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VELVETLEAF [*Abutilon theophrasti* Medik.] COMPETITIVENESS IN CORN AS AFFECTED BY PREEMERGENCE HERBICIDES

By

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ABSTRACT

VELVETLEAF [*Abutilon theophrasti* Medik.] COMPETITIVENESS IN CORN AS AFFECTED BY PREEMERGENCE HERBICIDES

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Experiments were conducted in 1992 and 1993 to assess velvetleaf interference in corn. Corn yield was not reduced from nine or less velvetleaf per m of row in 1992. One velvetleaf plant per m reduced corn yield in 1993. Velvetleaf seed production increased linearly with increasing weed density, and was approximately two times greater at 18 plants per m in 1993 compared to 1992.

Atrazine and pendimethalin at 1.1 kg/ha reduced velvetleaf growth and seed production, and prevented corn yield loss from a velvetleaf density of nine plants per m of row. Either herbicide applied at 0.6 kg/ha reduced velvetleaf growth and seed production in 1993, and competitiveness in both years. Corn yield was not affected by either herbicide in the absence of velvetleaf.

Greenhouse studies indicated atrazine reduced velvetleaf growth more than pendimethalin or alachlor. Velvetleaf competitiveness may be reduced by the addition of alachlor.

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CHAPTER 1

VELVETLEAF [*Abutilon theophrasti* Medik.]

REVIEW OF THE LITERATURE

INTRODUCTION

Velvetleaf [*Abutilon theophrasti* Medik.] was introduced into the United States nearly 300 years ago as a prospective fiber source (90). Its unsuccessful cultivation as a crop has perpetuated it to become one of the most serious weed problems of agricultural production in the United States (17). Annually, corn producers spend over $114 million on velvetleaf control (90). Annual economic losses, ten years ago, were estimated at $340 million in corn and soybean production (90) . Velvetleaf is becoming more troublesome every growing season.

The deleterious effects that weeds exert by interfering with crop growth is definitive. They compete for resources, have the ability to alter the environment by the addition of growth inhibiting compounds (allelochemicals), and act as hosts for insects and pathogens. These effects increase as weed growth increases (4).

Several studies have documented the levels and factors that determine crop yield loss due to weeds (98,116). However, most ecological studies evaluate the relationship of crops with weeds that may not represent true agricultural situations. The effect of herbicides on the competitive relationship between crops and weeds has only recently been investigated. This research will determine whether weeds exposed to herbicides (weed escapes) are competitive and if further control strategies should be implemented, such as postemergence applications or cultivation.

Name

Synonyms for *Abutilon theophrasti* Medic. (9,12) #[1] ABUTH are *Abutilon Avicennae* Gaertn.(12), and *Sida abutilon* L. (90). Common names for this species are Chinese jute, Indian mallow, piemarker, velvetleaf (12), abutilon, butterprint, elephant ears (5,6), velvetweed (84), buttonweed, Teintsin jute, or in Chinese, ching ma (90), cottonweed (84), abutilon hemp, Manchurian jute, American jute (90), Malvaceae, mallow family, and Malvacées (6).

The Arabic philosopher, Avicenna, coined the word "abutilon" c. 900 B.C. for plants resembling a mallow or mulberry (64). The species name *theophrasti* honors Theophrastus, a Greek philosopher, botanist, of the late 4th and early 3rd centuries B.C. (117). The "Medicus" citation which appears after our current

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[1]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

Abutilon theophrasti originates from Friedrich Casimir Medicus [Medikus], director of the Garden at Mannheim during the 18th century (13).

General Morphology

Velvetleaf is in the Malvaceae family. This plant has a simple erect stem, 1 - 4 m tall, much branched in the upper part, and covered with velvety hairs (90,108). Stems of velvetleaf seedlings often have a purple tinge (9). The taproot is slender with many small branches (108). The large alternate, long petiolate leaves are broadly ovate, deeply cordate, long acuminate, crenate, green on both sides and velvety with a dense covering of stellate hairs (90). The pale yellow to yellow - orange flowers have five sepals, and five petals which are slightly notched apically and the calyx is cleft to or just below the middle. Flowers are borne on both the main stem and short terminal branchlets in racemes or, in the case of large plants, in racemose - paniculate inflorescences. The fruit or capsule is cup - shaped, consisting of a circular cluster of 12 - 15 carpels (seed pods) that are dark brown to black at maturity, 1.3 - 2.5 cm long and 2.5 cm wide, densely covered with soft bristles, and beaked. Each carpel opens with a vertical slit along the outer edge and contains from one to three seeds. Seeds are purplish brown, kidney shaped, notched, flattened, one mm thick and two to three mm long (9,90,104,108). Velvetleaf is a hexaploid species containing 2n=6x=42 chromosomes (21,107).

Growth and Development

Velvetleaf is an annual herb, reproducing only by seed (108). This species is self - fertilizing, and will average 35 - 45 seeds per capsule and 70 - 199 mature capsules per plant (8,22,25,49,88,107,113). Velvetleaf is capable of producing 8,000 (90) to 17,000 seeds per plant (108). Germination and seedling emergence begins in the spring and may continue through the growing season. Immediate production of a tap root followed by lateral root development occurs one or two days after emergence. The root growth of velvetleaf exceeds that of several other weeds (84). The expansive root system can thoroughly explore the upper soil layer and grow to a depth of 1.7 to 1.9 m (25).

Velvetleaf seed exhibits a form of primary dormancy known as "hardseedness" that is attributed to an impermeability of the seed coat to water (36,52,62,107). This attribute is variable and diminishes over time (62). Everson (41) determined that this characteristic can be overcome by exposure to moisture and two days at 2 - 5 °C then 35 °C for 3 days. Steinbauer and Grigsby (94) discovered that exposing seeds to boiling water for 1 minute or concentrated sulfuric acid (H_2SO_4) for 15 minutes can alleviate up to 86% of hard seeds. Leuschen and Anderson (62) reported that velvetleaf seeds in soil that become permeable (nonhard) may later reverse and become water impermeable (hard). Seeds can remain dormant and viable for up to 50 years in the soil, partially due to their resistance to microbial degradation (57). Resistance to microbial attack is attributed to a dense palisade layer in the seed coat, tannin - like compounds localized in the seed coat, and antagonistic nonpathogenic bacteria associated with the seed. The hard seed coat also protects against damage from ingestion by poultry and most livestock, and from storage in manure (22,108)

Several researchers (36,52,62,107) revealed evidence of a second type of primary dormancy known as embryo dormancy. Seeds exhibiting this type of dormancy do not germinate immediately after the seed coat is broken, but show sporadic germination patterns.

The longevity of velvetleaf seed viability when buried in soil ranged from 58% after 2.5 years in Mississippi (25), 70% after 3 years in Illinois (99), 37% after 4 years in Minnesota (62), 36% after 5.5 years in Mississippi (37), to 43% after 39 years in Virginia (102). Egley and Chandler (36) determined that burial depth (8 - 38 cm) had little effect on seed longevity. However, Chandler and Dale (25) found that velvetleaf emerged best from 2 cm below the soil surface, but was capable of emerging from a depth of 7.6 cm.

Andersen *et al.* (8) examined the variability of velvetleaf collected from different areas of the United States. Mature seed capsule production was used as a measure of the reproductive capacity. The 14 accessions collected represented the northern and southern extremes in the known range of velvetleaf in North America and various latitudes in between. Plants were grown in the field at Rosemont, MN, Weslaco, TX, and Fairbanks, AK. Accessions exhibited similar phenotypic characteristics at all locations. At Rosemont, MN, the accessions fell into two distinct groups based on cumulative seed production over time. The southern group was delayed in maturity compared to the northern group, and the southern group continued to grow after the northern accessions reached their maximum height at Weslaco, TX. The northern accession produced 74 seed capsules per plant while the southern accession produced 188 seed capsules per plant at this location. Growth of all 14 accessions was terminated by frost in AK (88 frost free days per year), and no seed production occurred. Velvetleaf adaptability appeared to be greatest in an area nearest to the origin of the seed.

Habitat

Velvetleaf is commonly found in waste places, vacant lots, gardens, and cultivated fields, especially corn (*Zea mays*) and soybean [*Glycine max* (L.) Merr.] fields, and along fence rows (104).

Velvetleaf can exist on a range of soil types, including gray - brown Podzols (60), alluvial flood plains (73), and sandy loams to clay loams with a pH of 6.1 - 7.8 (32). Weaver and Hamill (109) compared velvetleaf growth at three pH levels on a sandy loam soil and found aboveground biomass production lower and leaf tissue nutrient levels higher at pH 4.8 when compared to pH 6.0 and 7.3.

History and Distribution

A. Asia and Europe

Conflicting reports exist as to the native origin of velvetleaf, including India (104) and China (59,90,105). Isozyme studies were conducted in an unsuccessful attempt to determine its parental species and hence its actual origin (93). Li (59) listed velvetleaf as having originated, as early as the beginnings of civilization, on the Southern China belt and although the Nan Ling Range acts as a natural boundary for southern distribution it is prevalent throughout a major part of China. This species, though infrequent, also occurs along the southwestern side of the Himalayas, Afghanistan, Pakistan, and Nepal (90). According to Sattin *et al.* (87) velvetleaf has been known in Italy for several centuries where it was first described in an herbarium in 1532 from samples collected around Rome. The first reported agricultural infestation in Italy was in 1969 (87) and it has now become one of the most troublesome weeds in the corn growing areas. He states that velvetleaf spread through Asia Minor to the Balkan States and Hungary, and eventually into Southern Europe.

B. America

Velvetleaf was introduced into the United States in the mid 1700's from England (90). However, reports of velvetleaf in Virginia and most other parts of Colonial America in the early 1700's dates its introduction to sometime prior to 1700 to allow for such a spread by the middle of the decade. A report by

Mease (63) in 1829 stated that velvetleaf migrated north into Pennsylvania. USDA records on the importation of seeds and plants indicated that as late as 1914 and 1917 the U.S. was importing seeds of velvetleaf from China (10,11).

This species is currently found throughout all of the U.S. except along the northern boundary, areas in northern Wisconsin, Michigan, and Maine, areas in southwestern and south central Texas, and areas in southern Arizona, New Mexico, and Florida (104).

Canada is not exempt from the migration of velvetleaf. The initial invasion occurred through eastern Canada (107) and continued into Quebec (35). Herbarium records from the 1860's to c. 1950 show that the infestation was restricted to small areas. Large populations in cultivated fields did not occur until the 1950's. Speculation presumed the Canadian climate would be the limiting factor of the spread of velvetleaf northward (60,86); however, during the 35 year period to 1984, velvetleaf extended its range to all but three counties in Ontario (22,86), 72 locations in Quebec (107), and at least one location near the Annapolis Valley in Nova Scotia (107). Velvetleaf has also been reported in York County, New Brunswick, on the Gulf of St. Lawrence (21,51).

Stegink and Spencer (93) note that velvetleaf is the only *Abutilon sp.* that grows in temperate climates and that velvetleaf does not exist in South and Central America.

Economic Importance

Velvetleaf is cultivated in China as a fiber source which is used to make rope, cordage, bags, coarse cloth, fishing nets, paper stock, and boat caulking (90,108). Usage in China may date back as far as 2000 B.C. or earlier. According to Kirby (53), several cultivars are grown in China, each region with its own variety adapted to climate, soil, and other edaphic factors. Velvetleaf seeds contain 15 - 30% lipids, 23% crude protein on a dry weight basis , and are suitable for use as a food source (22,90). Spencer (90) stated that the seeds of velvetleaf are eaten mainly by children in China and Kashmir. Mitich (64) noted that velvetleaf seeds were rather tasty when dried, resembling the taste of sunflower seeds.

Sattin (87) reported that velvetleaf is becoming an increasing problem in many Mediterranean countries and estimated that it has infested approximately 50,000 to 60,000 ha in Italy.

The introduction of velvetleaf into the United States occurred c. 1700 to supplement the cordage demands of maritime industry and Colonial America. The seed source probably came from England (90). Rope was so important to the early colonies that Boston imported a ropemaker from England as early as 1641. By 1794 there were 14 ropewalks (small rope manufacturing plants) in the Boston area alone. In 1810, there were 173 ropewalks in the U.S. (67). During the 19^{th} century most of the fiber used in ropemaking was imported from Russia and European countries. Attempts to cultivate velvetleaf as a fiber source never succeeded due to a lack of proper equipment to economically separate the fiber from the stem. However, farmers continued to cultivate velvetleaf for over a century (90). The latest known attempts were made in Illinois and New York (90). The spread of velvetleaf was perpetuated throughout this period as farmers and manufacturers of cordage hoped to establish an alternative to hemp as a source of fiber. A report given by a special committee at the Illinois State Fair of 1871 (103) expressed the problems and hopes of the period illustrating the weed vs. fiber conflict of the time. The potential for velvetleaf to become a pest in corn and soybeans was now being realized.

Velvetleaf has become a major weed in corn and one of the worst weeds in the United States. A 1985 survey of the North Central states ranked velvetleaf as the most troublesome weed by 9 of 14 states (84). A recent article in Ag Consultant Magazine[2] surveyed farm managers nationwide who ranked velvetleaf as the 5th most troublesome weed to control. Farmers spend millions of dollars annually for velvetleaf control (90). In 1982, a survey of weed scientists and extension specialists estimated that Michigan corn producers spent at least \$4 million on velvetleaf control (90). Nationwide estimates in 1982 reported \$114 million was spent on velvetleaf control (64). Annual economic losses attributed to velvetleaf, in 1984, exceeded \$340 million (90).

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[2]Ag Consultant. 1993 Weed Hit List. March, p. 9.

Velvetleaf persistence is attributed to its tolerance of commonly used PRE herbicides in sugarbeet, soybean, and corn production systems. The use of corn herbicide combinations with low rates of atrazine, less use of 2,4-D, and less cultivation have also contributed to velvetleaf infestations (64). Furthermore, triazine-resistant velvetleaf has been identified in Maryland where corn was continuously cropped for 5 years (83).

Weed Interference

Principles of Interference

Plant interactions are complex phenomena that occur in natural plant communities as well as agroecosystems. Burkholder (23) and more recently Odum (72) categorized these interactions between plants into 10 types. Generally, these interactions among species or populations within species are termed interference, or, the effect that a plant has upon the environment and its neighbors. Burkholder and Odum further described these interactions as positive or "on" when two populations are in contact, "off" when they are apart, or "neutral". Interactions that neighboring plants impose on one anothers environment and subsequent growth, either deleterious or beneficial (mutualism), may involve multiple mechanisms of interference (43,48,68,82). Interference is much more prevalent that mutualism among plant populations in agroecosystems (7).

Putnam and Tang (78) consider a much broader classification of interference. They list three sub - disciplines of interference: allelomediation, allelopathy, and competition.

Allelomediation is the selective harboring of an herbivore that selectively feeds on another, lending an advantage to the host plant (101). This is an important process in relation to microbial and insect populations. Allelomediation can also be an important process in the development and implementation of integrated pest management and biological control strategies for conventional and alternative farming systems.

Allelopathy, described by Molisch in 1937 (65), is the chemical interactions among all plants (microbes and higher plants) that are stimulatory as well as inhibitory. This mechanism of interference is distinguishable from competition in that the subsequent effect is the result of the release of a chemical factor into the environment by a plant. Scientists hypothesize allelopathy plays a role in altering plant distribution in both natural communities and agroecosystems (47,61,68,70,77,110,111). However, Stowe (100) determined there is no such correlation with shifts in plant distribution, at least in an agricultural system.

Alleged allelochemicals are derived from simple hydrocarbons and aliphatic acids to complex polycyclic structures (82). These chemicals are present in virtually all plant tissues including leaves, flowers, fruits, stems, roots, rhizomes, and seeds. Allelochemical release can occur through volatilization, root exudation, leaching, and decomposition of plant residues (79,82).

Several researchers have suggested allelopathic mechanisms in velvetleaf interference. Phytotoxic compounds exist in velvetleaf tissue. Gressel and Holm (45) determined that intact velvetleaf seeds, placed near other crop or weed seeds on filter paper, caused delayed germination and reduced root lengths of these others species. They also found that an extract prepared from ground velvetleaf seeds inhibited germination in a petri dish as well as in autoclaved soil. Rose *et al.* substantiated these results in the field. Further analysis of intact plant organs discovered the leaves contain about 85% as much as the seed components. In a macro-bioassay, unfractionated ground seed delayed germination 52 hours, while the fraction consisting of seed coats delayed germination 116 hours. The inhibitor was identified as free amino acids which were diffusible through the seed coat. Chromatographic analysis indicated that no single amino acid was responsible for the inhibition.

Colton and Einhellig (27) attempted to determine if extracts from fresh leaves of velvetleaf were phytotoxic and the mechanisms by which these effects were exerted. They characterized the inhibitory compounds only as water soluble phytotoxics that depressed the germination of several crop seeds. This was substantiated by Elmore (38,39). They also suggested that allelochemicals interfered with water balance and chlorophyll content.

LaCroix and Staniforth (58) prepared extracts from the leachate of velvetleaf seed coats and determined that this solution inhibited germination of velvetleaf seeds. The aqueous extract contained tannins, one or more amino acids, and nitrogenous compounds. They suggested that this self-inhibition may an important mechanism for delaying germination, but would not be integral in controlling long term dormancy.

Bhomik and Doll (18) investigated the allelopathic potential of velvetleaf residues on crop growth in the laboratory, greenhouse, and field. Velvetleaf residue inhibited corn growth in the greenhouse. The expression of allelopathy was greatest in a sand media, less in a sand and soil mixture, and least in a soil media, suggesting allelochemicals may bind to soil particles or organic matter so that they are unavailable to receiver plants.

Sterling and Putnam (97) investigated the allelopathic influence of exudates from velvetleaf trichomes. The trichome exudates were phytotoxic in petri plate bioassays. Under greenhouse conditions more exudate was collected compared to field experiments; loss due to ultraviolet degradation and leaching were postulated to occur in the field. Extracts of velvetleaf in autoclaved soil reduced indicator crop root length 30 - 95%, while extract activity was lost in soil that was not sterilized. Processes such as ultraviolet degradation, leaching, and microbial degradation could be responsible for decreased allelopathic activity in the field.

Paszkowski and Kremer (75) conducted laboratory bioassays with aqueous extracts of velvetleaf seed coats. They demonstrated the allelopathic effects of the flavonoid components of these extracts on several crop species and soil fungi. Paper chromatography identified the compounds as delphinidin, cyandin, quercetin, myricetin, catechin, and epicatechin. It was concluded that these compounds were more inhibitory on radicle growth than germination. Individual flavonoids had variable effects on fungi but appeared to inhibit growth and sporulation of potential seed-decomposing fungi rather than "beneficial" fungi. Kremer (57) substantiated this when he determined that phenolic compounds inhibited the growth of 117 of 220 bacteria and several strains of fungi.

Allelochemicals are also present in crop plant tissues and residues capable of inhibiting weed growth and development. Steinsiek *et al.* (95) determined that wheat (*Triticum aestivum*) straw inhibited velvetleaf germination and seedling growth. However, susceptibility was extract (soaked > leached) and temperature dependent. Ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.] was the only species tested that was more susceptible to the residue than velvetleaf.

Wolf *et al.* (114) examined the allelopathic activity of benzyl isothiocyanate (BITC), an extract of mature papaya (*Carica papaya* L.), on velvetleaf germination. Complete inhibition of germination occurred when imbibed velvetleaf were exposed to a 6×10^{-4} M solution of BITC extract. Complete death occurred in two days when BITC at a concentration of 4×10^{-4} M was applied to etiolated velvetleaf seedlings. Furthermore, this compound had no effect on corn germination and growth.

Competition

Competition is a mechanism of plant interference. Competition, interspecific or intraspecific, occurs when each of two or more organisms seek the measure it requires of a particular factor and when the immediate supply of the factor is below the combined demand of the organisms (34). By restricting the definition of competition to that of a factor that is in limited supply, competition is differentiated from allelopathy as a mechanism of interference. In relation to agriculture, competition occurs as a result of a finite system that contains a limited amount of resources for sustaining optimum growth at a specific density. If this density is exceeded, i.e. a weed infestation, growth of one or more of the less competitive plant species will be affected (89), possibly resulting in a yield loss.

In natural communities or agroecosystems, the resources plants compete for are light, water, nutrients, CO_2, and light. Aldrich (3) concluded that competition for light is the most frequent factor inhibiting plant growth factor because it cannot be stored or transferred within the plant. Research has determined that nitrogen is the macronutrient most important in crop competitiveness while phosphorus is the limiting factor in weed competitiveness in farming systems (71,91,106).

Several factors interact to make crop and weed competition a complex phenomenon. Species, density, pattern, and duration have profound effects on a weed's competitive ability. Similarly, planting pattern, date, rate, and duration play a key role in a crop's competitive ability. Crop and weed factors interact with weather, soil type, soil fertility, tillage, herbicides, and other pests which ultimately determines the degree of competition (20,48,81). This complexity can explain, to some extent, the variability that can result in determining crop and weed competitiveness.

Higher plants can be categorized by the photosynthetic pathway of CO_2 assimilation. Species that fix CO_2 by the reductive pentose phosphate cycle are commonly referred to as C_3 plants (15) and have very high respiratory rates in light (40,42). Species that fix CO_2 by the C_4-dicarboxylic acid pathway, such as velvetleaf, are commonly known as C_4 plants (50), and photorespiration is more difficult to detect (40,42).

Black *et al.* (19) have taken classification of higher plants one step further. After a review of the literature on biochemical characteristics, with emphasis on factors affecting photosynthesis, they have divided plants into two groups. C_4 plants are considered efficient and C_3 plants are non-efficient. They hypothesized that efficient plants often have been used in agriculture for their high productivity. Therefore, C_4 plants are better competitors than C_3 plants and most weeds in summer crops have C_4 photosynthesis (19). Furthermore, C_4 plants generally have greater photosynthetic efficiency at higher temperatures than do C_3 plants which would favor crop (C_4) growth and competitiveness during the growing season. Baskin and Baskin (14) concluded that examples exist of both C_3 and C_4 weeds that are poor competitors, many noxious weeds of cultivated crops have C_3 photosynthesis, and in general C_4 photosynthesis is less important than other features of plants in determining growth rate and competitive ability. Plant biologists consider these other features to include life form, food reserves available for growth, shade tolerance, earliness of starting growth, efficient uptake of nutrients and water, vegetative reproduction, genetic variability, phenotypic plasticity, leaf area and leaf arrangement (26,30,33,34).

Velvetleaf, according to Grime's model which describes biological strategies (sets of traits), can be classified as a competitive-ruderal (46). Parrish and Bazzaz (74) define velvetleaf as "a specialist within an early successional community co-adapted to fit into that community where other species are less abundant". Mitich (64) simply states "velvetleaf, a large, vigorously competitive plant, produces thousands of long-lived seeds". Velvetleaf exerts its competitive ability during the vegetative phase until the onset of flowering, which constitutes 30% of its growing cycle on a growing degree basis. This feature closely coincides with the fact that C_3 plant growth rates are greater than C_4 plants at lower ambient temperatures which occur early in the growing season (19,76).

Research in Mississippi (25) determined that under noncompetitive field conditions, maximum height and ground cover occurred 10 weeks after emergence and peak capsule production at 13 weeks. The most rapid growth occurs from sixth to ten weeks after emergence. Velvetleaf is efficient under conditions of low sunlight; it grows well when partially shaded and can produce seed under a crop canopy (64). Small end - of - season plants can successfully flower and produce seed. Because of its resiliency to low light and the capability to grow taller than corn, velvetleaf can infest a corn field even after the crop forms a dense canopy.

Methodology of Interference Research

Several factors influence the process of competition between plants, many of which cannot be experimentally controlled. Few, if any, field investigations have definitively separated the components of interference because of its complexity. Therefore, the term competition has been misused by many (particularly agricultural scientists) to describe interference. Harper (48) proposed a more rigorous protocol to examine cause and effect.

Several experimental methods have been developed that examine the interactions of crops and weeds. Each method considers density, spatial arrangement, and species proportion to varying degrees (80,85). In each method, total or individual plant yield, plant growth rate, or plant mortality (survival) is measured (81). These methods fall into four categories; additive, substitutive, systematic, and neighborhood. It is important to determine beforehand the weed/crop system of concern and define the objectives of the study before choosing the appropriate model.

The additive design usually examines one weed to crop interaction, however, more than two species can be grown together. The density of one species, such as the crop, is held constant while the density of the other is varied. The additive design is probably the most common approach used to study crop/weed interactions (98,116) because it closely resembles agricultural situations where one weed species infests an area already occupied by a fixed density of the crop or where different weed densities occur following different weed management strategies. This method is also best suited to address weed management questions such as: How much yield loss could be expected from a particular weed density?; What is the economic threshold for weed control?; Which weed species is likely to cause the most loss in yield?; Under present management conditions, is the weed likely to increase or decrease? (29). The relationship between crop yield and weed density is that as weed density increases, crop yield decreases (7). The additive design has been criticized (48,80) because it inadequately accounts for the influence of density and species proportion on the outcome of competition. The effects of either individual factor is difficult to interpret, and threshold levels are difficult to ascertain because of confounding and uncertainty of density, proportion, and arrangement of species (29).

The substitutive (replacement series) design consists of pure stands of both crop and weed, and varying proportions of crop:weed are also established while maintaining a constant total population (i.e. 0:10, 2:8, 4:6, 6:4, 8:2, 10:0). The premise of this design is to determine the yields of species mixtures by comparing them to monoculture species yields. The replacement series is most valuable for assessing the competitive effects of species proportion at a single total density. It is also possible to determine the relative effects of intra- and inter-specific competition, but partitioning the absolute effects cannot be accomplished (81). Experiments using this approach must be conducted at sufficiently high densities and/or over long enough periods to fall within the range of constant final yield (81). Harper (48) states that many of the problems of additive designs can be overcome by this approach because the two experimental variables are not confounded during the experiment.

Diallel experiments are a type of replacement design that utilize the same format for treatments. Plant communities are composed of several species and the diallel design combines individuals of each species, one or two of each per treatment, into all possible pairs. This method examines the complexity of plant communities (48).

Systematic methods include Nelder experiments (69) which have focused on the interference of individuals of a single species. This design consists of a grid of plants, usually arranged in an arc or circle, and plant density and spatial arrangement are based on a system where space available to each plant varies in a consistent manner throughout the grid of treatments. Advantages of Nelder experiments include the ability to study an array of densities, space economy to avoid gradients in the field, and the ability to study several densities in a small area.

Addition series experiments are another type of systematic design. Two or more species can be studied in this method with the design becoming more complex as the number of species increases. Several researchers are currently using this model to assess the degree to which density and proportion affect interactions among crops and weeds (7).

The neighborhood experiments focus on an individual plant called the target plant and the relationship it has with other plants in a given radius. This method is most often used when multi-species (weed) studies are the objective. Several interactions can be investigated with this method, but it takes many observations to develop trends between target and neighboring individuals (29). Performance of the target individual is recorded as a function of the number, biomass, cover, aggregation, or distance of its neighbors (29). Several equations have been developed from data collected from these studies to represent the relationship between target individual performance and interference level.

Cousens (29) states that amid recent criticisms of certain designs, the aforementioned methods are well suited for agronomic situations, species comparisons, and most other objectives. Regression analysis is most appropriate, especially where treatments include a range of densities and proportions. However, there are several pitfalls of interference experimentation not reported to date such as error structures and the use of over-elaborate equations. Hence, if the design and analysis of interference experiments is based on clear objectives, and the appropriate model is implemented within its limitations, meaningful results can be achieved.

Weed Interference in Corn

Grass Weeds

Many competition studies have documented the level of crop yield loss that can occur from weed presence. Zimdahl (116) and Stewart (98) cite more than 500 and 200 papers, respectively, which describe the outcome of various weed and crop associations. Research investigating the interactive effects of grass weeds in corn dates back more than 30 years. Staniforth (91) investigated the effect of heavy yellow foxtail [*Setaria glauca* (L.) Beauv.] populations (50 - 75 plants/ft^2) and three nitrogen levels on three corn hybrids planted in 102 cm wide rows in Iowa. The yield reduction of the late maturing variety, 20 - 65%, was double that of the early maturing variety. These differences occurred under conditions of highest N fertility, implying the importance of hybrid selection relative to experimental location in corn - weed ecology studies.

Nieto and Staniforth (71) studied the competitive effects of none, light, medium, and heavy giant and yellow foxtail populations on corn seeded at four populations and three nitrogen rates. Foxtail was removed in early July or allowed to compete for the entire season. Generally, nitrogen fertilizer application minimized the effects of foxtail competition as measured by corn yield loss. Corn yield reductions from mature foxtail populations averaged 20, 14, and 10 bu/A with applications of 0, 70, and 140 #/A elemental nitrogen. The response of weedy corn to nitrogen fertilizer was much greater than that of weed-free corn or that of foxtail as measured by dry matter production. Staniforth (92) substantiated this with similar results from an identical experimental design.

Knake and Slife (54) utilized natural giant foxtail (*Setaria faberi* Herrm.) infestations to achieve densities of 1.6, 3.3, 10, 20, 39, and 177 plants per meter of corn row. Corn was planted in 102 cm wide rows and plots were mechanically cultivated restricting weed growth to within the crop row. Full season interference significantly reduced stalk diameter, corn ear weight, grain yield, and increased lodging. The lowest density of giant foxtail reduced corn yield in one year of the experiment, and 3.3 giant foxtail plants per meter of row reduced corn yield each year. Reductions were directly correlated with increasing giant foxtail populations. However, corn height was not significantly reduced at populations below 177 foxtail plants per meter of corn row.

Knake and Slife (56) also examined the competitiveness of giant foxtail that emerged naturally and was removed at 3, 6, 9, and 12 inches in height and at maturity. Corn yield was reduced by 1, 2, 5, 7, and 18 bu/A respectively.

Knake and Slife (55), noting Gleason (44) determined that after 5 weeks corn shaded the interrow space sufficiently to reduce weed competition, conducted a study seeding giant foxtail at planting and 3, 6, 9, and 12 weeks after planting to determine the weed free period required to overcome the competitive effects of giant foxtail. They found that giant foxtail seeded at planting, and allowed to compete the entire season, reduced corn yield 13%. However, foxtail seeded three weeks after planting did not reduce corn yield significantly even though it produced 500 pounds of dry matter per acre.

Young *et al.* (115) determined that quackgrass [*Agropyron repens* (L.) Beauv.] densities ranging from 65 to 390 shoots per m^2 reduced corn yield 12 to 16%. A quackgrass density of 745 shoots per m^2 reduced corn yield an average of 37% and significantly reduced corn height, ear length, ear-fill length, kernels per row, rows per ear, and seed weight. In a soil moisture study, corn leaf tissue analysis showed that quackgrass did not interfere with the nutrient status of the crop. Finally, they concluded that if light and nutrients are not limiting factors, adequate soil moisture can eliminate the effects of quackgrass interference on corn growth, development, and yield.

Beckett *et al.* (16) determined that giant foxtail densities of 0.8, 1.6, 3.3, 6.6, and 13.1 plants per meter of corn row, in a 12.5 cm band over the corn row, reduced corn yield linearly with increasing foxtail populations of five to eight plants per meter of row. Corn was planted in 76 cm wide rows. A density of 13.1 plants per meter of row reduced corn yield by 18%. They also found that corn grain yield decreased linearly with increasing shattercane [*Sorghum bicolor* (L.) Moench] densities of two to three clumps per meter of row, reaching a maximum yield loss of 22% at 6.6 clumps of shattercane per meter of row.

Wilson and Westra (112) investigated the effects of wild-proso millet [*Panicum miliaceum* (L.)] interference in corn in Nebraska and Colorado in 1991. They determined that a density of 10 plants per m^2 reduced corn yield from 13 to 22%, as density increased, corn yield reduction could be predicted with a rectangular hyperbola regression model (28). They also found that corn yield was reduced 10% if wild-proso millet was removed 2 weeks after planting, and yield reductions ranging from 16 - 26% when wild-proso millet removal was delayed until 6 weeks after planting.

Broadleaf Weeds

Moolani *et al.* (66) studied the competitive effects of smooth pigweed (*Amaranthus hybridus* L.) on corn planted in 102 cm wide rows. Weeds were spaced in 10 to 15 cm bands 2.5, 13, 25, 50, and 102 centimeters apart. Corn yield reductions of 30, 50, and 36% occurred in 1959, 60, and 61, respectively.

They determined that corn dry matter production of weed free plots was equal to that of corn and weeds concluding that an increase in weed yield was compensated for by a decrease in corn dry matter production.

Campbell and Hartwig (24) conducted a greenhouse study to determine the competitive effects of yellow nutsedge [*Cyperus esculentus* (L.)] on corn. Two, four, six, or eight yellow nutsedge plants were grown in a pot with one corn plant for 2, 4, or 6 weeks. After 6 weeks the maximum reduction in corn dry matter due to yellow nutsedge competition was 7%. Corn dry matter yields in the presence of yellow nutsedge were not significantly different from corn grown alone after 2 or 4 weeks.

Weaver and Hamill (109) examined the effect of soil pH on the competitive ability of Powell amaranth (*Amaranthus powelli* S.Wats) with corn in the field. They found Powell amaranth dry matter production to be significantly lower at pH 4.8 than at 6.0 or 7.3; however, corn yield was significantly reduced at all three pH levels due to weed competition, but corn leaf nutrient content was not affected. This is further substantiated by Vengris (106) who determined that weed competition was not affected by differing levels of phosphorus and potassium.

Beckett *et al.* (16) studied season long interference of common lambsquarters [*Chenopodium album* (L.)] and common cocklebur [*Xanthium strumarium* (L.)]. Corn yield decreased curvilinearly, in 1985, with increasing common cocklebur density and a maximum predicted yield loss of 27% occurred at a density of 4.7 plants/m of row. In 1986 and 1987, corn yield decreased linearly as common cocklebur density increased to 6.6 plants/m of row where corn yield was 10% lower than weed free plots. Common lambsquarters reduced corn yield in only one of three years. Yields decreased curvilinearly with increasing weed density with a maximum of 12% reduction at a density of 4.9 plants/m of row. Weed density had no significant effect on corn or weed height at harvest.

Velvetleaf

Investigations on the ability of velvetleaf to interfere with corn began approximately 10 years ago. Campbell and Hartwig (24) found that one corn plant grown with velvetleaf in the greenhouse at densities of two, four, six, and eight plants per pot reduced corn dry matter production up to 70% after six weeks. They also noted that corn dry matter reduction due to velvetleaf alone was equal to that of velvetleaf and yellow nutsedge combined after 2, 4, and 6 weeks.

Weaver and Hamill (109) determined that velvetleaf reduced corn yield at three soil pH levels; however, aboveground dry matter production of velvetleaf was lower at pH 4.8 than at either 6.0 or 7.3.

Sterling and Putnam (96) indicated that depending on planting, growth of corn plants was reduced 51-91% by one velvetleaf plant growing 5 cm away.

DeFelice *et al.* (31) compared the competitive effect of velvetleaf in conventional and no-tillage corn when velvetleaf was seeded at the same time or 5 weeks after corn planting. Both corn and velvetleaf were grown in monoculture also. Delaying velvetleaf planting 5 weeks decreased biomass production, end-of-season population, and delayed flowering and seed production. Monoculture velvetleaf exhibited increased growth when compared to velvetleaf grown in association with conventional or no-tillage corn. Corn grain yield, number of kernels per ear, and soil moisture content were significantly lower due to full season velvetleaf competition in both conventional and no-tillage. Velvetleaf also exhibited intraspecific competition, but did not differ in vegetative or reproductive growth between conventional and no-tillage systems.

Effect of Preemergence Herbicides on Weed Competitiveness

Ecologically based research has addressed the effects weeds have on corn growth, development, and yield. Factors such as species, density, pattern, duration, etc. have been explored and correlated with weed competitiveness. However the weed populations utilized in previous research have not been exposed to an herbicide which is known to have herbicidal activity on certain species. The competitiveness of these weed "escapes" has not been ascertained.

Adcock *et al.* (2) used an equal ratio series design to examine the effect of metribuzin, pendimethalin, alachlor, and imazaquin on the competitiveness of sicklepod [*Cassia obtusifolia* (L.)], tall morningglory [*Impomoea purpurea* (L.) Roth], and common cocklebur with soybean in the greenhouse. Dry matter production of each crop:weed combination and herbicide treatment was compared 5 weeks after treatment. Soybean produced 4.8, 2, and 1.5 times more fresh weight than sicklepod, tall morningglory, and common cocklebur respectively. An herbicide response coefficient (HRC) was used to evaluate the effect of the herbicide, which is a gain or loss in crop fresh weight relative to weed fresh weight resulting from the herbicide treatment. A herbicide treatment that did not alter the crop:weed relationship would be equal to 1 and values greater than 1 indicate a change in the ratio in favor to the crop. An HRC of 1.1, 1.7, 1.8 occurred with soybean:sicklepod with pendimethalin, alachlor, imazaquin respectively. Imazaquin caused the greatest reduction in competitiveness of all three weed species. Increasing herbicide rates resulted in greater alteration of the crop:weed ratio.

Adcock and Banks (1) conducted a similar study to evaluate the effect of water use, leaf area, and dry weight on the competitiveness of sicklepod and common cocklebur with soybean when exposed to alachlor and metribuzin. Alachlor reduced leaf area and dry weight of sicklepod, and initially reduced water use. Metribuzin initially reduced water use of common cocklebur and soybean. Soybean competing with sicklepod injured by alachlor, produced soybean yields greater than soybeans competing with untreated sicklepod. Soybean yield did not increase when metribuzin was applied to common cocklebur.

Relatively few investigations have addressed the effect of herbicides on the relationship between crop and weed competitiveness. This question needs to be approached with several weed species and crops. Weed management strategies will be better suited to situations where preemergence herbicide failures occur and the question arises as to whether further control measures are needed to reduce the impact of these weeds on crop yield and economic return.

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CHAPTER 2

VELVETLEAF (*Abutilon theophrasti* Medik.) INTERFERENCE IN NON-IRRIGATED CORN

ABSTRACT

Field research was conducted in 1992 and 1993 to study full season velvetleaf interference in non-irrigated corn. The treatments consisted of velvetleaf densities of 0, 1, 3, 9, and 18 plants per m of corn row. Alachlor at 1.1 kg/ha was broadcast preemergence to suppress other weeds and was supplemented with handweeding. Velvetleaf growth was affected by density in 1993. Intraspecific competition caused velvetleaf mortality at a density of 9 plants per m in 1993 and at 18 plants per m in both years. Greatest velvetleaf growth and seed production occurred at a density of 3 plants per m in 1992 and 1993. The number of seeds produced per plant was not affected by density in 1992. Velvetleaf seed production per m^2 increased linearly with increasing density in both years, and was approximately two times greater at the highest velvetleaf density in 1993 compared with 1992. Significant corn yield reduction occurred at a velvetleaf density of 9

plants per m in 1992, and 1 plant per m in 1993. Corn grain yield was reduced 12% at a density of 9 plants per m in 1992, and 6% at a density of 1 plant per m in 1993. Corn yield was reduced 25% at the highest velvetleaf density in both years when compared to the weed free yields. Nomenclature: alachlor, 2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl)acetamide; corn, *Zea mays* (L.) #[1] ZEAMX,'Pioneer 3573'; velvetleaf, *Abutilon theophrasti* Medik. # ABUTH.

[1]Letters following this symbol are WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 309 W. Clark St., Champaign, IL 61820.

INTRODUCTION

Velvetleaf is a prolific weed that inhabits several environments and produces thousands of long-lived seeds (12,21,24,28,29,35,36). It is a troublesome weed in many agricultural crops, especially corn and soybeans. Annual economic losses attributed to velvetleaf in 1984 exceeded $340 million (29). Nationwide estimates report that $114 million was spent on velvetleaf control 12 years ago, with Michigan corn producers accounting for approximately $4 million (22).

Velvetleaf persistence is partially due to its tolerance of commonly used PRE herbicides in corn, soybeans, and sugarbeets. Low rates of atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine], reduced use of 2,4-D [(2,4-dichlorophenoxy)acetic acid], and less cultivation have also contributed to velvetleaf infestations in corn (22). Furthermore, triazine resistant velvetleaf was identified in a Maryland field where corn had been continuously cropped for five years (25).

Many experiments have documented the level of crop yield loss that can occur from weed interference (33,44). Several researchers have observed corn yield loss due to weed interference under a variety of environments (6,8,20,31,38,41,43). This is also true with respect to velvetleaf interference in crops such as cotton (15), soybeans (1,2), and sugarbeets (27). However, limited research has addressed the interactive relationship of corn and velvetleaf (8,11,32,38).

Weed science includes research in weed biology and ecology. Information gained from this research is essential to develop weed management strategies that are more efficacious and cost effective than current control programs. A regional research project entitled "NC202 Biological and Ecological Basis for a Weed Management Model to Reduce Herbicide Use in Corn" (5) is compiling data on several annual weeds, including velvetleaf, that will quantify corn and weed interactions under a range of growing conditions across the North Central region. One objective of this project is to assess the regional variation in competitive interactions and derive crop loss functions for selected weeds in corn. This data will also be used for refinement of computerized models currently under development that will predict the outcome of weed-crop interactions and subsequently support weed management decisions by weed scientists, agricultural consultants, and farmers (34,40). The objective of this research was to assess the competitive interactions of corn and velvetleaf in Michigan.

MATERIALS AND METHODS

Field research was conducted on adjacent sites in 1992 and 1993, on the Michigan State University Agronomy Research Farm at East Lansing. The soil was a Capac loam (fine - loamy, mixed, mesic Aeric Ochraqualfs) with 3.0% organic matter and a pH of 7.0 in 1992, and 2.3% organic matter and a pH of 6.5 in 1993. In 1992, the plot area was fall chisel plowed. In 1993, the plot area was spring moldboard plowed due to excessive precipitation the previous fall. Secondary tillage consisted of spring disking and field cultivation in 1992 and 1993 with two diskings in 1993. In 1992, 336 kg/ha 6-24-24, 224 kg/ha 0-0-60, and 305 kg/ha 46-0-0 was broadcast prior to field cultivation and incorporated based on soil test recommendations from Michigan State University. In 1993, similar amounts of 6-24-24 and 46-0-0 were applied, however, 0-0-60 was not applied. Corn hybrid 'Pioneer 3573' was planted in 76 cm wide rows with a Maxi-merge 7200[2] on May 11, 1992, and May 10, 1993 at a population of 63,500 seeds ha^{-1} (Table 1). In 1993, terbufos (S-[[(1,1-dimethylethyl)thio]methyl]O,O diethyl phosphorodithioate) insecticide was applied at a rate of 69 g/1000 m of row, in furrow, to avoid a possible infestation of corn rootworm since corn followed corn in the experimental area. Velvetleaf seed was collected from field grown plants,

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[2]Deere and Co., Moline, IL 61625-3104

dried at 49 °C for 7 d, threshed through a stationary plot thresher to separate the seeds from the carpels, hand sieved to obtain a pure seed lot, and stored in cold storage until planting. Velvetleaf seed was planted, immediately following corn planting, approximately 7.5 cm on each side of the corn row with a five-row, 60 cm wide nursery seeder[3], designed to plant small seeded legumes, with the center three rows plugged. Seeding rates were selected to obtain velvetleaf densities of 0, 1, 3, 9, and 18 plants per m of row. Velvetleaf seed was not pretreated to enhance germination in the field.

Alachlor was applied PRE at 1.1 kg/ha to the entire plot area to control other annual grass and broadleaf weeds. Application equipment consisted of a tractor mounted compressed air sprayer. Herbicide application utilized 8003 flat fan nozzles[4] which delivered 206 L/ha spray volume and 207 kPa spray pressure. All weeds, other than velvetleaf, escaping chemical control were subsequently removed by hand hoeing until crop and weed canopy closure.

The experimental design was a randomized complete block with five replications. Treatments consisted of velvetleaf densities of 0, 1, 3, 9, and 18 plants per m of row. This design is also referred to as an additive series design for interference research where one species density is held constant (i.e. corn), and

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[3]Carter Manufacturing Co. Inc., Brookston, Ind. 47923.

[4]Spraying Systems Co., North Ave. and Schmale Road, Wheaton, IL 60188.

the other species is varied (i.e. velvetleaf). Plots were 3 m (4 - 76 cm wide rows) wide and 16 m long.

Velvetleaf plants were thinned by hand to actual treatment densities using a 4-m stick approximately 2 weeks after planting, at which time plants ranged from cotyledon to one true leaf in size. Remaining velvetleaf plants were uniformly spaced along the corn row. Late emerging plants were thinned throughout the subsequent weeks. Immediately following thinning, a 5-m section in one of the center two rows of each plot was established to evaluate corn and velvetleaf growth throughout the growing season.

Five plants were selected from within the 5-m section of row and the following measurements were recorded 4 weeks after thinning in 1992 and 1993: corn height, number of leaf collars, velvetleaf height, and number of leaf scars. Corn and velvetleaf density in the 5-m section was also recorded.

At peak capsule set, velvetleaf height, stem diameter (10 cm above ground level), and the number of capsules per plant were recorded on five plants within the 5-m section of row. Corn and velvetleaf density was again recorded at velvetleaf maturity to evaluate corn and/or velvetleaf mortality. Velvetleaf seed production was estimated by harvesting three mature seed capsules from the top, middle, and bottom regions of five plants within the 5-m section. The number of seeds per capsule was determined and divided by the number of capsules collected to determine the average number of seeds produced per capsule. The number of seeds per capsule was multiplied by the average number of capsules per plant to determine the number of seeds produced per plant. That number was then multiplied by the number of plants per m^2 in each treatment to estimate the number of seeds produced per m^2. Corn yield was determined by mechanically harvesting the center two rows of each plot with a combine. Grain moisture was recorded, and yields were adjusted to 15.5% moisture. All data were subjected to analysis of variance and means separated by least significant difference at the 0.05 level of significance. Treatment by year interactions were significant therefore data are reported separately for each year.

RESULTS AND DISCUSSION

In 1992, the experimental site received 0.5 cm of rainfall 2 d after planting but this rainfall was inadequate for uniform velvetleaf germination. Therefore, 1.5 cm of irrigation water was applied on May 22 with stationary riser units. This caused a second emergence of velvetleaf seedlings. The initial stand was removed to achieve a uniformly sized population. To remain consistent from year to year and alleviate reliance on normal precipitation, 1.5 cm of irrigation was applied to the experimental site 4 d after planting with a pivoting traveler irrigation system in 1993. This resulted in delayed corn emergence and hastened velvetleaf emergence compared to 1992 emergence dates (Table 1). Freezing temperatures occurred 14 and 17 d after planting in 1992 resulting in foliar injury and temporary stunting of the corn. Velvetleaf had not yet emerged and did not appear damaged by the freezing temperatures. Velvetleaf were infected with leaf spot disease (*colletotrichum* sp.) in June of 1993. However, velvetleaf growth and seed production did not appear to be affected.

Velvetleaf Growth. Plant height increased significantly with increasing density 6 weeks after emergence (Table 2). Increases in total plant density (corn + velvetleaf) per m^2 most likely induced inter- and intraspecific competition for light resulting in greater plant height. Brown (7) determined that velvetleaf is capable of growing up to 300 cm in height in a non-competitive environment. At velvetleaf maturity, plants were taller at higher densities in 1992. In 1993, velvetleaf plants at the lowest density were shorter probably because of shading from surrounding corn plants.

Stem diameter of mature plants was similar, regardless of density in 1992 (Table 2). Velvetleaf had larger stem diameters at densities of 3 and 9 plants per m of row in 1993.

Seed Production. Several researchers have indicated that velvetleaf is capable of producing between 70 and 199 mature seed capsules per plant (4,9,19,28,37,42). In this research velvetleaf produced 15 capsules per plant in 1992 and 25 capsules per plant in 1993 when averaged across densities (Table 2). DeFelice *et al.* (11) determined that velvetleaf competing full season with no-tillage and conventional tillage corn averaged 37 capsules per plant over two years. Seed capsule production did not differ among densities in 1992 but the number of capsules per plant was lower at 1 plant per meter of row in 1993 (Table 2), suggesting that a density this low is not competitive with corn.

Seed production per capsule was the most static phenotypic trait of velvetleaf reproduction. Mature seed capsules will contain from 35 to 45 seeds under a wide range of environments (4,9,42). The number of seeds per capsule was virtually the same, across densities within each year (Table 2).

Velvetleaf has been reported to be capable of producing up to 17,000 seeds per plant when growing without interference from a crop (36). In this study, the maximum number of seeds produced per plant occurred at a density of three plants per m in both years (Table 2). Seed production did not exceed 1300 seeds per plant in 1993 and 610 seeds in 1992, indicating the impact of corn on velvetleaf seed production.

Velvetleaf seed production per unit area is a function of density and capsule production since the number of seeds per capsule and seed size remain relatively constant. Seed production per m^2 increased linearly with increasing velvetleaf density in 1992 and 1993 as described by regression analysis (Figure 1). In 1992, seeds/m^2 = density * 610: R^2=.94, and in 1993 seeds/m^2 = density * 1310.8: R^2=.91. The number of seeds produced at 18 plants per m was more than two times greater in 1993 than in 1992.

Mortality of individual plants may increase as plant density increases (18). Velvetleaf stand counts at harvest determined that velvetleaf mortality occurred at the higher densities. Mortality in both years averaged less than 1 and 3 plants per m at densities of 9 and 18 plants per m, respectively (data not presented). Dekker and Meggitt (13,14) reported similar decreases in velvetleaf stand due to mortality of individual plants during the growing season.

Corn Growth and Yield. Previous research has shown that velvetleaf interference can reduce corn grain yield and aboveground biomass production in a variety of environments (11,32,38). Time of emergence and proximity of crop and weed will dictate to a great extent the amount of reduction that can occur. Defelice *et al.* determined that full season competition from a velvetleaf density of 10 plants per m reduced corn yield 23%[5]. They also concluded that removal of velvetleaf plants by an application of a postemergence herbicide or by cultivation any time prior to corn tasseling may prevent corn yield losses due to velvetleaf competition.

Corn yield data was analyzed using a rectangular hyperbolic model (10) to estimate corn yield loss as a function of velvetleaf interference. This model is considered appropriate for the analysis of crop yield response in additive

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[5]DeFelice, M.S. 1987. Velvetleaf (*Abutilon theophrasti*) growth and development in conventional and no-tillage corn (*Zea mays*). Ph.D. Dissertation, University of Kentucky, 201 pp.

experiments but not in substitutive or replacement series experiments (17). The model below includes the following parameters:

$$Y = Y_{wf}\left[1 - \frac{Id}{100(1+Id/A)}\right]$$

Y = yield (kg/ha)

Y_{wf} = yield in the absence of weeds

d = weed density (plants per m of row)

I = percentage yield loss for the first unit weed density as $d \rightarrow \infty$

A = percentage yield loss as $d \rightarrow \infty$ (i.e. maximum crop yield loss asymptote)

The parameters Y_{wf} and I were estimated using a microcomputer statistical package (30). Since yield loss due to weed interference can never exceed 100%, A (maximum crop yield loss from an infestation of velvetleaf) was estimated arbitrarily at 56%. Statistically estimated values of parameters for the hyperbolic curves fitted to the 1992 and 1993 yield data were:

	1992	1993
Y_{wf}	165.74	154.68
I	1.93	2.23

The rectangular hyperbolic model predicted similar corn yield responses to velvetleaf interference in both years with an R^2 value of .62 and .71, and I values of 1.93 and 2.23 for 1992 and 1993, respectively (Figure 2). However, greater yield reductions occurred in 1993 compared with 1992 at velvetleaf densities below 18 plant per m. Significant yield loss occurred at one plant per m in 1993 whereas yield loss did not occur below 9 plants per m in 1992 (Figure 2).

Environmental conditions (e.g. soil moisture) affect the competitive ability of weeds from year to year (39). The experimental site received only 40% as much precipitation eight to twelve wks after planting in 1993 compared to 1992 (Table 3). This interval icluded the approximate time of ear set when corn is most sensitive to stress resulting in yield reduction (3). Moisture levels in 1992 were not limiting during this period which may explain why velvetleaf plants were taller 4 wks after thinning in 1992 (Table 2), yet velvetleaf were less competitive with corn. Corn emerged prior to velvetleaf in 1992, whereas velvetleaf emerged prior to corn in 1993. Irrigation 4 d after planting in 1993 may have kept soil temperatures low enough to delay corn emergence, since corn planted adjacent to the experimental area that was not irrigated emerged 7 d earlier. The soil temperature at weed seed depth, closer to the soil surface, warmed therefore hastening velvetleaf emergence 10 d when compared to 1992 (Table 1). These factors may explain why velvetleaf was more competitive with corn and produced more seed in 1993. However, the highest velvetleaf density caused a maximum corn yield loss in 1993 similar to that of 1992. Time of emergence of both corn and velvetleaf and environmental conditions can greatly effect potential velvetleaf seed production and the competitive relationship between crop and weed. Several factors must be considered when developing models to predict weed interference because seasonal variability will cause significant changes in the interaction between crops and weeds.

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Table 1. Experiment establishment operations and emergence dates in 1992 and 1993.

	1992	1993
	Date	
Planting	May 11	May 10
Herbicide Application	May 14	May 11
Irrigation	May 22	May 14
50% Corn Emergence	May 19	May 26
50% Velvetleaf Emergence	May 30	May 19
Velvetleaf Thinning	June 8 - 11	June 15 - 17

Table 2. Velvetleaf growth as influenced by density.

Density	Height[a]	Height[b]	Stem diameter[bc]	Capsules[b]	Seeds[b]	Seeds[b]
plants per m of row	—— cm ——			no. per plant	no. per capsule	no. per plant
	1992					
1	60	200	1.14	16	35	560
3	69	204	1.13	17	35	610
9	80	204	1.02	14	36	510
18	91	206	1.03	13	34	450
LSD (0.05)	5	NS	NS	NS	NS	NS
	1993					
1	27	161	0.77	17	38	650
3	30	216	1.01	31	41	1300
9	34	216	0.96	29	40	1170
18	44	207	0.88	23	40	860
LSD (0.05)	5	13	0.06	10	NS	440

[a]Velvetleaf height 4 wk after thinning.
[b]Measurements taken at velvetleaf maturity.
[c]Stem diameter 10 cm above ground level.

Table 3. Rainfall data for a 17 wk period of the growing season during 1992 and 1993.

Weeks after planting	1992	1993
	cm	
-1	0.53	2.03
0	0.51	1.50[a]
1	2.44[a]	0.38
2	4.14	0.00
3	5.46	3.40
4	0.00	4.06
5	2.29	2.51
6	0.56	0.61
7	0.00	0.13
8	1.22	0.58
9	12.34	0.00
10	1.45	3.07
11	4.34	4.72
12	1.73	0.53
13	1.04	5.56
14	0.10	1.24
15	2.79	0.94
total	40.94	31.26

[a]weekly total including 1.5 cm of irrigation water

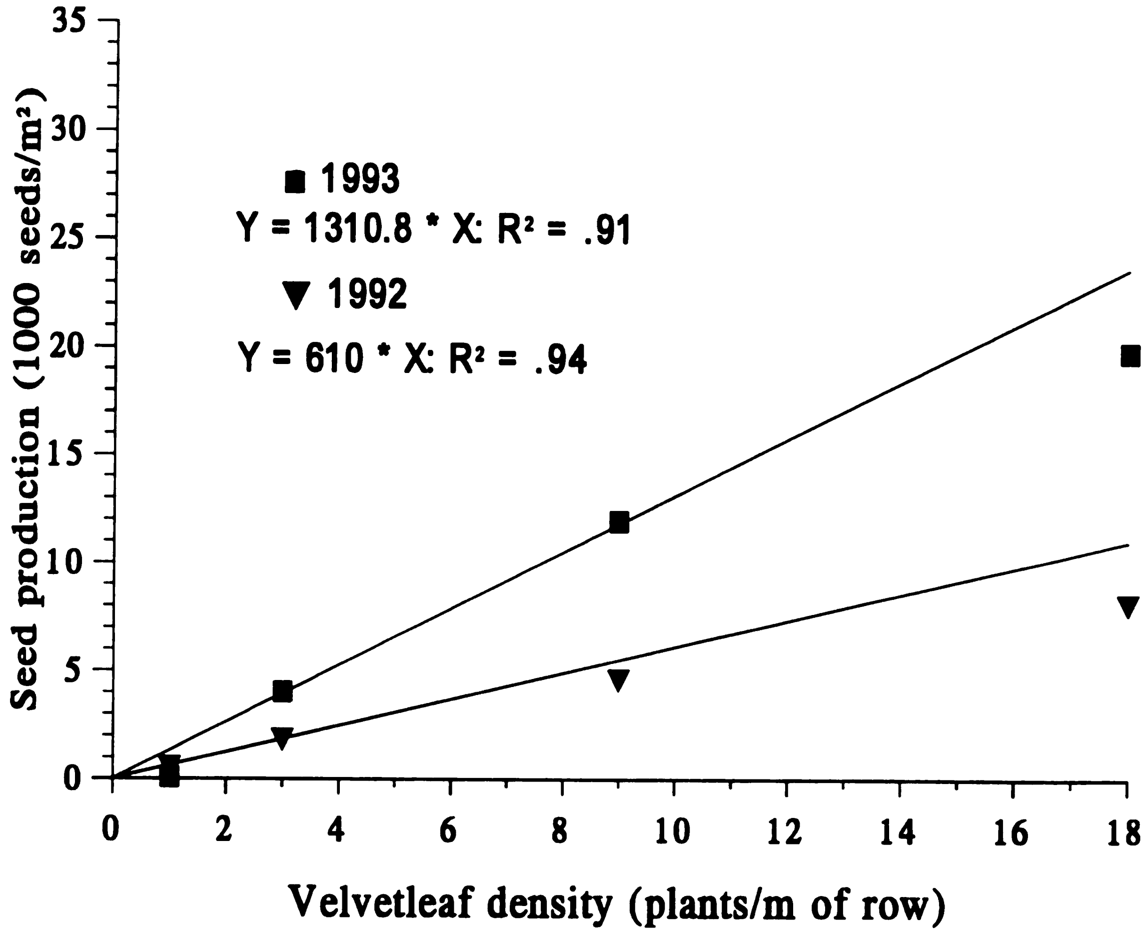

Figure 1. Velvetleaf seed production in 1992 and 1993 as influenced by density.

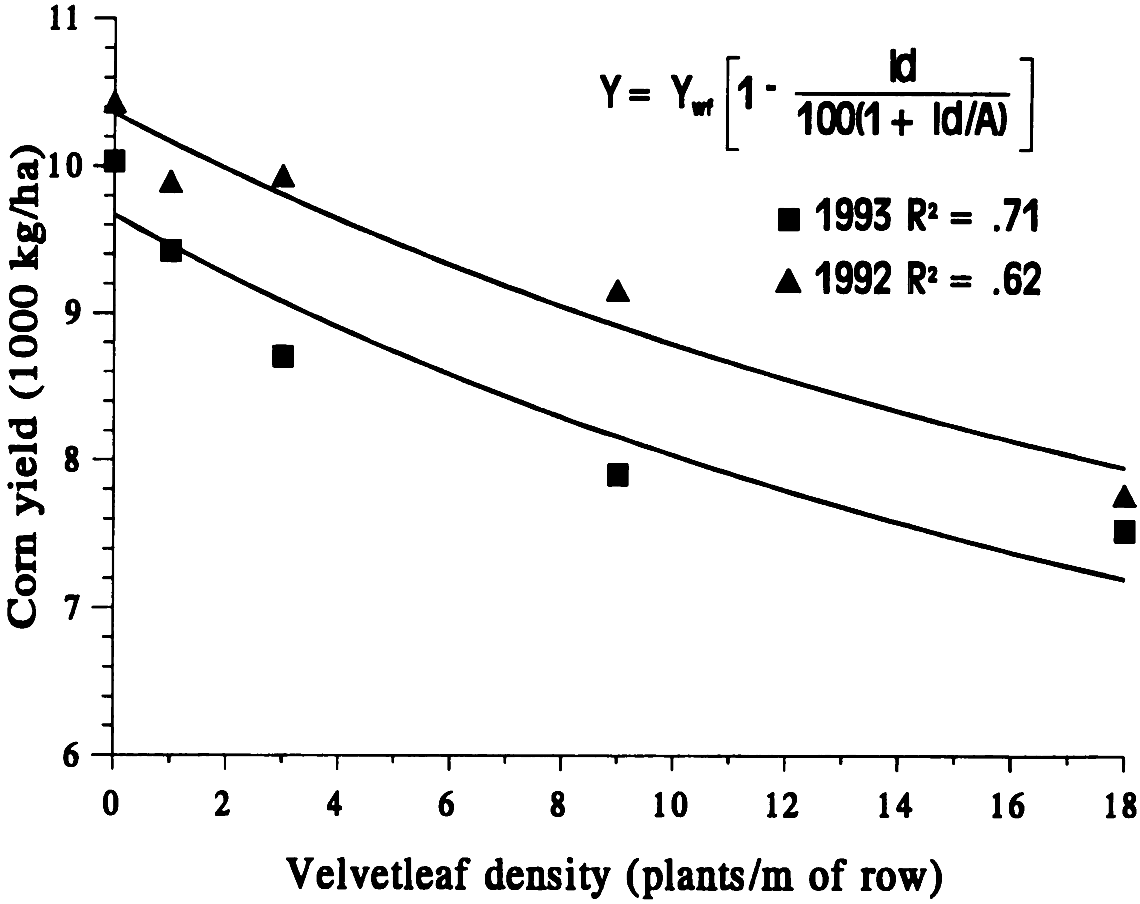

Figure 2. Corn yield in 1992 and 1993 as influenced by velvetleaf interference.

CHAPTER 3

EFFECT OF SELECTED PREEMERGENCE HERBICIDES ON VELVETLEAF (*Abutilon theophrasti* Medik.) COMPETITIVENESS IN NON-IRRIGATED CORN

ABSTRACT

Field and greenhouse research was conducted in 1992 and 1993 to determine the effect of selected preemergence herbicides on velvetleaf competitiveness in non-irrigated corn. A split-split plot design was utilized in the study. The main plot was herbicide, the sub plot was velvetleaf density (zero or nine plants per m of row), and the sub-sub plot was treatment (treated with herbicide or untreated). Herbicide treatments consisted of atrazine (0.6 and 1.1 kg/ha) or pendimethalin (0.6 and 1.1 kg/ha) applied preemergence. Other weeds were removed to ensure no additional weed competition. In 1992 and 1993, atrazine or pendimethalin applied at 1.1 kg/ha greatly reduced velvetleaf growth and seed production, and prevented velvetleaf from reducing corn yield. Atrazine or pendimethalin applied at 0.6 kg/ha reduced velvetleaf growth and seed production in 1993, but only

atrazine prevented yield loss in 1992. In the absence of velvetleaf, corn yield was not affected by either herbicide. Greenhouse experiments determined that atrazine was more effective at reducing velvetleaf plant height, leaf area, and total plant dry weight followed in order by pendimethalin and alachlor. Nomenclature: Atrazine, 6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine; pendimethalin, *N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine; alachlor, 2-chloro-2',6'-diethyl-*N*-(methoxymethyl)acetanilide; corn, *Zea mays* (L.) #[1] ZEAMX, 'Pioneer 3573'; velvetleaf, *Abutilon theophrasti* Medik. # ABUTH.

Additional index words: Competitiveness, interference

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[1]Letters following this symbol are WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 309 W. Clark St., Champaign, IL 61820.

INTRODUCTION

Plant competition is a complex interaction influenced by several factors. In agroecosystems, crops and weeds compete for a limited amount of resources. Extensive research has documented the level of crop yield loss that can occur as a result of weed competition (16,20). Velvetleaf is a vigorously competitive plant (11) that caused yield loss in cotton (7), soybeans (8), and sugarbeets (14). However, limited research has addressed the competitive affects of velvetleaf on corn (5,6,15,18).

Many experimental designs have been developed to examine crop and weed competition. These designs fall into four categories: additive, substitutive, systematic, and neighborhood (12). Each design considers density, spatial arrangement, and species proportion to varying degrees (13). However, most of these experiments are conducted in the absence of PRE herbicides. Simulation of a typical field situation where PRE or POST herbicides are applied is critical to gain knowledge on the competitiveness of weeds in this type of environment.

Weeds emerging after an application of a PRE herbicide known to have activity on that weed species are referred to as weed escapes. The competitiveness of weed escapes may be altered by herbicide activity, as well as crop competitiveness. Little information is available on the competitiveness of weeds that survived exposure to a PRE herbicide. Adcock *et al.* (1,2) examined the effect of alachlor, metribuzin, pendimethalin, and imazaquin on the competitive relationship of sicklepod, common cocklebur, and tall morningglory with soybean in the field and greenhouse. However, no information is available on the effect of PRE herbicides on velvetleaf competitiveness in corn. Commonly used corn herbicides known to have activity on velvetleaf include atrazine (9) and pendimethalin (10). Alachlor, another common corn herbicide primarily used for annual grass control, may also affect velvetleaf growth.

Knowledge of the competitiveness of escaped weeds may be useful in predicting their effect on crop yield. Such information could enhance existing models that predict crop-weed interference and estimate yield reduction by a weed population (17,19), thereby suggesting the need for POST herbicides application and/or cultivation. These estimates may be inaccurate if the competitiveness of this weed population has been altered.

The objectives of this research were: 1) to determine the effect of sub-lethal doses of atrazine and pendimethalin on the growth and reproductive capacity of velvetleaf, and 2) to determine if the competitive relationship between corn and velvetleaf is altered compared to untreated plants. Greenhouse experiments were conducted to determine the effect of atrazine, pendimethalin, and alachlor on initial velvetleaf growth.

MATERIALS AND METHODS

Field experiments. Field research was conducted on adjacent sites in 1992 and 1993, on the Michigan State University Agronomy Research Farm at East Lansing. The site consisted of a Capac loam soil (fine - loamy, mixed, mesic Aeric Ochraqualfs) with 3.0% organic matter and a pH of 7.0 in 1992, and 2.3% organic matter and a pH of 6.5 in 1993. In 1992, the plot area was fall chisel plowed. In 1993, the plot area was spring moldboard plowed due to excessive precipitation the previous fall. Secondary tillage consisted of spring disking and field cultivation in 1992 and 1993 with two diskings in 1993. In 1992, 336 kg/ha 6-24-24, 224 kg/ha 0-0-60, and 305 kg/ha 46-0-0 was broadcast prior to field cultivation and incorporated based on soil test recommendations from Michigan State University. In 1993, similar amounts of 6-24-24 and 46-0-0 were applied but 0-0-60 was not included. Corn hybrid 'Pioneer 3573' was planted in 76-cm wide rows with a Maxi-merge 7200[2] on May 11, 1992, and May 10, 1993 at a population of 63,500 seeds/ha (Table 1). In 1993, terbufos (S-[[(1,1-dimethylethyl)thio]methyl]O,O diethyl phosphorodithioate) insecticide was applied at a rate of 69 g/1000 m of row, in furrow, to avoid a possible infestation of corn root worm since corn followed corn in the experimental area. Velvetleaf seed was collected from field grown plants in Michigan, dried at 49 °C for 7 d, threshed

[2]Deere and Co., Moline, IL 61625-3104

through a stationary plot thresher to separate the seeds from the carpels, hand sieved to obtain a pure seed lot, and stored in cold storage until planting. Velvetleaf seed was planted, immediately following corn planting, approximately 7.5 cm on each side of the corn row with a five-row, 60-cm wide nursery seeder[3], designed to plant small seeded legumes, with the center three rows plugged. Seeding rates were selected to obtain velvetleaf densities of zero and nine plants per m of row.

Atrazine or pendimethalin was applied preemergence at either 0.6 or 1.1 kg/ha with a tractor-mounted compressed air sprayer calibrated to deliver 206 L/ha at 207 kPa using 8003[4] flat fan nozzles. Treatments were applied to one half of the plot area leaving the remaining half untreated. All weeds, other than velvetleaf, escaping chemical control were subsequently removed by hand hoeing.

The experimental design was a split-split plot with six replications. The main plot was herbicide, the sub plot was velvetleaf density (zero or nine plants/m), and the sub-sub plot was treatment (treated with herbicide or untreated). Plots were 3 m wide (4 76 cm wide rows) by 8 m long.

Velvetleaf plants were thinned by hand to actual treatment densities using a 4-m stick approximately 2 weeks after planting, at which time plants ranged from cotyledon to one true leaf in size. Remaining velvetleaf plants were uniformly

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[3]Carter Manufacturing Co. Inc., Brookston, Ind. 47923.

[4]Spraying Systems Co., North Avenue and Schmale Road, Wheaton, IL 60188.

distributed along the corn row. Late emerging plants were thinned throughout the subsequent weeks. Immediately following thinning, a 5-m section in one of the center two rows, in each half of the plot, was established to evaluate corn and velvetleaf growth throughout the growing season.

Five plants were selected from within the 5-m section of row and the following measurements were recorded four weeks after thinning in 1992 and 1993: corn height, number of leaf collars per corn plant, velvetleaf height, and number of leaf scars per velvetleaf plant. Stand counts of corn and velvetleaf plants in the 5-m section was also recorded. At peak capsule set, velvetleaf height, stem diameter (10 cm above ground level), and the number of capsules per plant was recorded on five plants within the 5-m section of row. Corn and velvetleaf stand counts per 5-m was again recorded to evaluate corn and/or velvetleaf mortality. Velvetleaf seed production was estimated by harvesting three mature seed capsules from the top, middle, and bottom regions of five plants within the 5-m section. The number of seeds per capsule was determined and divided by the number of capsules collected to ascertain the average number of seeds produced per capsule.

The number of seeds per capsule was multiplied by the average number of capsules per plant to determine the number of seeds produced per plant. That number was then multiplied by the number of plants per meter of row in each treatment and an estimate of seeds produced per square meter was then calculated. Corn yield was determined by mechanically harvesting the center two rows of each plot with a combine. Grain moisture was recorded, and yields were adjusted to 15.5% moisture. All data were subjected to analysis of variance and means separated by least significant difference at the 0.05 level of significance. Treatment by year interactions were significant so data are reported separately for each year.

Greenhouse experiments. Studies were conducted in the greenhouse to determine the effect of selected PRE herbicides on velvetleaf growth and competitiveness. Environmental conditions were maintained at 24 $\pm$ 2 C and a 16-h photoperiod of natural and supplemental metal halide lighting with an average midday photosynthetic photon flux density (PPFD) of 700 $\mu E/m^2/s$ measured with a photometer[5] at pot height, 70 cm from the light source. Five velvetleaf seeds, previously described, were seeded in 945-ml plastic pots, in a Spinks loamy sand (sandy, mixed, mesic Psammentic Hapludalfs) with 1.8% organic matter and a pH of 6.2. Pots were watered to field capacity immediately after planting, followed by the addition of 50 ml of a water soluble fertilizer solution (20% N, 20% P_2O_5, 20% K_2O, 2 g/L) which was incorporated with 50 ml of water. Herbicide treatments were applied the following day with a single 8001E[6] flat fan nozzle on a continuous link belt sprayer calibrated to deliver 206 L/ha at a spray pressure of

[5]Li-1985B Quantum Photometer. Lambda Instruments Corp., Lincoln, NE 68504.

[6]Spraying Systems Co., North Avenue and Schmale Road, Wheaton, IL 60188.

207 kPa. PRE herbicide treatments consisted of atrazine or pendimethalin at rates of 0, 0.3, 0.6, and 1.1 kg/ha, or alachlor at rates of 0, 0.6, 1.1, and 2.2 kg/ha. The equivalent of 1.25 cm of precipitation (120 ml) was applied one day after treatment (DAT)[7] to activate the herbicide. Pots were fertilized weekly, as previously described, and sub-irrigated as needed for the duration of the experiment. Pots were rotated by replication and within replication every second day to minimize variation in growth due to temperature and light differences in the greenhouse.

Velvetleaf emergence was recorded one week after treatment (WAT)[7], at which time plants were thinned to one per pot, and total emergence recorded for the duration of the experiment. Plant height and number of leaves per plant were measured 2 WAE, and then weekly for the duration of the experiment. All plants were harvested 5 WAE at which time total leaf area per plant was measured by using a leaf area meter[8], and dry weights determined. The experiment was conducted as a randomized complete block with 10 replications and repeated over time. All data were subjected to analysis of variance and means were separated by least significant difference at the 0.05 level. No significant differences were found between the repeated experiments, therefore data were pooled.

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[7]Abbreviations: DAT, days after treatment; WAT, weeks after treatment; WAE, weeks after emergence

[8]Licor Li 300 Portable Leaf Area Meter. Lambda Instruments Corp., Lincoln, NE 68504.

RESULTS AND DISCUSSION

Field experiments. In 1992, the experimental site received 0.5 cm of rainfall 2 d after planting but this rainfall was inadequate for uniform velvetleaf emergence. Therefore, 1.5 cm of irrigation water was applied on May 22 with stationary riser units resulting in a second emergence of velvetleaf seedlings. The initial stand was removed to achieve a uniformly sized population. To remain consistent from year to year and alleviate reliance on normal precipitation for velvetleaf emergence, 1.5 cm of irrigation was applied to the experimental site 4 d after planting with a pivoting traveler irrigation system in 1993. This hastened velvetleaf emergence while corn emergence was delayed 7 d compared to 1992 emergence dates (Table 1). Freezing temperatures occurred 14 and 17 days after planting in 1992 resulting in foliar injury and temporary stunting of corn. Velvetleaf had not yet emerged and did not appear damaged by the freezing temperatures. None of the herbicide treatments had any effect on corn height or number of leaf collars per plant 6 WAE (data not reported).

Atrazine at 0.6 kg/ha. Velvetleaf plant height was greatly reduced at 6 WAE and at maturity in 1992 herbicide treated plots (Table 2). However, stem diameter and seed production were not reduced by herbicide treatment. In 1993, velvetleaf in plots treated with atrazine at 0.6 kg/ha were shorter with a smaller stem diameter at maturity. Seed production was reduced by 50% or more when compared with untreated plants in 1993 (Table 2).

In the absence of velvetleaf, corn yield was not affected by herbicide treatment in 1992 and 1993 (Figure 1). Nine untreated velvetleaf plants per m of row reduced corn yield 38 and 32% in 1992 and 1993, respectively. Atrazine at 0.6 kg/ha reduced velvetleaf competitiveness which resulted in 34 and 14% greater corn yields than untreated weedy plots in 1992 and 1993, respectively. A smaller yield increase occurred in 1993 despite greater reduction in velvetleaf growth and seed production compared to 1992. Although competitiveness was reduced both years, treated velvetleaf caused a 21% yield reduction compared to weed-free plots treated with herbicide in 1993 (Figure 1).

Atrazine at 1.1 kg/ha. Velvetleaf were thinned to a density of 6 plants per m of row in herbicide treated and untreated plots due to increased mortality caused by the herbicide. Atrazine at 1.1 kg/ha reduced velvetleaf growth and seed production in 1992 and 1993, with greater reductions occurring in 1992 (Table 2).

Corn yield in weed-free plots treated with herbicide was equivalent to untreated weed-free yields in both years (Figure 2). Six untreated velvetleaf plants per m of row reduced corn yield 27% in 1992 and 22% in 1993 (Figure 2). Atrazine at 1.1 kg/ha reduced velvetleaf competitiveness and corn yields were greater than in untreated weedy plots in 1992 and 1993. Velvetleaf, although still present following atrazine application, were not competitive and yield loss due to velvetleaf competition was prevented in both years (Figure 2).

Pendimethalin at 0.6 kg/ha. Pendimethalin at 0.6 kg/ha reduced early season velvetleaf height in 1992 (Table 3), but had no effect on end-of-season plant growth and seed production. In 1993, velvetleaf growth was reduced by pendimethalin and seed production reduced by 50%. Treated velvetleaf however produced more seeds in 1993 than untreated plants in 1992. Generally, seed production was affected by exposure to the herbicide more than velvetleaf growth in 1993 (Table 3).

In the absence of velvetleaf corn yields in treated and untreated plots were equivalent in 1992 and 1993 (Figure 3). Nine untreated velvetleaf plants per m of row reduced corn yield 33% in 1992 and 27% in 1993. Weedy plots treated with pendimethalin at 0.6 kg/ha had higher yields compared to the untreated weedy plots in both years. However, velvetleaf competitiveness was not eliminated, and corn yields were reduced 16 and 8% compared to treated weed-free plots in 1992 and 1993, respectively (Figure 3).

Pendimethalin at 1.1 kg/ha. Velvetleaf growth was greatly reduced by pendimethalin in both years but seedling mortality did not occur. Seed production per m^2 by treated velvetleaf was 73 and 83% lower than untreated plants in 1992 and 1993, respectively (Table 3).

In the absence of weeds, corn yield was not affected by 1.1 kg/ha of pendimethalin (Figure 4). Untreated velvetleaf at 9 plants per m of row reduced corn yield 34% in 1992 and 21% in 1993. Weedy plots treated with pendimethalin had 35 and 22% higher corn yields compared to the untreated weedy plots in 1992 and 1993, respectively. Corn yields in treated weedy plots were equivalent to weed-free plots, indicating that velvetleaf competitiveness was eliminated by pendimethalin at 1.1 kg/ha (Figure 4).

Corn emerged prior to velvetleaf in 1992, whereas velvetleaf emerged prior to corn in 1993 (Table 1). Irrigation 4 d after planting in 1993 may have kept the soil temperature low to delay corn emergence since corn adjacent to the experimental site that was not irrigated emerged 7 d earlier. The soil temperature at weed seed depth, closer to the surface, warmed therefore hastening velvetleaf emergence. DeFelice *et al.* concluded that delaying velvetleaf emergence for only two or three weeks after corn planting with a PRE herbicide would be sufficient to prevent velvetleaf from reducing corn yields[9]. Despite the fact that exposure to atrazine or pendimethalin at 0.6 kg/ha had a greater effect on velvetleaf growth and seed production in 1993, compared with 1992, early velvetleaf emergence in 1993 resulted in plants that were more competitive, produced more seeds per m^2, and caused significant yield reductions. Soil moisture may have contributed to

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[9]DeFelice, M.S. 1987. Velvetleaf (*Abutilon theophrasti*) growth and development in conventional and no-tillage corn (*Zea mays*). Ph.D. Dissertation, University of Kentucky, 201 pp.

differential velvetleaf growth and competitiveness between 1992 and 1993. The experimental site received 40% as much precipitation eight to twelve wks after planting in 1993 compared to 1992 (Table 4). This interval included the approximate time of ear set when corn is vulnerable to stress resulting in yield reduction (3). Moisture levels in 1992 were not limiting during this period which may have reduced the competitive effects of velvetleaf on corn growth and yield. Atrazine and pendimethalin at 1.1 kg/ha greatly reduced velvetleaf growth and seed production in 1992 and 1993. Velvetleaf competitiveness was virtually and corn yield loss was prevented.

Greenhouse experiments. Velvetleaf growth was reduced by atrazine, pendimethalin, and alachlor. Atrazine had the greatest effect and alachlor the least effect on velvetleaf plant height, leaf area, and total plant dry weight (Figures 5,6,7). Atrazine at 0.3 kg/ha reduced velvetleaf height by 85%, while alachlor at 2.2 kg/ha reduced velvetleaf height by 55% (Figure 5). Similar results were observed with leaf area measurements. Atrazine at 0.3 kg/ha reduced velvetleaf area per plant by 90%, and alachlor at 2.2 kg/ha reduced leaf area 50% (Figure 6). Total plant dry weight data coincided closely with leaf area data. Atrazine and pendimethalin at 0.3 kg/ha reduced velvetleaf dry weight by 92 and 66% respectively (Figure 7). Malefyt and Duke (10) obtained similar velvetleaf control with pendimethalin in the greenhouse.

These data coincide with the field experiments and suggest that atrazine is more effective at reducing velvetleaf competitiveness than pendimethalin. Field experiments showed atrazine at 0.6 kg/ha reduced velvetleaf competitiveness and prevented corn yield loss in one of two years whereas pendimethalin did not prevent yield loss in either year. Atrazine and pendimethalin at 1.1 kg/ha greatly reduced velvetleaf growth in the greenhouse. Field research showed atrazine and pendimethalin reduced velvetleaf growth and seed production, and prevented corn yield loss in 1992 and 1993. Alachlor is generally more toxic to monocots than dicots (4). However, in the greenhouse, alachlor at 0.6 kg/ha reduced velvetleaf growth by 45%. This suggests that velvetleaf competitiveness may be affected where alachlor is applied for annual grass control in broadleaf in weed interference studies.

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Table 1. Experiment establishment operations and emergence dates in 1992 and 1993.

	1992	1993
	Date	
Planting	May 11	May 10
Herbicide Application	May 14	May 11
Irrigation	May 22	May 14
50% Corn Emergence	May 19	May 26
50% Velvetleaf Emergence	May 30	May 19
Velvetleaf Thinning	June 8 - 11	June 15 - 17

Table 3. Effect of pendimethalin applied PRE on velvetleaf growth and seed production in 1992 and 1993[a].

Velvetleaf Measurement	1992 Treated	1992 Untreated	1993 Treated	1993 Untreated
	0.56 kg/ha			
Plant Height[b]	59*	74	20**	45
Plant Height[c]	188	202	159*	212
Stem Diameter[d]	0.94	1.02	0.70*	0.97
Capsules/Plant	10	12	12*	23
Seeds/Plant	302	403	443*	924
Seeds/m^2	3564	4760	5227*	10915
	1.12 kg/ha			
Plant Height[b]	33**	80	13**	44
Plant Height[c]	143**	221	99**	195
Stem Diameter[d]	0.73**	1.20	0.50*	0.89
Capsules/Plant	5**	20	4**	20
Seeds/Plant	174**	634	138**	787
Seeds/m^2	2056**	7486	1624**	9298

[a]Means followed by asterisks (*/**) are significantly different from the untreated mean with the same year at the 0.05/0.01 level according to ANOVA.

[b]Plant height (cm) 6 weeks after emergence.

[c]Plant height (cm) at maturity.

[d]Stem diameter (cm) measured 10 cm above ground at maturity.

Table 4. Rainfall data for a 17 wk period of the growing season during 1992 and 1993.

Weeks after planting	1992	1993
	cm	
-1	0.53	2.03
0	0.51	1.50[a]
1	2.44[a]	0.38
2	4.14	0.00
3	5.46	3.40
4	0.00	4.06
5	2.29	2.51
6	0.56	0.61
7	0.00	0.13
8	1.22	0.58
9	12.34	0.00
10	1.45	3.07
11	4.34	4.72
12	1.73	0.53
13	1.04	5.56
14	0.10	1.24
15	2.79	0.94
total	40.94	31.26

[a]weekly total including 1.5 cm of irrigation water

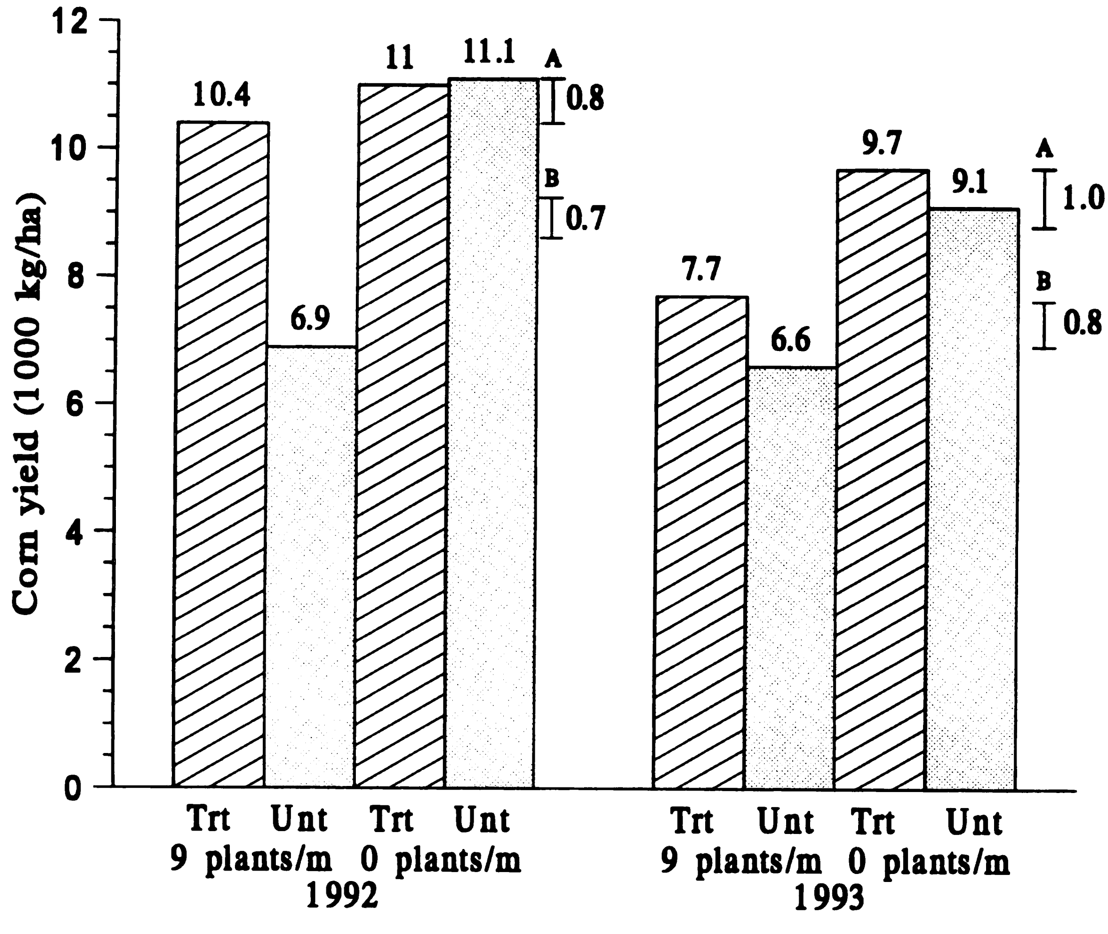

Figure 1. Effect of atrazine at 0.6 kg/ha applied PRE on velvetleaf competitiveness and corn yield. LSD (0.05) A compares means of the same treatment across densities within years, while LSD B (0.05) compares means within each density and year.

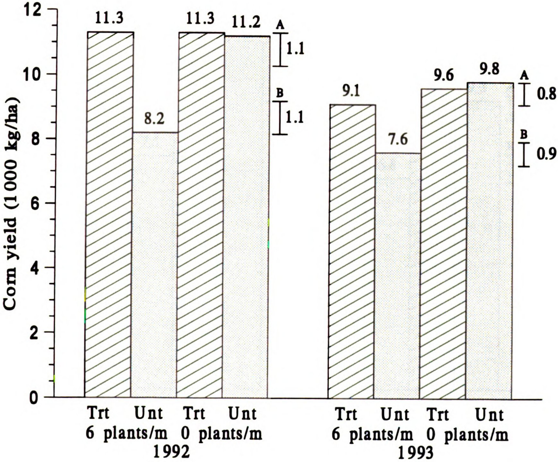

Figure 2. Effect of atrazine at 1.1 kg/ha applied PRE on velvetleaf competitiveness and corn yield. LSD (0.05) A compares means of the same treatment across densities within years, while LSD (0.05) B compares means within each density and year.

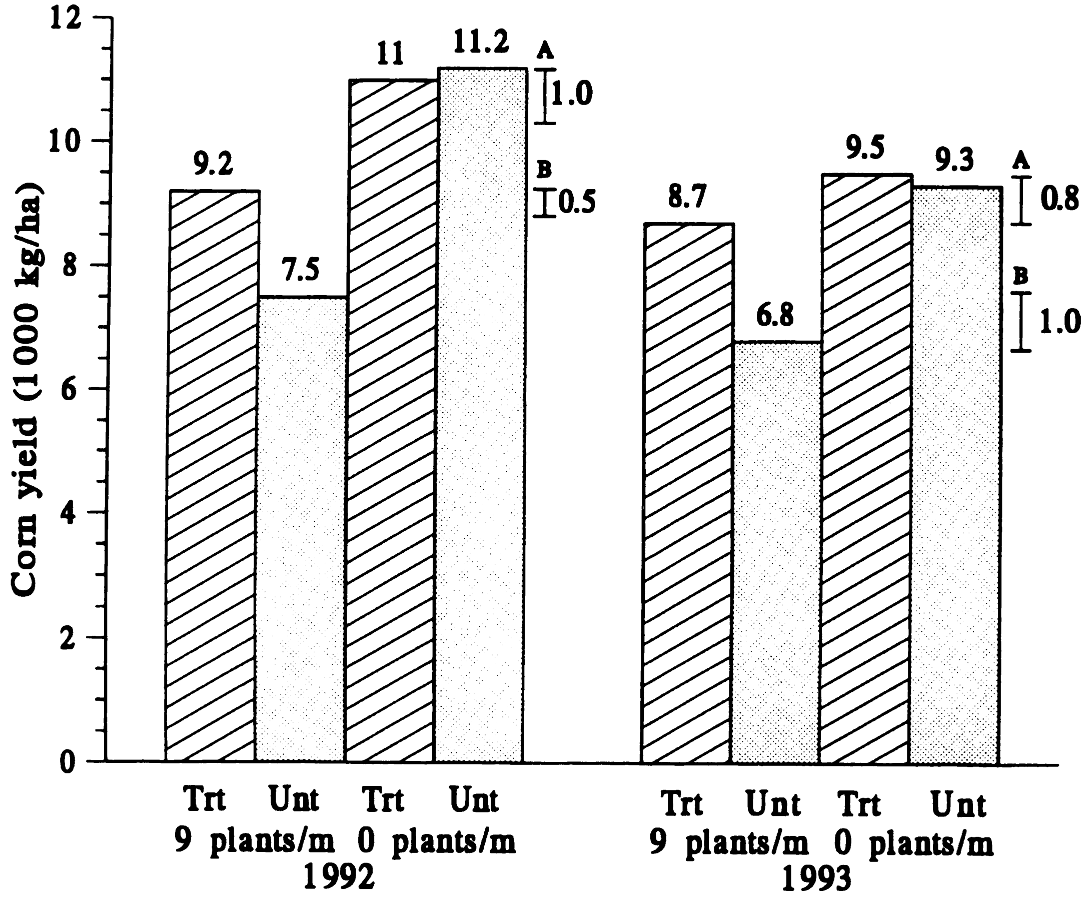

Figure 3. Effect of pendimethalin at 0.6 kg/ha applied PRE on velvetleaf competitiveness and corn yield. LSD (0.05) A compares means of the same treatment across densities within years, while LSD (0.05) B compares means within each density and year.

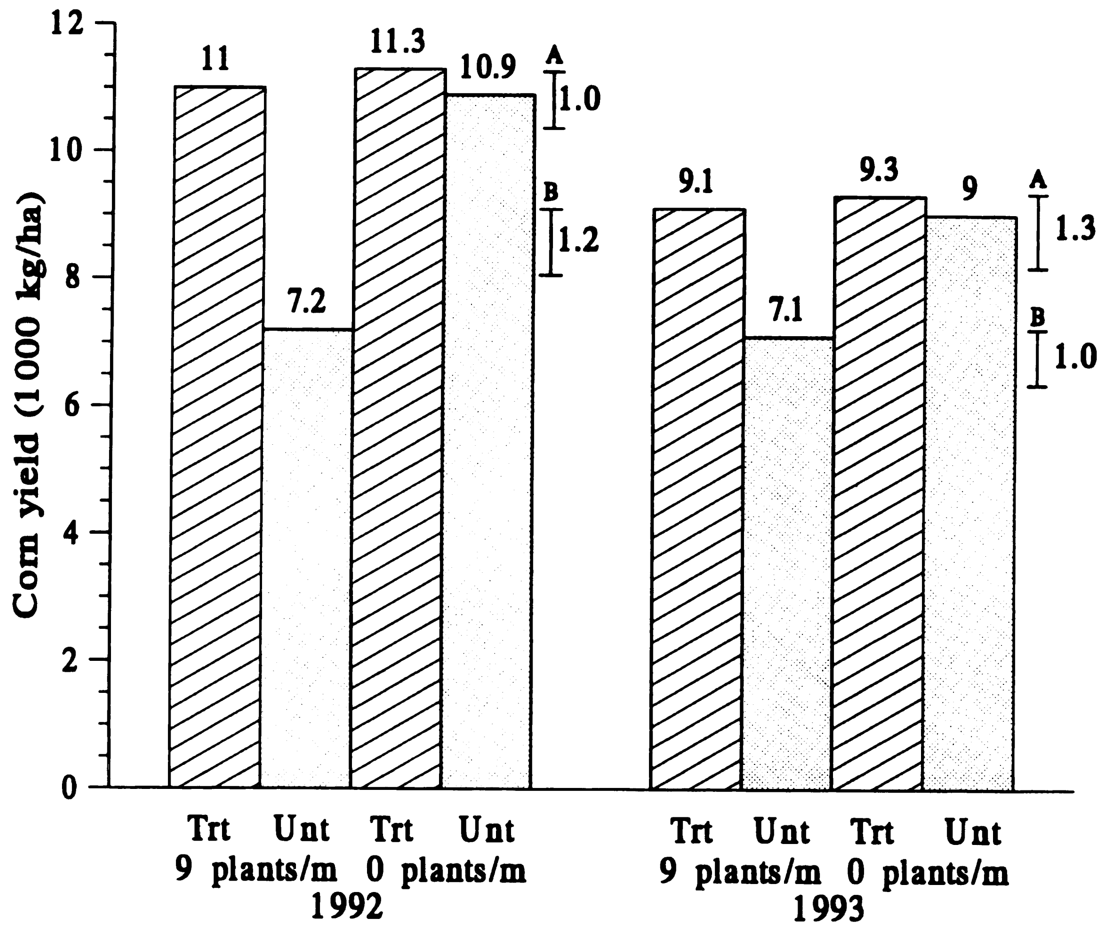

Figure 4. Effect of pendimethalin at 1.1 kg/ha applied PRE on velvetleaf competitiveness and corn yield. LSD (0.05) A compares means of the same treatment across densities within years, while LSD (0.05) B compares means within each density and year.

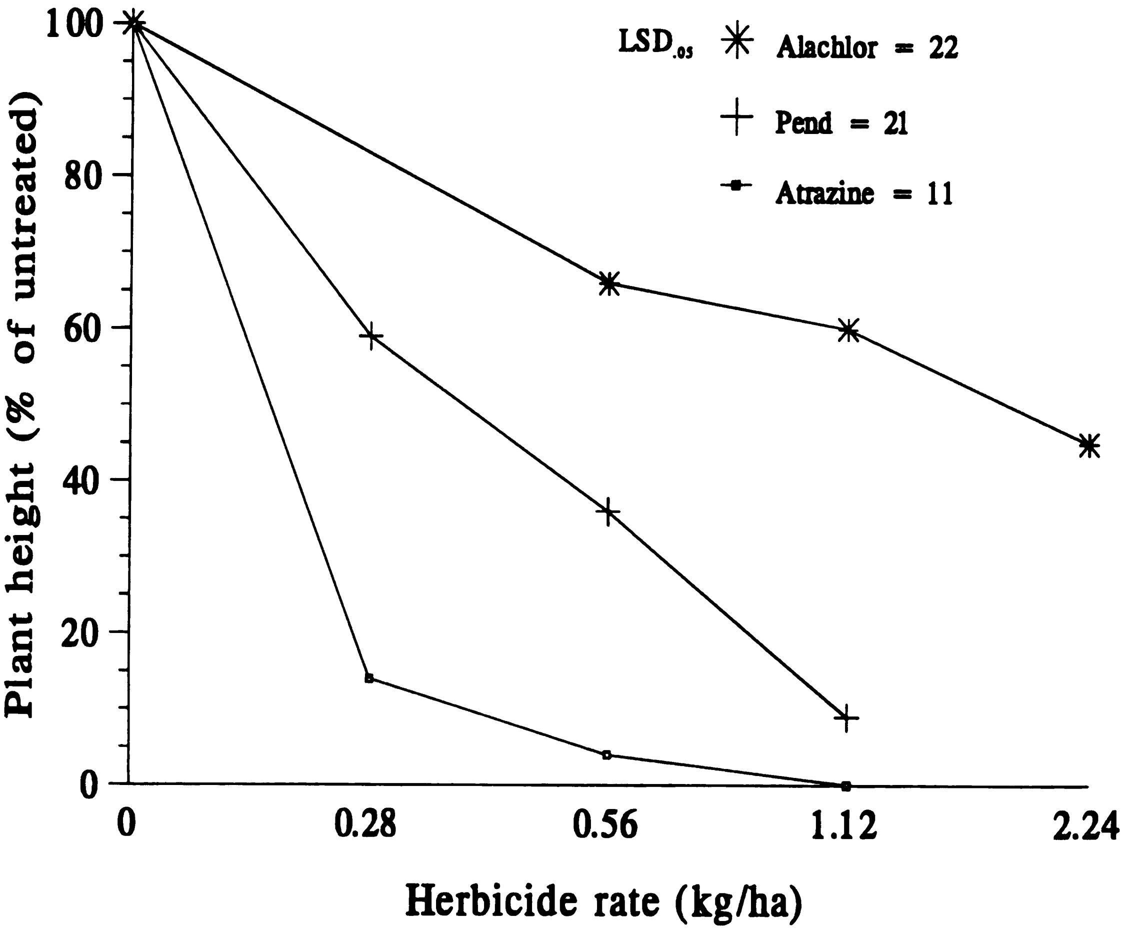

Figure 5. Effect of atrazine, pendimethalin, and alachlor applied PRE on velvetleaf plant height 5 wks after application. LSD (0.05) compares means within each herbicide.

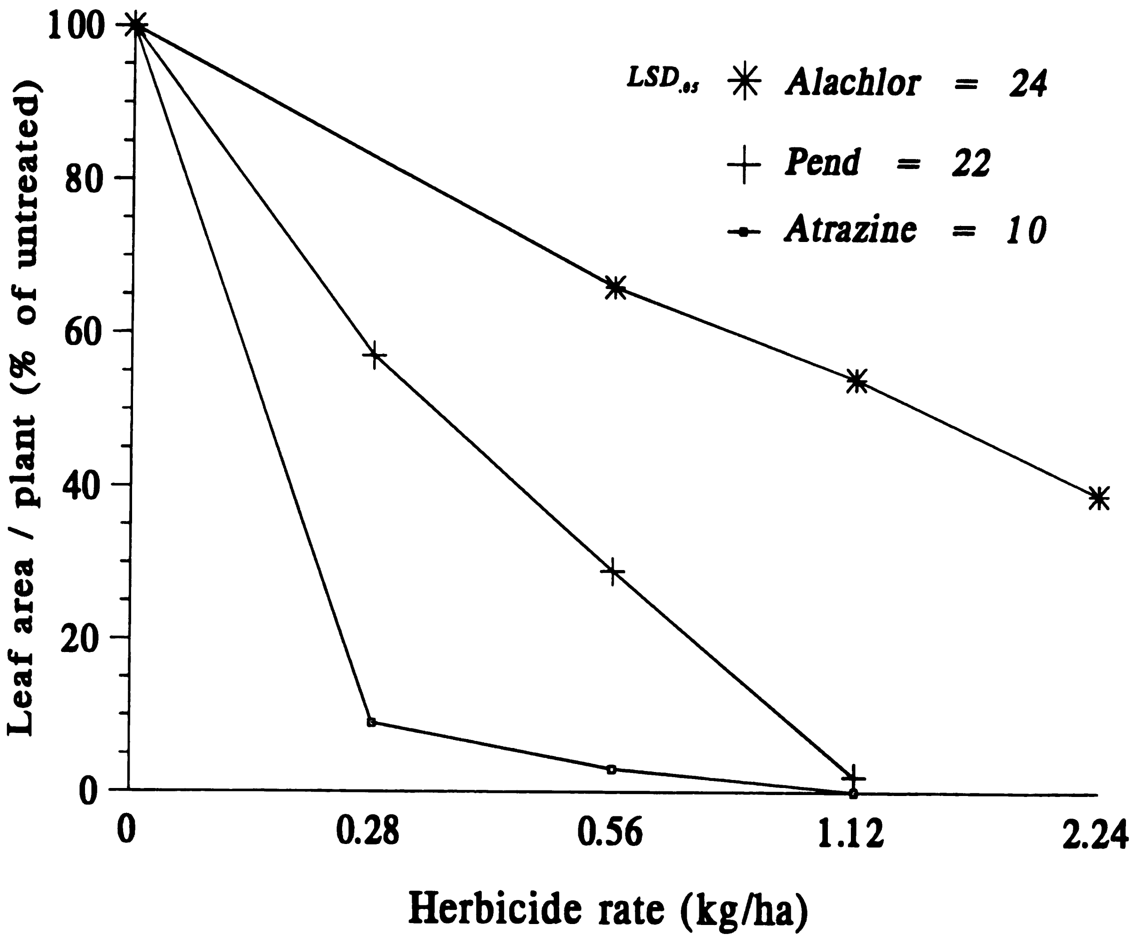

Figure 6. Effect of atrazine, pendimethalin, and alachlor applied PRE on velvetleaf leaf area per plant 5 wks after application. LSD (0.05) compares means within each herbicide.

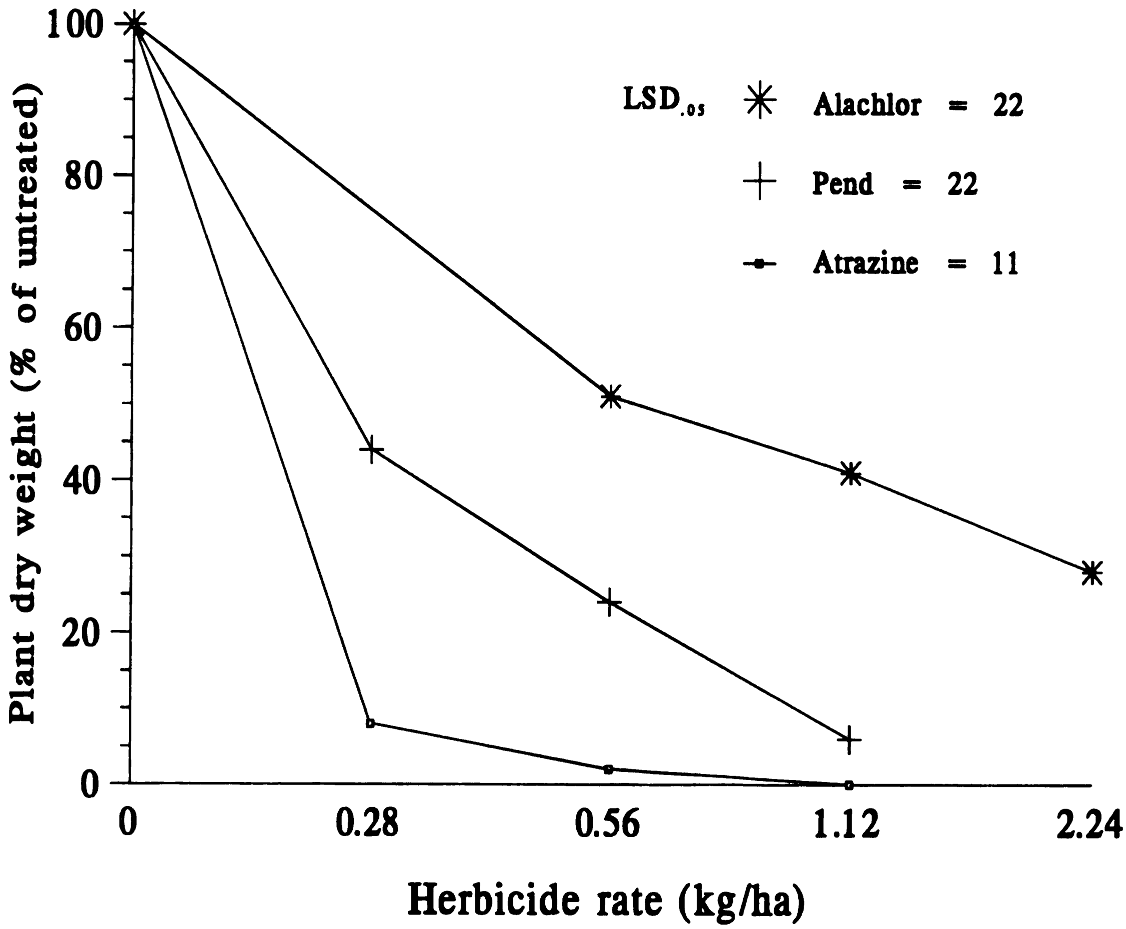

Figure 7. Effect of atrazine, pendimethalin, and alachlor applied PRE on velvetleaf total plant dry weight 5 wks after application. LSD (0.05) compares means within each herbicide.