS. Illinois Natural History Survey. 1990. Vegetation Management Guidelines. Cut-leaved teasel (*Dipsacus laciniatus* L.) and Common teasel (*Dipsacus sylvestris* Huds.). In Vegetation Management Manual Ed. Illinois Nature Preserve Commission. 1: 24.

Jurica, H.S. 1921. Development of head and flower of *Dipsacus sylvestris*. Botanical Gazette 71(2):138-145.

Lacey, J. R., C.B. Marlow, and J.R. Lane. 1989. Influence of spotted knapweed (*Centaurea maculosa)* on surface runoff and sediment yield. Weed Technology 3(4):627-631.

Little, R.C., G.A. Milliken, W.W. Stroup, and R. D. Wolfinger. 1996. SAS System for Mixed Models. Cary, NC: SAS Institute. 656 pp.

Missouri Vegetation Management Manual. 1997. Ed. Tim E. Smith. Missouri. Department Conservation, P.O. Box 180. Jefferson City. MO. 65102. 44-49 pp.

Nordby, D. and A.G. Hager. 2004. Weed control in small grains, pasture, and forages. In: Illinois Agricultural Pest Management Handbook. (Ed) University of Illinois Extension. University of Illinois at Urbana-Champaign. 358 pp.

Rector, B.G., V. Harizanova, R. Sforza, T.Widmer, and R.N. Wiedenmannn. 2006. Prospects for biological control of teasels, *Dipsacus spp*., a new target in the United States. Biological control 36: 1-14.

[SAS] Statistical Analysis Systems. 2003. SAS/STAT User's Guide. Release 9.1 Software version 8e. Cary, NC: Statistical Analysis Systems Institute.

Steel, R.G.D. and J. H. Torrie. 1980 Principles and Procedures of Statistics: A Biometrical Approach. 2nd ed. New York: McGraw-Hill. 633 pp.

Solecki, M.K. 1993. Cut-leaved and common teasel (*Dipsacus laciniatus* L and *D. sylvestris* Huds): profile of two invasive aliens. *In* McKnight, B.N. (Ed), BIOLOGICAL Pollution: The control and impact of invasive exotic species. Indiana Academic of Science, Indianapolis. 85-92 pp.

USDA. 2003. The PLANTS Database, Version 3.5 (http://plants.usda.gov). National Plant Data Center, Baton Rouge, LA 70874-4490 USA. Access January 20, 2006

Werner, P.A. 1975a. Predictions of Fate from Rosette Size in teasel (*Dipsacus fullonum* L.). Oecologia 20:197-201.

Werner, P.A. 1975b. The biology of Canadian weeds 12. *Dipsacus sylvestris* Huds. Canadian Journal Plant Science 55:783-794.

Werner, P.A. 1977. Colonization success of a "Biennial" plant species: experimental field studies of species cohabitation and replacement. Ecology 58:840-849.

WWSA. 2002. Herbicide Handbook. 8th ed. Weed Science Society of America. 810 East 10th Street Lawrence. KS. 493 pp.

Table 3.1. Herbicides, rates, and application timings for cut-leaved teasel (*Dipsacus laciniatus* L.) trials in central Missouri.[a]

Treatment	Herbicide	Rate	Timing
1	Untreated	--	--
2	Glyphosate + AMS	2.52 kg ae ha^{-1} 2.8 kg ai ha^{-1}	Fall
3	2,4-Dichlorophenoxyacetic acid	1.68 kg ai ha^{-1}	Fall
4	2,4-Dichlorophenoxyacetic acid + triclopyr	2.52 kg ai ha^{-1}	Spring
5	2,4-Dichlorophenoxyacetic acid + picloram	2.13 kg ai ha^{-1}	Spring
6	Dicamba + diflufenzopyr +NIS +UAN	0.29 kg ai ha^{-1} 0.25 % v/v 1.25 % v/v	Fall
7	2,4-Dichlorophenoxyacetic acid + clopyralid +NIS	2 kg ai ha^{-1} 0.5 % v/v	Spring
8	Metsulfuron-methyl +NIS	0.008 kg ai ha^{-1} 0.5 % v/v	Spring
9	Sulfosulfuron +NIS	0.11 kg ai ha^{-1} 0.5 % v/v	Spring
10	Paraquat +NIS	0.94 kg ai ha^{-1} 0.125 % v/v	Spring
11	Imazapyr +NIS	0.84 kg ai ha^{-1} 0.25 % v/v	Spring
12	Sulfometuron methyl +NIS	0.11 kg ai ha^{-1} 0.25 % v/v	Spring
13	2,4-Dichlorophenoxyacetic acid	1.68 kg ai ha^{-1}	Spring
14	Dicamba + diflufenzopyr +NIS +UAN	0.29 kg ai ha^{-1} 0.25 % v/v 1.25 % v/v	Spring
15	Glyphosate + AMS	2.52 kg ae ha^{-1} 2.8 kg ai ha^{-1}	Spring

[a]Abbreviations: AMS, ammonium sulfate; NIS, nonionic surfactant; UAN, urea ammonium nitrate.

Table 3.2. Dates and weather conditions of the chemical treatment made at Fairground, Highway 63, Bradford, and Moberly sites in central Missouri.[a]

	Fairground		Highway 63		Bradford		Moberly	
	11/07/03	04/27/04	11/07/03	04/27/04	12/03/04	04/27/05	12/03/04	04/27/05
Air temperature (C)	10	21.5	10	21.5	8.5	16.5	8.5	15
Soil temperature (C)	9	20	9	20	5	15	5	13.5
Relative Humidity (%)	60	30	60	30	100	39	100	40
Wind Speed (km hr^{-1})	1	4.8	1	4.8	4.8	8	4.8	8.8

[a] Data was recorded by Kestrel® 3000 Pocket Weather Station. Soil temperature was recorded by a temperature portable thermometer. probe.

Abbreviations: C, centigrade degree; %, percentage; km hr^{-1}, kilometers per hour.

Table 3.3. Mean visual injury to teasel 2 weeks after treatments at the Highway 63, Fairground, Bradford and Moberly locations in central Missouri[a]

Treatment	Highway 63	Fairground	Bradford	Moberly
	2003-2004	2003-2004	2004-2005	2004-2005
Glyphosate (Fall)	30 def	23 cd	28 b	28 b
2,4-D (Fall)	24 efg	6 d	13 c	15 c
2,4-D + triclopyr	48 bc	50 b	38 b	50 b
2,4-D + picloram	53 b	49 b	51 b	55 b
Dicamba + diflufenzopyr (Fall)	34 cde	19 d	25 b	20 b
2,4-D +clopyralid	39 bcd	39 b	35 b	42 b
Metsulfuron-methyl	15 fg	29 c	16 c	16 c
Sulfosulfuron	0 h	6 e	1 c	5 c
Paraquat	95 a	95 a	86 a	88 a
Imazapyr	16 fg	31 c	11 c	14 c
Sulfometuron-methyl	13 gh	23 c	23 c	18 c
2,4-D (Spring)	31 de	36 b	25 b	49 b
Dicamba + diflufenzopyr (Spring)	43 bcd	53 b	49 b	56 b
Glyphosate (Spring)	43 bcd	88 b	59 b	65 b

[a] Means followed by the same letter within columns are not significantly different according to Fisher's Potected LSD at $p \leq 0.05$.

Table 3.4. Mean visual injury to teasel 4 weeks after treatments at the Highway 63, Fairground, Bradford and Moberly locations in central Missouri.[a]

Treatment	Highway 63	Fairground	Bradford	Moberly
	2003-2004	2003-2004	2004-2005	2004-2005
Glyphosate (Fall)	66 c	60 eg	-[b]	-
2,4-D (Fall)	40 d	35 h	-	-
2,4-D + triclopyr	66 c	75 bcd	46 ef	66 bc
2,4-D + picloram	89 a	84 ab	61 cd	75 ab
Dicamba + diflufenzopyr (Fall)	45 d	51 g	-	-
2,4-D + clopyralid	73 bc	69 cde	45 ef	48 d
Metsulfuron-methyl	89 a	75 bcd	51 de	46 d
Sulfosulfuron	8 e	13 i	4 g	5 e
Paraquat	79 ab	68 cde	96 a	93 a
Imazapyr	86 a	81 b	63 c	45 d
Sulfometuron-methyl	80 ab	70 cde	51 de	51 cd
2,4-D (Spring)	65 c	65 de	39 f	54 cd
Dicamba + diflufenzopyr (Spring)	85 a	94 a	75 b	86 a
Glyphosate (Spring)	66 c	76 bc	64 bc	83 ab

[a] Means followed by the same letter within columns are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$.

[b] Data not collected due to snow cover.

Table 3.5. Mean visual injury to teasel 8 weeks after treatments at the Highway 63, Fairground, Bradford and Moberly locations in central Missouri.[a]

Treatment	Highway 63	Fairground	Bradford	Moberly
	2003-2004	2003-2004	2004-2005	2004-2005
Glyphosate (Fall)	95 a	90 a	96 ab	100 a
2,4-D (Fall)	89 ab	96 a	66 d	83 b
2,4-D + triclopyr	98 a	100 a	86 bc	100 a
2,4-D+ picloram	100 a	100 a	100 a	100 a
Dicamba + diflufenzopyr (Fall)	100 a	100 a	100 a	100 a
2,4-D + clopyralid	100 a	100 a	100 a	100 a
Metsulfuron-methyl	100 a	100 a	100 a	100 a
Sulfosulfuron	0 d	9 c	3 e	33 c
Paraquat	70 bc	88 b	100 a	100 a
Imazapyr	100 a	100 a	100 a	99 a
Sulfometuron-methyl	64 c	81 b	78 cd	98 a
2,4-D (Spring)	95 a	100 a	76 cd	100 a
Dicamba + diflufenzopyr (Spring)	95 a	94 a	100 a	100 a
Glyphosate (Spring)	85 abc	98 a	93 ab	100 a

[a] Means followed by the same letter within columns are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$.

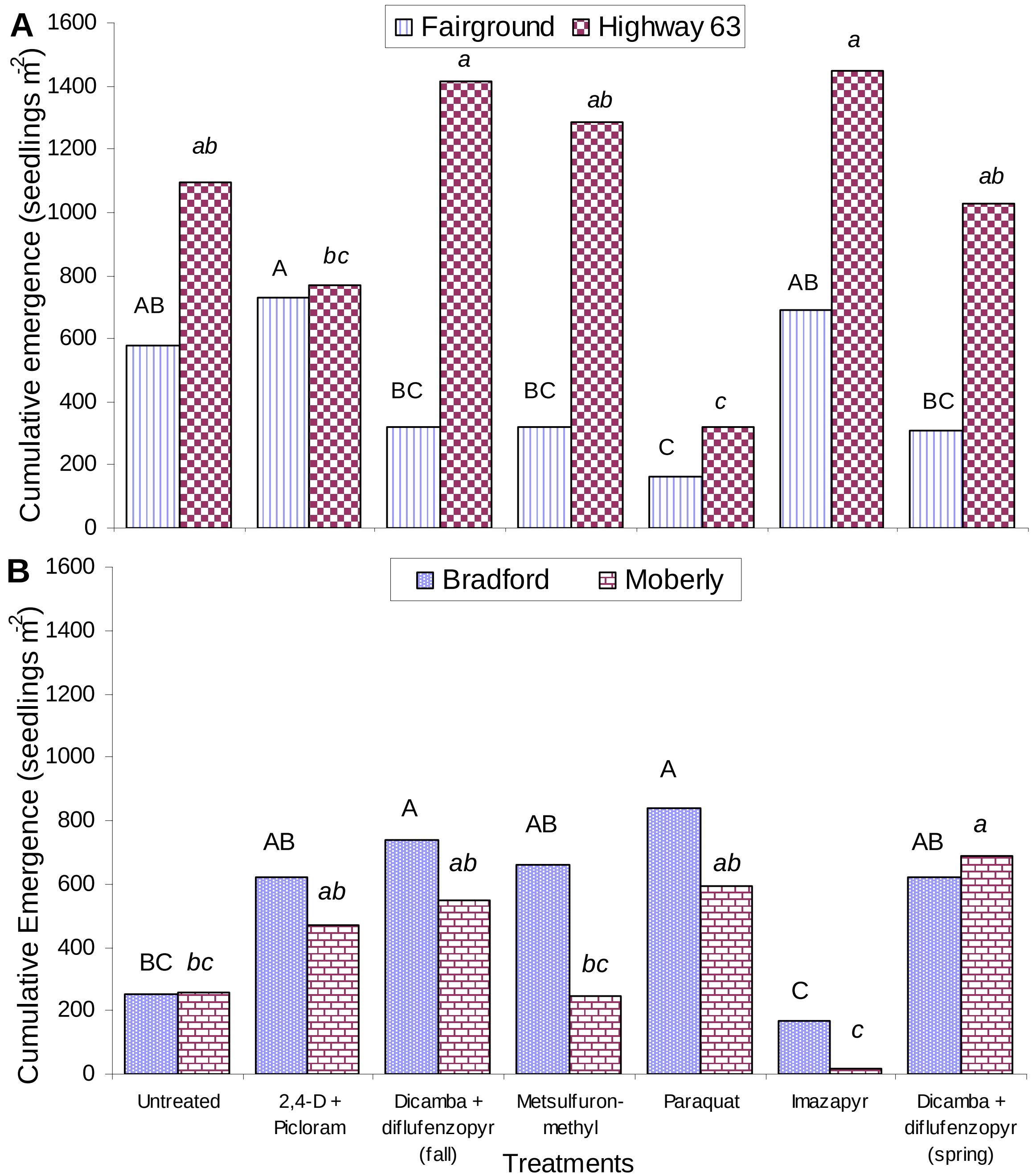

Figure 3.1. Cumulative emergence of cut-leaved teasel after 210 days of herbicides treatments at Fairground and Highway 63 in 2004 (A) and Moberly and Bradford in 2005 (B), Missouri. Means with the same letter within locations are not different according to Fisher's Protected LSD at $p \leq 0.05$.

CHAPTER IV

Seed Production of Cut-leaved Teasel (*Dipsacus laciniatus* L.) in Central Missouri[1]

DIEGO BENTIVEGNA and REID J. SMEDA[2]

Abstract: Cut-leaved teasel is an invasive weed in Missouri that reduces the diversification of native species along roadsides, and impairs traffic visibility. Teasel is a biennial and grows as a rosette in the first year and flowers the second year. Reproduction is only by seed. Field studies were conducted in 2004 and 2005 in two locations to assess the seed production of cut-leaved teasel. From natural stand, fifteen plants at the onset of flowering were tagged. Selected plants included those considered growing in a group and those growing alone; a plant was considered alone when no other plant was adjacent for at least 60 cm. Whenever a seedhead completed flowering, the head was covered with a cellophane bag and harvested one month later. Linearl regression was used between weight of seeds from a single seedhead and number of seeds to estimate the total seed production per head.

The number of seedhead per plant varied from 3 to 56. In average, plants living alone have 64% higher number of seedhead than plant living a group. Seed numbers in the primary seedhead ranged from 511 to 1,487. Total seed production per plant was from 1,309 to 33,527. Seed production was 61% higher for plants growing alone versus those growing in a group. Differences between years in seed production were registered only in plants growing alone. In addition, seed production was different between location in plants growing alone but not when is growing in groups.

Nomenclature: Teasel, *Dipsacus laciniatus*, noxious, invasive.

---

[1] Received for publication on _________and in revised form on__________

[2] Graduated Research Assistant and Associate Professor, Division Plant Science, University of Missouri. Columbia, MO 65211

Additional index words: reproduction, roadside.

INTRODUCTION

Cut-leaved teasel (*Dipsacus laciniatus* L.) is a native plant of southern Europe that was introduced in 1700's for the textile industry for processing of woolen cloth (Bobrov 1957; Mullins 1951; Rodale 1984). The rapid distribution of teasel in the last 30 years occurred along the highway system where dispersal has been aided by mowing equipment (Hoffman and Kearns 1997). In addition, teasel has a competitive advantage over other species in roadside habitats, because the plants can tolerate saline soil due to salt spread in winter months (Beaton 2004). Today, cut-leaved teasel is considered a noxious weed in several states: Colorado, Iowa, New Mexico, Oregon, and Missouri (Rector et al. 2006; USDA 2006).

Teasel colonizes undisturbed areas along roadsides, conservation areas, railroads and cemeteries (Solecki 1993; Werner 1975b). Cut-leaved teasel's negative impacts include: displaces of native species; increases soil erosion by reducing water penetration into the soil; and reduces traffic visibility by growing up to 2.5 meters (Rand Swanigan, personal communication). In conservation and natural areas produce the suppression or elimination of desirable species for altering the nutrients and hydrological cycle (Huenneke and Thomson 1994; Solecki 1993; Werner 1977). The taproot changes the soil moisture levels by reducing water infiltration in relation to fibrous roots; thus, increasing the runoff and erosion (Lacey et al. 1989).

Seeds germinate throughout the year, but mainly during the fall and spring. Following emergence, teasel develops a rosette with a large taproot extending up to 75 cm in the first year. In the second year, rosettes bolt and produce a flowering stalk reaching 2.5 meters. (Werner 1975c). Plants die after flowering, and complete a biennial life cycle (Jurica 1921, Solecki 1993, Werner 1975b).

The type of inflorescence is a head or capitulum, and the fruit is an achene. The method of flowering is unique, because it begins at the middle of the capitulum and extends upward and downward simultaneously (Jurica 1921). The number of seed per inflorescence varies directly with the size of the capitulum (Werner 1975b), and the number of inflorescences per plant varies with the size of the plant. In fact, plants that were taller and more vigorous were likely to have larger seedheads (Hedberfg and Hedberg 1977). Lower soil fertility and higher plant density decreases the number of branches, and ultimately total seed production (Caswell and Werner 1978). Seeds do not require stratification, scarification, or specific light conditions for germination (Solecki 1993). High germination (30 to 80%) and prolonged viability (more 7 years) are two important characteristics contributing to the success of teasel infestation (Glass 1991; Roberts 1986)

Neither teasel plants nor the seeds possess morphological characteristics for dispersal by wind or animal (Werner 1975b). Thus, more than 99% of the seeds fall within 1.5 m of the parent plant, producing dense communities (Werner 1975a). Seeds can float on water, and this dispersal mechanism was cited by several authors (Glass 1991; Neubert and Caswell 2000; Werner 1975b). Even though dispersed seeds were near the parent plant, Caswell and Werner (1978) suggest that the probability of colonization of new sites was related with the seed production.

Seed production of teasel was reported to be over 3,300 seeds for *D. sylvestris* in Michigan (Werner 1975b), and 3,000 seeds for *D. sylvestris* and *D. laciniatus* in Illinois

(Glass 1991). In central Missouri, there was no report of the amount of seed production for individual plants or any research showing the impact of intraspecific competition on seed production. Studies identifying seed production per seedheed as well as the number of seedheads per plant are also lacking. The quantification of seed production in cut-leaved teasel in central Missouri may lead to improved understanding of the reproduction step in the live cycle of teasel, and at the same time generate useful information regarding future strategies of control.

The objectives of this study were to quantify numbers of seedheads, total seed per primary seedhead, and total seed production for cut-leaved teasel plants. In addition, two levels of intraspecific competition were analyzed for the previous parameters.

MATERIAL AND METHODS

Research was conducted in 2004 and 2005 at two locations in central Missouri: Bradford Research and Extension Center at 10 km west and along the Highway 63 at 7 km north of Columbia. These will be referred to as the Bradford and Highway locations. Soil characteristics of the two sites are shown in Table 4.1. At the onset of flowering, fifteen plants in a group and alone were tagged. A plant was considered alone when no other teasel plant was adjacent within at least 60 cm, while a plant was considered in a group when it had at least two flowering teasel plants within 60 cm. When a capitulum completed flowering, the seedhead was covered with a cellophane bag and harvested one month later.

At harvest, seedheads produced by teasel plants were harvested and counted. To determine seed number and weight, seeds were extracted by hand and cleaned using a mesh screen with 1/8 cm holes. Weight of the seeds was recorded at room temperature (20 C) and

50% relative humidity. To estimate seed production, seed weight was regressed against the number of seeds from eleven randomly selected individual seedheads for each year, location and growth habits. Regression over the location and growth habits was pooled into one regression for each year. Primary seedheads were analyzed separately, because it flowers first and sometimes escapes control measures. Weather conditions during the growth cycle were recorded by the Missouri Historical Agricultural Database from the University of Missouri (Figure 4.1).

Data were tested for homogeneity of variance by plotting residuals. Normality was assessed using PROC UNIVARIATE with a probability ≤ 0.05 (SAS 2003). Analyses of the data were performed by the PROC GLM procedure of SAS (SAS 2003). Variables included location, year and growth habit. Where significant interactions occurred, data were subject to a one-way analysis. Mean separations for main effects were obtained by Fisher's LSD at P≤ 0.05 (SAS 2003).

RESULTS AND DISCUSSION

The relationship of seed weight and the number of seed (R^2) was of 0.95 and 0.97 for 2004 and 2005, respectively (Figure 4.2). Small seedheads that produced less of 0,25 grams of seeds was eliminated for the seed estimation because they not produced viable seeds. There was in average 307 seeds per gram of seed (0.95-0.97). Three-way interactions for the number of seedheads, seed per primary seedhead and total seed production per plant among year, place and growth habits were not significant. However, two-way interactions between location-growth habit, location-year, and growth habit-year were significant for number of seedheads, seeds from primary seedhead, and total seed production per plant. The number of seedheads per plant, seed per seedhead and total seed production was greater in average at Bradford compared with Highway location, even though the fertility at Highway, (P, K, Mg, and Ca) was higher compared with Bradford (Table 4.1). Other environmental variables such as rock depth may be important in the determining reproductive potential.

The number of seedheads per plant varied from 3 to 56 and 5 to 20 at Bradford and the Highway locations, respectively (Table 4.2). The larger number of seedheads per plant was for plants growing alone in Columbia (Table 4.2). Plants living alone had an average of 56% greater number of seedheads compared to plants living in a group. There was an effect of the year in the amount of seedhead per plant, but only for plants growing alone and at Bradford (Figure 4.3).

The degree of branching, and consequently the number of seedheads produced by one plant depends upon fertility levels in the soil (Chujo and Hanyu 1990; Jurica 1921). Previous research has documented that one plant of *D. fullonum* usually supports 1 to 40 flowerheads (Cheesman 1998). Werner(1975b) reported the number of inflorescences ranged from 3 to 9 for *D. sylvestris*, but as few as 1 or as many as 35 were common in a roadside population of Michigan. A Japanese population of *D. fullonum* was reported to produce from 60 to 100 seedheads per plant (Chujo and Hanyu 1990). Mullins (1951) illustrated in a population of *D. sativus* that values ranged from 3 to 100 seedheads per plant.

The number of seeds in the primary seedhead ranged from 511 to 1,487 and 734 to 1,266 for Bradford and Highway locations, respectively (Table 4.2). Plants growing alone had a greater number of seeds per primary seedhead than for plants growing in a group (Figure 4.4). There is a difference between years in the number of seeds per primary seedhead at both locations (Figure 4.4). Differences between years in the number of seeds per primary seedhead were only significant for plants growing alone. Plants growing in a group can extract all the resources available in the environmental, but not increase the production when the year was favorable. In the other hand, plants growing alone can take advantage of a good year and increase the production of primary seedheads. Evaluation of the primary seedhead is important, because it is the biggest and flowered early than the others seedheads, and sometimes escapes to the measure of control.

Seed production per plant ranged from 1,309 to 33,527 and 2,060 to 16,540 seeds at Bradford and Highway, respectively (Table 4.2). Across locations, seed production was 64% greater for plants growing alone versus those growing in a group. There were differences in seed production between Bradford and Highway in only plants growing alone. Seed production at Bradford was greater in 2005 than 2004 but similar for the Highway location (Figure 4.5). Differences between years for seed production were noted only for plants of growing alone habit (Figure 4.5). Lower winter temperatures were measured in 2004 than 2005 that could affect the seed production during 2004; especially, for plants growing alone that did not received protection of other teasel plants. Plants growing alone may take advantage of the resources available at flowering and increase seed production.

The number of seeds per plant in our study is higher than those reported by Werner (1975b) who found that *D. sativus* plants produced an average of 3,333 seeds in Michigan. Also, Werner suggested that values of 2,500 seeds per plant were typical for Michigan (Caswell and Werner 1978). Similarly, Glass (1991) reported that a single plant of cut-leaved teasel produced up to 3,000 seeds in Illinois.

Cut-leaved teasel seed production was more prolific in the absence of close competition compared to competing with others teasel plants (from 3,400 to 13,100 seeds more per plant).

Plant reproduction occurs on numerous seedheads (up to 56 seedheads) that mature at different rates (up to 1400 seed on the primary seedhead). As an invasive weed, when a plant invades a new site (alone growth habit), a higher number of seedheads and ultimately total seeds was produced compared to plants in dense stands. Seed dormancy following maturity is minimal; a large number of seedlings is expected (up to 10,000) for each plant. This will contribute to teasel rapidly become a monoculture. Since mowing is the dominant vegetation management technique used in habitats invaded by teasel, mowing equipment may be ideal for enhancing the area where teasel is present.

LITERATURE CITED

Beaton, L. L. and S.A.Dudley. 2004. Tolerance to salinity and manganese in three common roadside species. International Journal of Plant Science. 165 (1):37-51.

Bobrov, E. G. 1957. Genus 1411. *Dispasacus L. In* B.K. Shihkin and E. G. Bobrov, eds. Flora of the USSR, Vol XXIV. Izdaterl'stvo Akademii Nauk SSSR. Moskva-Leningrad. (Transl. from Russian.) Israel Prog for SCI. Transl., Jerusalem. 16-20 pp.

Caswell, H. and P. A. Werner. 1978. Transient behavior and life history analysis of teasel (*Dipsacus sylvestris* Huds.). *Ecology* 59(1)53-66.

Cheesman, O.D. 1998. The impact of some field boundary management practices on the development of *Dipsacus fullonum* L. flowering stems, and implication for conservation. Agriculture, Ecosystems and Environment 68: 41-49.

Chujo, H. and Y. Hanyu. 1990. Growth characteristics of teasel (Dipsacus fullonum L.). Japanese Journal of Crop Science 59(3):461-468.

Glass, W.D. 1991. Vegetation management guideline: cut-leaved teasel (*Dipsacus laciniatus* L.) and common teasel (*Dipsacus sylvestris* Huds.). Natural Areas Journal 11:213-214.

Hedberg, I and Hedberg, O. 1977. The genus *Dipsacus* in tropical Africa. Botaniska notiser 129: 383-389.

Hoffman, R. and K. Kearns. 1997. Wisconsin Manual of Control. Recommendation for ecologically invasive plants. Wisconsin Department of natural Resources, Madison, WI. 102 pp.

Huenneke, L. F. and J.K. Thomson. 1994. Potential interference between a threatened endemic thistle and an invasive nonnative plant. Conservation Biology 9 (2):416-425.

Jurica, H.S. 1921. Development of head and flower of Dipsacus sylvestris. Botanical Gazette 71(2):138-145.

Lacey, J. R., C.B. Marlow, and J.R. Lane. 1989. Influence of spotted knapweed (*Centaurea maculosa*) on surface runoff and sediment yield. Weed Technology 3(4):627-631.

Mullins, D. 1951. Teasel growing, an ancient practive. World Crops 3: 146-147.

Neubert, M.G. and H Caswell. 2000. Demography and dispersal: calculation and sensitivity of invasion speed for structured population. Ecology 81 (6): 1613-1628.

Rector, B.G., V. Harizanova, R. Sforza, T.Widmer, and R.N. Wiedenmannn. 2006. Prospects for biological control of teasels, *Dipsacus spp*., a new target in the United States. Biological control 36:1-14.

Roberts, H.A. 1986. Seed persistence in soil and seasonal emergence in plant species from different habits. Journal of Applied Ecology 23:639-656.

Rodale, R. 1984. Teasel in Our Lawn. Organic Gardening 31 (11)22-25.

[SAS] Statistical Analysis Systems. 2003. SAS/STAT User's Guide. Release 9.1 Software version 8e. Cary, NC: Statistical. Analysis Systems Institute.

Solecki, M.K. 1993. Cut-leaved and common teasel (*Dipsacus laciniatus* L and *D. sylvestris* Huds): profile of two invasive aliens. *In* McKnight, B.N. (Ed), BIOLOGICAL Pollution: The control and impact of invasive exotic species. Indiana Academic of Science, Indianapolis. 85-92 pp.

Werner, P.A. 1975a. A seed trap for determining patterns of seed deposition in terrestrial plant. Canadian Journal of Botany. 53:810-813.

Werner, P.A. 1975b. The biology of Canadian weeds 12. *Dipsacus sylvestris* Huds. Canadian Journal Plant Science 55:783-794.

Werner, P.A. 1975c. The biology of Canadian weeds 12. *Dipsacus sylvestris* Huds. Canadian Journal Plant Science 55:783-794.

Werner, P.A. 1977. Colonization success of a "Biennial" plant species: experimental field studies of species cohabitation and replacement. Ecology 58:840-849.

Table 4.1. Chemical and physical soil properties at Highway and Bradford during seed production study.

Soil Property	Highway	Bradford
pH	7.5	5.9
Organic Matter	2.1 %	2.9 %
texture	Clay loam	Silt Loam
Sand	22.5 %	20 %
Silt	40 %	57.5 %
Clay	37.5 %	22.5 %
Phosphor (Kg ha^{-1})	25.8	12.3
Potassium (Kg ha^{-1})	375	167
Magnessium (Kg ha^{-1})	1055	612
Calcium (Kg ha^{-1})	13168	4062
CEC (meq/100g)	33.7	14.5
Rock depth	≤ 20 cm	≥ 40 cm

Table 4.2. Means, standard deviation, maximum and minimum of number of seedhead, primary seedhead production and total seed production at Highway and Bradford locations.[a]

		Highway				Bradford			
		Alone		Group		Alone		Group	
		2004	2005	2004	2005	2004	2005	2004	2005
Number of seedheads	Means	10.6	14.8	9.5	6.4	25.2	35.7	6.6	8.5
	Std. dev.	4.4	3.3	5.2	2.6	12.1	8.2	3.8	2
	Min.	5	10	5	3	11	23	3	5
	Max.	18	20	20	13	49	56	16	11
Seed production of the primary seedhead	Means	1010	1219	988	961	1008	1383	775	934
	Std. dev.	156	109	104	107	131	88	87	188
	Min.	734	971	786	740	780	1236	656	511
	Max.	1266	1416	1158	1118	1253	1487	954	1155
Total seed production	Means	5912	10010	5225	3873	12358	21986	3364	4720
	Std. dev.	2755	2877	2725	1351	5657	4752	2292	1431
	Min.	1894	5827	2292	2060	5467	14346	1309	2144
	Max.	9732	16540	10429	6640	22905	33527	9916	6604

[a]Abreviations: alone, plant without other teasel plant closer to 60 cm; group, plant with at least two flowering plants within 60 cm.; 2004, year 2004; 2005, year 2005; Std. dev., standard deviation; Min, minimum; Max, maximum.

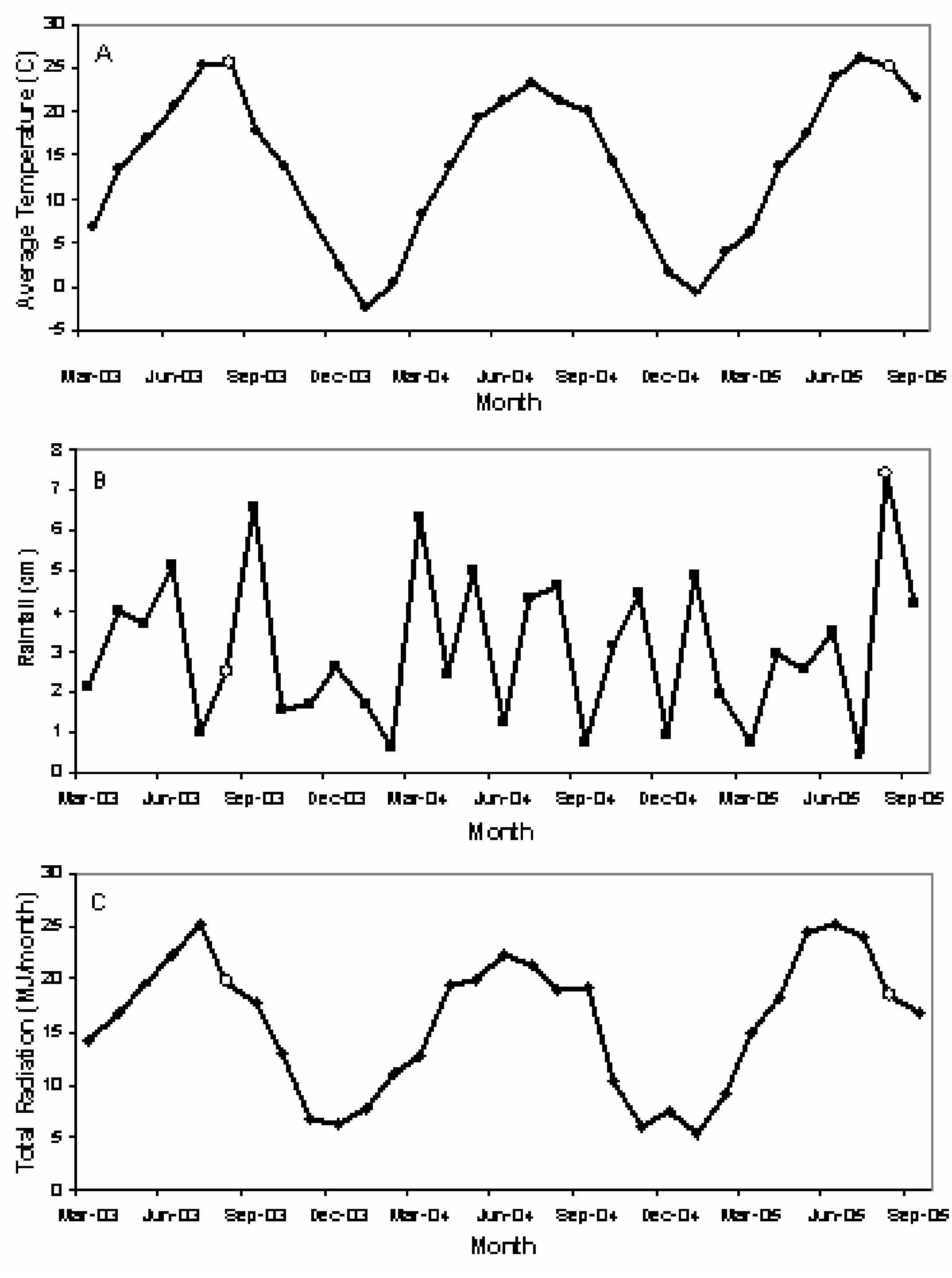

Figure 4.1. Monthly means of air temperature (A), total rainfall (B), and total solar radiation (C) registered during the seed production study in Boone County, Missouri.

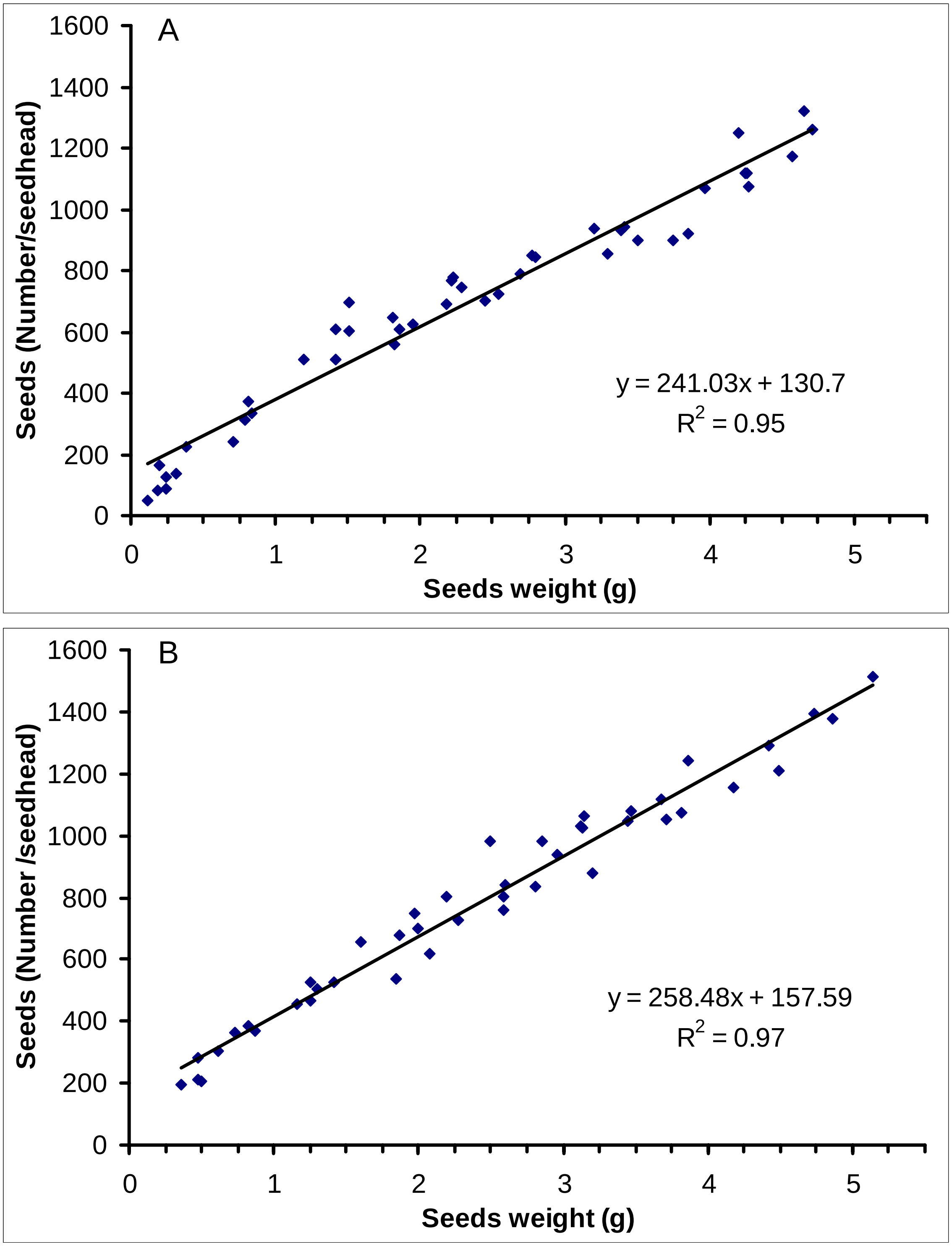

Figure 4.2. Regression of the seeds weight of cut-leaved teasel (*Dipsacus laciniatus* L.) from individual seedhead and number of seeds in year 2004 (A) and year 2005 (B).

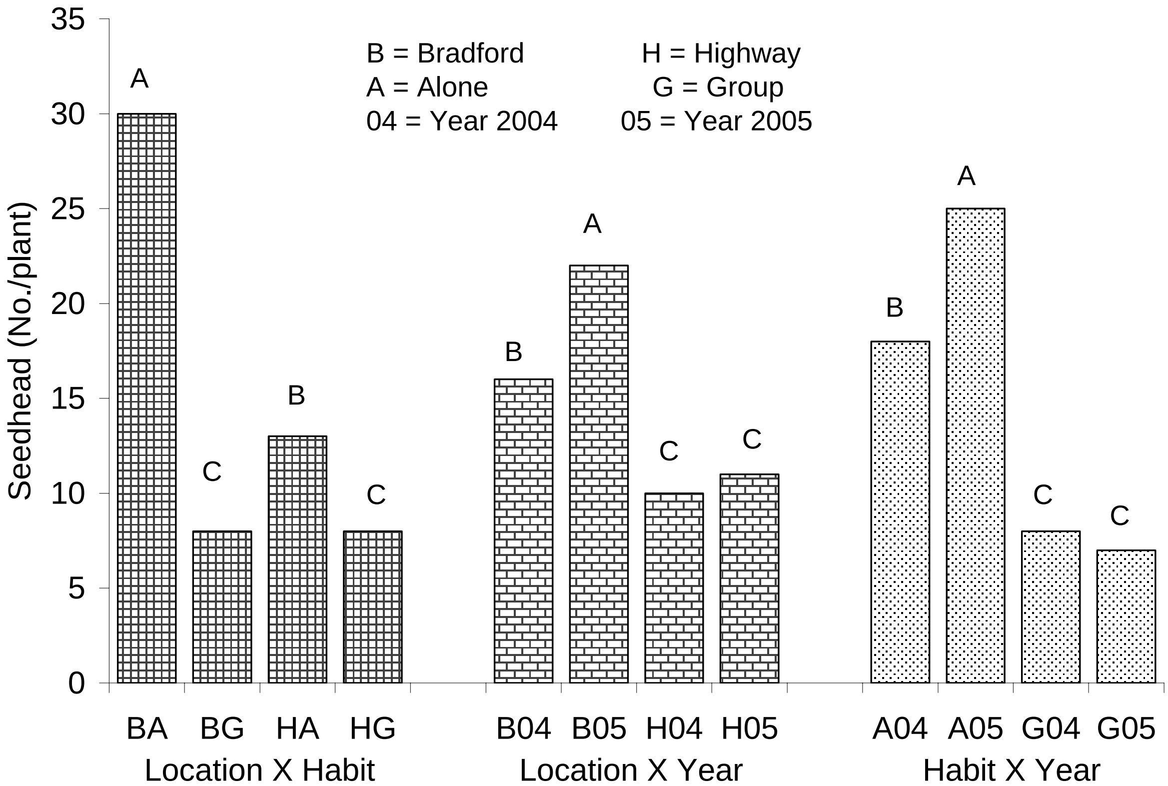

Figure 4.3. Combined two-way interactions among location, growth habit and year of the number of seedheads per cut-leaved teasel (*Dipsacus laciniatus* L.) plant.

Abbreviations: B, Bradford; H, Highway; 04, year 2004; 05, year 2005; A (Alone), plant without other teasel plant closer to 60 cm; G (Group), plant with at least two flowering plants within 60 cm.

Means followed by the same letter within a group are not significantly different according to Fisher's protected LSD test at p≤0.05.

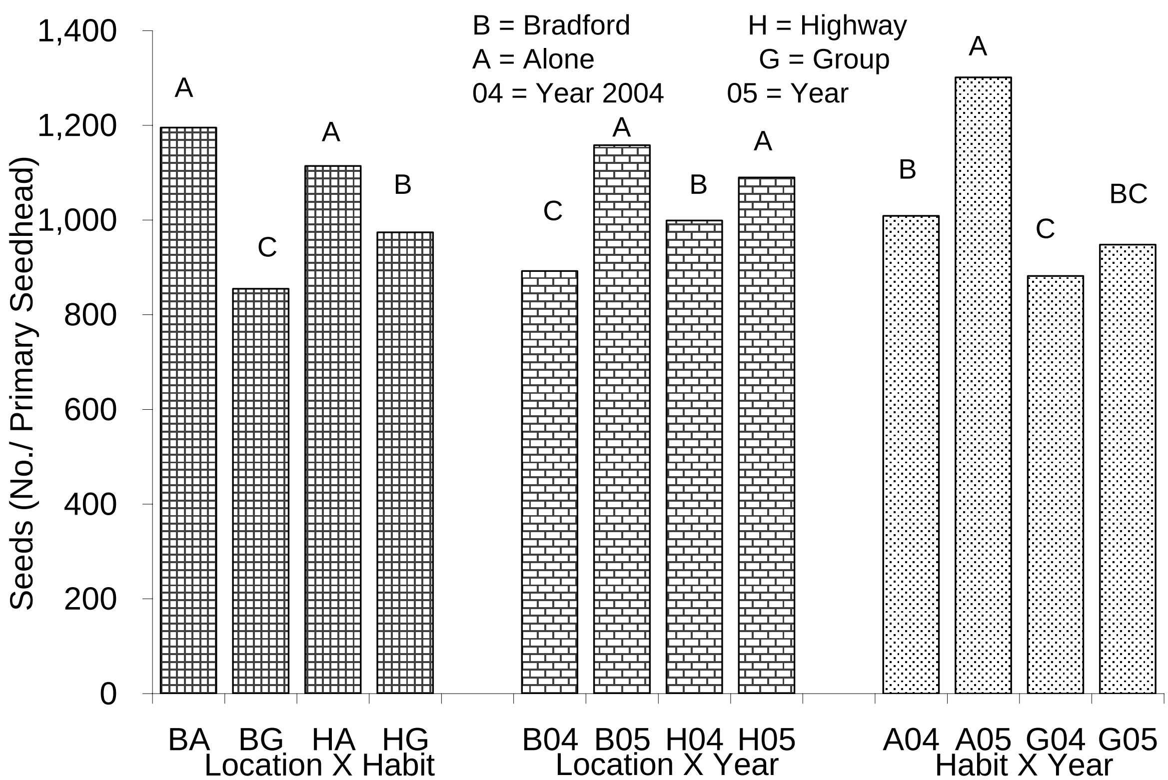

Figure 4.4. Combined two-way interactions among location, grow habit and year of the number of seeds per primary seedhead of cut-leaved teasel (*Dipsacus laciniatus* L.) Abbreviations: B, Bradford; H, Highway; 04, year 2004; 05, year 2005; A (Alone), plant without other teasel plant closer to 60 cm; G (Group), plant with at least two flowering plants within 60 cm.

Means followed by the same letter within a group are not significantly different according to Fisher's protected LSD test at p≤0.05.

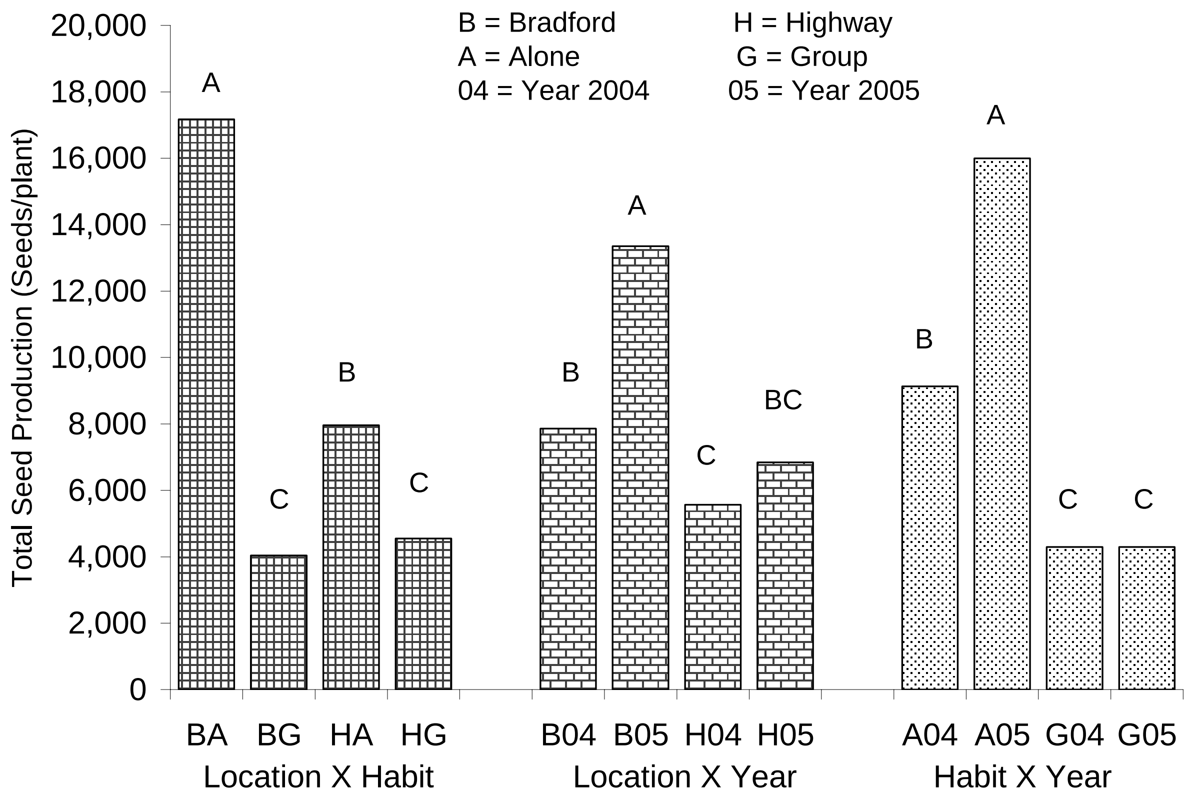

Figure 4.5. Combined two-way interactions among location, grow habit and year of the total seed production per cut-leaved teasel (*Dipsacus laciniatus* L.) plant.

Abbreviations: B: Bradford, H: Highway, 04: year 2004, 05: year 2005, A (Alone), plant without other teasel plant closer to 60 cm; G (Group), plant with at least two flowering plants within 60 cm.

Means followed by the same letter within a group are not significantly different according to Fisher's protected LSD test at $p \leq 0.05$.

APPENDIX

*Appendix 1***.** Diameter of the taproot and dry weight of the secondary root system at Columbia and New Franklin during the growth period.

	Columbia		New Franklin	
	Taproot diameter	Secondary Root weight	Taproot diameter	Secondary Root weight
	cm	g	cm	g
May -04	0.13 h	0.007 I	0.13 i	0.014 g
May	0.17 g	0.035 g	0.19 h	0.027 f
Jun	0.21 g	0.035 g	0.24 h	0.038 f
Jun	0.32 f	0.134 f	0.33 g	0.11 e
Jul	1.35 e	0.636 e	1.21 f	0.358 d
Aug	2.22 d	0.952 d	2.28 e	1.762 c
Sep	4.41 c	6.161 bc	4.11 d	3.276 b
Oct	4.96 bc	5.153 bc	4.92 cd	4.44 ab
Nov	5.57 ab	5.219 bc	5.09 bc	3.868 ab
Mar-05	4.25 c	3.612 c	4.98 bcd	4.216 ab
Apr	5.52 ab	7.838 ab	6.03 ab	4.043 ab
May	5.45 ab	10.425 a	5.94 abc	6.474 a
Jun	6.32 a	6.183 abc	7.11 a	4.641 ab
Jul	6 ab	5.294 bc	5.46 bc	2.249 c
Aug	6.37 a	5.876 abc	5.84 abc	3.939 ab

Abbreviations: cm, centimeter; g, grams.

Means followed by the same letter within columns are not significantly different according to Fisher's protected LSD test ($p \leq 0.05$).