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COMPETITIVENESS OF GIANT FOXTAIL (*Setaria faberi*) AND FALL PANICUM (*Panicum dichotomiflorum*)

By

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ABSTRACT

COMPETITIVENESS OF GIANT FOXTAIL (*Setaria faberi*) AND FALL PANICUM (*Panicum dichotomiflorum*)

By

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Studies were conducted in 1994 and 1995 to examine giant foxtail interference in corn. Corn yields were reduced 13% in 1994 and 14% in 1995 from 10 giant foxtail plants per m of row. Corn dry matter at maturity was decreased 24 and 23% from 10 giant foxtail plants per m of row in 1994 and 1995, respectively. Ten giant foxtail plants per m of row produced 15700 seeds per m^2.

Giant foxtail seed dormancy was overcome by an accelerated after ripening treatment of 3 days at 50 C. Fall panicum seed dormancy was overcome by a dark imbibition at 35 C for 7 days. Giant foxtail seed germination exceeded 60% when exposed to either a constant or alternating temperature. Fall panicum seed germination was less than 3% when exposed to a constant temperature, but was greater than 94% when exposed to an alternating temperature regime. Maximum emergence for giant foxtail and fall panicum was from seeds buried 1 cm and 1 to 2.5 cm, respectively. The seedling growth rate of giant foxtail was six times greater than that of fall panicum at equal temperatures.

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TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

LIST OF TABLES

CHAPTER 2. GIANT FOXTAIL (*Setaria faberi* Herrm.) INTERFERENCE IN NON-IRRIGATED CORN

CHAPTER 3. DORMANCY, GERMINATION, EMERGENCE, AND SURVIVAL OF GIANT FOXTAIL (*Setaria faberi* Herrm.) AND FALL PANICUM (*Panicum dichotomiflorum* Michx.)

LIST OF TABLES (cont.)

LIST OF FIGURES

CHAPTER 2. GIANT FOXTAIL (*Setaria faberi* Herrm.) INTERFERENCE IN NON-IRRIGATED CORN

PAGE

CHAPTER 1

REVIEW OF LITERATURE

INTRODUCTION

Giant foxtail [*Setaria faberi* (Herrm.)] and fall panicum [*Panicum dichotomiflorum* (Michx.)] are troublesome weeds in many agricultural crops, especially corn and soybeans (56, 72). Both species are prevalent grassy weeds in Michigan agriculture that produce thousands of seeds (6, 88).

There are many negative attributes associated with weeds in crops. Weeds compete with crops for limited environmental resources, they affect crop development, and act as hosts for pathogens and insects. Researchers note interference from giant foxtail and fall panicum reduces crop yields and profits (57, 72).

The correct weed management decisions are based on the relationship between weed densities and crop yield loss for each specific weed species. This research investigated the relationship between giant foxtail density and corn yield reduction, and examined differences in seed germination and growth characteristics of giant foxtail and fall panicum.

GIANT FOXTAIL *Setaria faberi* Herrm.

History and Distribution A: *Setaria* species. There are more than 60 species of the genus *Setaria* (84). *Setaria* is composed of both annual and perennial plants (46). In 1753, Linnaeus first described the morphological characteristics of two European species of *Setaria*, yellow foxtail [*Setaria glauca* (L.) Beauv.] and green foxtail [*Setaria viridis* (L.) Beauv.] (120). Yellow foxtail and green foxtail have spread westward and established themselves as two of the most problematic annual grass weeds in the United States and Canada (5, 7).

Twenty-eight *Setaria* species are native to North America, and 18 are native to the United States (120). Today, the most troublesome species of *Setaria* in the United States are giant foxtail, yellow foxtail, and green foxtail (156).

Many genus and species names may be present for a particular plant, though this species has not undergone any morphological or genetic change. Initially plants in this genus were called *Setaria*, but often these species were classified in the genus *Panicum* (64) or *Pennisetum* (39). The name later was changed to *Ehaetochloa*, and has recently been renamed *Setaria* (120).

B: *Setaria faberi*. Giant foxtail is native to Asia (46, 49, 162), and was first introduced into the United States from China through the importing of millet (47, 68). Common names included Chinese foxtail, Chinese millet, and nodding foxtail (7). In 1890 Herrmann published the first known morphological description of giant foxtail. This description was based on a plant collected by the Reverend Ernst Faber in the Szechwan providence of China. The first account of giant foxtail in the United States was in Philadelphia by Long on September 9, 1931 (47, 49). Allard (3) in 1941 reported the presence of plant species known as *Setaria faberi* in Virginia. In 1943 Fernald (49) cited giant foxtail from Pennsylvania, New Jersey,

Delaware, Massachusetts, and West Virginia. Wood (162) in 1946 described a rapid and uncontrollable spread of the Asiatic grass, *Setaria faberi* in North Carolina. Within the next two years giant foxtail was reported in Tennessee, Kentucky, Missouri, Nebraska and Illinois (46). Within 17 years after being identified in the United States, giant foxtail spread over half the country (7). Today, giant foxtail can commonly be found in all 50 states (104). The rapid infestation of giant foxtail has been attributed to the absence of any natural enemies (10) and prominent seed production (114).

Fairbrothers (47) found a herbarium specimen of giant foxtail dating back to September 19, 1925. Fairbrothers (47) speculated giant foxtail was introduced into the United States in the 1920's within a 100-mile radius of New York City.

Morphology. Giant foxtail is in the Poaceae family. This species is described as having a stem 0.9 to 2 meters in length branching at the base (5, 106). The leaf blades are typically 20 to 30 cm long and 1 to 2 cm in width (5, 115). Giant foxtail leaves are softly pubescent to glabrous on the underside with flattened straight stiff hairs on the upper surface (5, 49). The ligule is a dense fringe of white hairs 1 to 2 cm long and fused at the base (7). The panicle is dense and ranges from 7.5 to 20 cm in length, bending near the base so the panicle is drooping (106). The spikelets are 3 mm long with 3 to 6 bristles extending from the base (5, 7).

Giant foxtail is a tetraploid species containing 18 chromosomes (47, 115). Kishimoto (47) studied pollen of giant foxtail plants and reported a pollen grain size for giant foxtail of 45.74 ± 0.84 microns.

Growth and Development. Giant foxtail is an annual monocot that reproduces by seed only (5). This species produces seeds on 1 to 8 individual inflorescence (panicles) per plant (41,

106). Seed production by individual inflorescence, which ranges from 30 to 1400 seeds (41, 114), varies with the length of the inflorescence (9, 114). Individual giant foxtail plants can produce more than 10000 viable seeds (114).

Schreiber (114) found giant foxtail germinated and emerged early in the growing season, although giant foxtail can germinate throughout the growing season. Schreiber (114) concluded the earlier giant foxtail emerged, the larger the growth of the inflorescence, resulting in increased amounts of seed per inflorescence. Continuing with this work, Schreiber (114) documented the production of viable seeds from giant foxtail plants emerging as late as August, and seed viability was not correlated with seed color.

Initially, one treatment to control giant foxtail seed production was to mow the aboveground shoots. The results were mixed, as continuous cutting of giant foxtail at 6.5 cm of top growth did prevent seed production (131), but a single cutting enabled giant foxtail plants to produce multiple inflorescence containing viable seeds (114).

Defelice (41) and Harrison (58) reported a postemergence herbicide significantly reduced seed produced by giant foxtail plants. Defelice (41) determined herbicides did not change 1) the number of inflorescence produced per plant, 2) seed production per inflorescence, or 3) the number of seeds per plant. Defelice (41) concluded that the reduction in giant foxtail seed production from a herbicide application was a function of reducing the total number of giant foxtail plants. Conversely Biniak and Aldrich (20) reported a herbicide application at first anthesis reduced panicle density and seed production.

Freshly harvested giant foxtail seeds are predominantly dormant (135, 138) and unresponsive to light (138). Primary seed dormancy in giant foxtail seeds diminishes, through active metabolism, when exposed to room temperatures (10). Similar effects can be achieved

by exposing seeds to an elevated temperature (140). Roberts (100) noted the time required for seeds to after-ripen could be greatly reduced by exposing seeds to a temperature higher than normal room temperature.

Initiation of giant foxtail germination is dependent upon the availability of water. However, exposure to water stress can induce the breaking of seed dormancy (135). Taylorson (135) found 90% of giant foxtail seeds germinated when pretreated with polyethlyeneglycol, at a water potential of -0.3 MPa or less for 24 hours at 20 C. Similarly, solutions of KNO_3 have been used to stimulate germination of weed seeds (60, 145). Steinbauer and Grigsby (129) examined seeds of 85 species in 15 families and found half the seeds tested germinated better in nitrogen rich solutions. However, Fawcett and Slife (48) applied 112 to 336 kg ha^{-1} of nitrogen as ammonium nitrate ($(NH_4^+ (NO_3^-))$) to field soils and found increasing nitrogen levels failed to affect giant foxtail germination. After primary dormancy is broken, exposing giant foxtail seeds to temperatures greater than 30 C (136) or exposure for 7 days or longer to 60 C will induce a secondary seed dormancy (135).

Germination and growth of giant foxtail are temperature dependent (158). The estimated minimum temperature to initiate giant foxtail growth is 10 C (79, 90). Stoller and Wax (133) examined the variation in temperature within the surface layers of soils, and determined soil surface temperatures are affected by soil type. Temperature affects the growth of giant foxtail seedlings by altering plant biomass and the date of tiller initiation (81). Mester and Buhler (79) examined the effects of soil temperature on giant foxtail seedling development and reported lack of giant foxtail seed germination at 5 C, and concluded soil temperature did not affect seedling development.

Giant foxtail seeds will germinate and emerge from a wide range of planting depths

(80, 107). Mester and Buhler (80) analyzed giant foxtail emergence under field conditions in a no-tillage system and noticed half the emerged seedlings originated from a depth of 1 cm or less. They proposed a giant foxtail seedling survival rate of 100% if weeds germinated on the soil surface (79). Field studies conclude the maximum depth giant foxtail seeds can emerge from is 10 cm (80, 107, 138).

Schreiber (113, 117) exposed giant foxtail seedlings to various air temperature and photoperiods to examine their responses. Giant foxtail plants produced the most dry weight when exposed to an air temperature of 27 C. Schreiber (113, 117) also noted that longer photoperiods increased inflorescence length. Knake (69) studied the effects of shade on giant foxtail development and reported seed weight, plant dry weight, leaf number, stems per plant, and heads per plant decreased linearly with increased shade intensity. However, with 30% shade, mature inflorescence were longer than in plants grown without shade (69).

Mechanical removal of giant foxtail can be successful in controlling giant foxtail, but if the stems are not completely covered during the cultivation, rerooting can occur (107). Santelmann *et al.* (107) found that when given an opportunity, the main stem or first tillers of a giant foxtail seedling reroot 75% of the time, and half of the second and third tillers can reroot.

Giant foxtail plants produced tillers 10 to 20 days after emergence and continued to produce tillers up to 3 months after emergence (107). Average giant foxtail plants produced between 7 and 15 tillers (107). The total number of tillers produced per giant foxtail plant was reduced by increasing plant densities (107). The date of emergence also affects the number of tillers produced per plant, as late germinating giant foxtail plants produced fewer tillers (107).

Habitat. Giant foxtail is extremely troublesome in disturbed soils, row crops, spring seeded alfalfa and small grains, and along roadsides and in waste areas (5, 7, 156).

Schreiber (112) examined the competitiveness of various foxtail grass in undisturbed sites. Schreiber (112) studied robust white foxtail (*Setaria viridis* var. *robusta-alba*), robust purple (*Setaria viridis* var. *robusta-purpurea*), giant green foxtail [*Setaria viridis* var. major (Gaudin) Posp.], yellow foxtail, and giant foxtail for four years to decide whether all *Setaria* species posed the same threat to infest fields as giant foxtail. Schreiber discovered that despite the *Setaria* species planted, within four years of planting, giant foxtail was the dominant species. Similarly, Staniforth (122) conducted research on the competitive effects of giant, yellow, and green foxtail and discovered giant foxtail grew more vigorous and reduced soybean yields more than yellow or green foxtail.

FALL PANICUM *Panicum dichotomiflorum* (Michx.).

History and Distribution. Fall panicum is an annual grass in the genus *Panicum*. The genus *Panicum* is quite complex as it comprises more than 200 species (108). Fall panicum is native to North America, but has become a specific problem in field crops in the last 30 years (6). Today, the most common *Panicum* species in North America are fall panicum, wild proso millet [*Panicum miliacea* (L.)], and witchgrass [*Panicum capillare* (L.)]

Fall panicum was first described by Ada George in 1914 (93, 108). Traditionally, this species was called Western witchgrass (156), wild millet, sprouting panicgrass, sprouting crabgrass, kneegrass, and spreading panicum (93). Gray in 1950 described fall panicum as a species native from Maine to Nebraska and Florida to Texas (93). Vengris (149) conducted a survey in Massachusetts in 1950 and found farmers only considered fall panicum a weed in

cranberry bogs. A 1970 survey concluded fall panicum was a serious problem in 23 states (108). By 1975 fall panicum was present in 43 states, and a serious problem in 32 states (108). Today, fall panicum is found throughout the United States.

Morphology. Fall panicum is in the Poaceae family. This species is described as having an upright or spreading growth habit, up to 1 m in height (166). The leaf blades are 5 to 40 cm long and 0.5 to 1.5 cm in width (5). The leaves are usually hairless and contain a predominant white midrib. The ligule is a dense fringe of white hairs 1 to 2 mm long and fused at the base. The inflorescence is an open panicle. The spikelets are hairless and 1.8 to 3.6 mm long (7, 166).

Growth and Development. Fall panicum is an annual monocot that reproduces by seed only (5). Seeds are produced on 1 to 52 panicles per plant, depending on the time of emergence (148). A typical fall panicum plant, growing under field conditions, produces 500000 seeds (147).

Research has shown the greatest emergence of fall panicum occurs when seeds are buried 0.2 to 2.0 cm (147, 166). Maximum emergence for buried fall panicum seed is 7 cm (2, 148).

Fall panicum seed dormancy is not easy to overcome (137). Fall panicum seeds require an exposure to temperatures greater than 25 C for 9 to 21 days for germination (147). Freshly harvested fall panicum seeds are typically dormant (23). Fall panicum seeds require light exposure to induce germination (12, 137, 155). Dormancy can be overcome by exposing seeds to high temperatures, alternating temperatures, stratification, and mechanical or chemical scarification (137).

Vengris (147) studied the growth habits of fall panicum. He noted the number of

days, from emergence to flowering decreased progressively for later emerging fall panicum seedlings. Fall panicum seedlings emerging on May 23 and July 25, produced ripe seeds in 116 and 74 days, respectively. He concluded fall panicum plants can adjust their growth rate dependent on time of emergence. Vengris (147) also documented fall panicum seedlings emerging between June 23 and July 7 were the most vigorous and fastest growing plants in Massachusetts, and noted fall panicum plants emerging after August 9 were unable to produce ripe seed.

The use of specific herbicides has often been associated with the development of fall panicum infestations (63, 91, 141). Thompson *et al.* (142) compared the ability of fall panicum and giant foxtail to metabolize atrazine [2-chloro-4-(ethyl-amino)-6-(isopropylamino)-s-triazine]. In 6 hours, corn, fall panicum, and giant foxtail metabolized 96, 44, and 7%, respectively, of the ^{14}C atrazine applied. Thompson (141) reported conjugation of atrazine with peptides resulted in detoxification in fall panicum.

WEED INTERFERENCE PRINCIPLES

Weed Ecology. A weed was defined by the terminology committee of the North Central Weed Science Society of America in 1956, as a plant growing where it is not desired (66). Approximately 250 of the more than 200000 plant species in the world, are sufficiently troublesome to be called weeds (97). Holm (62) classified these 250 species by families and found nearly 70% of these weed species fall into 12 families, and 40% of these weeds are in either the Poaceae or Compositae family. Holm also categorized the most commonly found crops. He revealed that common crop families contribute many problematic weeds. Holm (62) concluded crops and weeds often share some taxonomic characteristics and perhaps a

common evolutionary origin (62).

Weeds are grouped by many different classification systems. These systems include grouping weeds by their habitat, ease of control, degree of undesirability (noxiousness), and morphology. The most common method to classify weeds involves the plant's life cycle (7). This classification system groups weeds as annual, biennial, and perennial plants. Annual plants complete their life cycle (seed to seed) in one year or less (97). Annuals are the largest and most troublesome segment of weeds throughout the world (97). Biennial plants require two years to complete their life cycle (31). Few biennial species are problematic weeds in agriculture systems (31). Perennial plants live for more than two growing seasons (7).

Weed Interactions. Plant interactions are complex and occur in natural plant communities and highly managed agricultural systems. Dewet and Harland documented plants respond differently when their habitats are disturbed (97). When the environment becomes altered, certain species flourish while others migrate or are replaced. Interactions between neighboring plants subsequently affect both species growth (either positively or negatively). Burkhold and Odum categorized the interactions between plants growing together. Both described an interaction between neighboring plants that is neither positive nor negative as neutralism. Neutralism occurs when two simultaneously growing species are neither negatively nor positively affected by the presence or growth of the other species (10).

It has been documented that specific weeds and crops, for example barnyardgrass [*Echinochloa crus-galli* (Beauv.)] and rice (97), seem to grow with one another. The association between barnyardgrass and rice may be explained by one of the three positive interactions (commensalism, protocooperation, and mutualism) (121). Commensalism is an interaction where one plant is stimulated by the presence of the other, and inhibited by its

absence (26). Protocooperation is a more common interaction where both plants are stimulated by the association, but are unaffected by the other absence (26, 97). An example of protocooperation is where fungal hyphae link two or more plants to facilitate nutrient uptake (163). Mutualism contrasts the other positive interactions in that it is an obligate interaction, meaning without the presence of both species, the growth of both species will be limited (26).

Of the interactions described by Burkhold and Odum, amensalism and competition are the most common. Both amensalism and competition display negative effects on plants. Amensalism is an interaction in which one plant is negatively affected by the other, whereas the growth of the second species remains constant (26, 97). The inhibition of one plant through the release of a selectively toxic by-product, which is known as allelopathy, is a form of amensalism (97).

Allelopathy. Specific plant residues contain allelopathic compounds (18, 116, 117). Natural compounds exist in plants to ensure species survival (10). Allelopathic substances reach the soil through the leaching of soluble compounds from plant decay (130). Allelopathic compounds, once in solution, can be taken up by a plant root system (19, 130). Bhowmik and Doll (19) conducted research on corn and soybean response to allelopathic effects of a weed residue and concluded allelopathic effects were dependent on the amount and concentration of weed residues.

Ecologically, giant foxtail and fall panicum are not the most competitive species for light, moisture or nutrients, which suggests an allelopathic substance would enable a competitive advantage to allow room for growth (117). Residues from mature giant foxtail and fall panicum plants contain compounds that affect corn (*Zea mays*) root development

(117) and growth (18, 117). Applying a 1% (w/v) giant foxtail and fall panicum residue extract reduced corn radical elongation 28 and 27%, respectively (19). Bell and Koeppe (18) noted giant foxtail residues inhibited corn growth by 35%.

Researchers have observed the selective nature of the inhibitors exuded from giant foxtail plants (18, 19). Bhowmik and Doll exposed soybeans [*Glycine max* (L.) Merrill.] seeds to extracts from giant foxtail residues and found no effect on hypocotyl extension.

Competition. Competition is the mutually adverse effect to organisms that use a common resource in short supply (10). Competition can be separated into two major categories, 1) interspecific competition, and 2) intraspecific competition. Interspecific competition involves the interference between plants of different species, whereas intraspecific competition is the interaction between plants of the same species (97). The level of competition is influenced by plant density (110). Competition within a specific ecosystem occurs when the population exceeds the required level needed to sustain optimal growth. Any resource that affects plant growth or survival potentially can influence competition between weeds and crops (69, 157). Physiologically weeds and crops are similar, and compete for environmental factors needed for growth and development (38, 39). Typically the most limiting resources for plants in an agricultural system are light, water, nutrients and CO_2 (1, 37).

Light and Shade Stress. The primary environmental resource in which weeds and crops compete for is light (169). Light, unlike other limited resources, does not have the capacity to be stored or transferred within the plant (1). When a photon of light contacts the surface of a plant the energy is either converted to chemical energy through photosynthesis or dissipated as heat (1).

Studies have examined the effects of light on the germination (118, 139, 153, 154,

155) and development (69) of weeds and crops. Many weed seeds require light for germination (51, 139). Phytochrome is a proteinaceous pigment that is the determining factor in the germination of light sensitive seeds. Phytochrome occurs in two forms within plants; P_r and P_{fr}. Numerous seeds display a dependence on a specific light to induce germination (139). Germination of phytochrome sensitive seeds requires a conversion of phytochrome to the active P_{fr} form by exposing the seeds to red (650 nm) light (39). The germination of phytochrome controlled seeds is prevented by increasing the ratio of P_r to P_{fr} (40). Light reaching the soil surface, once canopy closure has occurred, typically has a high ratio of far-red to red light (51, 97). Because this light is high in far-red light, it converts phytochrome to the inactive (P_r) form that prevents the germination of phytochrome sensitive seeds.

Taylorson (139) studied phytochrome controlled changes in the germination of both giant foxtail and fall panicum seeds. Fall panicum seeds displayed an effect, where exposure to red light converted P_r to P_{fr} and induced germination. Small increases in P_{fr} levels account for most of the fall panicum germination (139). The data on giant foxtail is less clear, as an increase in P_{fr} levels only increased giant foxtail germination, slightly (40). Taylorson (139) concluded that giant foxtail seed germination may be depend upon another mechanism, such as a cyclic germination pattern, to break seed dormancy rather than the reliance of phytochrome. Similarly, Roberts and Feast (102) examined numerous weed seeds and found in many seeds a peak in germination during the spring.

Research has been conducted to determine the effect shade has on plant growth and development. Researchers have found that both corn (88) and soybean (28, 122, 123) growth and development were reduced by shading.

Water Stress. Lack of water is one of the common environmental factors limiting crop

growth and yield (157, 169). Researchers consider water the environmental resource most limiting crop growth and yield (17, 92). Water stress occurs when transpirational water loss exceeds water uptake (103). Weeds compete with crops for water and contribute to crop water stress (169). Water use efficiency, transpiration rate, and response to declining water availability vary between weed species and crops (1, 92, 97, 160). This variance accounts for differences in the level of crop yields lost by competing weeds of different species (89, 92). Researchers have focused on the effect water stress has on corn yields (103). Studies conclude moisture is most critical during silking. If corn is under moisture stress at the time of silking, grain yields can be reduced by 50% or more (32, 42, 61, 103).

Water stress also influences the duration of the critical weed-free period. Coble *et al.* (33) reported the critical weed-free period of common ragweed [*Ambrosia artemisiifoilia* (*L.*)] in soybeans was two weeks in a dry year and four weeks in a year where moisture was readily available. However, a study in Illinois noted giant foxtail reduced soybean growth after 10 days when soil moisture was abundant, but significant growth reduction was delayed until 25 days after emergence during a drier year (58). Staniforth (124) reported weed interference reduced soybean yields 5% when soil moisture was adequate during the entire growing season, but when soil moisture was adequate until July and then became limited, soybean yields were reduced 15%.

Nutrient Stress. Nutrient availability alters the level of interference between weeds and crops through its differential effects on growth (37, 94). Weed growth can be stimulated more than crop growth from an application of fertilizer (149). Weeds are often more competitive with crops at high fertility levels (94, 124). Vengris *et al.* (149) studied the response of corn yields from phosphate fertilizer. Corn yields in 1952-53 were higher when

no weeds were present. However, in 1952, yields were lower when the corn was fertilized with 200 lbs. of P_2O_5 /A (149). Vengris *et al.* (149) concluded increased rates of fertilizer cannot maintain corn yields in the presence of weeds.

Staniforth (124) examined the effects of weed interference in four corn hybrids in 1958 and 1959. Yield reductions in the later maturing hybrids were double those of the early maturing hybrids, and yield reductions for all the varieties were greatest under high nitrogen fertilization. However, research has found the interference by yellow foxtail can be overcome by adding nitrogen to corn (125). Research at Cornell University (43) examined strategies to reduce crop yield loss from weed competition. Fertilization timing, cultivar selection, weed control practices, and row spacing are factors that can be altered to enhance crop nutrient use efficiency.

CO_2 Stress. Plants can be categorized by their photosynthetic pathway of CO_2 fixation. Yield and growth of plants depends on carbon assimilation by the photosynthetic process (21). The most common procedure for weeds to fix CO_2 is through the 3-carbon pathway or Calvin Cycle (134). Plants using the 3-carbon pathway are called C_3 plants. Plants fixing CO_2 by producing a 4-carbon compound, oxaloacetic acid, instead of a 3-carbon PGA, are referred to as C_4 plants. Each of these CO_2 fixation schemes can be beneficial. C_3 CO_2 fixation allows plants to more efficiently manage their CO_2 intake (39). However, when C_3 and C_4 plants are grown under a stressful environment, C_4 plants have photosynthetic rates two to three times higher than those of C_3 plants (134).

INTERFERENCE RESEARCH

Losses in crop quality and yield from interfering weeds are the backbone of modern

weed science (75). Numerous factors influence the level of crop loss from competing weeds (96). Interactions between weeds and crops are often complicated and difficult to determine the exact component limiting crop yield (110). The term interference should be used where one cannot determine the exact cause of crop yield loss. Agricultural scientists often misuse the term competition to describe interference (110).

There are four generally accepted designs to examine crop and weed interactions (35, 96). Each design accounts for the density, and spatial arrangement for each species (32). The most common designs are additive, replacement, systematic, and neighborhood (96). Each design is a form of a bioassay where the response of one species is used to describe a change within another species. Crop yields, growth rate and mortality are measured in each of these designs (96).

The most common design for interference studies is an additive design (35, 169). In this design the density of one species, most commonly the crop, is held constant, whereas the density of the second species varies between treatments (35). This design is popular because it most resembles an agricultural system (35). An additive design is suited for objectives involved with determining the crop yield loss from a specific weed density, multiple species, and when determining an economic threshold for weed control. The intraspecific competition in an additive design study is assumed to be zero because the spatial arrangement of the crop is uniform. However, the interspecific competition is often unknown because the placement of the weeds is often unrecorded (35). The additive design has been criticized because, in multiple species experiments, it does not account for the variability in the number of each species (55). Total weed density and the proportion between species often vary in a multiple species additive design study, making the interpretation of the data difficult (35).

In a replacement series design the density of the two species varies but the total density remains constant. In this design pure stands of each species are included in the experiment (96). The replacement series design determines the level of yield reduction in crops by comparing yields with the yields of weed-free stands (37). A replacement series design is appropriate when determining the competitive effects of a single species. The advantage of a replacement series design is that it determines the effects of intraspecific and interspecific competition (96). The criticism of this design is that it is artificial for field use because crops are planted at a constant population (35).

Systematic designed experiments study a single species by arranging the plants in a circular or arc pattern (96). The area in which plants have to grow changes between treatments in a systematic experiment (37). The advantage of this design is several different plant densities can be studied within a small area. However, placing a circular pattern in a field setting is often difficult. Another disadvantage of this design is that only individual plants can be measured, making it difficult to determine how neighboring plants effect growth.

In a neighborhood design experiment the attention is placed on how an individual plant responds in conjunction to neighboring plants. The advantage of this design is that it becomes possible to study the exact time competition begins to occur (96). Typically, the performance of the target plant depends on the number, biomass, and the distance between its neighboring plants (96).

The proper analysis for each of these designs starts with knowing the objective of the study. Different objective require different designs. A researcher first must state their objectives to design an interference study properly (32). According to Cousens (35), if the design and analysis of an interference experiment are based on the objectives of the study, and

the proper design is implemented within its limitations, the results will be meaningful.

WEED INTERFERENCE

Numerous interference studies report crop yields are lowered by competing weeds (13, 22, 33, 87, 134, 152). Researchers have investigated the effects of weeds and crop density on corn yields (105, 144, 149, 167). Zimdahl (169) and Stewart (136) cite more than 500 publications describing the outcome of various weed and crop interactions. The relationship between crop yield and plant density is of considerable interest (143). Different models have been developed to observe the interactions between crops and weeds, and considerable success has been achieved in finding empirical expressions that fit data from a variety of experiments.

Broadleaf Weeds. Researchers have investigated the level of interference in crops from weeds for more than 40 years (127). It is the opinion of many researchers that a specific yield loss function is correlated to, 1) the duration of the interfering weeds, and 2) the yearly environmental fluctuations (16, 52, 119, 126, 127, 168).

Cardina *et al.* (30) studied the competitive effects of velvetleaf [*Abutilon theophrasti* (Medik.)] in conventional and no-tillage corn. The main plots of these experiments were divided into two subplots, where either the velvetleaf seeds were planted simultaneously with corn or three weeks after the corn. The subplots consisted of four rows of corn with velvetleaf densities of 0, 1, 5, 10, 20, and 30 plants m^{-2}. The greatest reduction in corn yields, using the rectangular hyperbola model discussed by Cousens (35), resulted when the velvetleaf emerged early in a no-tillage system. Cardina *et al.* (30) reported the asymptote (A), which represents the maximum yield reduction, ranged from 17% in conventional tillage

in 1992 to 69% in no-tillage in 1990.

Cardina *et al.* (30) also developed an economic threshold level for velvetleaf in corn. The economic threshold ranged from 0.13 velvetleaf plants m^{-2} for early emerging velvetleaf in no-tillage to 18.2 m^{-2} for late emerging velvetleaf in conventional tillage. Differences between economic threshold values for early and late emerging velvetleaf varied with year and tillage. They concluded, that without reliable data on the biology of velvetleaf, a velvetleaf economic threshold in corn was difficult to predict. They stated the need for research focusing on understanding velvetleaf seed survival and production.

Lindquist *et al.* (75, 76) examined the level of interference from velvetleaf in soybeans. They found in 1992 and 1993 soybean yields were not significantly reduced by 32 and 45 velvetleaf plants m^{-2}, respectively. Other researchers have reported velvetleaf substantially reduced soybean yields (40). Schmenk (110) reported a significant corn yield reduction in Michigan occurred at a velvetleaf density of 9 plants per m of row in 1992, and 1 plant per m of row in 1993.

Lindquist *et al.* (75) developed a model to predict the population dynamics and economics of velvetleaf control in a corn-soybean rotation. Similar to Cardina *et al.*, Lindquist *et al.* (75) indicated the primary weakness of their model is the limited biological data available on the growth and development of velvetleaf.

Moolani *et al.* (85) studied the competitive effects of smooth pigweed [*Amaranthus hybridus* (L.)] on corn planted in 102 cm rows. Untreated smooth pigweed in a 15-cm band, reduced corn yields 30, 50, and 36% in 1959, 60, and 61, respectively. Moolani *et al.* (85) concluded that whether the total dry matter for each plot consisted of corn alone or corn and weed biomass, the total dry matter accumulation remained constant.

Beckett *et al.* (16) studied the level of interference of common cocklebur [*Xanthium strumarium* (L.)], common lambsquarters [*Chenopodium album* (L.)], shattercane [*Sorghum bicolor* (L.)], and giant foxtail. Beckett *et al.* (16) reported a common cocklebur density of 5 plants per m of row decreased corn yields in Illinois 27% in 1985. In 1986 and 87, corn yields were reduced 10% from 7 common cocklebur plants per m of row. Common lambsquarters, shattercane, and giant foxtail only significantly reduced corn yields in one of the three years tested. In 1985, corn yields were reduced, 12% from 5 common lambsquarters plants per m of row, 22% from 17 shattercane plants per m of row, and 18% from 85 giant foxtail plants per m of row (16). Other researchers found untreated infestations of common cocklebur reduced soybean yields as much as 52% (11). Similarly, 208 common lambsquarters (119), 60 shattercane (59), and 180 giant foxtail (72) plants per m of row have reduced corn yields by as much as 58, 75, and 26%, respectively.

Grass Weeds. Young *et al.* conducted field studies to evaluate the effects of quackgrass [*Agropyron repens* (L.) Beauv.] interference on soybean (168) and corn (167) yields. They reported a 19 and 55% reduction in soybean yields by quackgrass densities of 520 and 910 shoots m^{-2}, respectively. Interference by a natural stand of quackgrass for 6 weeks, 8 weeks, and full-season decreased soybean yield 11, 23, and 33%, respectively. Analysis of corn tissue suggested quackgrass did not interfere with the nutrient status of corn. Young *et al.* concluded that a sufficient supply of soil moisture can overcome the effects of quackgrass interference on corn yields if light and nutrients are not limiting.

Wilson and Westra (161) studied the effects of wild proso millet interference in irrigated corn yields. Interference by wild proso millet for 2 and 6 weeks after corn planting reduced corn yield 10 and 24%, respectively. Corn yield reductions, predicted with a

rectangular hyperbola regression model, ranged from 13 to 22% from a wild proso millet density of 10 plants m^{-2} (161).

Peterson and Nalewaja (94) examined the effects of green foxtail interference on the development of spring wheat. Wheat fresh weights were reduced 50% by green foxtail seeded four days before wheat seeding. However, fresh weight was only reduced 13% by green foxtail seeded four days after wheat. Peterson and Nalewaja (94) also reported doubling the nitrogen and nutrient concentration did not increase wheat growth, but significantly increased green foxtail fresh weight.

Sibuga and Bandeen (119) conducted field experiments to study the effects of full-season interference of green foxtail and common lambsquarters on corn yield. Corn yield reductions were observed at densities greater than 56 and 20 green foxtail plants m^{-2} and 46 and 109 common lambsquarters plants m^{-2} in 1976 and 1977, respectively.

Nieto and Staniforth (88) examined the interference of yellow foxtail and green foxtail on corn yield. A three-factor field study was conducted to determine the effect's nitrogen, and weed density had on corn yield. Adding, 0, 70, and 140 pounds of elemental nitrogen per acre resulted in a corn yield reduction of 20, 14, and 10 bushels per acre, respectively. They concluded that the addition of nitrogen fertilizer to corn generally overcame yield losses from heavy foxtail infestations.

Giant Foxtail. The extent in which grain is lost from interfering giant foxtail plants is dependent upon its duration. Gleason (52) noted the longer giant foxtail plants were present, the more crop yields were suppressed. Knake and Slife (70) examined the effect of time of giant foxtail removal from corn and soybeans in 1963 to 1965. Giant foxtail reduced corn yields 63, 126, 315, 441, and 1133 kg ha^{-1} and soybean yield 0, 0, 63, 126, and 1133 kg ha^{-1},

respectively, when removed at 7.5, 15, 22.5, and 30 cm in height and at maturity. Knake and Slife (70) also reported total dry matter remained constant whether the dry matter consisted of a weed-free crop or a crop and giant foxtail.

A field study by Knake and Slife (68, 71) investigated the level of interference from giant foxtail seeded when the crop was planted and 3, 6, 9, and 12 weeks after planting. Giant foxtail seeded with the crop reduced corn and soybean yields 13 and 27%, respectively. They found giant foxtail plants seeded 3 weeks after the crop did not significantly reduce corn or soybean yields.

Knake and Slife (72) conduced a three-year giant foxtail interference study in Illinois utilizing corn and soybeans planted in 102 cm wide rows. Interfering giant foxtail plants reduced corn yield, cob weight, ear weight, stalk diameter, soil temperature, and soybean yield and pod number. Corn and soybean yields, from 180 giant foxtail plants per m of row, were reduced 25 and 28%, respectively. Giant foxtail plants did not affect corn or soybean grain moisture content, crop height, and oil or protein content of soybeans.

Harrison *et al.* (58) studied the interference and control of giant foxtail in soybeans. They reported every clump (3-6 plants) of giant foxtail plants per 9 m of row, reduced soybean yield 0.8%. They estimated 10 giant foxtail plants per m of row reduced soybean yield 16%.

Langston and Harvey (74) designed a giant foxtail interference study using alachlor impregnated on dry fertilizer to create varying densities of giant foxtail. Thirty giant foxtail plants per m of row did not reduce corn yield in 1993. However, 30 giant foxtail plants per m of row reduced corn yield 18% in 1994. Similarly, Lambert *et al.* (73) reported comparable giant foxtail densities reduced corn yield 0 to 20% in 1993, and 15 to 52% in 1994.

Walker and Williams documented giant foxtail interfered with the growth and development of a container grown bush cinquefoil [*Potentilla fruticosa* (L.)] (150) and Bailey's redosier dogwood (*Cornus* x *baileyi*) (151). Bush cinquefoil shoots dry weight decreased up to 75% after 83 days of interference from giant foxtail. A growth reduction in Bailey's redosier dogwood was noted 21 days after transplanting giant foxtail seedlings into the containers.

Fall panicum. Harris and Ritter (56, 57) studied the effects of a natural stand of fall panicum and giant green foxtail on soybean. Plots maintaining weed free for 2 weeks after soybean emergence produced yields equaling plots maintained weed free the entire growing season. Harris and Ritter (57) noted fall panicum and giant green foxtail growing naturally with soybeans for 8 weeks after soybean emergence did not reduce yields. However, soybean yields were reduced if fall panicum and giant green foxtail were not removed after 8 weeks.

Ambrose and Coble (4) investigated the effects of fall panicum interference on soybean yields and found 0.3, 0.5, 1.7, and 6.7 fall panicum plants per m of row reduced soybean yields 1, 5, 15, and 15%, respectively. Soybean yields were not significantly reduced if fall panicum was removed within 10 weeks after soybean emergence or if soybeans remained weed free 2 or more weeks after emergence.

York and Coble (165) reported 1 fall panicum plant per 4.9 m of row reduced peanut [*Arachis hypogaea* (L.) 'Florigiant'] seed yield 25%. They also detected peanut seed yields was reduced less by fall panicum interference if establishment was 2 weeks after peanut emergence.

SEED LONGEVITY

The rate at which the percentage of viable seeds decreases is dependent on several factors (101). Egly and Williams (45) reported 61 to 88% of weed seeds emerge during the first year and 9 to 23% emergence during the second year. In contrast Forcella *et al.* concluded the percentage of seasonal emergence ranged from 0.1% to 30%. There is extensive evidence to show seeds of many weed species remain viable for long periods when buried in undisturbed soil (99). Dawson and Brans (32) examined the longevity of weed seeds and determined subtle differences in environmental conditions had an extreme affect on seed longevities. In 1879, Beal buried weed seed in glass bottles with soil (36). Yellow foxtail seeds remained viable 30 years after burial.

Researchers note weed seeds are commonly lost by germination, predation, and pathogenetic attacks (95). Roberts (100) found the total viable seed population in soil declined at a rate leaving the number of seeds present in 1 year, approximately half that of the previous year.

Tillage. Farmers in the mid-1960's considered no-tillage as a way to cut production costs, achieve more timely planting, and lessen soil erosion losses (54). Today, no-tillage cropping systems can produce corn yields equal to or higher than yields obtained in conventional tillage systems (44, 53).

Mohler (83) developed a model that predicts the density of weed seedlings that will emerge by relating 1) the capability of seedlings to emergence, 2) seed survival, and 3) burial depth. This model assumes, in the first year following seed input, no-tillage will have more seedlings than tillage (83). No-tillage, in later years, will provide fewer seedlings unless seed dormancy is high or seed survival near the soil surface is unexpectedly high.

Tillage affects many factors determining the initiation of weed seed germination. Johnson and Lowery (65) reported the maximum difference in daily temperature observed between no-tillage, chisel, till-plant, and conventional tillage occurred on May 2, 1982. They documented a 5.9, 2.3, and 1.8 C reduction in soil temperature at 5 cm depths between no-tillage, chisel, and till-plant when compared with conventional tillage. The reductions in soil temperature observed with conservation tillage practices was attributed to differences in thermal admittance, heat flux to deeper depth, and total heat inputs to the soil surface.

Staricka *et al.* (128) traced the vertical distribution of weed seed in different tillage systems. The maximum depth weed seeds were buried under a chisel and conventional tillage was 12 and 32 cm, respectively. Similarly, 50% of the seeds in chisel systems were within 4 cm of the soil surface, compared with 10% in conventional tillage (128). Researchers found a marked increase in annual grass densities in no-tillage systems, but no change in annual broadleaf species (25, 164).

Wiese and Binning (159) examined the effect tillage date has on the initiation of seed germination. Yellow foxtail was the predominant species after the first tillage timing, but emergence decreased with delayed tillage (159). Weeds that emerged early in the growing season were common lambsquarters and ladysthumb [*Polygonum persicaria* (L.)]. Redroot pigweed [*Amaranthus retroflexus* (L.)] was a poor competitor early, but by June 24 was the fastest growing species.

A: Giant Foxtail. Giant foxtail emergence is often greatest from seeds at or near the soil surface, and decreases as depth of seeding increases (39). Buhler and Daniel (25) noted as tillage decreased, depth of giant foxtail germination decreased and density increased.

Schreiber (111) examined tillage effects on giant foxtail population dynamics.

Reducing tillage from conventional to no-tillage increased giant foxtail seed in the top 0 to 2.5 cm of soil (111). Becker and Staniforth (15) found disturbing the top 2.5 cm of soil resulted in a 30% increase in giant foxtail density. Buhler and Mester (24) reported 40% of giant foxtail plants originated in the upper 1 cm of soil in no-tillage compared to 25% in chisel, and 15% in conventional tillage, and reported giant foxtail control, with the same herbicide treatment, was often less under no-tillage systems.

B: Fall panicum. Researchers conclude under various tillage systems weed spectrums shift rapidly (31, 146). Buhler and Daniel (25) noted the weed spectrum shift in no-tillage is dependent upon the original species present and the herbicide used. Triplett and Lytly (146) determined in no-tillage corn, fall panicum was the most problematic annual weed where triazine herbicides were used. Bauman and Ross (14) reported previous corn crop residues prevented as much as 30% of the atrazine from reaching the soil surface. Long-term use of atrazine in North Carolina was associated with replacement of large crabgrass [*Digitaria sanguinalis* (L.) Scop.] by fall panicum (34). Williams and Wicks (159) observed a shift in annual grass species, in no-tillage systems, from *Setaria* species to fall panicum.

Predation. Ground cover has shown to provide weed suppression and provide a habitat for seed predators. Researchers have documented post-dispersal seed predation reduces both seed supply and seedling emergence in old fields, pastures, and grasslands (86, 98). Reader (98) conducted a field experiment on seed losses from predation. Reader (98) concluded ground cover limits seedling emergence by providing a habitat for seed predators.

Mittleback and Gross (82) conducted studies in old field habitats in Michigan to determine the rate seeds are lost to post-dispersal predators. Seed removal by predators was higher in vegetated habitats than in areas of disturbed soil. Mittleback and Gross (82)

reported up to 20% of the seeds in undisturbed vegetation were removed in one day.

Marino *et al.* (78) studied the association between the distance from hedgerows and the amount of seeds lost by predation. Most weed seeds lost by predation occurred overwinter (78). Marino *et al.* (78) concluded the distance from hedgerows did not affect seed losses.

Lund and Turpin (77) examined the affinity of four species of Carabidae beetles to various weed seeds. They reported the preference for one weed seed over another maybe due to the ease of opening rather than selection based on textural or chemical seed qualities. The size and shape of the weed seeds affect the easy in which the beetles can open the seeds. This idea would explain why only 7% of the smaller fall panicum seeds were damaged by beetles, while 54% of the larger giant foxtail seeds were damaged.

Seedbanks. The weed seedbank, containing viable seed in the soil or on its surface, is the primary source of annual weeds. Reducing the size of the weed seedbank is a long-term goal of weed management (29).

Ball (8) evaluated the effects of tillage, herbicide use, and crop rotation on weed species changes in the soil seedbanks. Crop rotation was the dominant factor influencing species composition in the seedbank. Ball (8) accounted this to herbicides shifting the weed spectrum to favor species less susceptible to the applied herbicide.

Determining the initial density of viable seed in the soil seedbank is critical for bioeconomic weed management models (67, 109). Bioeconomic models can devise a weed control strategy, based on seedbank numbers, necessary to provide season-long weed control. Forcella *et al.* (50) examined seedbanks and seedling emergence of annual weeds in agricultural fields at eight locations in the corn belt. Percent viable seeds, emerging as

seedlings, ranged from less than 1% for yellow rocket [*Barbarea vulgaris* (R. Br.)] to 30% for giant foxtail. This information is a necessity in developing a reliable bioeconomic model for predicting weed seed emergence.

LITERATURE CITED

1. Aldrich, R.J. 1984. Weed Crop Ecology: Principles of Weed Management. Breton Publishers, North Scituate, MA. 465 pp.

2. Alex, J.F. 1980. Emergence from buried seed and germination of exhumed seed of fall panicum. Can. J. of Plant Sci. 60:635-642.

3. Allard, H.A. 1941. Some plants found in northern Virginia and West Virginia. Virginia J. Sci. 2:119.

4. Ambrose, L.G. and H.D. Coble. 1975. Fall panicum competition in soybeans. Proc. South. Weed Sci. Soc. 28:36.

5. Anonymous. 1981. Weeds of the North Central States. North Central Region Research Publication No. 281, Bulletin 772. University of Illinois at Urban-Champaign.

6. Anonymous. 1972. Panic(um) in Ontario. Weeds Today. 3(3):16.

7. Anonymous. 1970. Selected Weeds of the United States. Agriculture Handbook No. 366, Agricultural Research Service. United States Department of Agriculture. 72-82 pp.

8. Ball, D.A. 1992. Weed seedbank response to tillage, herbicides, and crop rotation sequence. Weed Sci. 40:654-659.

9. Barbour, J.C., III., and F. Forcella. 1993. Predicting seed production by foxtails (*Setaria spp.*). Proc. North Cent. Weed Sci. Soc. 48:100.

10. Barbour, M.G., J.H. Burk, and W.D. Pitts. 1987. Terrestrial Plant Ecology, 2nd ed. Benjamin/Cummings Publishing Company, Inc., California. 105-154 pp.

11. Barrentine, W.L., 1974. Common cocklebur competition in soybeans. Weed Sci. 22:600-603.

12. Baskin, J.M. and C.C. Baskin. 1983. Seasonal changes in the germination responses of fall panicum to temperature and light. Can. J. of Plant Sci. 63:973-979.

13. Bauer, T.A., D.A. Mortensen. 1992. A comparison of economic and economic

optimum thresholds for two annual weeds in soybeans. Weed Technol. 6:228-235.

14. Bauman, T.T. and M.A. Ross. 1983. Effect of three tillage systems on the persistence of atrazine. Weed Sci. 23:512-515.

15. Becker, R.L. and D.W. Staniforth. 1979. Effects of soil disturbance on weed seedling establishment. Proc. North Cent. Weed Sci. Soc. 34:43.

16. Beckett, T.H., E.W. Stoller, and L.M. Wax. 1988. Interference of four annual weeds in corn (*Zea mays*). Weed Sci. 36:764-769.

17. Begg, J.E. and N.C. Turner. 1976. Crop water deficits. Adv. Agron. 28:161-217.

18. Bell, D.T. and D.E. Koeppe. 1972. Noncompetitive effects of giant foxtail on the growth of corn. Agron. J. 64:321-325.

19. Bhowmik, P.C. and J.D. Doll. 1982. Corn and soybean response to allelopathic effects of weed and crop residue. Agron. J. 74:601-606.

20. Biniak, B.M. and R.J. Aldrich. 1986. Reducing velvetleaf (*Abutilon theophrasti*) and giant foxtail (*Setaria faberi*) seed production with simulated roller herbicide applications. Weed Sci. 34:256-259.

21. Black, C.C., T.M. Chen and R.H. Brown. 1969. Biochemical basis for plant competition. Weed Sci. 17:338-344.

22. Bloomberg, J.R., B.L. Kirkpatrick, and L.M. Wax. 1982. Competition of common cocklebur (*Xanthium pensylvanicum*) with soybeans (*Glycine max*). Weed Sci. 30:507-513.

23. Brecke, B.J. and W.B. Duke. 1980. Dormancy, germination, and emergence characteristics of fall panicum (*Panicum dichotomiflorum*) seed. Weed Sci. 28:683-685.

24. Buhler, D.D. and T.C. Metser. 1991. Effect of tillage systems on the emergence depth of giant foxtail (*Setaria faberi*) and green foxtail (*Setaria viridis*). Weed Sci. 39:200-203.

25. Buhler, D.D. and T.C. Daniel. 1988. Influence of tillage systems on giant foxtail, *Setaria faberi*, and velvetleaf, *Abutilon theophrasti*, density and control in corn, *Zea mays*. Weed Sci. 36:642-647.

26. Burkholder, P.R. 1952. Cooperation and conflict among primitive organisms. Am. Sci. 40:601-631.

27. Burnside, O.C., C.R. Fenster, L.L. Evetts, and R.F. Mumm. 1981. Germination of

exhumed weed seed in Nebraska. Weed Sci. 29:577-580.

28. Buttery, B.R. 1970. Effects of variation in leaf area index on growth of maize and soybeans. Crop Sci. 10:9-13.

29. Cardina, J., E. Regnier, and K. Harrison. 1991. Long-term tillage effects on seed banks in three Ohio soils. Weed Sci. 39:186-194.

30. Cardina, J., E. Regnier, and D. Sparrow. 1995. Velvetleaf (*Abutilon theophrasti*) competition and economic thresholds in conventional and no-tillage corn (*Zea mays*). Weed Sci. 43:81-87.

31. Chen, T.M., R.H. Brown, and C.C. Black. 1969. Biochemical basis for plant competition. Weed Sci. 17:338-344.

32. Claassen, M.M. and R.H. Shaw. 1970. Water deficit effects on corn. II. Grain components. Agron J. 62:652-655.

33. Coble, H.D., F.M. Williams, and R.L. Ritter. 1981. Common ragweed (*Ambrosia artemisiifolia*) interference in soybeans (*Glycine max*). Weed Sci. 29:339-342.

34. Coffman, C.B. and J.R. Frank. 1992. Corn-weed interactions with long-term conservation tillage management. Agron. J. 84:17-21.

35. Cousens, R. 1991. Aspects of the design and interpretation of competition (interference) experiments. Weed Technol. 5:664-673.

36. Darlington, H.T. 1951. The seventy-year period of Dr. Beal's seed vitality experiment. Am. J. Bot. 38:379-381.

37. Dawson, J.H. 1970. Time and duration of weed infestations in relation to weed-crop competition. Proc. South. Weed Sci. Soc. 23:13-25.

38. Dawson, J.H. and V.F. Bruns. 1975. Longevity of barnyardgrass, green foxtail, and yellow foxtail seeds in soil. Weed Sci. 23:437-440.

39. Dawson, J.H. and V.F. Bruns. 1962. Emergence of barnyardgrass, green foxtail, and yellow foxtail seedlings from various soil depths. Weeds. 10:136-139.

40. Dekker, J. and W.F. Meggit. 1983. Interference between velvetleaf (*Abutilon theophrasti* Medic.) and soybean (*Glycine max* (L). Merr.). I. Growth. Weed Res. 23:91-101.

41. Defelice, M.S., W.B. Brown, R.J. Aldrich, B.D. Sims, D.T. Judy, and D.R. Guethle. 1989. Weed control in soybeans (*Glycine max*) with reduced rates of postemergence herbicides. Weed Sci. 37:365-374.

42. Denmead, O.T. and R.H. Shaw. 1960. The effects of soil moisture stress at different stages of growth on the development and yield of corn. Agron. J. 52:272-274.

43. Di Tomaso, J.M. 1995. Approaches for improving crop competitiveness through the manipulation of fertilization strategies. Weed Sci. 43:491-497.

44. Edwards, J.H., D.L. Thurlow, and J.T. Eason. 1988. Influence of tillage and crop rotation on yields of corn, soybean, and wheat. Agron. J. 80:76-80.

45. Egley, G.H. and R.D. Williams. 1990. Decline of weed seeds and seedling emergence over five years as affected by soil disturbances. Weed Sci. 35:504-510.

46. Evers, R.A. 1949. *Setaria faberii* in Illinois. Rhodora. 51:391-392.

47. Fairbrothers, D.E. 1959. Morphological variation of *Setaria faberii* and *S. viridis*. Brittonia. 11:44-48.

48. Fawcett, R.S. and F.W. Slife. 1978. Effects of field applications of nitrate on weed seed germination and dormancy. Weed Sci. 26:594-596.

49. Fernald, M.L. 1944. *Setaria faberii* in Eastern America. Rhodora. 46:57-58.

50. Forcella, F., R.G. Wilson, K.A. Renner, J. Dekker, R.G. Harvey, D.A. Alm, D.D. Buhler, and J. Cardina. 1992. Weed seedbanks of the U.S. corn belt: Magnitude, variation, emergence, and application. Weed Sci. 40:636-644.

51. Ghersa, C.M., M.A. Martinez-Ghersa, J.J. Casal, M. Kaufman, M.L. Roush, and V.A. Deregibus. 1994. Effect of light on winter wheat (*Triticum aestivum*) and italian ryegrass (*Lolium multiflorum*) competition. Weed Technol. 8:37-45.

52. Gleason, L.S. 1958. Weed control in corn in the wet tropics. Proc. North Cent. Weed Sci. Soc. 13:54.

53. Griffith, D.R., E.J. Kladivko, J.V. Mannering, T.D. West, and S.D. Parsons. 1988. Long-term tillage and rotation effects on corn growth and yield on high and low organic matter, poorly drained soils. Agron. J. 80:599-605.

54. Griffith, D.R., J.V. Mannering, H.M. Galloway, S.D. Parsons, and C.B. Richey. 1973. Effect of eight tillage-planting systems on soil temperature, percent stand, plant growth, and yield of corn on five Indiana soils. Agron. J. 65:321-326.

55. Harper, J.L. 1977. Population Biology of Plants. Academic Press, London, UK. 892 pp.

56. Harris, T.C. and R.L. Ritter. 1987. Giant green foxtail (*Setaria viridis* var. major) and fall panicum (*Panicum dichotomiflorum*) competition in soybeans (*Glycine max*). Weed Sci. 35:663-668.

57. Harris, T.C. and R.L. Ritter. 1983. Fall panicum (*Panicum dichotomiflorum* Michx.) and green foxtail (*Setaria viridis* var. major (Gaud.) Posp.) interference in soybeans. Abstr. Weed Sci. Soc. Am. 21:6-7.

58. Harrison, S.K., L.M. Wax and C.S. Williams. 1985. Interference and control of giant foxtail (*Setaria faberi*) in soybeans (*Glycine max*). Weed Sci. 33:203-208.

59. Hayden, T.A. and O.C. Burnside. 1987. Effects of herbicide incorporation methods on shattercane (*Sorghum bicolor*) control in corn (*Zea mays*). Weed Sci. 35:364-372.

60. Hendricks, S.B. and R.B. Taylorson. 1974. Promotion of seed germination by nitrate, nitrite, hydroxylamine, and ammonium salts. Plant Physiol. 54:304-309.

61. Holt, R.F. and D.R. Timmons. 1968. Influence of precipitation, soil water, and plant population interactions on corn grain yields. Agron. J. 60:379-381.

62. Holm, L.G., Plunkett, J.V. Pancho, and J.P. Herberger. 1977. The World's Worst Weeds: Distribution and Biology. University Press of Hawaii, Honolulu. 176-178 pp.

63. Houghton, J.M. and F.W. Slife. 1969. Environmental factors that affect the development and control of panicum species. Proc. North Cent. Weed Sci. Soc. 24:82.

64. Hubbard, F.T. 1915. A taxonomic study of *Setaria italica* and its immediate allies. Amer. J. of Bot. 2:169-198.

65. Johnson, M.D. and B. Lowery. 1985. Effect of three conservation tillage practices on soil temperature and thermal properties. Soil Sci. Soc. Am. J. 49:1547-1552.

66. King, J.J. 1966. Weeds of the World: Biology and Control. Interscience, New York, 1-48 pp.

67. King, R.P., D.W. Lybecker, E.E. Schweizer, and R.L. Zimdahl. 1986. Bioeconomic modeling to simulate weed control strategies for continuous corn (*Zea mays*). Weed Sci. 34:972-979.

68. Knake, E.L. 1977. Giant foxtail: The most serious annual grass weed in the Midwest. Weeds Today. 9:19-20.

69. Knake, E.L. 1972. Effect of shade on giant foxtail. Weed Sci. 20:588-592.

70. Knake, E.L. and F.W. Slife. 1969. Effect of time of giant foxtail removal from corn and soybeans. Weed Sci. 17:281-283.

71. Knake, E.L. and F.W. Slife. 1965. Giant foxtail seeded at various times in corn and soybeans. Weeds. 13:331-334.

72. Knake, E.L. and F.W. Slife. 1962. Competition of *Setaria faberii* with corn and soybeans. Weeds. 10:26-29.

73. Lambert, W.J., T.T. Bauman, M.D. White, and R.A. Vidal. 1994. Giant foxtail (*Setaria faberi*) interference in corn (*Zea mays*). Proc. North Cent. Weed Sci. Soc. 49:137-138.

74. Langston, S.J. and R.G. Harvey. 1994. Using alachlor impregnated on dry fertilizer to create varying giant foxtail populations for corn competition studies. Proc. North Cent. Weed Sci. Soc. 49:18.

75. Lindquist, J.L., B.D. Maxwell, D.D. Buhler, and J.L. Gunsolus. 1995. Velvetleaf (*Abutilon theophrasti*) recruitment, survival, seed production, and interference in soybean (*Glycine max*). Weed Sci. 43:226-232.

76. Lindquist, J.L., B.D. Maxwell, D.D. Buhler, and J.L. Gunsolus. 1995. Modeling the population dynamics and economics of velvetleaf (*Abutilon theophrasti*) control in corn (*Zea mays*) - soybean (*glycine max*) rotation. Weed Sci. 43:269-275.

77. Lund, R.D. and F.T. Turpin. 1977. Carabid damage to weed seeds found in Indiana corn fields. Environ. Entomol. 6:695-698.

78. Marino, P.C., D.A. Landis, and K.L. Gross. Unpublished Report. Post-dispersal weed seed loss in Michigan maize fields in relation to landscape structure. Michigan State University, East Lansing, MI.

79. Mester, T.C. and D.D. Buhler. 1991. Effects of soil temperature, seed depth, and cyanazine on giant foxtail (*Setaria faberi*) and velvetleaf (*Abutilon theophrasti*) seedling development. Weed Sci. 39:204-209.

80. Mester, T.C. and D.D. Buhler. 1986. Effects of tillage on the depth of giant foxtail germination and population densities. Proc. North Cent. Weed Sci. Soc. 41:4-5.

81. Michael, J.L., R.S. Fawcett, and S.E. Taylor. 1984. Effects of soil temperature on early growth of giant foxtail (*Setaria faberi*) and velvetleaf (*Abutilon theophrasti* Medic.) in soybeans. Abstr. Weed Sci. Soc. Am. 22:9.

82. Mittelbach, G.G. and K.L. Gross. 1984. Experimental studies of seed predation in old-fields. Oecolgia. 65:7-13.

83. Mohler, C.L. 1993. A model of the effects of tillage on emergence of weed seedlings. Ecol. Appl. 53-73 pp.

84. Monachino, J. 1959. Type of *Setaria faberi.* Rhodora. 61:220-223.

85. Moolani, M.K., E.L. Knake, and F.W. Slife. 1964. Competition of smooth pigweed with corn and soybeans. Weeds. 12:126-128.

86. Moore, M.J., T.J. Gillespie, and C.J. Swanton. 1994. Effect of cover crop mulches on weed emergence, weed biomass, and soybean (*Glycine max*) development. Weed Technol. 8:512-518.

87. Moyer, J.R., G.B. Schaalje, and P.Bergen. 1991. Alfalfa *(Medicago sativa)* seed yield loss due to Canada thistle *(Cirsium arvense)*. Weed Technol. 5:723-728.

88. Nieto, J.H. and D.W. Staniforth. 1961. Corn-foxtail competition under various production conditions. Agron. J. 53:1-5.

89. Orwick, P.L. and M.M. Schreiber. 1979. Interference of redroot pigweed (*Amaranthus retroflexus*) and robust foxtail (*Setaria viridis* var. *robusta-alba* or var. *robusta-purpurea*) in soybeans (*Glycine max*). Weed Sci. 27:665-674.

90. Orwick, P.L., M.M. Schreiber, and D.A. Holt. 1978. Simulation of foxtail (*Setaria viridis* var. *robusta-alba, Setaria viridis* var. *robusta-purpurea*) growth: The development of SETSIM. Weed Sci. 26:691-699.

91. Parochetti, J.V. 1974. Yellow nutsedge, giant green foxtail, and fall panicum control in corn. Weed Sci. 22:80-82.

92. Patterson, D.T. and E.P. Flint. 1983. Comparative water relations, photosynthesis, and growth of soybean (*Glycine max*) and seven associated weeds. Weed Sci. 31:318-323.

93. Peters, R.A. 1975. Fall panicum workshop. Proc. Northeast Weed Sci. Soc. 29:7-19.

94. Peterson, D.E. and J.D. Nalewaja. 1992. Environment influences green foxtail (*Setaria viridis*) competition with wheat (*Triticum aestivum*). Weed Technol. 6:607-610.

95. Pitty, A., D.W. Staniforth, and L.H. Tiffany. 1987. Fungi associated with caryopses of *Setaria* species from field-harvested seeds and from soil under two tillage systems. Weed Sci. 35:319-323.

96. Radosevich, S.R. 1987. Methods to study interactions among crops and weeds. Weed Technol. 1:190-198.

97. Radosevich, S.R. and J.S. Holt. 1984. Weed Ecology: Implications for Vegetative Management. John Wiley & Sons, New York. 139-194 pp.

98. Reader, R.J. 1991. Control of seedling emergence by groundcover: A potential mechanism involving seed predation. Can. J. of Bot. 69:2084-2087.

99. Roberts, H.A. 1964. Emergence and longevity in cultivated soil of seeds of some annual weeds. Weed Res. 4:296-307.

100. Roberts, H.A. 1962. Dormancy in rice seed. III. The influence of temperature, moisture, and gaseous environment. J. Exp. Bot. 13:75-94.

101. Roberts, H.A. and P.M. Feast. 1972. Fate of seeds of some annual weeds in different depths of cultivated and undisturbed soil. Weed Res. 12:316-324.

102. Roberts, H.A. and P.M. Feast. 1970. Seasonal distribution of emergence in some annual weeds. Exp. Hort. 21:36-41.

103. Robins, J.S. and C.E. Domingo. 1953. Some effects of severe soil moisture deficits at specific growth stages in corn. Agron. J. 45:618-621.

104. Rominger, J.M. 1963. Taxonomy of *Setaria* (Gramineae) in North America, The University of Illinois Press, Urbana-Champaign. 130 pp.

105. Roush, M.L., S.R. Radosevich, R.G. Wagner, B.D. Maxwell, and T.D. Petersen. 1989. A comparison of methods for measuring effects of density and proportion in plant competition experiments. Weed Sci. 37:268-275.

106. Santelmann, P.W. and J.A. Meade. 1961. Variation in morphological characteristics and dalapon susceptibility within the species *Setaria lutescens* and *S. faberii*. Weeds. 9:406-410.

107. Santelmann, P.W., J.A. Meade, and R.A. Peters. 1963. Growth and development of yellow foxtail and giant foxtail. Weeds. 11:139-142.

108. Selleck, G.W. 1975. The distribution of fall panicum. Proc. Northeast Weed Sci. Soc. 29:9.

109. Schafer, D.E. and D.O. Chilcote. 1969. Factors influencing persistence and depletion in buried seed populations. Crop Sci. 9:417-419.

110. Schmenk, R.E. 1994. Velvetleaf (*Abutilon theophrasti* Medik.) competitiveness in

corn as affected by preemergence herbicides. M. S. Thesis, Michigan State University, East Lansing, MI. 19-20 pp.

111. Schreiber, M.M. 1992. Influence of tillage, crop rotation, and weed management on giant foxtail (*Setaria faberi*) population dynamics and corn yield. Weed Sci. 40:645-653.

112. Schreiber, M.M. 1977. Longevity of foxtail taxa in undisturbed sites. Weed Sci. 25:66-72.

113. Schreiber, M.M. 1965. Development of giant foxtail under several temperatures and photoperiods. Weeds. 13:40-43.

114. Schreiber, M.M. 1965. Effect of date of planting and stage of cutting on seed production of giant foxtail. Weeds. 13:60-62.

115. Schreiber, M.M. and L.R. Oliver. 1971. Two new varieties of *Setaria viridis*. Weed Sci. 19:424-427.

116. Schreiber, M.M. and P.L. Orwick. 1978. Influence of nitrogen fertility on growth of foxtail (*Setaria*) taxa. Weed Sci. 26:547-550.

117. Schreiber, M.M. and J.L. Williams, Jr. 1966. Toxicity of root residues of weed grass species. Weed Sci. 15:80-81.

118. Scopel, A.L., C.L. Ballare, and R.A. Sanchez. 1991. Induction of extreme light sensitivity in buried weed seeds and its role in the perception of soil cultivations. Plant, Cell, and Environ. 14:501-508.

119. Sibuga, K.P. and J.D. Bandeen. 1980. Effects of green foxtail and lamb's-quarters interference in field corn. Can. J. of Plant Sci. 60:1419-1425.

120. Slife, F.W. 1956. A new setaria species in Illinois. Proc. North Cent. Weed Sci. Soc. 11:6-7.

121. Smith, D.T. 1974. How weeds influence the crop environment. Proc. South. Weed Sci. Soc. 27:24-28.

122. Staniforth, D.W. 1965. Competitive effects of three foxtail species on soybeans. Weeds. 13:191-193.

123. Staniforth, D.W. 1962. Responses of soybean varieties to weed competition. Agron. J. 54:11-12.

124. Staniforth, D.W. 1961. Responses of corn hybrids to yellow foxtail competition. Weeds. 9:132-136.

125. Staniforth, D.W. 1957. Effects of annual grass weeds on the yield of corn. Agron. J. 49:551-555.

126. Staniforth. D.W. 1955. Levels of weed infestations as related to yield losses and control practices in corn. Proc. North Cent. Weed Sci. Soc. 10:44-46.

127. Staniforth, D.W. and C.R. Weber. 1956. Effects of annual weeds on the growth and yield of soybeans. Agron. J. 48:467-471.

128. Staricka, J.A., P.M. Burford, R.R. Allmaras, and W.W. Nelson. 1990. Tracing the vertical distribution of simulated shattered seeds as related to tillage. Agron. J. 82:1131-1134.

129. Steinbauer, G.P. and B. Grigsby. 1957. Interaction of temperature, light, and moistening agent in the germination of weed seeds. Weeds. 5:175-182.

130. Steinsiek, J.W., L.R. Oliver, and F.C. Collins. 1982. Allelopathic potential of wheat (*Triticum aestivum*) straw on selected weed species. Weed Sci. 30:495-497.

131. Stevens, O.A. 1932. The number and weight of seeds produced by weeds. Amer. J. of Bot. 19:784-794.

132. Stoller, E.W. and L.M. Wax. 1973. Periodicity of germination and emergence of some annual weeds. Weed Sci. 21:574-580.

133. Stoller, E.W. and L.M. Wax. 1973. Temperature variations in the surface layers of an agricultural soil. Weed Res. 13:273-282.

134. Stoller, E.W., L.M. Wax and F.W. Slife. 1979. Yellow nutsedge (*Cyperus esculentus*) competition and control in corn (*Zea mays*). Weed Sci. 27:32-37.

135. Taylorson, R.B. 1986. Water stress-induced germination of giant foxtail (*Setaria faberi*) seeds. Weed Sci. 34:871-875.

136. Taylorson, R.B. 1982. Anesthetic effects on secondary dormancy and phytochrome responses in *Setaria faberi* seeds. Plant Physiol. 70:882-886.

137. Taylorson, R.B. 1980. Aspects of seed dormancy in fall panicum (*Panicum dichotomiflorum*). Weed Sci. 28:64-67.

138. Taylorson, R.B. 1972. Phytochrome controlled changes in dormancy and germination of buried weed seeds. Weed Sci. 20:417-422.

139. Taylorson, R.B. and H.A. Borthwick. 1969. Light filtration by foliar canopies: Significance for light-controlled weed seed germination. Weed Sci. 17:48-51.

140. Taylorson, R.B. and M.M. Brown. 1977. Accelerated after-ripening for overcoming seed dormancy in grass weeds. Weed Sci. 25:473-476.

141. Thompson, L., Jr. 1972. Metabolism of chloro *s*-triazine herbicides by *Panicum* and *Setaria*. Weed Sci. 20:584-587.

142. Thompson, L., Jr., J.M. Houghton, F.W. Slife, and H.S. Butler. 1971. Metabolism of atrazine by fall panicum and large crabgrass. Weed Sci. 19:409-412.

143. Thornley, J.M. 1983. Crop yield and planting density. Ann. Bot. 52:257-259.

144. Tollenaar, M., A.A. Dibo, A. Aguilera, S.F. Weise, and C.J. Swanton. 1994. Effect of crop density on weed interference in maize. Agron. J. 86:591-595.

145. Toole, E.H., S.B. Hendricks, H.A. Borthwick, and V.K. Toole. 1956. Physiology of seed germination. Annu. Rev. Plant Physiol. 7:299-324.

146. Triplett, G.B., Jr. and G.D. Lytle. 1972. Control and ecology of weeds in continuous corn grown without tillage. Weed Sci. 20:453-457.

147. Vengris, J. 1975. Field growth habits of fall panicum. Proc. Northeast Weed Sci. Soc. 29:8.

148. Vengris, J. and R.A. Damon, Jr. 1976. Field growth of fall panicum and witchgrass. Weed Sci. 24:205-208.

149. Vengris, J., W.G. Colby, and M. Drake. 1955. Plant nutrient competition between weeds and corn. Agron. J. 47:213-216.

150. Walker, K.L. and D.J. Williams. 1989. Annual grass interference in container-grown bush cinquefoil (*Potentilla fruticosa*). Weed Sci. 37:73-75.

151. Walker, K.L. and D.J. Williams. 1988. Grass interference in container-grown bailey's redosier dogwood (*Cornus* x *baileyi*). Weed Sci. 36:621-624.

152. Weber, C.R. and D.W. Staniforth. 1957. Competitive relationships in variable weed and soybean stands. Agron. J. 49:440-444.

153. Wesson, G. and P.F. Wareing. 1969. The role of light in the germination of naturally occurring populations of buried weed seeds. J. Exp. Bot. 20:402-413.

154. Wesson, G. and P.F. Wareing. 1969. The induction of light sensitivity in weed seeds by burial. J. Exp. Bot. 20:414-425.

155. Wesson, G. and P.F. Wareing. 1967. Light requirements of buried seeds. Nature.

213:600-601.

156. Whitson, T.D., ed. 1991. Weeds of the West. Western Society of Weed Science, Wyoming. 490-491 pp.

157. Wiese, A.F. and C.W. Vandiver. 1970. Soil moisture effects on competitive ability of weeds. Weed Sci. 18:518-519.

158. Wiese, A.M. and L.K. Binning. 1987. Calculating the threshold temperature of development for weeds. Weed Sci. 35:177-179.

159. Wiese, A.M., and L.K. Binning. 1982. Effect of tillage date on weed spectrum emerging. Proc. North Cent. Weed Sci. Soc. 37:11.

160. Willis, W.O., W.E. Larson and D. Kirkham. 1957. Corn growth as affected by soil temperature and mulch. Agron. J. 49:323-328.

161. Wilson, R.G. and P. Westra. 1991. Wild proso millet (*Panicum miliaceum*) interference in corn (*Zea mays*). Weed Sci. 39:217-220.

162. Wood, C.E. 1946. *Setaria faberii* in North Carolina. Rhodora. 48:391-392.

163. Woods, F.W., and K. Brock. 1964. Interspecific transfer of Ca-45 and P-32 by root systems. Ecol. 45(4): 886-889.

164. Wrucke, M.A. and W.E. Arnold. 1985. Weed species distribution as influenced by tillage and herbicides. Weed Sci. 33:853-856.

165. York, A.C. and H.D. Coble. 1977. Fall panicum interference in peanuts. Weed Sci. 25:43-47.

166. York, A.C. and W.M. Lewis. 1976. Today's weed: Fall panicum. Weeds Today. 8:(1)18

167. Young, F.L., D.L. Wyse, and R.J. Jones. 1984. Quackgrass (*Agropyron repens*) interference on corn (*Zea mays*). Weed Sci. 32:226-234.

168. Young, F.L., D.L. Wyse, and R.J. Jones. 1982. Influence of quackgrass (*Agropyron repens*) density and duration of interference on soybeans (*Glycine max*). Weed Sci. 30:614-619.

169. Zimdahl, R.L. 1980. Weed-Crop Competition. A Review. Int. Plant Prot. Cent. Oregon State Univ., Corvallis. 195 pp.

CHAPTER 2

GIANT FOXTAIL (*Setaria faberi* HERRM.) INTERFERENCE IN NON-IRRIGATED CORN

ABSTRACT

Studies were conducted at East Lansing, MI in 1994 and 1995 to examine corn yield response to giant foxtail [*Setaria faberi* (Herrm.)] interference and to examine the effect of giant foxtail density on giant foxtail biomass, seed production, and seed germination. Treatments consisted of 0, 10, 30, 60, 84, and 98 giant foxtail plants per m of row in 1994 and 0, 10, 27, 30, 60, and 69 plants per m of row in 1995. The influence of giant foxtail density on corn yield fit a hyperbola equation. Corn yields were reduced 13% in 1994 and 14% in 1995 from 10 giant foxtail plants per m of row. Corn dry matter at maturity was decreased 24 and 23% from 10 giant foxtail plants per m of row in 1994 and 1995, respectively. Seed production increased linearly as inflorescence length increased. The length of giant foxtail inflorescence increased as plant density increased and the number of inflorescence produced per plant decreased. Seed production ranged from 518 to 2544 seeds per plant. Ten giant foxtail plants per m of row produced 15700 seeds per m^{-2}. Giant foxtail seed germination was not affected by plant density. Nomenclature: giant foxtail, *Setaria*

faberi Herrm. #[1] SETFA; corn, *Zea mays* L. # ZEAMX, 'Pioneer 3573'. *Additional index words*. Bioeconomic model, competition, *Setaria*, SETFA.

[1]Letters following this symbol are WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 1508 W. University Ave., Champaign, IL 61821-3133.

INTRODUCTION

Giant foxtail is among the most widespread annual grasses in crop production in the United States (18). Giant foxtail is not native to the United States and before 1930 there were only isolated reports of its existence in the United States (9). The rapid infestation of giant foxtail is attributed to its ability to adapt to several environments and its tremendous reproductive capabilities (20).

Researchers have documented that giant foxtail germinated and emerged early in the growing season and concluded the earlier giant foxtail emerged, the larger the growth of the inflorescence (20). The date of emergence also affects the number of tillers produced per plant and, subsequently, the number of inflorescence produced per plant as late germinating giant foxtail plants produced fewer tillers (18). Increasing the number of inflorescence produced per plant and the length of the inflorescence resulted in increased amounts of seed produced per plant (20).

Weed escapes present a serious problem on Midwestern farms (13). Weeds reduced crop yields primarily by competing for light, water, and nutrients (21). Interference from giant foxtail reduces corn yield and profit (13). The correct weed management decisions are based on the relationship between weed density and corn yield loss.

The severity of yield losses due to interfering weeds is dependent upon the duration of the weed competition (23). Gleason (7) noted that the longer giant foxtail plants were present, the more crop yields were suppressed. Giant foxtail reduced corn yield 63, 124, 315,

441, and 1133 kg ha^{-1} and soybean yield 0, 0, 63, 124, and 1133 kg ha^{-1} when removed at 7.5, 15, 22.5, and 30 cm in height and at maturity, respectively (11). In addition, total dry matter remained constant whether the dry matter consisted of a weed-free crop or a crop and giant foxtail biculture. Field studies by the same authors (9, 12) investigated the interference from giant foxtail seeded 3, 6, 9, and 12 weeks after crop planting. Giant foxtail reduced corn and soybean yield 13 and 27%, respectively, when seeded with the crop. Giant foxtail plants seeded three weeks after the crop did not reduce corn or soybean yields. Interfering giant foxtail plants reduced corn yield, cob weight, ear weight, stalk diameter, soil temperature, and soybean yield and pod number (13). Corn and soybean yields, from 180 giant foxtail plants per m of row, were reduced 25 and 28%, respectively. Giant foxtail plants did not affect corn or soybean grain moisture content, crop height, or oil content of soybeans.

Harrison *et al.* (8) studied the interference and control of giant foxtail in soybeans and reported every clump (3 to 6 plants) of giant foxtail plants per nine m of row reduced soybean yield 0.8%. Ten giant foxtail plants per m of row reduced soybean yield 16%.

Langston and Harvey (15) reported 30 giant foxtail plants per m of row did not reduce corn yields in 1993. However, the same density reduced corn yield 18% in 1994. Similarly, Lambert *et al.* (14) reported giant foxtail densities of 265 plants per m of row reduced corn yield 20% in 1993 and 200 plants per m of row reduced corn yield 52% in 1994.

Researchers have documented the need for research on the biology of weeds (4). The North Central Regional project NC-202 "Biological and Ecological Basis for Weed Management Decision Support Systems to Reduce Herbicide Use" (1) is developing data sets to quantify the interference of giant foxtail in the North Central region of the United States. One objective of the project is to improve the accuracy and reliability of corn yield loss

estimations. Data will provide the framework for objective evaluation of costs and benefits from weed control practices (1). These data will refine a bioeconomic model that will support weed management decisions. The objectives of this research were: 1) to assess the yield and dry matter loss in corn from giant foxtail interference in Michigan, 2) to estimate giant foxtail seed production, and 3) to examine the effects of density on giant foxtail seed germination.

MATERIALS AND METHODS

Field Experiment. Experiments were conducted at the Michigan State University Agronomy Research Farm in East Lansing, MI in 1994 and 1995. The soil was a Capac loam (fine - loamy, mixed, mesic Aeric Ochraqualfs) with 3.5% organic matter and a pH of 7.1 in 1994 and 3.4% organic matter and a pH of 6.5 in 1995. The sites were fall moldboard plowed and spring secondary tillage consisted of two diskings. Sites were fertilized according to soil nutrient analysis. In 1994, 336 kg ha^{-1} 6-24-24 and 305 kg ha^{-1} 46-0-0 were applied broadcast before spring disking. In 1995, 140 kg ha^{-1} 6-24-24 and 336 kg ha^{-1} 46-0-0 were applied. Corn 'Pioneer 3573' was planted May 10, 1994 and May 8, 1995 at 59280 seeds per ha in 76-cm-wide rows (Table 1). Corn emergence was 11 and 10 days after planting (DAP) in 1994 and 1995, respectively. Giant foxtail emergence was 2 days after the corn in both years. The experimental design was a randomized complete block, and treatments were replicated four times. Treatments consisted of 0, 10, 30, 60, 84, and 98 giant foxtail plants per m of row in 1994 and 0, 10, 27, 30, 60, and 69 giant foxtail plants per m of row in 1995. Plots were four rows wide and 10.5 m long in 1994 and 9.0 m long in 1995.

Metolachlor (2-chloro- *N*-(2-ethyl-6-methylphenyl)- *N*-(2-methoxy-1-methylethyl) acetamide) at 2.2 kg ha^{-1} was applied in a 38-cm band between the corn rows, to the experimental area, and bentazon (3-(1-methylethyl)-1*H*-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide) at 1.1 kg ha^{-1} was applied broadcast to control late emerging broadleaves in 1994 and 1995.

Natural infestations of giant foxtail were hand thinned to treatment densities 10 days after emergence. Giant foxtail plants were spaced evenly along the corn row and remained in the field for the entire growing season. Plots were hand-weeded throughout the growing season to remove weeds other than giant foxtail. Corn density was recorded at maturity to evaluate mortality.

All data were collected from plants in the inner two rows of each four-row plot. A 1-m section of row, in one of the two middle rows, was monitored and removed at corn maturity to measure the following: corn grain, corn dry matter, and giant foxtail dry matter.

Giant foxtail seed production was calculated by hand-harvesting seed inflorescence as they matured, measuring their length, and counting the seeds. Seed production estimates were based on the number of inflorescence and the length of inflorescence produced per plant. The number of seeds produced for a given inflorescence length was multiplied by the number and the length of inflorescence to estimate the number of seeds produced per plant. The number of giant foxtail plants per m of row was multiplied by 1.32 to convert plants per m of row to plants m^{-2}. The number of seeds produced per plant was multiplied by the number of plants m^{-2} in each treatment to estimate the number of seeds m^{-2}.

Plots were trimmed at corn maturity to 9.5 m and 8.0 m in 1994 and 1995, respectively. Corn was mechanically harvested from the center two rows of each plot and weights were adjusted to 15.5% moisture. Rainfall, growing degree days (GDD) and air temperatures were recorded daily.

Seed Study. Giant foxtail inflorescence were collected on September 21, 1994 and 1995 from 1 m of row in each of the above mentioned plots. Seeds were hand removed, cleaned and stored dry at room temperature. Studies were initiated approximately four months after

harvest. Lots of twenty-five seeds were placed on No. 2 Whatman filter paper in a 9 cm petri dish and 8 ml of distilled water was added and the petri dishes were sealed. Seeds were placed in growth chambers and exposed to 16 h of darkness at 20 C and 8 h of light (300 μE m^{-2} s^{-1}) at 30 C. Seeds were considered germinated when the radicle exceeded 2 mm in length. Germination was recorded 4, 7, and 14 days after light exposure. Studies consisted of four replications and were repeated two times each year.

Data Analysis. Data were subjected to analysis of variance and means were separated by least significant difference at the 0.05 level. When a variable significantly interacted with years, a regression was performed separately for each year. When the interaction was not significant, a regression was performed with the years combined.

The rectangular hyperbola model developed by Cousens (6) and the nonlinear regression procedure of SAS (19) was used to relate corn yield loss to giant foxtail density for the 1994 and the 1995 individually and in the pooled sample.

The relationship between inflorescence length and seed production was best described by a linear equation. Seed production m^{-2} and giant foxtail density fit a quadratic equation.

RESULTS AND DISCUSSION

Experiment establishment dates for the two field studies were similar (Table 1). The first rainfall (more than 0.5 cm) after corn planting was within 7 DAP in 1994 and 1995 (Table 2). Sufficient rainfall within the first four weeks of study establishment led to similar emergence patterns in 1994 and 1995. Mid season environmental conditions were vastly different. Twenty-eight cm of rain fell between 5 and 8 weeks after planting in 1994. Conversely in 1995, 8 cm of rain fell in the same period (Table 2). However, cumulative GDD in 1994 and 1995 from corn planting to silking (11 weeks after planting) were similar (Table 2). Stand counts taken at maturity determined there was no corn mortality in either 1994 or 1995 (data not presented).

Corn Yield. Researchers have a wide range of models available for predicting crop yield loss as a function of weed density. For low weed densities a linear regression may be used; however, the selection of an equation should not be based solely on a high r^2 value (16). A quadratic equation will often give the highest r^2 value but forces a maximum and eventual decline on data that may be asymptotic (5). The rectangular hyperbola equation is considered one of the most appropriate mathematical forms for relating crop yield loss to weed density.

The rectangular hyperbola equation provided a representative fit for the relationship between corn yield loss and giant foxtail density. This equation considers four parameters in determining the predicted yield (5). The equation, $Y = (WFY + D95*Z) [1- Ix/ (100(1 + Ix/ A))]$, employs the following variables and parameters:

Y = predicted yield

x = weed density

Z = "Dummy" (0/1) for years

WFY = weed-free yield

D95 = correction estimate for 1995 in pooled data

A = maximum percentage crop yield loss asymptote as $x \rightarrow \infty$

I = percentage loss for the first weed density unit

Weed-free yields ranged from 7590 kg ha^{-1} in 1994 to 12044 kg ha^{-1} in 1995 (Table 3). The asymptote (A) varied between 57% in 1994 and 28% in 1995. The I parameter ranged from 1.8 to 2.4% between 1994 and 1995, respectively.

The hyperbolic equation predicted that initial giant foxtail densities contributed similarly to corn yield reduction in 1994 and 1995 (Figure 1). T values indicate the I parameter did not significantly differ from 0 in 1994 or the pooled data set. Our values are generally higher, but are consistent with the literature. Corn yield was reduced 13% in 1994 and 14% in 1995 from 10 giant foxtail plants per m of row. The predicted maximum percentage corn yield reduction varied greatly between the two years with maximum yield reduction two times greater in 1994. Statistically the A parameter was greater than 0 and less than 100 at a 95% confidence level in 1994, 1995 and in the pooled data. This estimate indicates that maximum yield loss from giant foxtail ranges from 28% in 1995 to 57% in 1994. Our results show higher reliability of the A parameter estimates than previous studies (22).

Swinton *et al.* (22) evaluated various multi-species data sets to estimate weed

interference parameters in Michigan. Weed densities were regressed on crop yields using the rectangular hyperbola equation and non-linear regression. Weed densities were based on either stand counts or visual estimation in reduction in weed biomass compared to a weedy check plot, along with actual weed densities for the weedy check plot. Because these trials were repeated over years, it made it possible to evaluate the interaction of years with weed competitiveness. Three model formulations were tested: a model in which the years had no effect, a model in which year affects only the maximum reduction in weed-free yield, and a model in which year affects both the weed-free yield and the competitiveness of weeds (22). Maximum corn yield reduction from competing weeds (A) was estimated at 70% in these data. It was then estimated that the first foxtail plant per ft^2 (I) reduced corn yield 0.8 to 1.1%. Swinton *et al.* concluded that though the year significantly affects weed-free yields, it does not interact significantly with weed-crop interference (22).

Similarly, Cardina *et al.* (4) studied the competitive effects of velvetleaf [*Abutilon theophrasti* (Medik.)] in conventional and no-tillage corn. Early emerging velvetleaf were found more competitive than late emerging velvetleaf. The asymptote (A) ranged from 17% in conventional tillage in 1992 to 69% in no-tillage in 1990. Similar to these data, seasonal environmental variation in Michigan affected the maximum percent crop yield from giant foxtail interference (asymptote).

Total Dry Matter. The dry matter of corn grain, corn stalks and cobs, and giant foxtail were combined to obtain total dry matter production for each treatment (Table 4). In 1994 there was no statistical difference in the total dry matter produced between treatments. Conversely, in 1995 corn grown alone produced more total dry matter than corn grown in competition with giant foxtail.

Ten giant foxtail plants per m of row, in the 1-m subplot, decreased corn grain weight 31% and corn dry matter 24% when compared with the weed-free plots in 1994. These data suggest the increase in giant foxtail dry matter compensates for the reduction in corn dry matter and the total dry matter remains constant. Ten giant foxtail plants per m of row decreased corn grain weight 13% and corn dry matter 23% in 1995. The total dry matter produced in 1995 was higher when corn was grown alone but in plots containing giant foxtail, the production of total dry matter remained constant. This suggests the absence of giant foxtail may enable corn to produce higher levels of total dry matter.

Studies have documented the reduction in corn dry matter is proportional to the amount of resources giant foxtail utilizes (11, 13, 17). Researchers concluded that there is a limited amount of resources available for plant growth and development (11, 17). These same limited resources are required for corn and giant foxtail. Other researchers have noted residues from mature giant foxtail plants contain allelopathic compounds that affect corn root development and growth (3). Allelopathic compounds are water soluble and may have leached through the root zone in 1994, but in the dry year of 1995, their presence may have limited corn growth and total dry matter.

Seed Production. Giant foxtail plants growing without competition can produce more than 10000 seeds per plant (20). The maximum number of seeds produced per plant occurred at 10 plants per m of row. Maximum seed production was 2514 seeds per plant in 1994 and 2544 seeds per plant in 1995. The reduction in total seed production as compared with the potential seed production is attributed to intraspecific and interspecific competition. Corn not only competes for similar soil nutrients as giant foxtail but also shades the existing giant foxtail plants. Nutrients and light are both important environmental factors in the

development of giant foxtail (10).

Researchers have noted a correlation between the number of giant foxtail seeds produced and the inflorescence length (2, 20). Seed number per inflorescence, for giant foxtail plants grown in Michigan, exhibited a linear relationship with inflorescence length (Figure 2). However, the total number of seeds produced per plant decreased as giant foxtail density increased.

Researchers have documented plant density and shading influences inflorescence production. The total number of inflorescence produced per plant decreased as giant foxtail density increased (18). Shade reduced the number of leaves, number of stems, and the number of inflorescence produced per giant foxtail plant (10). In our research, inflorescence length increased 21% in 1994 and 22% 1995 as giant foxtail density increased from the minimum to maximum density (Table 5). However, the number of inflorescence produced per plant decreased 78 and 76% in 1994 and 1995, respectively.

Total giant foxtail seed production, which was a function of the number of inflorescence and the length of the inflorescence produced per plant, was estimated. The relationship between giant foxtail density and seeds produced m^{-2} best fits a quadratic equation (Figure 3). This equation depicts an increase in seed production m^{-2} with increased giant foxtail density followed by a plateau, and subsequent decline in total seed production. Cardina *et al.* (4) noted similar effects in velvetleaf seed production. The lowering of total seed production at high density was associated with increased intraspecific competition.

Seed Study. Giant foxtail seed from densities greater than or equal to 30 plants per m of row had greater germination 4 and 7 DAP in 1994 (Table 6). However, 14 DAP there was no significant difference in seed germination. This could be explained by a gradient in dormancy

of the seeds produced by different inflorescence. Because giant foxtail plants grown at low densities produce numerous inflorescence, the dormancy of the seeds from the various inflorescence may be affected. Seed from the more mature inflorescence may have less initial seed dormancy. Giant foxtail density did not affect seed germination in 1995. Overall germination suggests giant foxtail density does not significantly affect seed germination. Other researchers have shown giant foxtail seed color (20) and inflorescence length (2) does not affect seed viability.

LITERATURE CITED

1. Anonymous. 1995. Biological and ecological basis for weed management decision support systems to reduce herbicide use. NC202 Regional Research Project Proposal.

2. Barbour, J.C., III., and F. Forcella. 1993. Predicting seed production by foxtails (*Setaria spp.*). Proc. North Cent. Weed Sci. Soc. 48:100.

3. Bhowmik, P.C. and J.D. Doll. 1982. Corn and soybean response to allelopathic effects of weed and crop residue. Agron. J. 74:601-606.

4. Cardina, J., E. Regnier, and D. Sparrow. 1995. Velvetleaf (*Abutilon theophrasti*) competition and economic thresholds in conventional and no-tillage corn (*Zea mays*). Weed Sci. 43:81-87.

5. Cousens, R. 1991. Aspects of the design and interpretation of competition (interference) experiments. Weed Technol. 5:664-673.

6. Cousens, R. 1985. A simple model relating yield loss to weed density. Ann. Appl. Biol. 107:239-252.

7. Gleason, L.S. 1958. Weed control in corn in the wet tropics. Proc. North Cent. Weed Sci. Soc. 13:54.

8. Harrison, S.K., L.M. Wax and C.S. Williams. 1985. Interference and control of giant foxtail (*Setaria faberi*) in soybeans (*Glycine max*). Weed Sci. 33:203-208.

9. Knake, E.L. 1977. Giant foxtail: the most serious annual grass weed in the Midwest. Weeds Today. 9:19-20.

10. Knake, E.L. 1972. Effect of shade on giant foxtail. Weed Sci. 20:588-592.

11. Knake, E.L. and F.W. Slife. 1969. Effect of time of giant foxtail removal from corn and soybeans. Weed Sci. 17:281-283.

12. Knake, E.L. and F.W. Slife. 1965. Giant foxtail seeded at various times in corn and soybeans. Weeds. 13:331-334.

13. Knake, E.L. and F.W. Slife. 1962. Competition of *Setaria faberii* with corn and

soybeans. Weeds. 10:26-29.

14. Lambert, W.J., T.T. Bauman, M.D. White, and R.A. Vidal. 1994. Giant foxtail (*Setaria faberi*) interference in corn (*Zea mays*). Proc. North Cent. Weed Sci. Soc. 49:137-138.

15. Langston, S.J. and R.G. Harvey. 1994. Using alachlor impregnated on dry fertilizer to create varying giant foxtail populations for corn competition studies. Proc. North Cent. Weed Sci. Soc. 49:18.

16. Little T.M. and F.J. Hill. 1978. Agricultural Experimentation: Design and Analysis. John Wiley & Sons, New York. 195-227 pp.

17. Moolani, M.K., E.L. Knake, and F.W. Slife. 1964. Competition of smooth pigweed with corn and soybeans. Weeds. 12:126-128.

18. Santelmann, P.W., J.A. Meade, and R.A. Peters. 1963. Growth and development of yellow foxtail and giant foxtail. Weeds. 11:139-142.

19. SAS Institute, Inc. 1988. SAS/STAT User's Guide: Release 6.03 Edition. Cary, NC. SAS Inst., Inc., 675-712 pp.

20. Schreiber, M.M. 1965. Effect of date of planting and stage of cutting on seed production of giant foxtail. Weeds. 13:60-62.

21. Staniforth, D.W. 1957. Effects of annual grass weeds on the yield of corn. Agron. J. 49:551-555.

22. Swinton, S.M, J. Sterns, K.A. Renner, and J.J. Kells. 1994. Estimating weed-crop interference parameters for weed management models. Michigan agricultural experiment station, Michigan State University. Research Report 538

23. Young, F.L., D.L. Wyse, and R.J. Jones. 1982. Influence of quackgrass (*Agropyron repens*) density and duration of interference on soybeans (*Glycine max*). Weed Sci. 30:614-619.

Table 1. 1994 and 1995 experiment establishment dates and applications.

	Year	
Event	1994	1995
	---------- Date ----------	
Corn Planting	May 10	May 8
Metolachor Application	May 11	May 10
50% Corn Emergence	May 21	May 18
50% Giant Foxtail Emergence	May 23	May 20
Giant Foxtail Thinning	June 1-3	May 30-31
Bentazon Application	June 11	June 10

Table 2. Rainfall and cumulative growing degree days (base temperature 30/10 C: max /min) data of the 1994 and 1995 growing season.

Weeks after planting	1994		1995	
	Rainfall	GDD	Rainfall	GDD
	cm		cm	
-1	1.8	-----	0.6	-----
0	0.6	28	5.1	38
1	0.0	106	1.6	89
2	0.6	191	1.5	137
3	0.0	274	0.4	230
4	1.0	371	0.5	329
5	7.6	542	0.0	468
6	9.9	656	2.6	621
7	1.7	780	2.9	726
8	9.2	922	2.0	846
9	1.3	1050	3.1	1018
10	3.3	1207	2.6	1160
11	0.0	1332	0.1	1316
12	2.5	1428	4.3	1482
13	6.1	1514	0.7	1666
14	4.1	1632	6.4	1827
15	0.0	1766	0.0	1961
Total	49.7		34.4	

Table 3. Corn yield reduction from giant foxtail density: Rectangular hyperbola regression parameter estimates (and standard errors).

	Estimate		
Parameter	1994	1995	Pooled data
WFY[a]	7590**	12044**	6978**
	(520)	(276)	(426)
D95	------	------	5499**
			(413)
I	1.8	2.4	2.0
	(1.3)	(1.0)	(1.5)
A	57*	28**	39**
	(16.3)	(3.5)	(7.2)
Regression statistics			
Calculated r^{2} [b]	0.84	0.94	0.96

[a] Weed-free yield in kg/ha.
[b] Calculated by 1- (number of observations -1) residual mean square/ total sum square.
*= t value significant at the 0.05 level.
** = t value significant at the 0.01 level.

Table 4. Total dry matter as influenced by giant foxtail density.

	Dry matter			
Density	Corn grain	Corn stalk/ cob	Giant foxtail	Total
plants/ m row	---------- g/ m row ----------			
	---------- 1994 ----------			
0	636	1477	0	1477
10	440	1155	75	1255
30	404	1101	180	1280
60	425	1184	235	1409
84	384	1288	332	1620
98	399	1299	336	1635
LSD (0.05)	206	304	64	NS
	---------- 1995 ----------			
0	986	2287	0	2287
10	853	1651	95	1866
27	842	1641	184	1825
30	829	1512	206	1817
60	717	1680	198	1878
69	685	1380	316	1696
LSD (0.05)	131	238	115	214

Table 5. Giant foxtail seed production as influenced by density.

	Inflorescence length	Inflorescence	Seed
Density	cm	---------- no./ plant ----------	
plants/ m row	---------- 1994 ----------		
10	73	4.6	2514
30	85	2.3	1427
60	86	1.3	704
84	94	1.4	883
98	92	1.0	518
LSD (0.05)	16	0.6	619
	---------- 1995 ----------		
10	65	5.1	2544
27	69	2.6	1239
30	71	2.0	934
60	82	1.3	594
69	83	1.2	586
LSD (0.05)	16	0.7	594

Table 6. Giant foxtail cumulative seed germination as influenced by density.

	Cumulative germination		
	days after exposure		
Density	4	7	14
plants/ m row	%		
	1994		
10	23	45	64
30	34	51	62
60	36	56	62
84	37	54	60
98	40	54	64
LSD (0.05)	7	5	NS
	1995		
10	20	39	59
27	16	40	58
30	16	37	56
60	16	41	55
69	20	46	65
LSD (0.05)	NS	NS	NS

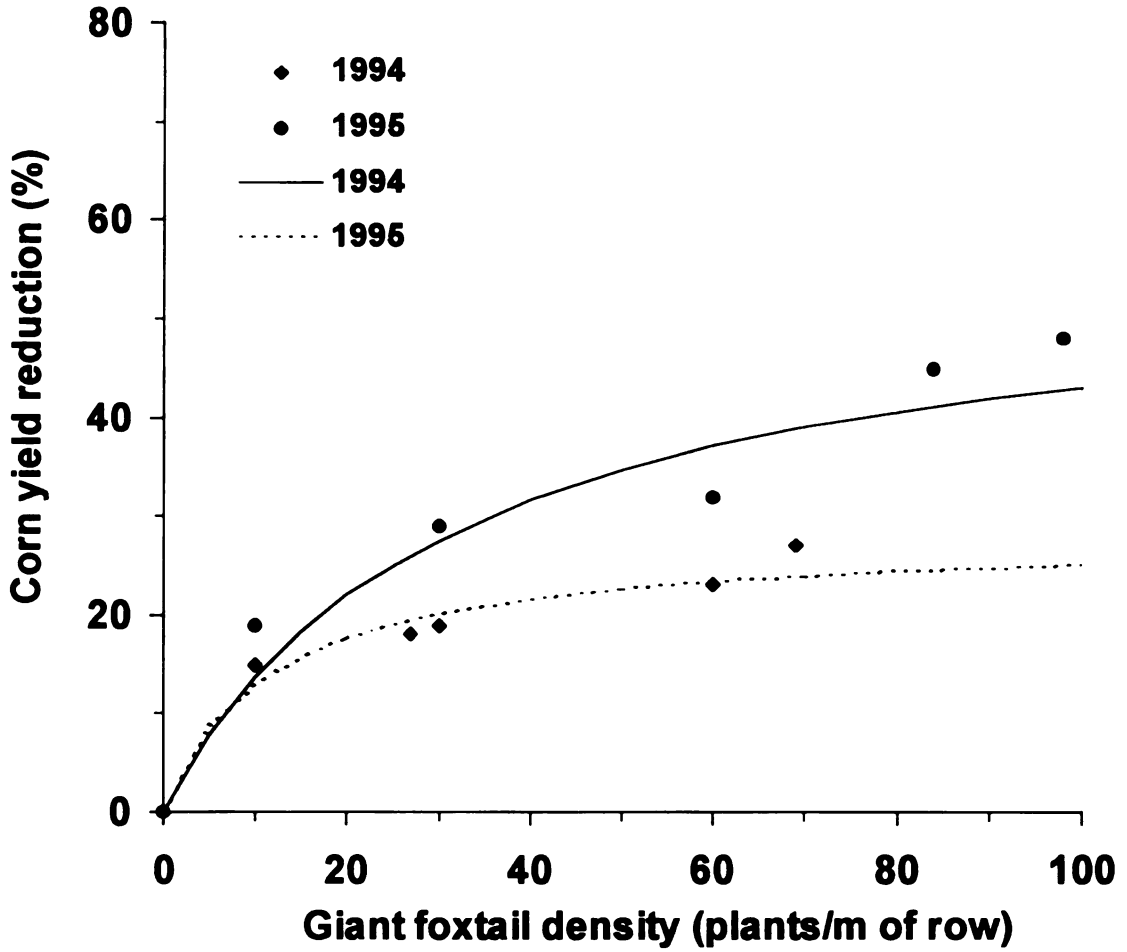

Figure 1. Predicted corn yield reduction in 1994 and 1995 as influenced by giant foxtail density. Equation parameters for these functions are given in Table 3.

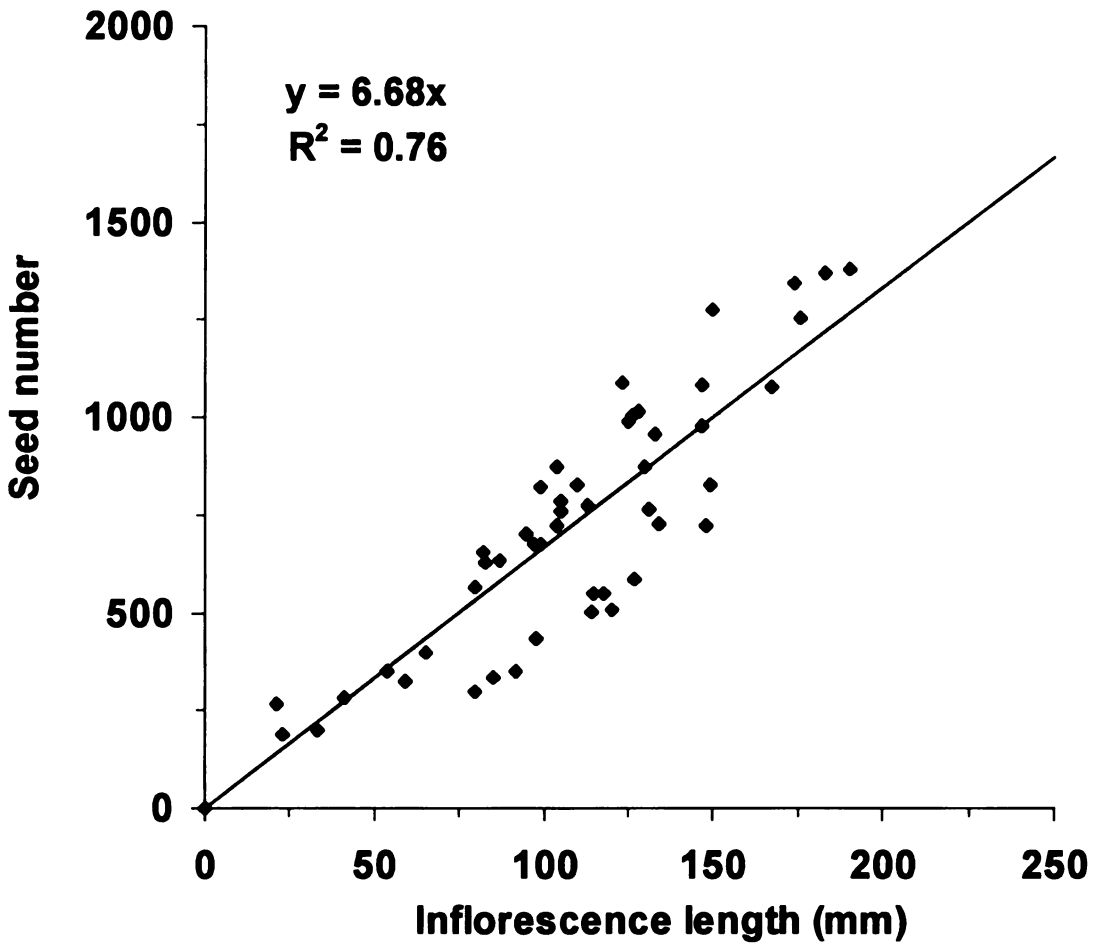

Figure 2. Giant foxtail seed production as affected by inflorescence length.

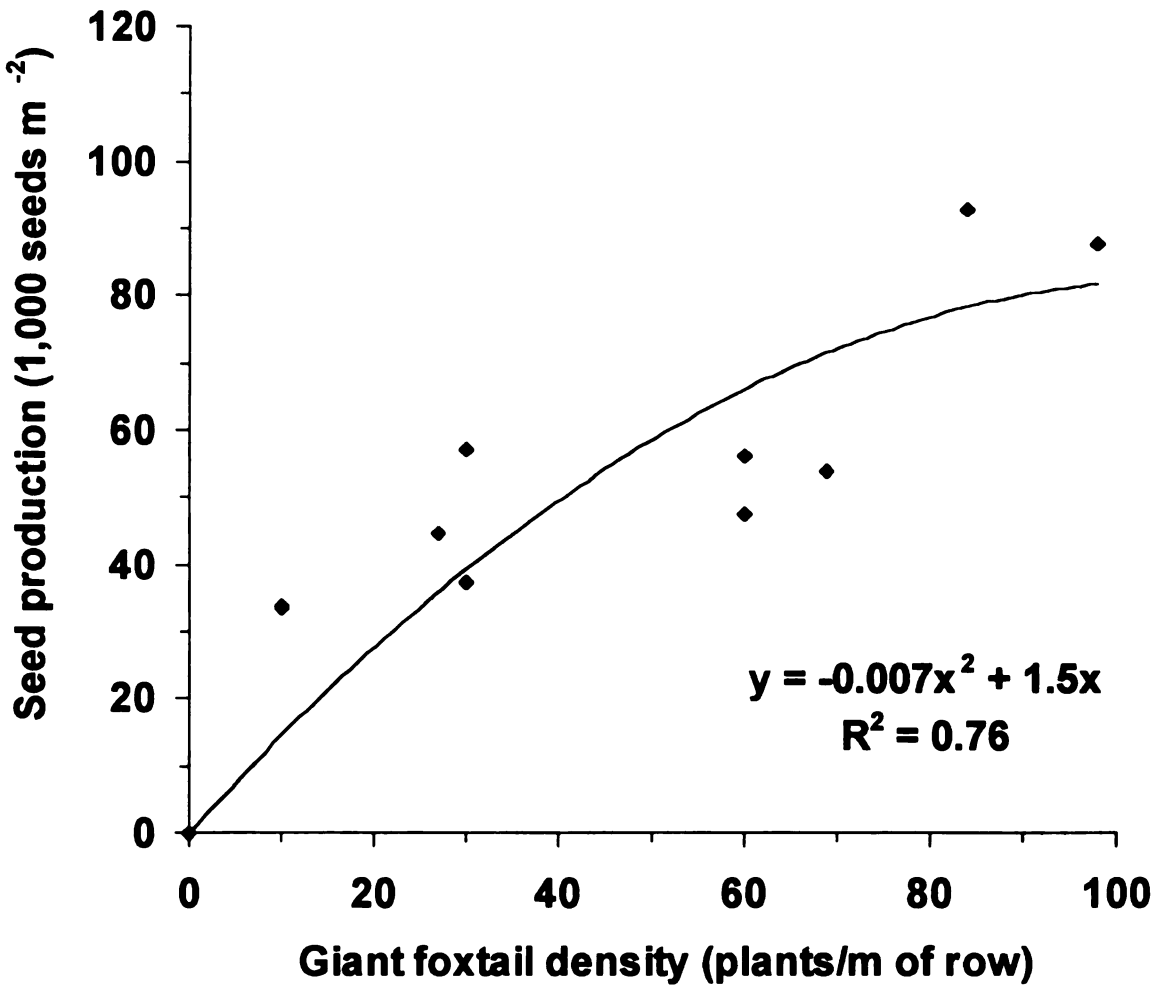

Figure 3. Giant foxtail seed production as influenced by density.

CHAPTER 3

DORMANCY, GERMINATION, EMERGENCE AND SURVIVAL OF GIANT FOXTAIL (*Setaria faberi* Herrm.) AND FALL PANICUM (*Panicum dichotomiflorum* Michx.)

ABSTRACT

Studies were completed to determine giant foxtail [*Setaria faberi* (Herrm.)] and fall panicum [*Panicum dichotomiflorum* (Michx.)] germination, emergence, growth rate, and survival. Freshly harvested giant foxtail and fall panicum seeds were dormant at harvest. Giant foxtail seed dormancy was overcome by an accelerated after ripening treatment of 3 days at 50 C. Fall panicum seed dormancy was overcome by a dark imbibition at 35 C for 7 days. Giant foxtail seed germination exceeded 60% when exposed to either a constant or alternating temperature. Fall panicum seed germination was less than 3% when exposed to a constant temperature, but was greater than 94% when exposed to an alternating 14 C (9 h) 28 C (15 h) temperature regime. Maximum emergence for giant foxtail and fall panicum was from seeds buried 1 cm and 1 to 2.5 cm, respectively. Giant foxtail seedling growth rate was six times greater than that of fall panicum at each temperature regime. Giant foxtail seed viability increased when seeds were buried for six months. However, fall panicum seed viability was not affected by burial. Incorporation of this information into bioeconomic models could result in accurate predictions of weed germination for effective weed

management strategies. Nomenclature: giant foxtail, *Setaria faberi* Herrm. #[1] SETFA; fall panicum, *Panicum dichotomiflorum* # PANDI. *Additional index words*. After-ripening, dormancy, emergence, germination, seed burial, *Setaria faberi*, *Panicum dichotomiflorum*.

[1]Letters following this symbol are WSSA approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 1508 W. University Ave., Champaign, IL 61821-3133.

INTRODUCTION

Giant foxtail and fall panicum are prolific weeds that compete in crop production and produce thousands of viable seeds (10, 16). Ten giant foxtail plants per m of row reduced soybean yield 16% in Illinois (5), while seven fall panicum plants per m of row reduced soybean yield 15% in North Carolina (2). Field grown giant foxtail and fall panicum plants can produce more than 10000 (9) and 500000 (15) seeds, respectively. Giant foxtail and fall panicum escapes not only produce seeds that germinate the following year, but many seeds remain dormant and viable for several years (12). Differences in giant foxtail and fall panicum infestations in the field, may be due to differences in the maximum depth of emergence, seed production, herbicide use, or a differential response to temperature and light.

Freshly harvested giant foxtail seeds were predominantly dormant (10) and unresponsive to light (13). Primary giant foxtail seed dormancy diminished over time at room temperature (14), and similar effects in a shorter time period could be achieved by exposing seeds to higher temperatures. Taylorson and Brown (14) reported increased germination in 81% of the seed lots tested although accelerated after-ripening (AAR) at 50 C caused a decline in germination of some species (14). Secondary seed dormancy in giant foxtail was induced by exposing seed to temperatures greater than 30 C for an extended period, or to 60 C for 7 days (11).

Freshly harvested fall panicum seeds were typically dormant, but dormancy diminished with time (3). Researchers reported maximum fall panicum germination after a

4 to 5 month after-ripening period at 22 C (4). Fall panicum seeds require exposure to light and temperatures greater than 25 C for 9 to 21 days to induce germination (3, 12, 15). Dormancy was also overcome by exposing fall panicum seeds to high temperatures, alternating temperatures, stratification, and mechanical or chemical scarification (12).

Field studies concluded the maximum depth for giant foxtail emergence was 10 cm, but half the emerged giant foxtail seedlings originated from a depth of 1 cm or less in a no-tillage system (7). The greatest emergence of fall panicum was from a 0.2 to 2.0 cm depth (15), while in other research, the maximum emergence depth for buried fall panicum seed was 7 cm (1, 16).

Germination and growth of giant foxtail were temperature dependent (17). Researchers estimated the minimum temperature to initiate giant foxtail germination was 10 C (6). Temperature affects plant biomass and the date of tiller initiation (8). Giant foxtail plants produced the maximum amount of dry matter when exposed to an air temperature of 27 C (9).

Many fields in agricultural production systems are infested with giant foxtail and fall panicum. The use of herbicides has often been associated with the development of specific weed infestations. Researchers have documented, that in 6 hours, fall panicum and giant foxtail metabolized 44 and 7%, respectively, of the ^{14}C atrazine [2-chloro-4-(ethyl-amino)-6-(isopropyl amino)-s-triazine] applied. We could not find and field or greenhouse studies directly comparing the dormancy, germination, and growth of these two grass species under similar environmental conditions. We were interested in whether differences in seed biology could explain the differences in infestations between these two species.

The objectives of this research were: 1) to determine the optimal conditions to

overcome giant foxtail and fall panicum seed dormancy, 2) to determine the effect of temperature on giant foxtail and fall panicum seed germination and emergence, 3) to determine the effect of planting depth on giant foxtail and fall panicum seed emergence, and 4) to quantify giant foxtail and fall panicum seed mortality.

MATERIALS AND METHODS

Seeds were collected in October of 1994 at the Michigan State University Agronomy Research Farm in East Lansing, MI. The mature seeds were hand cleaned and stored dry in sealed containers at room temperature.

Overcoming Seed Dormancy. A three-factor factorial experiment containing four replicates was conducted three times to determine the optimal conditions to initiate giant foxtail and fall panicum seed germination. Twenty-five seed samples were placed in 15 by 45 mm glass vials and sealed with screw caps. The sealed vials were held in an oven at 40 or 50 C (±2 C) for 3 to 14 days. Following the accelerated after ripening (AAR) period, the seeds were placed in 20 by 100 mm petri dishes containing No. 2 Whatman filter paper. Eight ml of distilled water were added and the petri dishes were sealed. Following imbibition, seeds were placed in the dark at 35 C for one week. Seeds were transferred to growth chambers and exposed to an alternating 20 C (16 h) 30 C (8 h) or 20 C (10 h) 30 C (14 h) temperature regime. Seeds were exposed to 300 $\mu E \cdot m^{-2} \cdot s^{-1}$ of fluorescent and incandescent light during the 30 C period. Seeds were considered germinated when the radicle exceeded 2 mm in length. Germination was recorded 14 days after light exposure.

Constant Temperature. A single factor petri dish experiment examined the germination of giant foxtail and fall panicum seeds when exposed to a constant temperature of 20 or 30 C. Pre-treated giant foxtail (3 days AAR 50 C) and fall panicum (3 days AAR 40 C, followed by 7 days dark imbibition at 35 C) seeds were placed in growth chambers after following the

same procedures as the dormancy study. Seeds were exposed to 8 h light (300 $\mu E \cdot m^{-2} \cdot s^{-1}$) and 16 h darkness. Germination was recorded 21 days after light exposure (DAE). The experiment contained six replicates and was repeated twice.

A two-factor factorial experiment examined the effect of constant temperature (20 or 30 C) on giant foxtail and fall panicum seed emergence. Seeds were planted in a Capac loam (fine-loamy, mixed, Mesic Aesic Ochraqualfs) with 1.8 % organic matter and a soil pH of 6.1, at depths of 0, 1, 2.5, 5, 7.5, and 10 cm. Fifteen seeds were planted and emergence was recorded 7, 14, and 21 days after planting (DAP) and plant dry weights recorded. Each treatment was replicated four times and the experiment was repeated twice.

Alternating Temperature. Seed lots of twenty-five pre-treated giant foxtail and fall panicum seeds, using the same procedures as the constant temperature study, were imbibed, transferred to growth chambers, and exposed to three alternating temperature regimes. These were: 1) 7 C (9.4 h) 20 C (14.6 h), 2) 13 C (8.7 h) 26 C (15.3 h), and 3) 14 C (9.0 h) 28 C (15.0 h). Growth chamber settings simulated growing conditions for East Lansing, MI on the 15th of May, June, and July. Seeds were exposed to 8.5, 10.4, and 9.9 h light (300 $\mu E \cdot m^{-2} \cdot s^{-1}$) in the May, June, and July temperature regimes, respectively. Germination was recorded 4, 7, 14, and 21 DAE. The study contained six replicates and was repeated twice.

Another experiment examined the effects of alternating temperatures on seed emergence. Seeds were planted in the same soil at the same depths as in the above-mentioned experiment. Procedures were identical to the constant temperature experiment. Treatments were replicated four times and the experiment was repeated twice.

Seed Burial. Fifty giant foxtail and fifty fall panicum seeds were placed in separate 10 by 10 cm nylon bags. On October 16, 1994 the bags were buried horizontally at 0, 1, 2.5, 5, 10,

20 cm depth in two field locations. The first location was a sandy loam soil with 1.8% organic matter and a soil pH of 6.1. The second location was a sandy clay loam soil with 2.9% organic matter and a soil pH of 6.8%. On April 16, 1995, the bags were exhumed and the seeds removed. All seeds recovered from each bag were tested for germination by placing the seeds in 20 by 100 mm petri dishes containing No. 2 Whatman filter paper and 8 ml of distilled water was added and the petri dishes were sealed. The petri dishes were then placed in growth chambers at 20 C (16 h) 30 C (8 h). Seeds were considered germinated when the radicle exceeded 2 mm in length. Twenty-one DAE the petri dishes were opened and the germinated seeds were removed. Ungerminated seeds were air dried for 7 days and imbibed with 8 ml of distilled water and placed in the growth chambers for an additional 7 days. Seeds were then visually examined to determine if they were nonviable seeds.

Data Analysis. Data were subjected to analysis of variance and in each experiment data is presented separately for each grass species. Means were separated by least significant difference at the 0.05 level.

RESULTS AND DISCUSSION

Overcoming Seed Dormancy. Because both giant foxtail and fall panicum seeds have a strong innate seed dormancy, some external conditioning was required before conducting research on the germination and emergence of these species. Germination of giant foxtail and fall panicum seeds were significantly increased by an AAR treatment, but in a contrasting manner (Table 1). Giant foxtail seed germination was higher when exposed to the 50 C AAR treatment whereas fall panicum seed germination decreased when exposed to the 50 C AAR treatment. The length of AAR was also tested. Previous research noted a decline in germination of giant foxtail when the seeds were exposed to an AAR treatment for greater than 14 days at 50 C or greater than 3 days at 60 C (14). Exposing giant foxtail seeds to three days or longer at either of the AAR temperatures significantly increased germination, when compared with unexposed seed that agrees with research by Taylorson and Brown (14). There was no difference in the germination of fall panicum seeds for any of the AAR lengths tested. Taylorson (12) reported an AAR treatment of 50 C was not sufficient to overcome fall panicum seed dormancy completely, and seed required imbibition and exposure to complete darkness to overcome dormancy. Our results in preliminary studies were similar (data not reported).

Seeds of both species were exposed to two photoperiods (Table 2). Fall panicum germination was not affected by either of the photoperiods tested, but giant foxtail germination was decreased by the 20 C (10 h) 30 C (14 h) photoperiod. Our results support

Alex (1) and others in that the optimum germination condition for fall panicum is either a 20 C (16 h) 30 C (8 h), or a 20 C (10 h) 30 C (14 h) temperature regime (13).

Constant Temperature. Giant foxtail germination decreased when exposed to a constant 30 C, when compared with 20 C (Table 3). Germination of giant foxtail at 20 C was similar to results when the seeds were exposed to alternating temperatures for 21 days (Table 5). Giant foxtail germination was independent of the type of temperature exposure (constant or alternating), but dependent upon the maximum temperature with 30 C reducing germination. Fall panicum germination was less than 3% when exposed to either 20 or 30 C. This supports Taylorson's (12) research in which fall panicum seeds required exposure to alternating temperatures to initiate germination.

The effect of constant temperature on the emergence and individual plant dry weight was also examined (Table 4). Giant foxtail emergence at a constant 20 or 30 C was similar. However, plant dry weight at 20 C was less than plant dry weight at 30 C, and individual plant dry weight decreased by 89% when grown at a constant 30 C when compared to an alternating 14 C (9 h) 28 C (15 h) temperature regime (Table 6). Fall panicum emergence was less than 6% when exposed to a constant temperature, and biomass accumulation by plants emerging in the 30 C chambers was reduced 74% when compared with plants emerging in the 14 C (9 h) 28 C (15 h) alternating temperature regime.

Alternating Temperature. Cumulative germination of giant foxtail seeds 14 and 21 DAE were greatest when exposed to the June and July temperature regimes (Table 5). Fall panicum seeds did not germinate in petri dishes when exposed to the May temperature regime. Fall panicum seeds grown in the June temperature regime required 7 days to initiate germination whereas the July temperature regime required four days to initiate germination.

There was less cumulative emergence of giant foxtail and fall panicum from the six burial depths 7, 14, and 21 DAP when seeds were exposed to the May temperature regime (Table 6). Although none of the fall panicum seeds germinated in petri dishes, 8% of the seeds emerged when placed at the six burial depths in soil for 21 days and exposed to the May temperature regime. This is attributed to soils buffering capabilities and the eventual accumulation to a temperature that induces fall panicum seed germination. Although giant foxtail and fall panicum cumulative germination was greater than 80% in petri dishes, June exposed seeds cumulative emergence was less than 50% for both species. This is attributed to little to no seeds emerging from greater than a 5 cm planting depth. One difference between these species was that June exposed fall panicum seed emergence was greatest 14 and 21 DAP whereas giant foxtail germination in the June and July temperature regimes were equivalent. Meaning that subtle changes in air temperature effects fall panicum emergence more than giant foxtail.

Temperature affected the accumulation of plant biomass by these species. Individual giant foxtail and fall panicum plant dry weight were greater in the July than the June temperature regime. Although June grown plants were exposed 20 minutes longer to the maximum temperature (which was 2 C less than the July maximum temperature), this was not enough to offset the biomass accumulated in either giant foxtail or fall panicum. Giant foxtail plants, when grown under the same conditions, produced six times more individual plant biomass compared with fall panicum. In contrast, Vengris (15) observed fall panicum seedlings emerging between June 23 and July 7 were the most vigorous and fastest growing plants in Massachusetts. These phenomena are intriguing because, as this researcher stated, shading from a crop may reduce the light intensity reaching the soil surface by 70% which will

reduce weed growth. The discrepancy in the growth rates between these data may be explained by a differential rate in growth between giant foxtail and fall panicum when exposed to low light intensities.

Emergence patterns between these species were similar (Table 7). The greatest emergence of giant foxtail and fall panicum in the loam soil was from 1 and 1 to 2.5 cm planting depth, respectively. Giant foxtail and fall panicum seedlings emerging from the soil surface to a 2.5 cm soil depth accumulated the greatest biomass. However, maximum emergence of giant foxtail and fall panicum seeds was from a 7.5 cm planting depth in this loam soil. This could be explained by seedlings emerging from seeds buried 2.5 cm expend less initial energy to develop roots because expanding roots are naturally surrounded by soil.

Seed Burial. Seed recovery was 98% (±2%) for both grass species. Giant foxtail germination decreased when seeds had remained on the soil surface for 6 months but fall panicum did not (Table 8). Ungerminated seeds were visually examined and determined to have lost viability. There was no difference in germination of either grass seed after burial in 1 to 20 cm in the soil for 6 months. Alex (1) conducted a similar seed burial study in Branford, Ontario. He placed fall panicum seeds at the same five burial depths and reported germination after 5 months burial from 73 to 91%, and concluded the average germination increased with increased depth of burial. The lowering in germination in Alex's study could be accounted for in the increase in northern latitude.

Giant foxtail and fall panicum emergence patterns were similar but response to light temperature, were different, as were species growth rates (Table 9). Fall panicum requires an exposure to warm, alternating temperatures and light to initiate seed germination. Implications of this in weed management are that early crop planting could reduce

competition from late emerging fall panicum. Conversely giant foxtail germinated at lower temperatures, and higher temperatures decreased germination. Delaying planting may reduce the number of competing giant foxtail plants if spring soil temperatures exceed 30 C for an extended period of time. Germination decreased by 25% for giant foxtail but only 7% for fall panicum when on the soil surface. Implications are giant foxtail and fall panicum seed germination will decrease if left on the soil surface for 6 months due to induced dormancy, decay, predation, and reduced emergence from the soil surface. Shallow seed burial (upper 1 cm of soil) may optimize emergence, and seed burial will increase giant foxtail seed survival. Researchers increased understanding of weed seed biology my lead to accurate predictions of weed emergence and the ability to develop preventive weed control strategies. Incorporation of this information into bioeconomic models would more precisely predict the time of emergence, the maximum depth in which each weed species can emerge, and the percent of giant foxtail and fall panicum seeds that are not viable by the next growing season.

LITERATURE CITED

1. Alex, J.F. 1980. Emergence from buried seed and germination of exhumed seed of fall panicum. Can. J. of Plant Sci. 60:635-642.

2. Ambrose, L.G. and H.D. Coble. 1975. Fall panicum competition in soybeans. Proc. South. Weed Sci. Soc. 28:36.

3. Baskin, J.M. and C.C. Baskin. 1983. Seasonal changes in the germination responses of fall panicum to temperature and light. Can. J. of Plant Sci. 63:973-979.

4. Brecke, B.J. and W.B. Duke. 1980. Dormancy, germination, and emergence characteristics of fall panicum (*Panicum dichotomiflorum*) seed. Weed Sci. 28:683-685.

5. Harrison, S.K., L.M. Wax and C.S. Williams. 1985. Interference and control of giant foxtail (*Setaria faberi*) in soybeans (*Glycine max*). Weed Sci. 33:203-208.

6. Mester, T.C. and D.D. Buhler. 1991. Effects of soil temperature, seed depth, and cyanazine on giant foxtail (*Setaria faberi*) and velvetleaf (*Abutilon theophrasti*) seedling development. Weed Sci. 39:204-209.

7. Mester, T.C. and D.D. Buhler. 1986. Effects of tillage on the depth of giant foxtail germination and population densities. Proc. North Cent. Weed Sci. Soc. 41:4-5.

8. Michael, J.L., R.S. Fawcett, and S.E. Taylor. 1984. Effects of soil temperature on early growth of giant foxtail (*Setaria faberi*) and velvetleaf (*Abutilon theophrasti* Medic.) in soybeans. Abstr. Weed Sci. Soc. Am. 22:9.

9. Schreiber, M.M. 1965. Development of giant foxtail under several temperatures and photoperiods. Weeds. 13:40-43.

10. Schreiber, M.M. 1965. Effect of date of planting and stage of cutting on seed production of giant foxtail. Weeds. 13:60-62.

11. Taylorson, R.B. 1986. Water stress-induced germination of giant foxtail (*Setaria faberi*) seeds. Weed Sci. 34:871-875.

12. Taylorson, R.B. 1980. Aspects of seed dormancy in fall panicum (*Panicum*

dichotomiflorum). Weed Sci. 28:64-67.

13. Taylorson, R.B. 1972. Phytochrome controlled changes in dormancy and germination of buried weed seeds. Weed Sci. 20:417-422.

14. Taylorson, R.B. and M.M. Brown. 1977. Accelerated after-ripening for overcoming seed dormancy in grass weeds. Weed Sci. 25:473-476.

15. Vengris, J. 1975. Field growth habits of fall panicum. Proc. Northeast Weed Sci. Soc. 29:8.

16. Vengris, J. and R.A. Damon, Jr. 1976. Field growth of fall panicum and witchgrass. Weed Sci. 24:205-208.

17. Wiese, A.M. and L.K. Binning. 1987. Calculating the threshold temperature of development for weeds. Weed Sci. 35:177-179.

Table 1. Cumulative germination of giant foxtail and fall panicum seeds 0, 3, 7, and 14 days after exposure to 40 or 50 C accelerated after-ripening.

	Cumulative germination	
	40 C	
Day after-ripening	Giant foxtail	Fall panicum
	%	
0	43	85
3	58	87
7	62	85
14	64	89
LSD (0.05)[a]	7	NS
	50 C	
Day after-ripening	Giant foxtail	Fall panicum
	%	
0	44	82
3	71	84
7	68	84
14	70	84
LSD (0.05)[a]	7	NS
LSD (0.05)[b]	**	**

[a]Significance between 4 times of after-ripening within each temperature.
[b]Significance between 40 and 50 C accelerated after-ripening temperatures, when averaged over 4 exposure periods.

Table 2. Germination of giant foxtail and fall panicum seeds when exposed for 14 days to two photoperiods.

	Photoperiod		
	8 hrs light	14 hrs light	
Species	Germination		LSD (0.05)
	---------- % ----------		
Giant foxtail	65	55	**
Fall panicum	85	85	NS

Table 3. Germination of giant foxtail and fall panicum seeds following 21 days at a constant (20 or 30 C) temperature.

	Giant foxtail	Fall panicum
Temperature	Germination	
C	---------- % ----------	
20	77	2
30	61	1
LSD (0.05)	**	NS

Table 4. Cumulative emergence and individual plant dry weight of giant foxtail and fall panicum following exposure of seeds to 7, 14 and 21 days at a constant (20 or 30 C) temperature.

	Days after planting							
	7	14	21		7	14	21	
	Giant foxtail				Fall panicum			
Temperature	Emergence			Dry wt.	Emergence			Dry wt.
C	----- % -----			μg	----- % -----			μg
20	21	23	23	0.5	2	5	5	0.7
30	24	24	25	1.6	2	2	2	0.6
LSD (0.05)	NS	NS	NS	**	NS	NS	NS	NS

Table 5. Cumulative germination of giant foxtail and fall panicum seeds in petri dishes 4, 7, 14 and 21 days after exposure to three photoperiods.

	Days after exposure							
	4	7	14	21	4	7	14	21
	Giant foxtail				Fall panicum			
Temperature	Cumulative germination							
	%							
1[a]	60	65	65	70	0	0	0	0
2[b]	68	76	78	82	10	88	88	93
3[c]	68	69	72	81	85	90	92	95
LSD (0.05)	NS	8	8	6	7	4	4	2

[a] Thirty year average for East Lansing, MI for May 15th.
[b] Thirty year average for East Lansing, MI for June 15th.
[c] Thirty year average for East Lansing, MI for July 15th.

Table 6. Cumulative emergence of giant foxtail and fall panicum seeds from 6 planting depths 7, 14 and 21 days after planting and individual plant dry weight when exposed to three photoperiods.

	Days after planting							
	7	14	21		7	14	21	
	Giant foxtail				Fall panicum			
Temperature	Emergence			Dry wt.	Emergence			Dry wt.
	----- % -----			μg	----- % -----			μg
1[a]	22	28	33	2.4	0	1	8	0.3
2[b]	30	43	44	7.9	16	41	50	1.6
3[c]	33	41	42	14.0	22	36	41	2.3
LSD (0.05)	5	6	6	2.6	3	3	3	0.3

[a] Thirty year average for East Lansing, MI for May 15th.
[b] Thirty year average for East Lansing, MI for June 15th.
[c] Thirty year average for East Lansing, MI for July 15th.

Table 7. Cumulative emergence of giant foxtail and fall panicum seeds buried at 0, 1, 2.5, 5, 7.5, and 10 cm 7, 14 and 21 DAP and individual plant dry weight.

	Days after planting							
	7	14	21		7	14	21	
	Giant foxtail				Fall panicum			
Depth	Emergence			Dry wt.	Emergence			Dry wt.
cm	----- % -----			μg	----- % -----			μg
0.0	45	45	49	11.8	28	43	49	2.7
1.0	65	74	74	13.2	32	48	56	2.8
2.5	40	57	64	15.2	16	48	55	2.0
5.0	18	43	47	7.8	1	14	36	0.8
7.5	3	3	3	0.7	0	3	3	0.2
10.0	0	0	0	0.0	0	0	0	0
LSD (0.05)	11	8	8	3.6	5	4	5	0.5

Table 8. Germination of giant foxtail and fall panicum seeds buried six months at 0, 1, 2.5, 5, 10 and 20 cm soil depth and then exposed to 16 hrs 20 C, 8 hrs 30 C.

	Germination	
Depth	Giant foxtail	Fall panicum
cm	---------- % ----------	
0.0	75	98
1.0	87	99
2.5	88	100
5.0	90	99
10.0	96	99
20.0	95	99
LSD (0.05)	10	NS

Table 9. Characteristics of giant foxtail and fall panicum.

Characteristic	Species	
	Giant foxtail	Fall panicum
Seed dormancy at harvest.	Yes	Yes
Requires light to induce germination.[a]	No	Yes
Requires alternating temperature for germination.	No	Yes
Temperature affects germination.	Yes	Yes
Germination May temperature regime.[b]	Yes	No
Germination June temperature regime.[c]		
4 DAE	Yes	No
7 DAE	Yes	Yes
Germination July temperature regime.[d]	Yes	Yes
Germination reduced after 6 mo on soil surface.	Yes	No
Seed survival affected by burial depth.[e]	No	No
Optimal emergence depth.	1 cm	1- 2.5 cm
Percent emergence of seed from the soil surface.	49	49
Growth rate.[f]	14.0 μg	2.3 μg

[a] Preliminary results and Taylorson, 1980.
[b] Thirty year average for East Lansing, MI for May 15th.
[c] Thirty year average for East Lansing, MI for June 15th.
[d] Thirty year average for East Lansing, MI for July 15th.
[e] Seed burial for 6 months.
[f] Individual plant dry weight 21 DAP when exposed to 14 C (9 h) 28 C (15 h) temperature regime.