RESPONSE OF GREEN AND YELLOW FOXTAIL
TO VARYING LEVELS OF SHADE AND FERTILITY

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Carol Jean Bubar

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TABLE OF CONTENTS

PAGE

LIST OF TABLES

TABLE | PAGE

LIST OF FIGURES

ABSTRACT

Bubar, Carol Jean. M.Sc., The University of Manitoba, October, 1981. Response of Green and Yellow Foxtail to Varying Levels of Shade and Fertility. Major Professor; I.N. Morrison.

The growth characteristics of green and yellow foxtail under varying levels of shade and fertility were compared under field and controlled-environment conditions. Field studies conducted at Graysville, Manitoba in 1979 and 1980 showed a differential response of the two foxtail species to shade. Green and yellow foxtail were grown in full sunlight, under polyethylene mesh tents providing 55 and 73% shade, and within a wheat stand. In full sunlight, green foxtail produced significantly greater dry matter and numbers of tillers than yellow foxtail. Under 55 and 73% shade, dry matter production and total leaf area was similar for the two species. Under 55% shade, yellow foxtail was significantly taller and had longer leaves than plants grown in full sunlight. Green foxtail did not react similarly and instead responded to both shade levels with a large reduction in tiller number which was proportionately greater than the decreases seen with yellow foxtail. Within the crop, decreased light availability and crop competition caused even greater effects on foxtail growth. Green foxtail experienced greater reductions in tiller and head number than yellow foxtail. Yellow foxtail grew taller than green foxtail and eventually reached above the crop canopy.

Field studies which examined the response of green and yellow foxtail to low, medium and high nitrogen levels while growing in competition

with wheat, failed to show any consistent trends in 1979 and 1980. Fertility studies were conducted in the growth room in which the effect of six levels of added nitrogen at 0, 50, 100, 200, 300 and 400 ppm on the growth of green and yellow foxtail was examined. Results indicated that at low nitrogen levels, yellow foxtail was more efficient than green foxtail since it produced an equal or greater amount of dry matter per unit of nitrogen applied. The greater dry matter production appeared to be manifested in increased plant height. Head length was also longer in yellow foxtail than in green foxtail and less affected by variations in nitrogen level. At the intermediate nitrogen levels, the two species acted similarly. At higher levels of nitrogen, green foxtail utilized the added nitrogen more efficiently and produced greater numbers of tillers than yellow foxtail. Total protein content was similar in the two species except at the highest nitrogen level where additional nitrogen was not utilized by the yellow foxtail in increasing protein production.

Root and shoot growth patterns of green and yellow foxtail were studied under greenhouse conditions to supplement field and growth room observations. No difference in shoot dry weight between the two foxtail species was found over the growth period. Significant differences in root dry weight were found due to a large increase in yellow foxtail root dry weight just prior to heading. Visual observation of root appearance noted that the root system of yellow foxtail was much coarser than green foxtail.

A small additional study of two Manitoba biotypes and one Ontario biotype of yellow foxtail was included to assess the potential for adaptation and spread of this species in Manitoba. Field studies showed that the two Manitoba biotypes from Carman and Winnipeg were not significantly different in any respect. The Ontario biotype was similar in most respects to the Manitoba biotypes except in the requirement for a longer time to heading and the observed ability to assume a prostrate growth habit in less dense populations. The overall results tend to indicate that yellow foxtail has the potential to spread in this province and become a more serious competitor than green foxtail where conditions of moderate shade and low nutrient status prevail.

INTRODUCTION

> In competition, supremacy may be attained by the species or variety which is able, by virtue of greater physiological activity and morphological adaptability, to utilize the environment most efficiently (Pavlychenko and Harrington 1934).

This tenet pertains not only to species or varieties in direct competition with one another, but may also refer to the relative ability of similar species to morphologically adapt and utilize the environment most efficiently. It seems appropriate that two closely related weed species which occur in similar habitats be investigated. In this category are the two foxtail species, green and yellow foxtail, which are widely distributed throughout North America.

Green foxtail (Setaria viridis L. Beauv.) and yellow foxtail (Setaria glauca L. Beauv., Terrell 1976) are common weeds of cultivated land and waste areas that were introduced from the old world and spread by agronomic practices (Williams and Schreiber 1976). The extent of this spread is exemplified by the results of the 1979 Manitoba weed survey where green foxtail is listed as the province's most abundant weed since it was found on 85% of the fields surveyed, at an average of 65 plants per square meter (Thomas 1979). Although yellow foxtail is much less abundant in Manitoba, 1979 weed survey reports from North Dakota cite it to be the fifth most prevalent weed in wheat fields with an average density of 24 plants per square meter (Dexter, personal communication). Since both these weeds are known for their ability to spread swiftly, it is reasonable to expect that yellow foxtail may increase in abundance in Manitoba in the future.

History has shown that after the first detection of green foxtail in Manitoba in 1883, infestations had become widespread only 50 years later (Alex _et al_. 1972). These researchers stated that by 1965 dense infestations were common in many areas of the Prairies with Manitoba having a total infested acreage of 53%. A survey carried out from 1963 to 1967 by Alex _et al_. (1972) indicated that of the three prairie provinces, green foxtail was most abundant in Manitoba appearing in 84% of the fields as compared to 32% in Saskatchewan and 28% in Alberta. In fact the highest density observed was in a field in central Manitoba and was an amazing 10,000 plants per square meter (Alex _et al_. 1972).

The high densities of green foxtail in Manitoba have been ascribed to several factors. Firstly, the time the land has been under cultivation may be significant. Since Manitoba was settled before the other prairie provinces, there has been more opportunity for spread of this weed (Alex _et al_. 1972). Secondly, the cropping systems in Manitoba may have influenced the spread. Summerfallowing, which is known to hinder build up of seed, is a more common practice in Saskatchewan and Alberta than in Manitoba where sufficient moisture allows for more intensive continual cropping (Alex _et al_. 1972). Thirdly, control methods used for other problem weed species have been a contributing factor in the increase of green foxtail. Since shallow tillage in early spring combined with delayed seeding used for wild oat control is thought to favour germination of green foxtail, these cultural practices may have aided in the build up of this weed. Also, the use of herbicides such as 2,4-D and other broadleaf weed killers as well as the newer wild oat herbicides, which have been used extensively across the Prairies for a number of years, may have allowed green foxtail to survive and grow unchecked by competition from other weeds.

Regardless of which factors were responsible for the spread of green and yellow foxtail, the important consideration is that both species are present in ever increasing numbers sufficient to compete and cause crop yield losses. Therefore, any information which would increase our knowledge of the factors affecting their relative competitive ability would be beneficial. It is especially important to learn more about the growth characteristics of yellow foxtail under Manitoba conditions before this weed becomes well established in this province. The most useful parameter of comparison is green foxtail which has already been the subject of much research in western Canada.

The main purpose of this study was to examine and compare the growth patterns of green and yellow foxtail under varying levels of shade and fertility both in the field and in a controlled environment. In addition, a small study of the growth characteristics of three biotypes of yellow foxtail was undertaken to assess the potential for adaptation and spread of this species in Manitoba.

LITERATURE REVIEW

Competition

As early as 1960, Friesen and Shebeski (1960) recognized that although green foxtail was not as competitive as wild mustard (Sinapis arvensis L.) or wild oat (Avena fatua L.), yields of cereals could be significantly reduced by heavy infestations of 3765 to 4840 green foxtail plants per square meter. Dryden and Whitehead (1963) emphasized that moderate infestations of green foxtail of 1075 to 1615 plants per square meter would have little or no effect on barley or oat yields, but might harm wheat since this crop offers less competition to green foxtail plants. However, some controversy exists in the literature with respect to the actual density of green foxtail required to cause significant wheat yield losses. Alex (1967) reported that 1575 green foxtail plants per square meter could reduce the yield of wheat by 35%, while Rahman and Ashford (1972) found that green foxtail infestations of up to 1550 plants per square meter had no effect on the growth or yield of wheat plants. At the other extreme, Sturko (1978) noted that as few as 100 green foxtail plants per square meter reduced the yield of both semi-dwarf and normal height wheat varieties.

The degree of competition between green foxtail and wheat was shown by Sturko (1978) to vary with the environmental conditions present at the time of seeding and early plant growth. Several other researchers have also concluded that plant density is not as important in determining the competitiveness of green foxtail as the climatic conditions that prevail during germination and plant emergence (Blackshaw 1979; Rahman and Ashford

1972). According to Banting *et al*. (1972), green foxtail must emerge at the same time or a little ahead of the crop in order to provide highest levels of competition. As Blackshaw (1979) outlined, green foxtail requires higher levels of soil moisture and higher soil temperatures than does wheat for optimum germination and early seedling growth. Therefore, the cool weather usually associated with early spring seedings will delay emergence of the green foxtail and normally would allow wheat to become established free from intense competition. Should seeding be delayed or warm weather prevail in early spring, there will be more competitive injury due to green foxtail infestations (Vanden Born 1971).

Alex *et al*. (1972) imply, however, that the relationship between weather and emergence of the crop and weed may not always be clearcut. In their tests, wheat and green foxtail emerged together regardless of the date of seeding. They concluded that since wheat is usually sown 5 to 7.5 cm deep and green foxtail plants generally emerge from close to the soil surface, the difference in temperature between these two levels may allow the foxtail and wheat to emerge more or less together.

Other factors may also have a bearing. Banting *et al*. (1973) indicated that soil texture could be an important factor. Since coarse textured soils warm up earlier in the spring than fine textured soils, green foxtail may be a more serious problem in the former situation. Obviously, there is no simple means of predicting the level of green foxtail competition in a crop like wheat.

Yellow foxtail has received considerably more attention in the United States than Canada as a weed in corn, soybeans, sugar beets, wheat, oats, sorghum and in first year plantings of alfalfa (Schoner *et al*. 1978). Work done by Huemoeller (1967) in North Dakota showed that a yellow foxtail population of 130 or more plants per square meter was sufficient to reduce wheat grain yields. Vengris (1963) noted that although early seedings of yellow foxtail did not compete well with corn; in later seedings the height of the yellow foxtail approached that of plants seeded in pure stands. He concluded that the competitiveness of yellow foxtail continues throughout most of the growing season.

In competition experiments with soybeans, Staniforth (1965) observed that the competition offered by green and yellow foxtail was approximately equal since mature plant yields were essentially the same for the two species. Yellow foxtail was not found to be extremely competitive with sorghum since large numbers of plants were required for durations longer than 6 weeks from crop emergence to significantly affect sorghum yields (Feltner _et al_. 1969). It is readily apparent that the degree of competition offered by yellow foxtail, as with green foxtail, is strongly dependent upon the associated crop and the duration of competition.

The threat to crop production may not always be measured in terms of immediate crop yield reductions. Vanden Born (1971) stated that green foxtail plants emerging as late as the middle of August are unlikely to compete and lower crop yield. However, these green foxtail plants may still produce a significant amount of mature seed in a short time. Vengris (1963) found that seedings of yellow foxtail made in mid-August in Massachusetts were able to mature and produce ripe seeds. Therefore, it is important to emphasize that even noncompetitive infestations of these weeds are capable of producing enough viable seed to ensure serious infestations the next year. Rahman and Ashford (1972) have calculated that if only 50 to 70% of the seeds produced by green foxtail plants growing in competition with wheat were to germinate in the following year, the infestation of foxtail would be increased two- to three-fold. As well, seeds of both foxtail species have been shown to remain viable in the soil after 13 years of burial (Dawson and Bruns 1975). It was shown by Banting et al. (1973) that seed viability tended to increase with depth in the soil and thus it is necessary to perform shallow tillage to avoid deep burial of seeds.

Growth Characteristics

Staniforth (1965) pointed out that although differences in competitive efficiencies among various crop and weed species have been shown, less is known about the differences between crop varieties or similar species of weeds. This is especially true in the case of green and yellow foxtail. It is important to gain information about the growth characteristics of these two weeds in order to predict their individual competitive effects on crop yields. Peters et al. (1963) emphasized that such information is needed to further our understanding of the biology and ecology of these weeds to permit a more intelligent approach to their control.

In both green and yellow foxtail, photosynthetic carbon fixation is by the Hatch Slack C_4 pathway (Black et al. 1969; Chen et al. 1970). Therefore, these two species belong to a group of plants which have characteristic photosynthetic responses to light intensities and temperature which will be discussed further in the next section. In this section, the basic growth characteristics of green and yellow foxtail will be reviewed and compared with those of other C_4 plant species including barnyardgrass (*Echinochloa crusgalli* L. Beauv.), fall panicum (*Panicum dichotomiflorum* Michx.) and witchgrass (*Panicum capillare* L.), in order to determine whether or not distinct development patterns exist within the C_4 group.

As far as germination of these C_4 species is concerned, it appears that temperature is the most important factor. Vanden Born (1971) found that while green foxtail seed germinated readily over a range of 15 to 35 C, germination was significantly reduced at temperatures above or below that range. At 10 C there was no sign of germination for a period of nearly 4 weeks. Blackshaw (1979) noted in field experiments that a temperature of 14 C accounted for a 1 week delay in time to 50% emergence of green foxtail as compared to emergence at 22 C. Santelmann *et al*. (1963) observed that germination of yellow foxtail in the greenhouse continued over a long period with 60% of the seeds emerging within 1 week after seeding. In field experiments conducted by Dawson and Bruns (1962), yellow foxtail emerged earlier in the spring than either green foxtail or barnyardgrass which led the authors to state that yellow foxtail germinates at lower temperatures and thus would be most likely to germinate during short periods of warm weather in the winter or spring and suffer cold injury.

Vengris and Damon (1976) pointed out that weeds which are taller and produce higher yields of foliage are better competitors. Therefore, it is important to consider relative height and dry matter production of different species. It was well established that plants emerging early in the season produced the highest dry matter yields and tallest plants as compared to plants emerging later in the season (Vanden Born 1971; Santelmann et al. 1963; Vengris *et al*. 1966; Vengris and Damon 1976). Vengris *et al*. (1966) noted that the later barnyardgrass seedlings emerged, the shorter the plants. Santelmann *et al*. (1963) found that height of yellow foxtail plants followed a typical sigmoid growth pattern regardless of plant density or location. They observed that all plants had a slow initial growth period for 10 to 20 days after emergence which was followed by a rapid growth period for up to 70 days before tapering off.

When tillering and heading characteristics of a number of C_4 species are examined, it appears that there are distinct differences in response to environmental stimuli. In yellow foxtail, fall panicum and witchgrass the greatest number of tillers and heads were produced on plants which emerged early in the season (Santelmann et al. 1963; Vengris and Damon 1976). It was felt that daylength was the controlling factor so that the longer growing period and longer exposure to light helped to accumulate more dry matter. On the other hand, Vengris et al. (1966) noted a slight but consistent increase in the number of tillers and heads for barnyardgrass plants emerging later in the season. They hypothesized that tillering of barnyardgrass is not controlled by daylength, but instead by other unidentified factors. In the case of green foxtail, Vanden Born (1971) observed that tiller number per plant was not affected by planting dates ranging from May 15 to July 24 in the field.

In seed production studies, Vanden Born (1971) found that the majority of green foxtail heads were 7 to 9 cm long and contained from 350 to 500 seeds. Consequently, he felt that under good growing conditions with limited crowding, a green foxtail plant could produce from 5000 to 12,000 seeds. In comparison, Santelmann et al. (1963) reported that each yellow foxtail had an average of 180 seeds. With an average of 47 heads per plant under favourable conditions, a single yellow foxtail plant could produce over 8000 seeds.

Shade

Studies of a variety of plant species have established that light intensity during plant growth affects overall plant and leaf morphology as well as the photosynthetic process within the leaf (Boardman 1977). Gross plant morphology reacts to a reduction in light intensity by stem elongation through etiolation. In general, leaves which grow under shaded conditions are thinner with less well developed palisade and spongy mesophyll regions and larger chloroplasts than associated sun grown leaves (Boardman 1977). More specifically, Friend et al. (1962) showed that a decrease in irradiance caused an increase in leaf length and leaf area with a corresponding decrease in leaf breadth and thickness. Although their investigations were with wheat, they indicate that this type of response is typical of other species within the grass family.

Photosynthesis increases with light intensity up to some maximum level where diffusion of carbon dioxide becomes the limiting factor. This maximum level, known as the saturation light intensity, is determined by the genetic make-up of the plant. Black et al. (1969) have categorized plants with the C_4 cycle as "efficient" since they have the ability to increase their photosynthetic rate as light intensity increases to full sunlight. This maximum rate at full sunlight is two- to three-fold higher than the rate achieved by so-called "non-efficient" C_3 plants (Black et al. 1969). Moreover, the increased rate of photosynthesis is also associated with increases in temperature so that the maximum rate is achieved at temperatures between 30 to 40 C with sharp decreases below 15 to 20 C (Black et al. 1969). Therefore, C_4 plants like green and yellow foxtail are capable of increased growth and vigour which could make them serious weed pests under favourable conditions of high light intensity and temperature. However, since both of these weeds are chiefly a problem within crop stands where light intensity is reduced to some extent by crop shading; it is important to know how they grow and react under reduced light intensities.

Harper (1972) reported that one major effect of shade is to slow down the rate of photosynthesis relative to respiration which may be manifested in a decreased rate of growth. In the remainder of this section the growth response to varying levels of shade of not only green and yellow foxtail but other C_4 grass species including fall panicum, witchgrass, giant foxtail (Setaria faberii Herrm.) and itchgrass (Rottboellia exaltata L.f.) as well as a nongrassy C_4 species, yellow nutsedge (Cyperus esculentus L.) will be reviewed. For the sake of comparison, a C_3 grass, timothy (Phleum pratense L.), will be included.

In all of the species studied, low light intensities significantly reduced total dry weight although the level of shade required to bring about dry weight reductions varied. With green foxtail, yellow foxtail, giant foxtail and yellow nutsedge, the decrease in total dry weight was almost directly proportional to the increasing shade level (Vanden Born 1971; Peters et al. 1963; Knake 1972; Keeley and Thullen 1970). Huemoeller (1967) found that 75% shade was required to significantly reduce shoot dry weight of yellow foxtail.

With respect to plant height, both Knake (1972) working with giant foxtail and Vengris and Damon (1976) working with fall panicum and witchgrass noted that although height was decreased under shade, it was less affected by variations in light intensity than other morphological characteristics. Patterson (1979b) found that 40% shade actually stimulated elongation of itchgrass, but greater shading limited overall growth to sufficiently reduce height when compared to the unshaded control. He stated that other studies have shown plant height to increase with increasing shade until photosynthate production becomes limiting.

Shading reduced tiller production in green and yellow foxtail, itchgrass and giant foxtail (Vanden Born 1971; Santelmann et al. 1963; Patterson 1979b; Knake 1972). However, Knake (1972) emphasized that even with 80% shading, individual giant foxtail plants produced an average of 21 culms. He observed that while the number of basal tillers decreased with increased shade, the shaded plants had more tillers produced along the stems.

Regarding the C_3 grass timothy, Ryle (1961) found that shade decreased tiller number markedly with a significant response occurring 2 to 3 weeks after the plants were shaded. Under 77% shade, new tillers were produced but the plants were unable to sustain them.

In growth chamber experiments, Vanden Born (1971) discovered that reproductive growth of green foxtail was influenced more seriously by reduced light intensity than was vegetative growth. At 60 days after planting green foxtail at the lowest light intensity (252 $\mu Em^{-2}s^{-1}$) only had an average of three heads per plant compared to 22 at the highest light intensity (576 $\mu Em^{-2}s^{-1}$). Vengris and Damon (1976) noticed a similar sensitivity of head number to reduced light intensity in fall panicum and witchgrass. Not only were seed yields decreased but head appearance and maturity were also delayed by shading with significant differences between shade levels apparent in witchgrass (Vengris and Damon 1976). Knake (1972) not only found a linear decrease in head production with increased shade levels in giant foxtail, but also saw a trend toward shorter length of heads. A similar reaction to shade was noted by Ryle

(1961) in timothy, with a decrease in head length from 10 to 6 cm as the shading was intensified from 0 to 77% shade. These results seem to bear out the general conclusion of Vengris and Damon (1976) that low light intensities comparatively harm flowering and seed production to a much greater extent than vegetative development.

Nitrogen Fertility

Plants differ in their ability to take up and respond to applied nitrogen. According to Brown (1978) grasses depend primarily on inorganic forms of nitrogen and growth responds strongly to increased nitrogen supply. However, he also feels that there is a difference within the grass family between C_3 and C_4 plants in their use of nitrogen. Cultivated tropical C_4 grasses respond to nitrogen to a much greater degree in terms of dry matter produced per unit nitrogen applied than do temperate C_3 grasses (Brown 1978). Therefore, it would seem that green and yellow foxtail would compete strongly with C_3 grass crops like wheat for nitrogen fertilizer additions.

Alex (1967) found that green foxtail competed well with wheat for soil nitrogen and a similar response was noted by Moyer and Dryden (1976). They saw that green foxtail responded to nitrogen fertilizer additions and was able to compete successfully with wheat. They discovered that green foxtail growing within wheat deprived the crop to the extent that the nitrogen content of the grain was lowered. It would appear that the use of broadcast fertilizer and especially high rates of nitrogen encourage the growth of green foxtail and aid in its competitiveness. Sturko (1978) concurs with this conclusion as he stated that the higher rate of nitrogen may have enhanced green foxtail's vegetative growth and therefore caused the weed to be more competitive than at lower levels of nitrogen.

However, yellow foxtail competition for nitrogen in wheat does not seem to be so clearcut. Huemoeller (1967) stated that the addition of fertilizer allowed wheat to compete favourably with increased populations of yellow foxtail over the unfertilized plots. He felt the fertilizer raised the competitiveness of the wheat against the foxtail by stimulating early growth of the crop. This type of response has been shown for both green and yellow foxtail in competition with corn. Nieto and Staniforth (1961) and Staniforth (1961) observed that the greatest effect of both foxtail species on corn yields was seen under conditions of low nitrogen availability. After a high rate of nitrogen application, the crop was apparently able to utilize the added fertility first to grow rapidly and shade out the foxtail. The fact that corn is also a C_4 species may have some effect on its competitive efficiency at high nitrogen levels.

Brown (1978) proposed that the greater nitrogen use efficiency of C_4 grasses may give them an adaptative advantage particularly in sites low in nitrogen. Schreiber and Orwick (1978) pointed out the significance of this adaptability to low fertility sites since weeds growing in these areas along fence rows and roadsides serve as sources of infestation for crop fields. This statement is especially true in the case of foxtail and these two investigators examined yellow foxtail, giant foxtail, giant green foxtail (Setaria viridis var. major Gaud. Posp.), robust white foxtail (Setaria viridis var. robusta-alba Schreiber) and robust purple foxtail (Setaria viridis var. robusta-purpurea Schreiber) to ascertain whether or not differences in growth and response to low, medium and high levels of nitrogen existed. It was noted for all five taxa that there is a direct relationship between the amount of nitrogen fertility and the dry weight produced. However, with the exception of yellow foxtail, significantly more dry matter was produced at the medium than at the low nitrogen level. This response seems to indicate that yellow foxtail is better able to grow on low fertility soils than the other taxa. Schreiber and Orwick (1978) discovered that yellow and giant foxtail had significantly greater leaf area than the other taxa at all three fertility levels studied which led these researchers to suggest that these two taxa should be better competitors for light, especially at low nitrogen fertility levels. Yellow foxtail also produced significantly more root matter than the other taxa at the lowest nitrogen level with giant foxtail being equal to yellow foxtail at the other levels. The root:shoot ratios followed a similar trend, especially at the low nitrogen level, with ratios for yellow foxtail being greater than for giant foxtail, which in turn, was greater than the other three taxa which were roughly equivalent. In light of these results, it is not surprising that Schreiber (1977) found giant foxtail and yellow foxtail to be the dominant members of the same five taxa studied on undisturbed areas of low fertility soils.

According to Bosemark (1954), there is an inverse relationship between nitrogen supply and root development. Under low levels of nitrogen, roots tend to be long, thin and sparsely branched while increasing levels of nitrogen cause the roots to grow shorter and thicker with more branches (Black 1968). Consequently, when examining the competitive abilities of different species at varying nitrogen levels, it is necessary to be aware of the possible effects on root growth.

Root Growth

Initial root growth and development of plants is extremely important as it not only determines whether or not the plant survives but also has a marked effect on the ability of the plant to compete with other plants for water, nutrients and space (Evetts and Burnside 1973). As Pavlychenko and Harrington (1935) pointed out, competition between overlapping root systems takes place long before the tops begin to interact and shade one another.

Although several studies describing differential root growth between unrelated genera have been carried out (Pavlychenko and Harrington 1935; Dittmer 1948; Evetts and Burnside 1973) variation in root growth among closely related species or varieties of a species has received little attention (Orwick and Schreiber 1975). In studies of differential root growth of giant foxtail, giant green foxtail, robust white foxtail and robust purple foxtail, it was shown that the first 3 days of growth were important to overall root growth patterns in foxtail (Orwick and Schreiber 1975). Robust white foxtail showed the greatest root length followed by giant green foxtail, robust purple foxtail and lastly, giant foxtail. Similar to the results of Hackett (1969), it was noted that the root systems of the four taxa maintained a constant relationship among root members during growth (Orwick and Schreiber 1975). It was also discovered that robust white foxtail had the highest root mean extension rate (M.E.R.) of the four taxa which illustrated its superior growth potential. These M.E.R. values supported Hackett's hypothesis that C_4 grasses have mean extension rates five to eight times higher than those of C_3 grasses (Hackett 1973). Orwick and Schreiber (1975) feel that higher mean extension rates may be yet another identifying characteristic of C_4 grasses influencing competitive ability.

Although very little information is available on the root growth of green and yellow foxtail specifically, Schreiber and Orwick (1976) did point out that root dry weight was higher in yellow foxtail under a 12 hour photoperiod than all of the other foxtail taxa studied regardless of the fertility level. Dittmer (1948) studied the root growth of green foxtail and found it to be the only species examined which had only secondary branching with no tertiary branches evident. Since Pavlychenko and Harrington (1934) emphasized that competitive efficiency is due to the distribution rather than the size of the root system, the larger root mass of yellow foxtail may not necessarily be an advantage while the root system of green foxtail may be at a disadvantage, if branching is restricted under normal growing conditions.

Biotypes

Variations in morphology and vegetative growth within a species have been recorded for many plants (Schoner et al. 1978). Vanden Born (1971) discussed the possibility of "ecological strains" existing within green foxtail which had significant differences in length of seed dormancy. In a collection of giant foxtail selections from Maryland and Connecticut, Peters et al. (1963) noted a substantial variation in height from 104 to 150 cm and in tiller number from 7.1 to 15.1 between the different selections. Roche and Muzik (1964) collected seed of barnyardgrass from different areas of Washington state which comprised five separate biotype categories. The five categories varied in morphology from prostrate to upright and in characteristics of the panicle ranging from a tight panicle with many short awns to an open panicle with few awns. In studies carried out with six ecotypes of johnsongrass (Sorghum halpense L. Pers.) collected from several regions of the United States, McWhorter and Jordan (1976) discovered quite a variation in height between the different ecotypes. However, this variation in height was only evident during the first 4 to 6 weeks of growth with height differences decreasing after that period. Differences in time to flowering were also noticeable and supported the hypothesis of an existence of latitudinal ecotypes within this species.

In the case of yellow foxtail, Peters et al. (1963) observed considerable variation in size of plant, habit of growth, number of tillers and time of flowering between seedlots collected from several sites in Maryland and Connecticut. Perhaps the most noticeable difference was in growth habit which ranged from prostrate to upright. More recent studies by Schoner et al. (1978) compared yellow foxtail biotypes from three areas in California with biotypes from Connecticut, Masachusetts, Pennsylvania and Iowa under uniform conditions in California. It was observed that the three California biotypes were almost identical in every respect. However, basic differences were shown to exist between the California biotypes and those from the eastern states with the most noticeable difference being in growth habit. All four biotypes from the eastern states were erect in habit while the California biotypes were prostrate. The authors suggested that increased plant height would be useful when competing with other weeds or tall crop plants but the prostrate growth habit might be advantageous for the California yellow foxtail. Since the chief areas of infestation of yellow foxtail in California are within alfalfa fields, the prostrate habit allows the weed to escape mowing and thus does not prevent seedset.

With respect to reproductive capacity, a high number of heads would obviously be an advantage in maintaining and increasing the population of the biotype. In this study, the California and Massachusetts biotypes were found to be by far the most prolific seed producers. The Connecticut biotype, which produced the least number of heads was also the earliest maturing which would undoubtedly be a necessity in areas where the growing season is short (Schoner et al. 1978). This research indicates that yellow foxtail has the ability to adapt to very specific environmental and cultural conditions which gives it the potential to be a very serious weed in a variety of locations, including Manitoba.

MATERIALS AND METHODS

General Procedures

Field experiments were conducted at the Graysville Weed Research Station in 1979 and 1980. The soil is classified as an Almasippi very fine sandy loam composed of 79% sand, 7% silt, 14% clay, 3.6% organic matter and a pH of 7.5. Weather data for 1979 and 1980 are presented in the Appendix in Tables 1 and 2, respectively.

The plot areas were fumigated with methyl bromide[1] to eradicate all weeds and weed seeds prior to planting. The application rate was based on a dosage of six 6.8 kg cans per 84 m^2 of plot area. The exposure time was increased from the recommended 24 to 48 hour period up to 5 days in 1980 as a result of cold weather. After the exposure period the plot areas were aerated for a minimum of 72 hours before seeding. Soil fertility was determined from a soil test[2] and fertilizer was hand broadcast at recommended rates at the time of seeding. In 1979, 176 kg/ha ammonium nitrate (34-0-0) and 94 kg/ha ammonium phosphate (11-55-0) were applied. In 1980, soil fertility was higher so that only 91 kg/ha 34-0-0 and 82 kg/ha 11-55-0 were used.

Unless otherwise specified, the green and yellow foxtail seed used in all experiments was obtained in 1978 from a commercial seed cleaning

[1]Methyl bromide application procedures as outlined by the Dow Chemical Company Limited, in the Dowfume MC-2 information phamphlet.

[2]Analysis of soil fertility was done by the Provincial Soil Testing Laboratory, Winnipeg, Manitoba.

plant courtesy of D. Lumgair, Thornhill. The germination percentage was determined by placing two 50 seed samples on moist filter paper in petri dishes. The petri dishes were placed in the dark at room temperature and germination counts were made for 2 weeks. According to the germination percentage and 100 seed weight, seed samples were then weighed to give predetermined densities of 300 to 400 plants per m^2 for each plot. In 1979, the green foxtail had a germination percentage of 90 which yielded 0.50 g of seed per m^2. The yellow foxtail had a lower germination percentage of 80 which equalled 1.0 g of seed per m^2. In 1980, seed weights were based on a higher initial plot density of 450 plants per m^2. Soon after emergence the plots were thinned to the lower densities. Both the green and yellow foxtail seed had a germination percentage of 80 which resulted in 0.64 and 1.2 g of seed per m^2, respectively.

In 1979, after fertilizer application and just prior to seeding, the plots were disced twice and then harrowed with a spike toothed harrow. In 1980, only the harrowing procedure was necessary. After raking the plot areas to ensure even seed distribution, the green and yellow foxtail seed was hand broadcast. Immediately after seeding, the areas were once again raked lightly to incorporate the seed.

In 1980, due to broadleaf weed infestations, the plots were sprayed with bromoxynil/MCPA[3] at a rate of 0.56 kg/ha in 110 l/ha of water. Because of the very dry soil conditions in 1980, the plots were hand watered five times using a 1365 liter tank and pump during the period from June 5 to June 24. During this period, approximately 76 to 88 mm of water was applied.

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[3]Buctril M, a commercial formulation of 1:1 bromoxynil/MCPA, was supplied by the May and Baker Chemical Company.

After emergence, green and yellow foxtail counts were taken using two 1/16 m^2 quadrats. Hand thinning was carried out where necessary to ensure that densities were uniform from plot to plot. In 1979, it was very difficult to ensure that plants selected were of a comparable age, especially during more advanced stages of growth. Consequently, in 1980 coloured ring markers were used to indicate plants that had emerged at the same time. Once the plants reached the three- to four-leaf stage sampling was initiated and continued on a weekly basis until maturity. Sampling involved selection of five representative plants per plot which were placed in plastic bags. The plants were kept in styrofoam coolers with ice packs until they could be measured. Within 48 hours, the five plants were washed and the roots removed. Fresh and dry weight determinations were made on all five plants while measurements of leaf area, height, tiller and head number were taken of the median two (1979) or three (1980) plants. Dry weights were determined after oven drying the sample at 80 C for 48 hours. Leaf areas per plant were measured using a leaf area meter[4].

All data was analyzed statistically and the Least Significant Difference (LSD) test was used at the test of significance. Only differences at the 5% level of significance were considered meaningful.

Shade Experiment

The experimental design was a split-plot, replicated four times with the overall plot area equalling 89.6 m^2 and each main plot measuring 2 by 2.8 m. The main plots consisted of 0% shade (control), 55% shade, 73%

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[4]Portable Leaf Area Meter, Model L1-3000, Lambda Instruments Corporation, Lincoln, Nebraska.

shade and the shade offered by a wheat crop under normal competitive conditions. The subplots were green and yellow foxtail with the fourth treatment oversown to Neepawa wheat. The wheat plots were planted by hand, since the design of the experiment did not allow the use of a seed drill. The predetermined density of planting was 180 plants per m^2 and 16 rows 2 m in length and 15.2 cm apart were planted in each plot. In 1979, the wheat was sown on June 6, while in 1980, planting was on June 4. In both years the foxtail was hand broadcast the following day early in the morning when there was little wind to ensure even distribution of seed throughout the plot.

Once the foxtail had reached the two-leaf stage, the shade tents were erected on June 23 in 1979 and June 26 in 1980. The shade tents consisted of black polyethylene mesh cloths[5] supported on a framework of aluminum hoops. These hoops fit into metal pipes which in turn were inserted through boards and driven into the ground. The tents were set up in a north-south orientation (see Figures 1 and 2). In 1980, moveable mesh flaps were added to the south end of each tent to ensure that the plants on the south end were not exposed to full sunlight at midday.

A light integrator[6] was placed in the field to continuously monitor the amount of light reaching a pyranometer (400 - 1200 nm) sitting 5 cm above the ground within the wheat canopy. In 1979, the integrator was placed in the field on June 26 as compared to July 9 in 1980 and weekly measurements and observations in crop stage and height were recorded. In addition, weekly light measurements were taken using a light meter[7] at two sites and

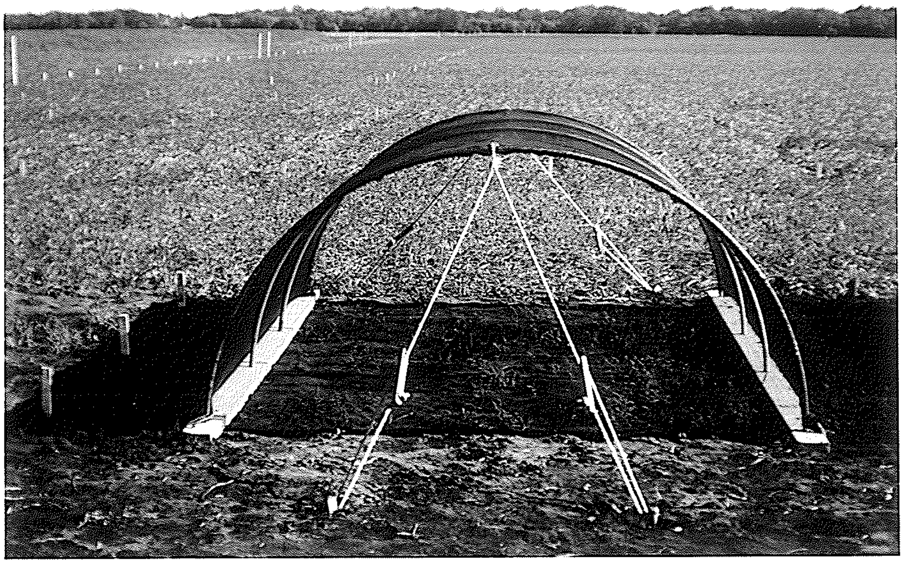
[5]Supplied by Ball Superior Company Limited, Mississauga, Ontario.

[6]Light Integrator, Model L1-510, Lambda Instruments Corporation, Lincoln, Nebraska.

[7]Light Meter, Model L1-185A, Lambda Instruments Corporation, Lincoln, Nebraska.

Figure 1. Close-up view of polyethylene mesh shade tent. Note that in 1980, rope guidelines were removed and a moveable flap was placed on south end of tent.

Figure 2. Field layout of experiment with shade tents set up in north-south orientation.



three heights within the crop canopy consisting of ground level (0 cm), midway into the canopy (30 cm) and near the top of the canopy (60 cm). In 1979, only the quantum sensor (400 - 700 nm) was used while in 1980 readings were taken with both the quantum and pyranometer sensors. The light reduction for each level with the canopy was calculated as:

$$\% \text{ Light Reduction} = 100 - \left(\frac{\text{Light Intensity Within}}{\text{Light Intensity Above}} \times 100\right)$$

The light meter was also used to check the percent shade beneath the shade cloths. It was found under both bright and cloudy conditions that the cloths were accurate ($\pm$ 1%).

Thermometers were placed under one of the shade tents for each treatment as well as in the full sunlight to determine whether or not variations in temperature occurred beneath the black cloths. It was found that regardless of the weather conditions the temperatures under the tents never varied more than 2 C from outside (Appendix Table 3).

Soil moisture was measured on August 6, 1980 after several days of wet weather to see if the tents affected the amount of moisture reaching the foxtail plants. Soil samples were taken from depths of 0 to 5 cm and 5 to 15 cm using a soil auger. The soil samples were placed in previously weighed and labelled tins. The wet weight was taken and the soil samples were oven dried at 105 C for 72 hours. Soil moisture as a percent of dry soil weight was calculated as:

$$\% \text{ Soil Moisture} = \left(\frac{\text{Wet Soil Weight} - \text{Dry Soil Weight}}{\text{Dry Soil Weight}}\right) \times 100$$

It was determined that there was no significant difference in soil moisture between the shade treatments.

Sampling was carried out weekly until the foxtail plants reached maturity. Measurements included dry weight, fresh weight, leaf area, extended length of the fourth leaf, height, tiller and head number.

The wheat plots were hand harvested at maturity. Samples from two 1/4 m^2 quadrats per plot were sickled, dried and threshed with a Vogel stationary thresher. The threshed sample was cleaned using a Clipper seed cleaning machine and the weights recorded. Harvesting took place on September 12, 1979 and September 16, 1980.

Fertility Experiments

Field

The experiment was designed to determine the response of green and yellow foxtail to low, medium and high levels of nitrogen while in competition with Neepawa wheat. The level of nitrogen present in the soil was determined by a soil test. Sufficient quantities of ammonium nitrate (34-0-0) were added to raise the soil nitrogen level up to the required treatment levels of 30, 60 and 90 kg/ha N in 1979 and 50, 100 and 150 kg/ha N in 1980. The experiment was a split-plot design replicated four times with the overall plot area equalling 216 m^2 and each main plot measuring 4.5 by 4 m. The main plots consisted of the three nitrogen levels with subplots of green foxtail, yellow foxtail and no foxtail (control). The wheat was sown on June 6, 1979 and June 4, 1980, with a double disc press drill at a rate of 98 kg/ha and a depth of 6 cm with a 15 cm row spacing. In both years, the foxtail was hand broadcast the following day. Measurements taken included plant counts and dry weights of both the wheat and foxtail. To obtain final grain yields, the wheat was straight combined with a Hege small plot combine in 1979. However, since this method was not considered accurate enough for such small plots, in 1980 harvesting was done by hand sickling 1 m^2 quadrats from each plot.

Each sample was dried, threshed, cleaned and the weights recorded. Harvesting occurred on September 17, 1979 and September 25, 1980.

Growth Room

The experimental design was a split-plot, replicated four times. The main plots consisted of six levels of added nitrogen at 0, 50, 100, 200, 300 and 400 ppm with subplots of green and yellow foxtail. The experiment was carried out twice in 1980 with the first trial beginning February 1 and ending April 15 and the second trial beginning July 1 and ending September 18.

Soil was collected for each trial from the Graysville Weed Research Station and the level of nitrogen and other elements present was determined by a soil test. Soil collected for the second trial was higher in all three major elements (N, P, K) than in the first trial but the same amount of nitrogen was added both times. In addition to the nitrogen source, 50 ppm phosphate, 160 ppm potassium and 65 ppm sulfur was added to each pot. The nitrogen source for the six treatments was lab grade ammonium nitrate (NH_4NO_3) and the amounts added consisted of 0, 0.43, 0.86, 1.72, 2.57 and 3.43 g per 3000 kg of soil. The other nutrient requirements were satisfied by 0.61 g Ca $(H_2PO_4)_2.H_2O$ and 1.07 g K_2SO_4.

Field capacity was determined by taking the wet weight of soil which had been saturated with water over a 48 hour period and then oven dried at 105 C for 48 hours. In a similar manner, moisture was determined by taking the wet weight of representative soil samples and then oven drying the same samples. Both values were calculated as a percent of dry soil weight.

After determining the field capacity to be 24% and the soil moisture to be 3 to 4%, a constant volume of soil (3.5 kg) was weighed out for each pot. The soil was then ground by hand as uniformly as possible and the nutrients were mixed evenly throughout the soil. The fertilized soil was then placed in 3.8 l plastic pots with no drainage holes. The pots were watered by weight to slightly above field capacity to ensure complete wetting of the soil. Once the soil equilibrated to field capacity, 20 seeds each of green and yellow foxtail were shallowly planted to a depth of 1 cm or less in separate pots.

The pots were placed in the growth room under day/night temperatures of 23/16 C in the first trial and 21/15 C in the second trial and light intensities averaging 145 $\mu Em^{-2}s^{-1}$ at bench level. To compensate for variations in light intensity across the bench, the pots were systematically rotated every 2 to 3 days within the replicate and within the subplot. At the end of the second trial, light readings were also taken to determine whether or not the light intensity changed over the experimental period. It was found that the light intensity was reduced to approximately one-half of the original reading.

The pots were watered every 2 to 3 days by weight to field capacity. After the foxtail emerged the pots were thinned to five plants per pot and observations were taken throughout the growth period.

Harvesting of the foxtail occurred when the plants exposed to the lower nitrogen treatments began to senesce. The plants were cut off at soil level and measurements taken included dry weight, height, tiller and head number and head length per plant. Dry samples were then ground up and protein content per shoot was determined[8]. Soil samples were taken from each treatment and analyzed to determine levels of nitrogen remaining.

[8]Protein content was determined by the Kjeldahl Laboratory, University of Manitoba, Winnipeg, Manitoba.

Growth Curves Experiment

The design of the experiment was a split-plot with four replications. The main plots consisted of eight sampling dates with subplots of green and yellow foxtail. The experiment was run twice in 1980 with the first trial beginning on February 23 and ending on May 12 and the second trial beginning on September 23 and ending on December 6. A greenhouse soil mix of two parts sand, two parts soil and one part perlite (V/V/V) was used with 45 g of ammonium phosphate (16-20-0) per 280 kg soil mix. This mix was chosen to facilitate washing of the roots. In the first trial, filter paper was placed in the bottom of each 15 cm plastic pot to allow for sufficient drainage of water and maximum retention of soil mix. However, since it was found that the roots were difficult to separate from this paper, the technique was modified in the second trial. Masking tape was used to cover all but one hole which was covered loosely with a small stone to allow for drainage. Twenty seeds each of green and yellow foxtail were shallowly planted to a depth of 1 cm or less in separate pots. In addition to the treatment pots, guard row and replacement pots of both green and yellow foxtail were sown.

The pots were placed in a greenhouse bench under two high light intensity banks. Prior to commencement of the experiment, the light intensities of the two banks were made equivalent to an intensity of 170 to 180 $\mu Em^{-2}s^{-1}$ during the daytime. Watering was done on a daily basis.

After emergence, the foxtail were thinned to 10 plants per pot. Once the plants reached the four- to five-leaf stage, sampling occurred weekly until the latter stages of the experiment when growth diminished. Sampling consisted of carefully removing the soil from the roots with a gentle stream of water. Observations were made on growth stage, tiller and head number. Finally, the roots and shoots were separated and the dry weight per 10 plants was recorded. Each time pots were removed from the experiment by sampling, all remaining pots were shifted systematically to the left and replacement pots filled the gaps when necessary.

After 7 and 8 weeks, two applications of full strength Hoaglands solution was added to the remaining pots. In the second trial, the plants were sprayed with morestan[9] to control spider mites.

Yellow Foxtail Biotype Study

The experiment was a randomized complete block design replicated four times with the overall plot area equalling 27 m^2 and individual plots measuring 1.5 by 1.5 m. The three treatments consisted of Ontario, Winnipeg and Carman biotypes of yellow foxtail. The Ontario seed came from seed which originally was obtained from Harrow, Ontario and was grown out for 1 year at the Graysville Research Station in 1978. The Winnipeg seed came from seed which was similarly grown out at the station in 1978. The Carman seed was originally obtained from D. Lumgair in 1978.

Plots were sown on June 11, 1979 and June 5, 1980. Sampling began when the plants were in the three- to five-leaf stage and continued until the Winnipeg and Carman biotypes reached maturity. The Ontario biotype was delayed in maturing. Measurements taken included dry weight, leaf area, height, tiller and head number. As the biotypes reached maturation, the seed heads were harvested, placed in cloth bags and dried outdoors. The heads were hand threshed and the seed cleaned with an air column. The seed was then divided into five different lots for storage and germination tests.

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[9]Morestan, a product of Chemagro Chemical Company.

RESULTS

Shade Experiment

As is reported in Table 1, in 1979 green foxtail had higher final plant densities than yellow foxtail in the control and 55% shade treatments while under 73% shade and within the crop densities were more nearly equal. In 1980, the situation was reversed with higher populations of yellow foxtail in the control as well as in the 55 and 73% shade plots. In both years densities of green and yellow foxtail within the crop were quite low.

TABLE 1. Final plant densities of green foxtail (GF) and yellow foxtail (YF) at three shade levels and within the crop in 1979 and 1980.

Shade level	Density			
	1979		1980	
	GF	YF	GF	YF
	(plants/m^2)			
0%	408	342	308	432
55%	436	386	356	412
73%	416	424	364	416
In Crop	314	306	326	260

With few exceptions, yellow foxtail had a higher fresh weight per plant (Table 2) than green foxtail at the 0, 55 and 73% shade levels.

TABLE 2. Shoot fresh weight per plant of green foxtail (GF) and yellow foxtail (YF) at three shade levels and within the crop in 1979 and 1980.[1]

Shade level	Shoot Fresh Weight													
	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		Week 8	
	GF	YF	GF	YF	GF	YF	GF	YF	GF	YF	GF	YF	GF	YF
	(g)													
1979														
0%	0.04	0.10*	0.44	0.70*	1.2	1.6	17.7	25.3	37.2	66.5*	32.8	108.3*	29.4	72.5*
55%	0.06	0.12*	0.40	0.68*	1.1	1.3	24.5	33.0	30.4	38.8	38.8	84.3*	33.3	64.6*
73%	0.08	0.11*	0.36	0.61*	1.0	1.7	18.2	24.5	21.5	26.8	30.3	53.2	36.8	41.3
In Crop	0.05	0.08*	0.21	0.38	1.5	3.9*	5.3	8.5	11.3	9.2	10.4	11.7	7.6	9.0
LSD (0.05)[2]	0.02		0.17		0.8		11.5		18.7		44.0		24.7	
1980														
0%	0.24	0.30*	0.87	0.93	2.3	2.2	8.0	8.9	25.9	28.1	43.2	50.6	92.6	91.8
55%	0.17	0.20	0.51	0.69	1.1	1.6	5.1	7.4*	13.7	21.0*	16.9	29.6*	37.3	53.6*
73%	0.16	0.20*	0.43	0.52	0.9	1.2	4.0	3.4	9.8	12.0	9.5	11.9	18.3	32.1*
In Crop	0.07	0.12*	0.48	1.01*	1.5	2.6*	2.3	4.1	6.6	9.1	7.8	7.9	5.8	6.1
LSD (0.05)	0.04		0.28		0.7		2.0		3.0		7.8		11.1	

[1]Asterisk indicates that mean is significantly greater than comparable species mean at same shade level, same date ($p = 0.05$).

[2]LSD (0.05) is used for column comparisons between shade levels within each species at same date.

High yellow foxtail fresh weights in the 0% shade (control) plots resulted in significant differences occurring between green and yellow foxtail in 1979 while in 1980 no differences in fresh weight were observed after the first sampling date. Under 55% shade, yellow foxtail had a significantly greater fresh weight than green foxtail toward the end of the season in both years. No significant differences between the fresh weights of either species grown in full sunlight and under 55% shade were evident in 1979. Compared to the control plots, the 55% shade level caused a 60% reduction in green foxtail fresh weight in contrast to a 40% reduction in yellow foxtail fresh weight in 1980.

Under 73% shade differences between species only existed early in the season. Under this higher shade level, yellow foxtail fresh weight was affected to the same extent as green foxtail fresh weight. No significant fresh weight reductions were found with green while with yellow foxtail significant differences occurred only at the end of the season in 1979. In 1980, fresh weight reductions under 73% shade were very similar for the two species, increasing from 30 to 80% over the season.

Comparisons between fresh weights under the 55 and 73% shade levels for each species showed that while there was no significant difference in fresh weight of green foxtail under the two shade levels, the higher shade level caused a significant reduction of up to 60% in yellow foxtail fresh weight. Foxtail growing within the crop showed a decrease in fresh weight which was similar to those plants growing under 73% shade. Significant differences between the two foxtail species existed early in the season with yellow foxtail having a higher fresh weight than green foxtail. However, as the season progressed the fresh weight of yellow foxtail was reduced to the same level as that of green foxtail.

The dry weights of green and yellow foxtail under 55 and 73% shade were not significantly different at any sampling date in 1979 or 1980 (Table 3). In contrast, plants in the unshaded control plots showed a significant difference in green and yellow foxtail dry weight by the end of the season in 1979 and throughout most of the season in 1980. No consistent trend was seen, however, as the final dry weight per plant under 0% shade differed between the two species over the 2 years. In 1979, yellow foxtail plants showed a higher final dry weight than green foxtail with the reverse situation occurring in 1980. In the second year, green foxtail was able to attain a final dry weight which was twice that of 1979 while the final dry weight of yellow foxtail was very similar in both years.

In comparing dry weights of foxtail growing under 0% shade with those under 55 and 73% shade levels in 1979, significant differences occurred only at the end of the season. In 1980, significant reductions in dry weight in the shaded plants were present throughout the season. The extent of reduction in dry weight occurring under 55% shade was similar for the two species in both years with reductions of approximately 30 to 50% in dry weight evident over most of the season. Under 73% shade, dissimilar results were noted between the 2 years with greater percent dry weight reductions of approximately 50 to 80 occurring in both species in 1980. This variation in the extent of dry weight reductions in the 2 years might explain why no differences were seen between plants of either species under 55 and 73% shade in 1979 while significant differences were evident by the end of the season in 1980.

The dry weight of the two foxtail species growing within the wheat crop was roughly the same for most of the season. As would be expected,

TABLE 3. Shoot dry weight per plant of green foxtail (GF) and yellow foxtail (YF) at three shade levels and within the crop in 1979 and 1980.[1]

Shade level	Shoot Dry Weight													
	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		Week 8	
	GF	YF	GF	YF	GF	YF	GF	YF	GF	YF	GF	YF	GF	YF
	(g)													
1979														
0%	0.006	0.011*	0.06	0.07	0.17	0.17	3.7	3.0	9.3	9.8	9.2	15.0*	11.2	15.8*
55%	0.008	0.010	0.04	0.06	0.12	0.13	3.6	3.0	5.7	4.3	8.3	10.9	8.8	9.2
73%	0.007	0.008	0.04	0.05	0.12	0.16	2.5	2.3	3.6	2.8	6.1	6.8	9.3	6.0
In Crop	0.006	0.008	0.02	0.04	0.22	0.45*	1.7	1.2	2.7	1.6	2.8	2.3	2.8	2.2
LSD (0.05)[2]	0.004		0.04		0.08		1.2		2.9		4.3		3.9	
1980														
0%	0.031	0.037*	0.12	0.10	0.30*	0.22	1.39*	1.05	4.8*	3.2	8.7*	6.2	26.7*	16.0
55%	0.021	0.021	0.06	0.06	0.12	0.14	0.75	0.77	2.3	2.2	3.0	3.3	9.2	8.3
73%	0.023	0.019	0.05	0.05	0.10	0.10	0.56	0.37	1.5	1.2	1.4	1.1	4.3	4.7
In Crop	0.006	0.011*	0.05	0.08	0.19	0.22	0.48	0.50	1.7	1.6	2.1	1.5	2.0	1.3
LSD (0.05)	0.007		0.04		0.07		0.33		0.7		1.1		4.0	

[1]Asterisk indicates that mean is significantly greater than comparable species mean at same shade level, same date ($p = 0.05$).

[2]LSD (0.05) is used for column comparisons between shade levels within each species at same date.

dry weights were significantly reduced in comparison to the plants in the unshaded control plots in both years. However, in 1979 the differences in dry weights did not show up until later in the season while in 1980 they were evident all season long.

Although variations in dry weight between green and yellow foxtail occurred over the 2 years, the rate of dry matter accumulation or relative growth rate (Table 4) showed a very consistent trend. The relative growth rate, which is defined as the increase of plant material per unit of material present per unit of time (Radford 1967), was not significantly different for green and yellow foxtail at any shade level or in either year, with a few exceptions in 1979. Both species showed a similar growth pattern under 0, 55 and 73% shade with the most rapid growth occurring in the third week which corresponded with the early tillering stage. Later in the season, the growth rate gradually slowed. Although the 55 and 73% shade levels did not appreciably affect the relative growth rate of either species, the pattern for foxtail growing within the crop was quite different compared to 0% shade. These plants had their period of highest growth rate early in the season, before the initiation of tillering, after which the growth rate diminished rapidly.

Measurements of total leaf area per plant (Table 5) showed no differences between green and yellow foxtail under the 55 and 73% shade levels in either 1979 or 1980. In the unshaded control plots, results were very inconsistent and showed no conclusive trend in either year. Leaf area in week 4 of 1979 was at least twice as great as in the same date in 1980, regardless of the shade level. This indicates that in the early stages of development, leaf growth was slower and less vigorous in 1980 than in 1979. Comparisons between plants in the control plots and those under

TABLE 4. Relative growth rate of green foxtail (GF) and yellow foxtail (YF) at three shade levels and within the crop in 1979 and 1980.[1]

Growth interval (weeks)	Relative Growth Rate							
	Shade Level (%)						In Crop	
	0		55		73			
	GF	YF	GF	YF	GF	YF	GF	YF
	($gg^{-1}wk^{-1}$)							
1979								
1-2	2.08	1.88	1.68	1.85	1.72	1.98	1.45	1.52
2-3	1.25	0.85	1.10	0.79	1.17	0.10	2.27	2.62
3-4	3.08	2.93	3.43	3.10	3.04	2.70	1.96*	0.97
4-5	0.87	1.17*	0.44	0.38	0.32	0.24	0.56	0.31
5-6	0.06	0.44	0.37	0.82	0.57	0.88	-0.01	0.34
6-8	0.11	0.03	0.03	-0.11	0.21*	-0.09	-0.13	-0.04
1980								
1-2	1.34	0.98	1.10	1.15	0.76	0.96	2.16	2.14
2-3	0.91	0.82	0.69	0.77	0.69	0.75	1.27	0.89
3-4	1.55	1.56	1.76	1.67	1.76	1.28	0.92	0.79
4-5	1.23	1.11	1.15	1.06	1.00	1.11	1.28	1.21
5-6	0.61	0.66	0.29	0.41	-0.10	-0.03	0.24	-0.09
6-8	0.37	0.32	0.36	0.31	0.38	0.47	-0.01	-0.04

[1]Asterisk indicates that mean is significantly greater than comparable species mean at same shade level, same growth interval ($p = 0.05$).

TABLE 5. Leaf area per plant of green foxtail (GF) and yellow foxtail (YF) at three shade levels and within the crop in 1979 and 1980.[1]

Shade level	Leaf Area							
	Week 1		Week 2		Week 3		Week 4	
	GF	YF	GF	YF	GF	YF	GF	YF
	(cm^2)							
1979								
0%	2.1	2.8	13.1	19.3*	48.0	35.7	243.0	437.1*
55%	3.3	4.0	17.0	20.2	43.6	36.6	502.9	573.5
73%	3.5	4.0	16.6	19.9	38.9	52.0	413.7	465.2
In Crop	2.7	4.5*	11.8	12.8	48.8	106.7*	156.9	160.2
LSD (0.05)[2]	1.5		5.6		21.0		128.8	
1980								
0%	6.3	6.8	20.6	17.7	57.0*	42.0	191.5	177.6
55%	5.8	5.5	17.0	15.4	35.1	38.2	137.8	167.8
73%	5.5	6.2	12.7	12.8	27.3	26.4	117.2	88.7
In Crop	2.8	4.8*	15.9	28.9*	49.6	61.3	74.4	85.8
LSD (0.05)	1.6		6.2		15.5		43.1	

[1]Asterisk indicates that mean is significantly greater than comparable species mean at same shade level, same date ($p = 0.05$).

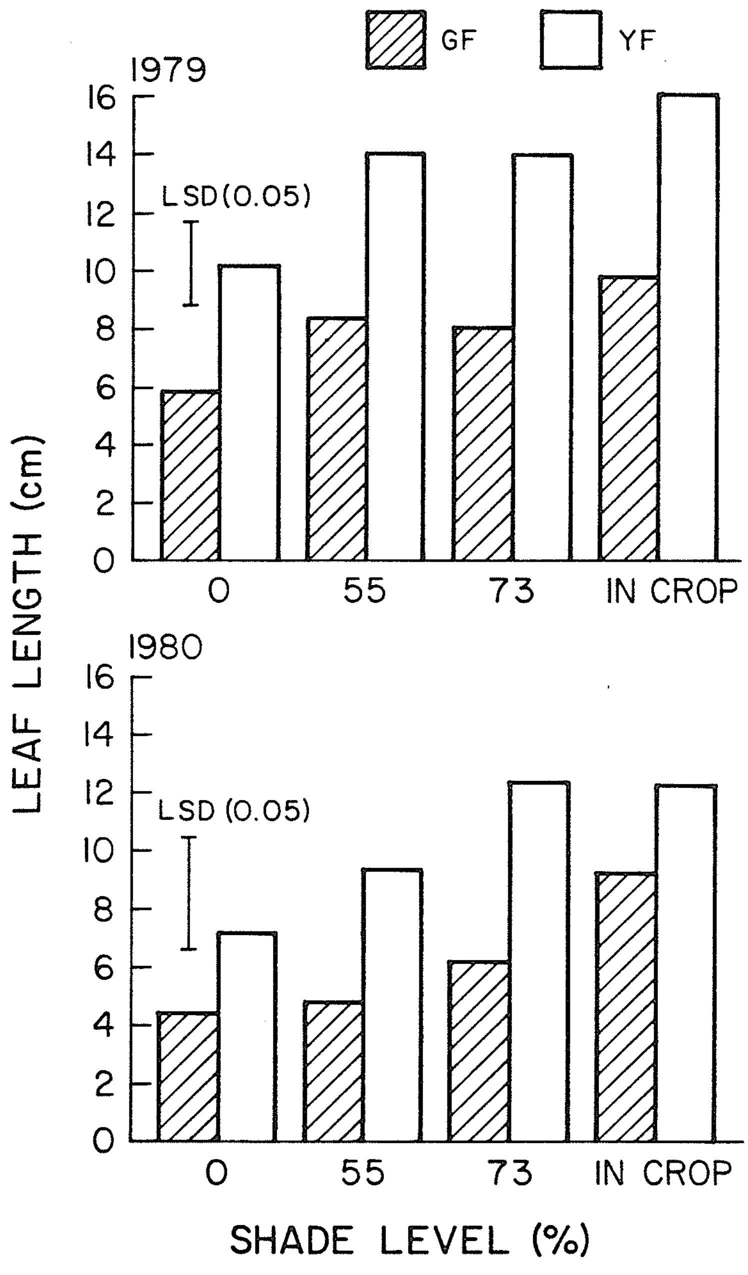
[2]LSD (0.05) is used for column comparisons between shade levels within each species at same date.

shade showed equally variable results for each species. At the end of the 4th week in 1979, green and yellow foxtail under 55 and 73% shade levels showed increased leaf area compared to control plants. However, in 1980 both species showed significant decreases in leaf area with up to 50% reductions under 73% shade.

The response of the two species growing in the crop was also inconsistent. Although yellow foxtail had a greater leaf area at all dates in both years, significant differences were not always present. In 1979, no trend was apparent while in 1980 differences in leaf area between the two species were only significant at the beginning of the season, after which time the leaf area of green foxtail was the same as that of the yellow foxtail. In comparing leaf areas of foxtail growing within the crop with those in the control plots, it is evident that while green foxtail plants either showed no difference or a reduction in leaf area, yellow foxtail plants showed significant increases of approximately 40 to 60% in leaf area early in the season.

The extended length of the fourth leaf of both species was examined in week 2 when plants were in the five- to six-leaf stage, just prior to tillering. As shown in Figure 3, yellow foxtail had a longer fourth leaf than green foxtail regardless of the shade level. However, significant differences between the two species only existed at the 55 and 73% shade levels. At these levels, yellow foxtail leaves were almost twice as long as those of green foxtail. There was also a trend toward increasing leaf length with increasing shade level from 0 to 55 and 73% shade for both species although trends were not consistent over the 2 years. In 1979, green and yellow foxtail responded similarly to changes in shade level from 0 to 55% and 0 to 73% with increases in leaf length of close to 40%. In

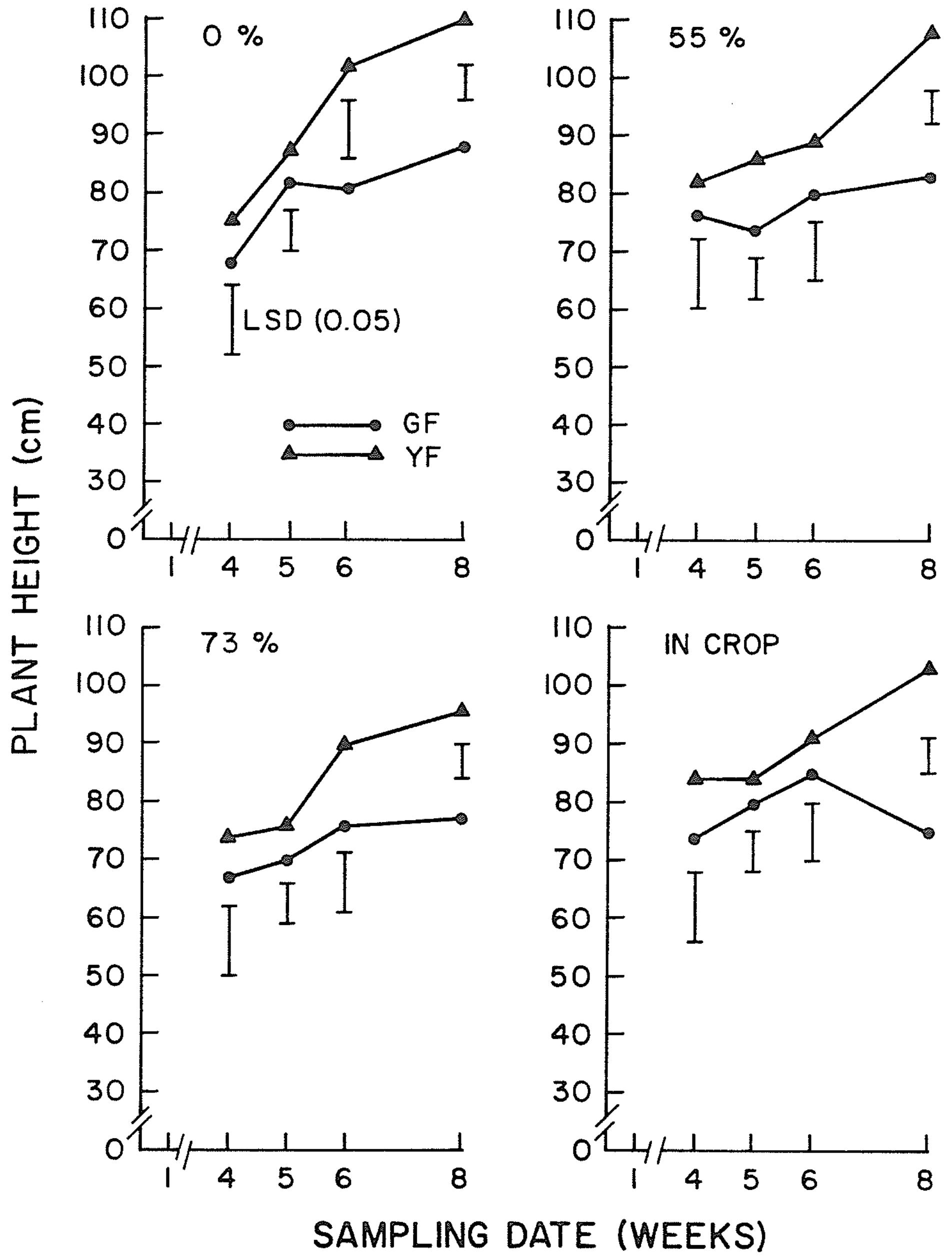
Figure 3. Extended length of fourth leaf of green foxtail (GF) and yellow foxtail (YF) at three shade levels and within the crop in 1979 and 1980.


GF
YF
1979
LSD(0.05)
1980
LSD (0.05)
LEAF LENGTH (cm)
0
55
73
IN CROP
SHADE LEVEL (%)

1980, yellow foxtail was more responsive to both 55 and 73% shade than green foxtail with proportionately greater increases in leaf length. An increase in shade level from 55 to 73% was not sufficient to cause significant increases in leaf length in either green or yellow foxtail. There was a twofold increase in leaf length for both foxtail species growing within the crop compared to plants in the unshaded control plots. Yellow foxtail leaves were longer than those of green foxtail in plots sown to wheat.

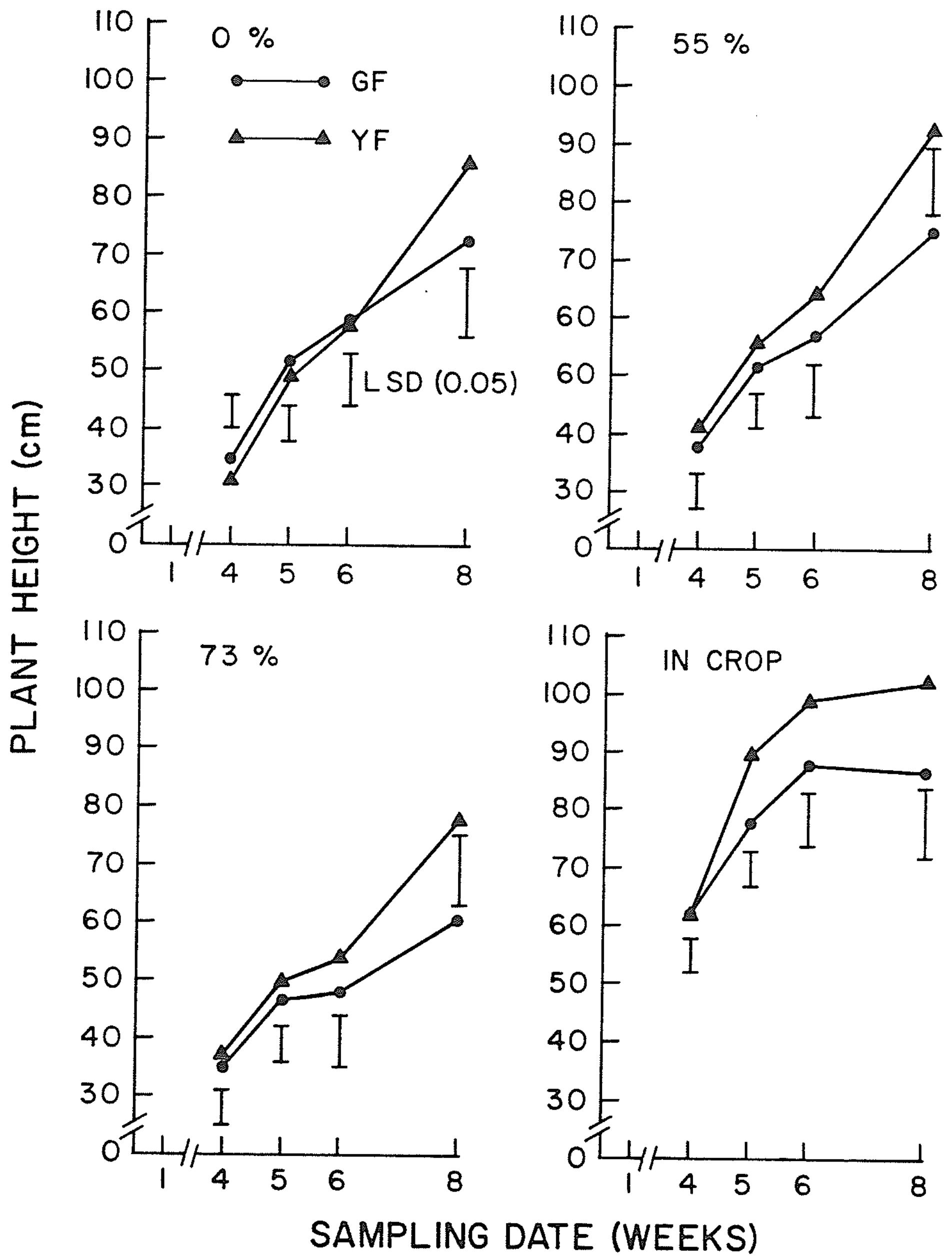
Measurements of total plant height were taken only on the last four sampling dates in 1979, while in 1980 data was collected throughout the season. But since no major consistent differences between green and yellow foxtail were seen at any shade level in the first three dates in 1980, only the last four dates are reported (Figures 4 and 5). In both years, yellow foxtail was always taller than green foxtail under the 55 and 73% shade levels with significant differences appearing by the end of the season. In the unshaded control plots, the results were less consistent. In 1979, the yellow foxtail was taller throughout the season, while in 1980, there was no significant difference between the two species until the final sampling date at which time the yellow foxtail was taller. In the 2nd year, yellow foxtail responded to the 55% shade level by a small increase in height, but the green foxtail was unaffected. Under 73% shade, the height of yellow foxtail was reduced to that of the control plants while the height of green foxtail was reduced by up to 16% compared to the unshaded plants. In 1979, the results were much less clear-cut, due to the more vigorous growth of yellow foxtail under 0% shade. However, green foxtail showed a similar response as in 1980. Under 55% shade, it was no different in height compared to the control plants while

Figure 4. Plant height of green foxtail (GF) and yellow foxtail (YF) at three shade levels and within the crop in 1979.



0 %
55 %
73 %
IN CROP
LSD (0.05)
GF
YF
PLANT HEIGHT (cm)
SAMPLING DATE (WEEKS)

Figure 5. Plant height of green foxtail (GF) and yellow foxtail (YF) at three shade levels and within the crop in 1980.


0 %
GF
YF
LSD (0.05)
55 %
73 %
IN CROP
PLANT HEIGHT (cm)
SAMPLING DATE (WEEKS)
110
100
90
80
70
60
50
40
30
0
1
4
5
6
8

under 73% shade its height was reduced significantly. Growth of foxtail within the crop was similar in the 2 years with yellow foxtail growing significantly taller than green foxtail by the end of the season. Yellow foxtail continued to increase in height after green foxtail had attained its maximum height in week 6 of both years.

In the case of tiller number per plant, Figures 6 and 7 show that results from the 0, 55 and 73% shade treatments were quite different in the 2 years. In 1979, there were no significant differences in tiller number between the two species under any of the shade levels, while in 1980 significant differences were very apparent. This is especially true in the unshaded control plots where green foxtail had over twice as many tillers per plant as did yellow foxtail at the end of the season. Under the 55 and 73% shade levels, green foxtail had a greater number of tillers per plant than yellow foxtail although significant differences were not always evident. Shade reduced tillering in both species, but there were no consistent trends over the 2 years. When tillering of both species under the 55 and 73% shade levels was examined, neither species showed a significant difference between shade levels in 1979. In 1980, green foxtail under 73% shade had a 35% reduction in tiller number from plants under 55% shade and a 70% reduction from plants in the unshaded control. The final tiller number of yellow foxtail, however, showed little difference under 55 or 73% shade. In the crop, green foxtail plants always had more tillers than yellow foxtail plants all season. Yellow foxtail, however, produced more tillers along the main stem compared to green foxtail which tillered from the base of the stem only.

Head number per plant followed a similar pattern as tiller number with variable results over the 2 years. The data in Table 6 shows that

Figure 6. Tiller number per plant of green foxtail (GF) and yellow foxtail (YF) at three shade levels and within the crop in 1979.

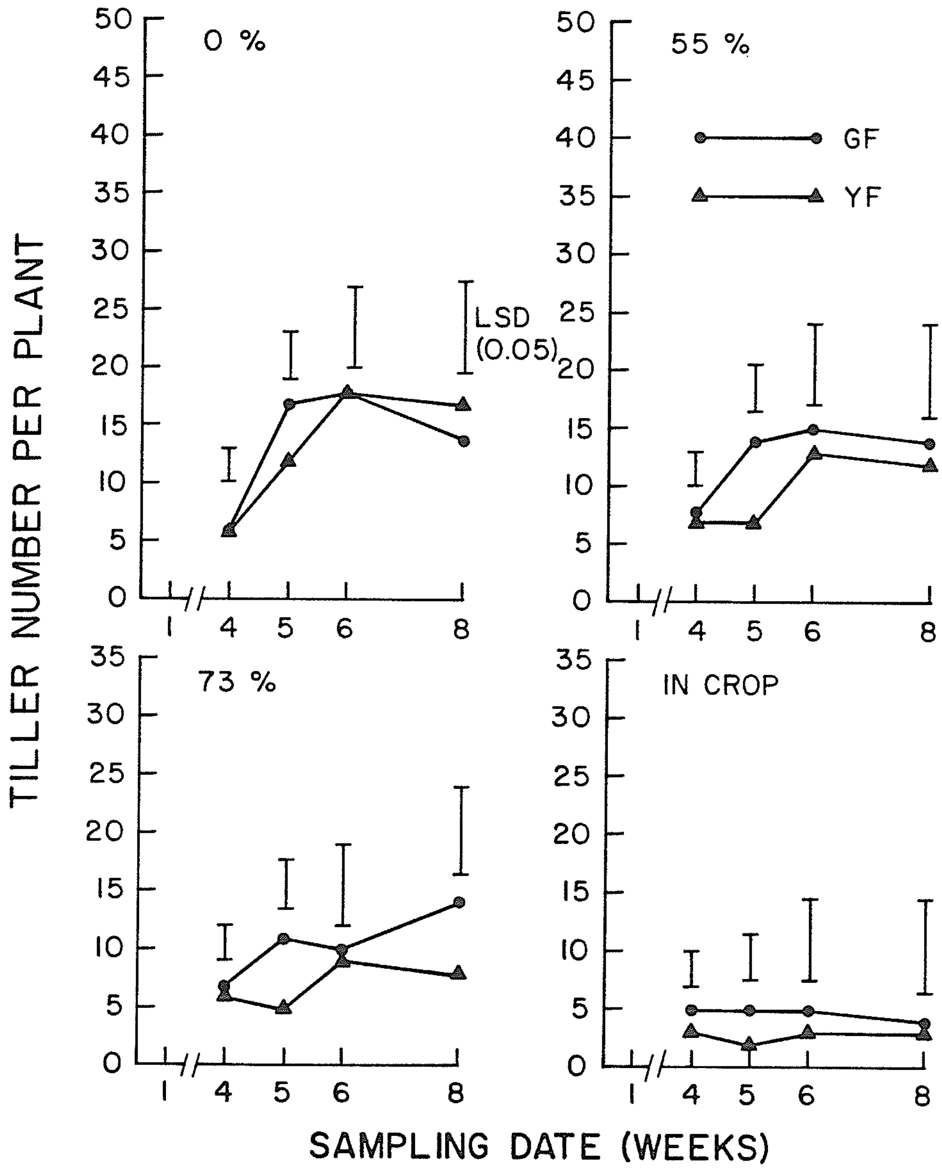
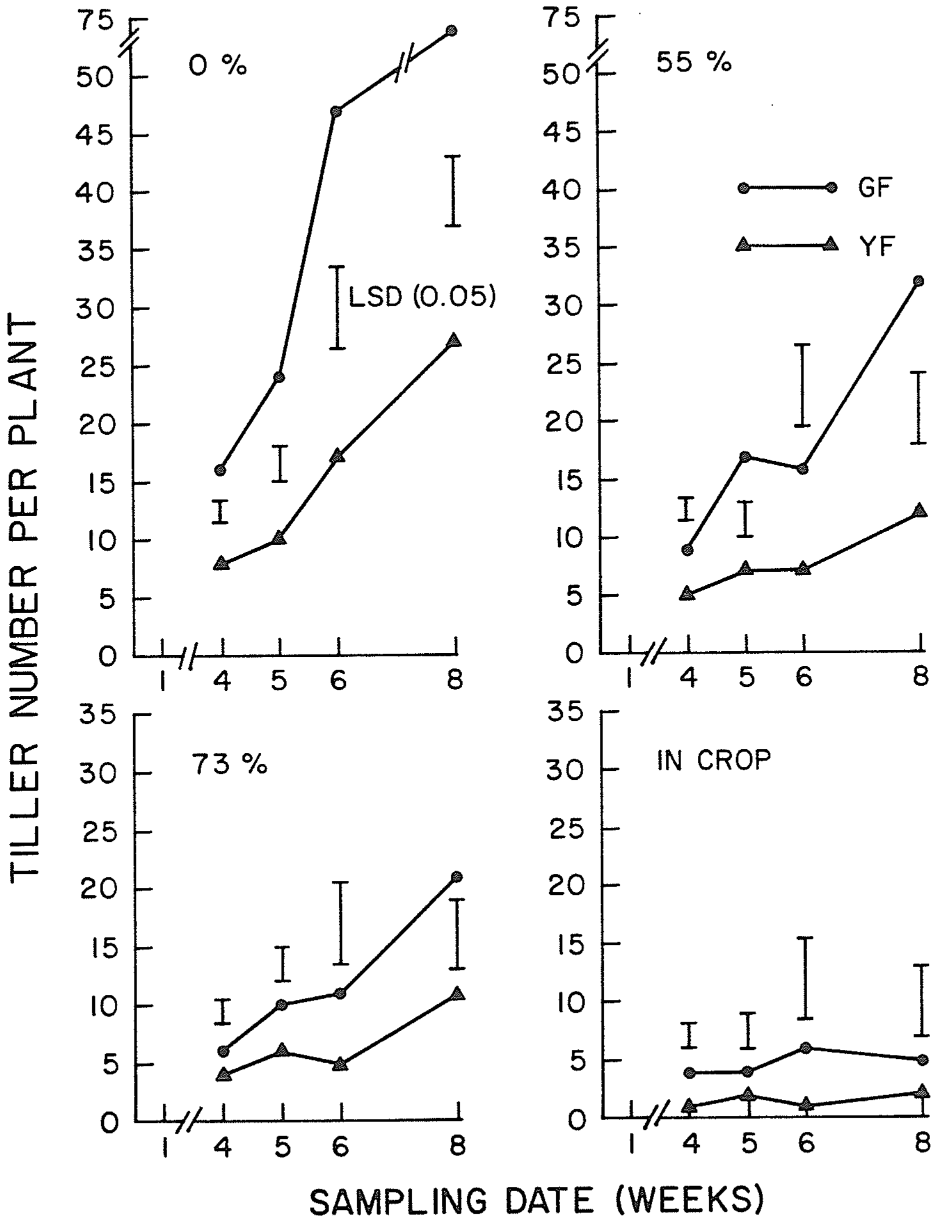

TILLER NUMBER PER PLANT
0 %
LSD (0.05)
55 %
GF
YF
73 %
IN CROP
SAMPLING DATE (WEEKS)

Figure 7. Tiller number per plant of green foxtail (GF) and yellow foxtail (YF) at three shade levels and within the crop in 1980.



TILLER NUMBER PER PLANT
SAMPLING DATE (WEEKS)
0 %
55 %
73 %
IN CROP
LSD (0.05)
GF
YF
0
5
10
15
20
25
30
35
40
45
50
75
1
4
5
6
8

TABLE 6. Head number per plant of green foxtail (GF) and yellow foxtail (YF) at three shade levels and within the crop in 1979 and 1980.[1]

Shade level	Head Number					
	Week 5		Week 6		Week 8	
	GF	YF	GF	YF	GF	YF
	(No./plant)					
1979						
0%	9.6	8.0	10.3	15.5*	12.1	17.1
55%	9.1*	5.0	12.1	10.5	11.8	10.9
73%	3.7	2.7	8.5	7.5	12.1	7.9
In Crop	3.4	1.7	3.9	3.0	2.9	3.0
LSD (0.05)[2]	2.8		4.1		5.7	
1980						
0%	11.1*	2.8	21.3*	8.9	66.6*	26.6
55%	6.5*	1.0	6.2	4.8	28.6*	12.3
73%	1.8	0.0	2.2	0.7	17.7*	10.5
In Crop	2.7	1.5	3.9	1.0	4.4	1.6
LSD (0.05)	2.2		4.9		8.3	

[1]Asterisk indicates that mean is significantly greater than comparable species mean at same shade level, same date ($p = 0.05$).

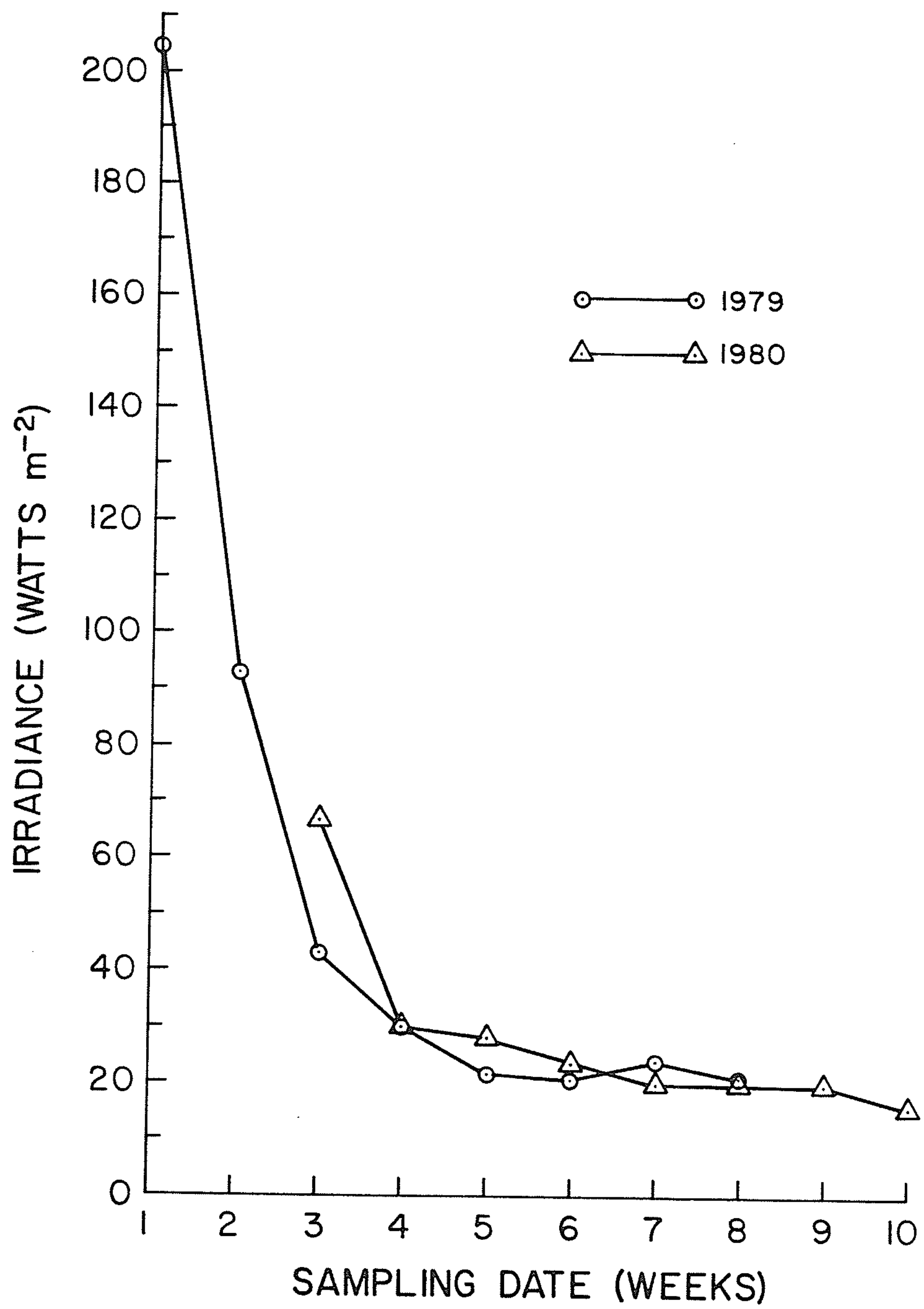
[2]LSD (0.05) is used for column comparisons between shade levels within each species at same date.

there was no significant differences in head number between green and yellow foxtail under 0, 55 and 73% shade in 1979, while in 1980 significant differences appeared by the end of the season. In the control plots the green foxtail had two and a half times the number of heads as yellow foxtail and heading occurred 1 week earlier. Under the 55 and 73% shade levels heading was delayed uniformly in both species by 1 and 1.5 weeks, respectively, later than the control plots. In both years green foxtail had more heads than yellow foxtail under shade but differences were not always significant. While it is readily apparent that increasing levels of shade reduced the number of heads produced by both species, a comparable trend was not evident over the 2 years. Head numbers of plants growing within the crop were drastically reduced compared to control plants for both species with reductions of 75 to 90% in the 2 years.

In addition to the growth parameters examined, two types of light measurements were made to gain specific information on light intensities within the crop canopy. The first entailed the use of an integrator which continually monitored the amount of light reaching a sensor deep within the crop. Results in Figure 8 indicated that the amount of light reaching near ground level within the wheat crop declined dramatically over the first 4 weeks of foxtail growth. Data from 1979 showed that during this period the average weekly irradiance experienced a sixfold decrease from 205.5 to 30.4 watts per m^2 while the wheat grew in height from 25 to 90 cm and developed from the five-leaf to the heading stage. After this date, the light levels decreased more gradually, finally reaching a value at the end of the season which was only 12% of the initial reading.

Weekly light readings were also taken at three heights within the crop canopy to determine the actual shade levels existing within the

Figure 8. Irradiance measured with a pyranometer sensor within the wheat crop over 10 weeks in 1979 and 1980.



200
180
160
140
120
100
80
60
40
20
0
IRRADIANCE (WATTS m^{-2})
1979
1980
1
2
3
4
5
6
7
8
9
10
SAMPLING DATE (WEEKS)

crop during the critical early period of foxtail growth (Table 7). In 1979, a quantum sensor was used to measure the reduction in photosynthetically active radiation (PAR). In 1980, a pyranometer sensor which

TABLE 7. Light reduction measured at three heights within the crop with a quantum sensor in 1979 and 1980 and a pyranometer sensor in 1980.

Week	Height (cm)	Light Reduction		
		Quantum Sensor		Pyranometer Sensor
		1979	1980	1980
		(%)		
2	0	99	98	84
	30	93	92	25
	60	0	5	2
3	0	99	98	88
	30	94	96	50
	60	8	19	2
4	0	99	99	90
	30	60	94	76
	60	43	44	23

measures total irradiance, was also used to compare the effects of sensor in light reduction values. It was found that the pyranometer sensor did not detect as large a reduction in irradiance at any height within the crop canopy as did the quantum sensor which was especially evident at the 30 cm height. In week 2 of 1980, the quantum sensor detected a light reduction that was three times the amount shown by the pyranometer sensor.

In week 3 the pyranometer reading was about one-half that of the quantum sensor.

Results using the quantum sensor were quite consistent in the 2 years with light reductions close to 100% occurring at ground height (0 cm) as early as the second sampling date. At the 30 cm height, reductions in PAR averaging 95% appeared by the 3rd week. A decrease in shade occurred at this level in week 4 of 1979 due to flattening of the wheat crop in some areas by heavy rains. In the 2 years both sensors noted very gradual reductions in light at the 60 cm level as the wheat crop increased in height.

Fertility Experiments

Field

Because the results from the 2 year field study of the effect of low, medium and high nitrogen levels on growth of green and yellow foxtail in competition with wheat were highly variable and showed no consistent trends, the data will not be presented. In both years the wheat emerged earlier than either of the foxtail species. Emergence of green foxtail occurred approximately 2 weeks after the wheat while emergence of yellow foxtail was delayed another 0.5 to 1 week. However, in 1980, not only was foxtail emergence delayed and very erratic, but plant development was also slowed during early establishment despite the fact the plots were irrigated at the time of wheat emergence. Until the first major rainfall of the season on June 29, the majority of the foxtail was still in the one- to three-leaf stage, while the wheat was 15 to 20 cm tall with two to three tillers. After the rainfall, the wheat rapidly doubled in size, leaving the foxtail with little chance to exert competitive effects.

The plant counts indicated that in both years there were greater numbers of green foxtail than yellow foxtail at all three nitrogen levels. In 1979, the delayed emergence caused very few foxtail plants of either species to become established and develop to maturity. In 1980, twice as many plants of both species were established, but few were able to develop to maturity. This is reflected by the dry weight data which showed that foxtail dry weight per m^2 was one-half as great in 1980 as in 1979.

As far as the wheat was concerned, no clear pattern was seen in either year. Not only were there no consistent differences between dry weight and final grain yield of the control plots and the foxtail-infested plots but in many cases the foxtail-infested plots showed significantly higher grain yields than the foxtail-free plots. The wheat also did not show any apparent response to nitrogen with no significant differences in dry weight or final grain yield at any of the three nitrogen levels.

Growth Room

When examining the results from the growth room studies, it is important to stress that the six nitrogen levels represent the amount of applied nitrogen and not the total amount of nitrogen present. In the second trial, a different batch of soil was used which had higher initial amounts of all four macronutrients (Table 8). However, in both trials the total amount of nitrogen utilized by both species was similar at the low (0 and 50 ppm) and intermediate levels (100 and 200 ppm) while at the two highest levels (300 and 400 ppm), considerably more nitrogen was utilized by the green foxtail. Despite the differences in nitrogen utilization at the high levels, similar amounts of phosphorous and potassium were taken up by the two species with increased growth resulting in greater uptake of these

TABLE 8. Nutrient analysis of the Almasippi very fine sandy loam soil used in the experiment examining the effect of six levels of added nitrogen on growth of green foxtail (GF) and yellow foxtail (YF) in two trials.

Nitrogen level (ppm)	Nutrient Analysis									
	pH		Nitrate-Nitrogen		Phosphorous		Potassium		Sulphate-Sulphur	
	GF	YF	GF	YF	GF	YF	GF	YF	GF	YF
			(ppm)							
Trial 1										
Base Amount	7.7		2.8		4.2		128		3.2	
0	7.3	7.2	1.8	1.6	33.8	32.6	199	175	20+	20+
50	7.2	7.1	1.2	1.8	29.6	25.0	160	135	20+	20+
100	7.2	7.1	1.6	1.4	25.0	22.2	150	127	20+	20+
200	7.1	7.1	2.0	2.4	23.6	19.6	125	120	20+	20+
300	7.2	7.0	25.6	57.0	20.7	21.2	123	119	20+	20+
400	6.8	6.6	144.0	204.0	19.8	20.6	130	127	20+	20+
Trial 2										
Base Amount	6.2		7.0		26.6		223		4.8	
0	6.6	6.4	2.2	4.8	54.4	57.4	314	272	40	37
50	6.5	6.2	2.8	2.8	50.4	62.8	255	250	55	81
100	6.4	6.0	2.8	1.8	41.8	51.0	220	170	44	80
200	6.2	6.0	5.6	6.2	44.8	47.4	160	155	41	64
300	5.9	5.6	120.0	132.0	46.4	51.0	175	174	41	74
400	5.3	5.4	290.0	310.0	47.4	54.4	245	202	47	62

nutrients.

Shoot dry weight determinations (Table 9) showed no significant differences between green and yellow foxtail in trial 1 except at the highest nitrogen level, in which case green foxtail had the greater dry weight. In trial 2, green foxtail also had a significantly greater dry weight than yellow foxtail at the 400 ppm level. But in this trial, there was a significant difference at the three lowest nitrogen levels as well with yellow foxtail having the greater dry weight at 0, 50 and 100 ppm added nitrogen.

TABLE 9. Shoot dry weight per plant of green foxtail (GF) and yellow foxtail (YF) at six nitrogen levels in two trials.[1]

Nitrogen level (ppm)	Shoot Dry Weight			
	Trial 1		Trial 2	
	GF	YF	GF	YF
	(g)			
0	1.49	2.01	1.00	1.62*
50	4.26	4.39	2.69	3.84*
100	4.31	4.69	3.80	4.77*
200	6.04	6.01	4.66	4.33
300	7.08	6.56	4.35	4.36
400	6.72*	5.86	4.89*	3.93
LSD (0.05)[2]	1.02		0.71	

[1]Asterisk indicates that mean is significantly greater than comparable species mean at same nitrogen level, same trial (p = 0.05).

[2]LSD (0.05) is used for column comparisons between nitrogen levels within each species in the same trial.

Comparisons between nitrogen levels within each species showed that both green and yellow foxtail have a similar trend of increasing dry weight with increasing nitrogen level. Maximum production of shoot dry matter occurred at a level below 400 ppm in the two species. However, the results from the second trial especially indicate that yellow foxtail may reach maximum dry weight at a lower nitrogen level than green foxtail.

Height measurements of the two species at each nitrogen level shown in Figure 9 revealed that yellow foxtail was significantly taller than green foxtail regardless of the nitrogen level at LSD (0.05) = 5.0 (trial 1) and 6.0 (trial 2). But significant differences between the two species were greatest at the lower nitrogen levels, which is shown clearly in the second trial. At 0 ppm nitrogen, yellow foxtail was almost twice as tall as green foxtail while at 400 ppm the yellow foxtail was only 14% taller than the green foxtail. Similar results were noted in trial 1 with a 30% decrease in height differential between the two species over the same range of nitrogen levels.

Clearly, the two species showed marked differences in response to changes in nitrogen level. Green foxtail increased in height at nitrogen levels up to 200 and 300 ppm while at the 400 ppm level, plant height decreased slightly. In contrast, yellow foxtail attained maximum height at only 50 ppm nitrogen with significant decreases in height at the higher 300 and 400 ppm levels. In trial 2, the yellow foxtail plants in the treatment with no applied nitrogen were even taller than plants at the two highest nitrogen levels. In both species, however, the 400 ppm nitrogen level caused depressions in height.

With respect to tiller number per plant, the situation was different than for plant height for the two species. As seen in Figure 10, in both trials green foxtail had a greater number of tillers than yellow foxtail

Figure 9. Plant height of green and yellow foxtail at six nitrogen levels in two trials. Note that LSD (0.05) values represent differences between nitrogen levels within each foxtail species.

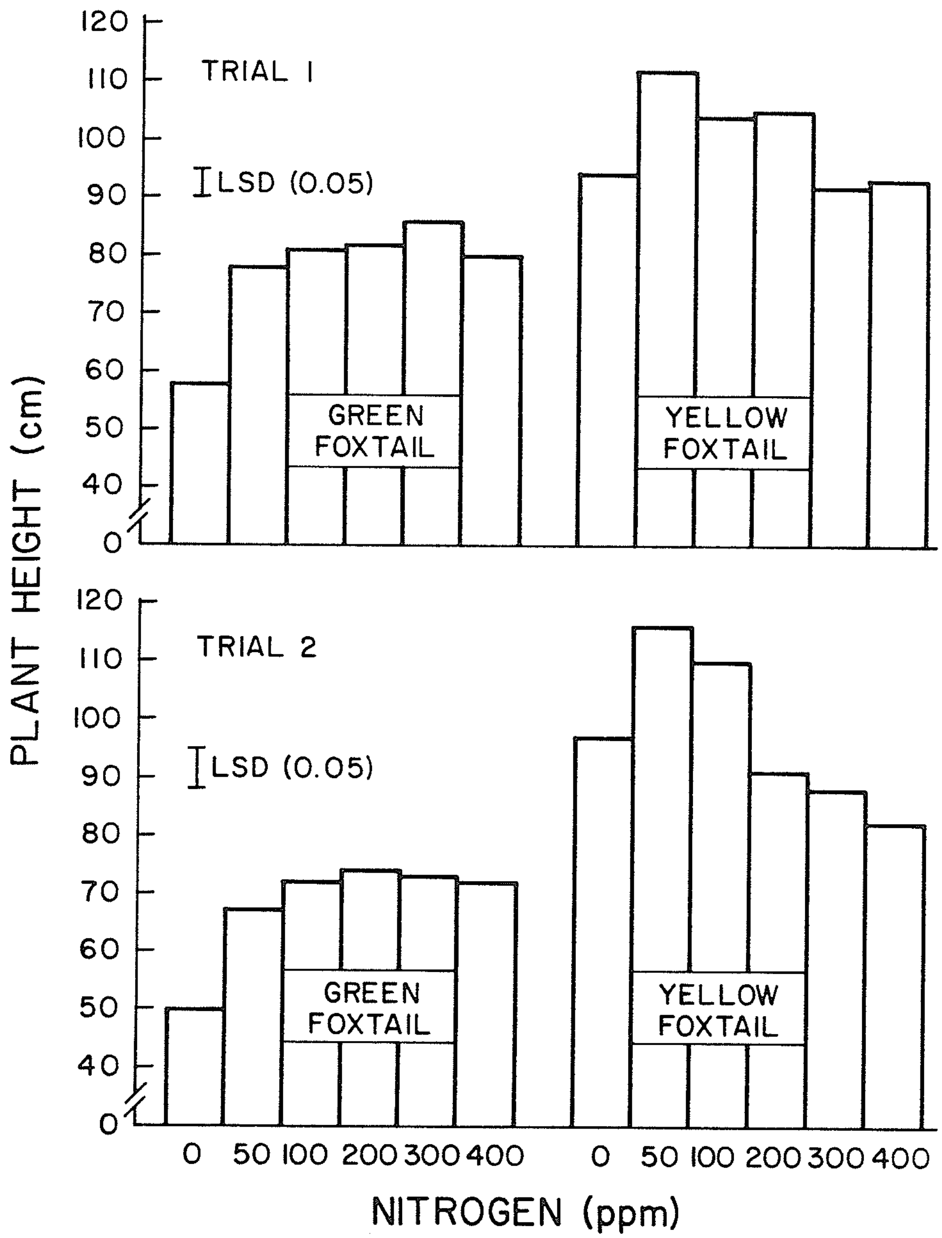
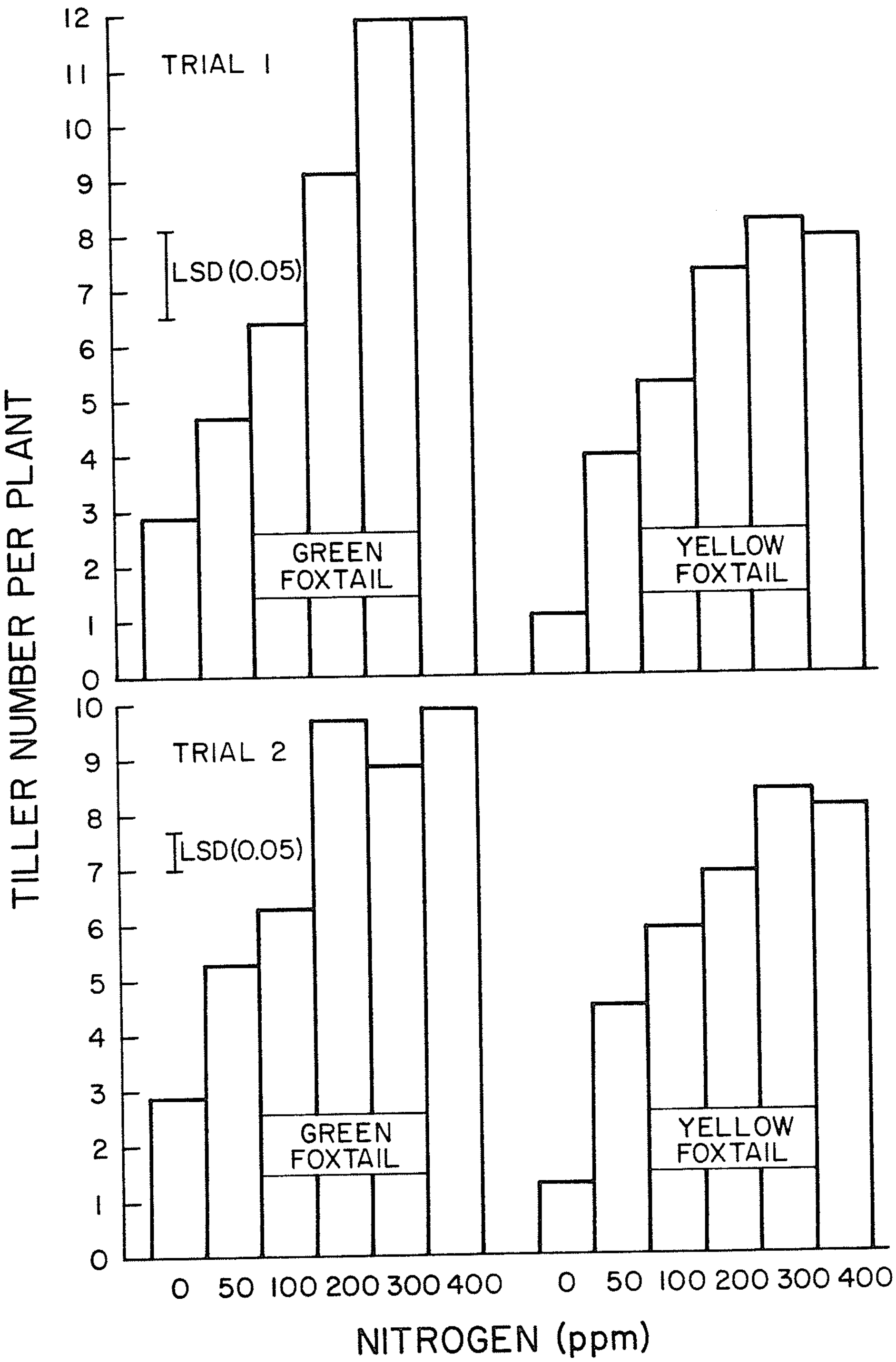

PLANT HEIGHT (cm)
TRIAL 1
LSD (0.05)
GREEN FOXTAIL
YELLOW FOXTAIL
TRIAL 2
LSD (0.05)
GREEN FOXTAIL
YELLOW FOXTAIL
0 50 100 200 300 400
0 50 100 200 300 400
NITROGEN (ppm)

Figure 10. Tiller number per plant of green and yellow foxtail at six nitrogen levels in two trials. Note that LSD (0.05) values represent differences between nitrogen levels within each foxtail species.


TRIAL 1
LSD (0.05)
GREEN FOXTAIL
YELLOW FOXTAIL
TRIAL 2
LSD(0.05)
GREEN FOXTAIL
YELLOW FOXTAIL
TILLER NUMBER PER PLANT
0 50 100 200 300 400
0 50 100 200 300 400
NITROGEN (ppm)
0 1 2 3 4 5 6 7 8 9 10 11 12
0 1 2 3 4 5 6 7 8 9 10

at all the nitrogen levels, although differences were not always significant at LSD (0.05) = 1.6 (trial 1) and 0.6 (trial 2). In the first trial, green foxtail had significantly more tillers at the low (0 ppm) and high (200, 300 and 400 ppm) nitrogen levels while at 50 and 100 ppm, there were no differences between the two species. The difference in tiller number between green and yellow foxtail was twice as large at the higher nitrogen levels than at the low 0 ppm nitrogen level. The results of trial 2 were less clear since at the 300 ppm level the tiller numbers of the two species were very close. Since the values for yellow foxtail were very similar for all nitrogen levels over the two trials, it is assumed that the value for green foxtail at this level was abnormally low.

The changes in tiller number within each species in response to increasing levels of nitrogen were similar. In general, both foxtail species had increases in tiller number with each increment of nitrogen up to the 200 to 300 ppm levels. It would appear that the 300 ppm nitrogen level is sufficient to cause maximum tiller initiation for both species with no significant increases occurring at the higher nitrogen levels.

Head number per plant was the only parameter which did not show a consistent trend over the two trials. As can be seen in Table 10, in trial 1 green foxtail had a greater number of heads than yellow foxtail at all nitrogen levels with significant differences at 300 and 400 ppm nitrogen. However, in the second trial, significant differences were seen at the four highest nitrogen levels, with yellow foxtail having a higher head number than green foxtail. Although yellow foxtail consistently had fewer tillers than green foxtail, in both trials approximately 85 to 90% of these tillers produced viable heads. Green foxtail, on the other hand, had more tillers but in trial 2 only about one-half of them

TABLE 10. Head number and head length per plant of green foxtail (GF) and yellow foxtail (YF) at six nitrogen levels in two trials.[1]

Nitrogen level (ppm)	Head Number		Head Length	
	GF	YF	GF	YF
	(No./plant)		(cm)	
Trial 1				
0	2.1	1.0	3.0	5.3*
50	4.1	3.3	3.8	5.0*
100	5.8	4.8	4.4	5.8*
200	7.4	7.2	4.8	6.0*
300	9.4*	7.9	5.3	5.7
400	9.1*	7.6	4.8	5.8*
LSD (0.05)[2]	1.4		0.8	
Trial 2				
0	1.5	1.1	3.7	5.5*
50	3.1	3.7	3.7	5.1*
100	4.1	5.7*	4.9	5.6
200	4.5	6.7*	5.4	6.1
300	5.6	7.5*	4.7	5.8*
400	5.7	7.4*	4.6	5.5*
LSD (0.05)	1.3		0.7	

[1]Asterisk indicates that mean is significantly greater than comparable species mean at same nitrogen level, for same parameter ($p = 0.05$).

[2]LSD (0.05) is used for column comparisons between nitrogen levels within each species for the same parameter.

produced heads compared to approximately 75 to 80% in trial 1.

The response of head number to increasing nitrogen level within each species emphasized that yellow foxtail showed a similar pattern over the two trials while the results for green foxtail were different. With yellow foxtail, increases from 0 to 50 and 100 ppm nitrogen caused significant increases in head number while at the higher nitrogen levels, no significant differences were seen. With green foxtail, however, head number responded the same as tiller number with significant increases apparent up to 300 ppm nitrogen. The higher nitrogen levels were also responsible for a delay in heading of up to 2 weeks compared to the lower nitrogen levels in both species.

Measurements of mean head length per plant (Table 10) showed yellow foxtail to have longer heads than green foxtail at every nitrogen level in the two trials. But significant differences were evident only at the lowest and highest nitrogen regimes in both trials. In between these values differences were not always significant indicating that at intermediate nitrogen levels yellow foxtail does not necessarily have a longer head than green foxtail. However, the difference between the two species was most apparent in the treatment with no applied nitrogen in which case yellow foxtail had head lengths that were 75 and 40% longer than green foxtail in trials 1 and 2, respectively. The differences between species were not as great at the higher nitrogen levels. Head length of green foxtail showed a much greater response to varying nitrogen levels with proportionately greater changes over the range of nitrogen additives than did yellow foxtail. Yellow foxtail only showed an approximate 10% increase in head length from 0 to 400 ppm while green foxtail showed an increase of nearly 60% in trial 1.

The percent protein content of green and yellow foxtail, which was determined by multiplying the total nitrogen present in a sampling shoot dry matter by 6.25, showed a dissimilar trend in the two trials (Table 11). In trial 1, there was no significant difference in percent protein between the two species except at the 300 ppm nitrogen level where yellow foxtail had the higher protein content. In the second trial, significant differences were evident only at the three lowest nitrogen levels where green foxtail had a greater percent protein content than did yellow foxtail.

Total protein content was calculated on the basis of the amount of dry matter produced and is shown in Table 11. No significant difference was noted between the two species in either trial except at the highest nitrogen level where green foxtail synthesized more total protein than yellow foxtail. Both species responded similarly to increases in nitrogen with increases in total protein up to 300 ppm. However, at the highest nitrogen level, green foxtail continued to show an increase in total protein while the total amount of protein produced by yellow foxtail remained the same.

Growth Curves Experiment

Although yellow foxtail had a greater root dry weight than green foxtail over the 9 sampling weeks in both trials, significant differences between the two species were not evident until near maturity in week 6 of trial 1 and week 7 of trial 2 (Figure 11). Both species experienced steady increases in root dry weight up until these dates at which time the root weight of yellow foxtail underwent a dramatic increase while green foxtail root weight continued to increase very gradually (trial 1) or levelled off (trial 2). On the 9th week, yellow foxtail had a final root dry weight that was nearly three and six times larger than that of green foxtail in

TABLE 11. Percent and total protein[1] of green foxtail (GF) and yellow foxtail (YF) at six nitrogen levels in two trials.[2]

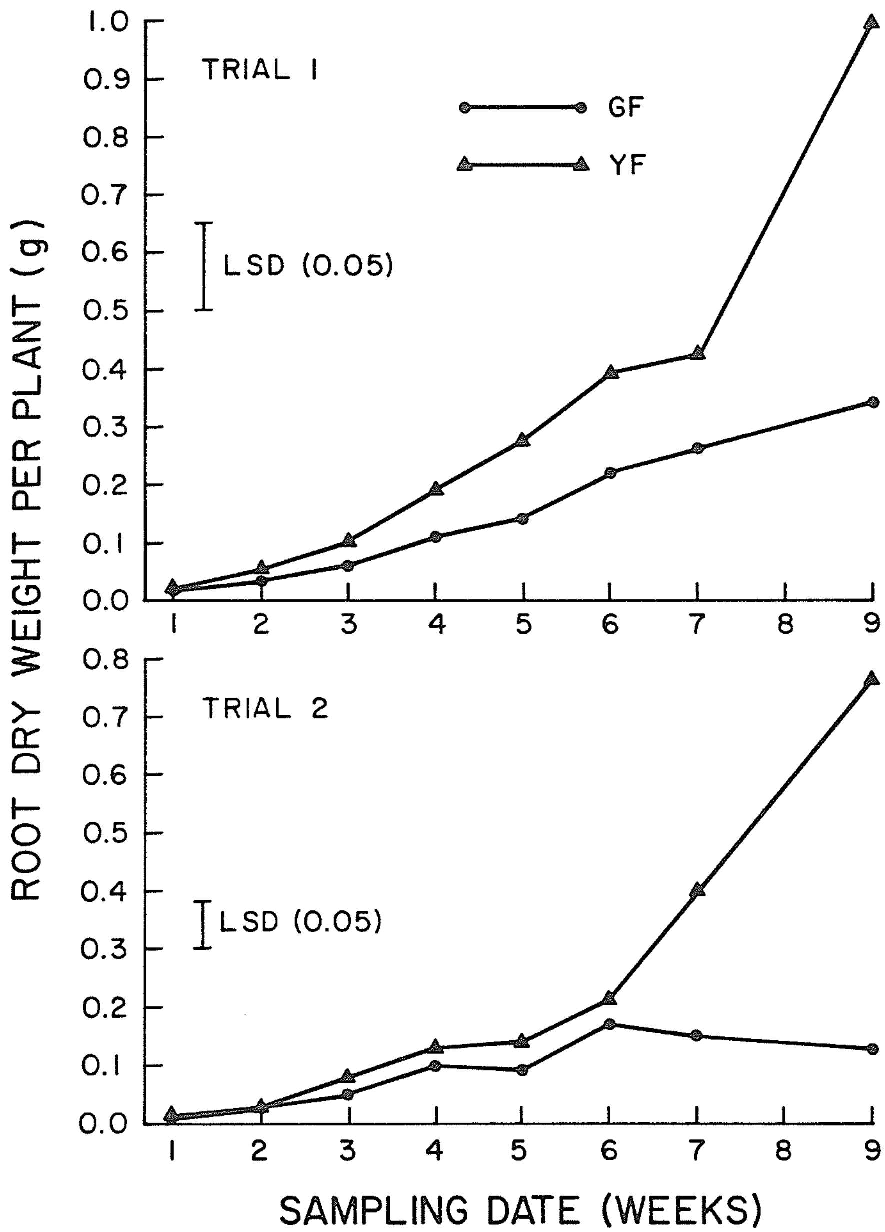
Nitrogen level (ppm)	Protein		Total Protein	
	GF	YF	GF	YF
	(%)		(g)	
Trial 1				
0	4.65	3.77	6.90	7.63
50	4.95	5.17	21.34	22.60
100	6.77	8.23	21.14	38.50
200	11.29	12.47	67.30	74.99
300	13.43	15.63*	94.69	102.74
400	15.77	16.20	108.97*	92.30
LSD (0.05)[3]	1.56		19.29	
Trial 2				
0	6.73*	4.23	6.63	6.84
50	6.25*	4.60	16.55	17.64
100	7.85*	6.75	29.60	31.94
200	13.30	13.83	61.26	59.09
300	15.43	15.80	66.92	68.72
400	16.40	16.73	78.93*	65.42
LSD (0.05)	1.51		9.51	

[1]Percent protein = % Kjeldahl digestible N x 6.25. Total protein = percent protein x dry matter.

[2]Asterisk indicates that mean is significantly greater than comparable species mean at same nitrogen level, for the same parameter (p = 0.05).

[3]LSD (0.05) is used for column comparisons between nitrogen levels within each species, for the same parameter.

Figure 11. Root dry weight per plant of green foxtail (GF) and yellow foxtail (YF) over 9 weeks in two trials.


ROOT DRY WEIGHT PER PLANT (g)
TRIAL 1
GF
YF
LSD (0.05)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1 2 3 4 5 6 7 8 9
TRIAL 2
LSD (0.05)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1 2 3 4 5 6 7 8 9
SAMPLING DATE (WEEKS)

trials 1 and 2, respectively.

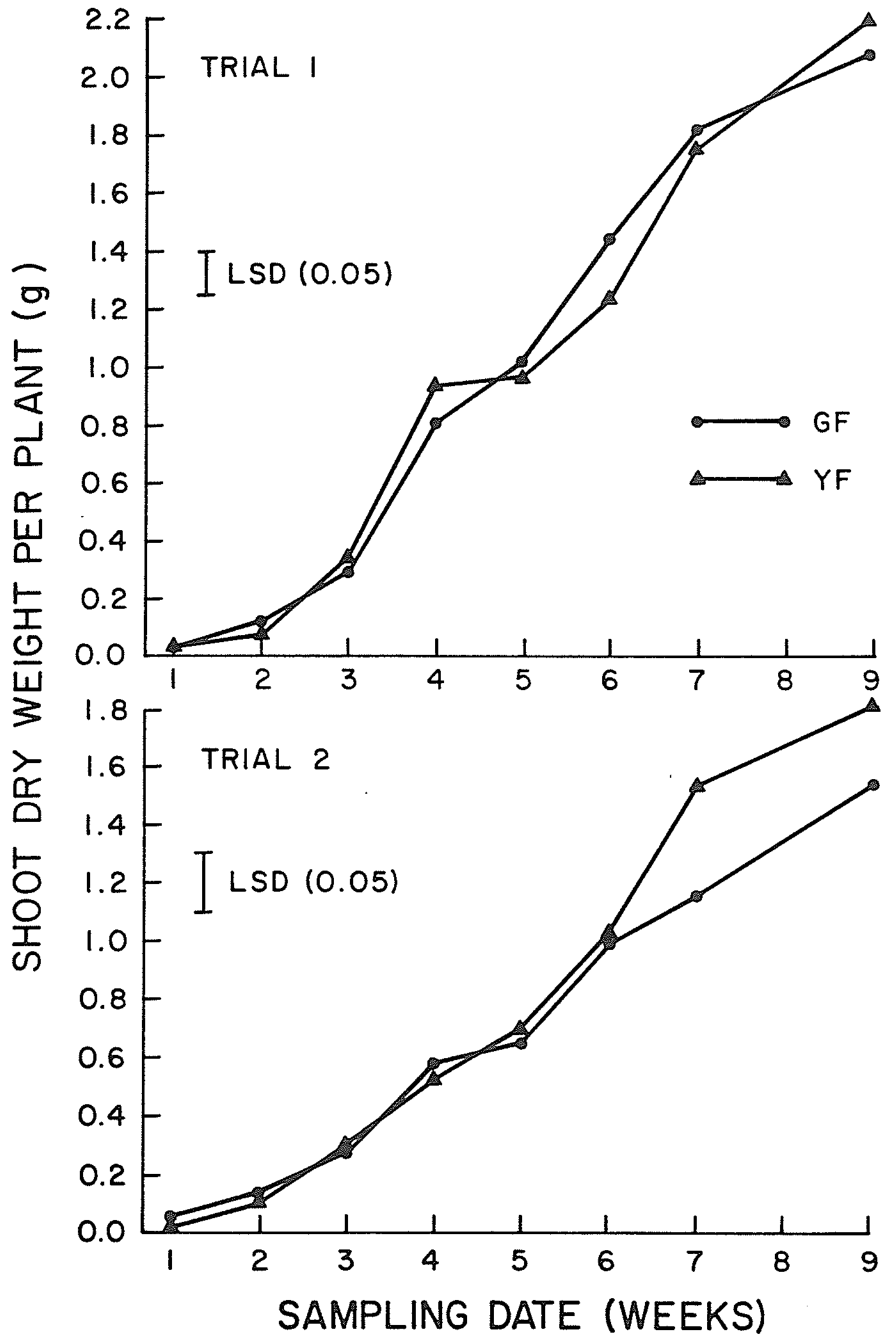
Root dry weights in the first trial were consistently greater than comparable values in the second trial for both species. However, yellow foxtail showed a proportionately greater reduction in root growth in trial 2 compared to trial 1, except at the first and final two sampling dates. It was also observed throughout the two trials that the root system of yellow foxtail was much coarser and the rootlets appeared to have a larger diameter than the more finely textured root system of green foxtail.

Shoot dry weight measurements (Figure 12) showed no significant differences between the two species except at week 6 in trial 1 and weeks 7 and 9 in trial 2. However, these differences did not appear to form any consistent trend over the two trials since not only did they occur at different times, but in the first trial green foxtail had a greater shoot weight than yellow foxtail while the reverse situation occurred in the second trial. Green foxtail had proportionately greater reductions in shoot growth in trial 2 as compared to trial 1 than yellow foxtail which might explain why significant differences between the species showed up at the end of the second trial but not the first.

Observations throughout the experiment showed that green foxtail had more tillers than did yellow foxtail in trial 1 while opposite results occurred in trial 2, with yellow foxtail having the larger number of tillers. Head emergence was noted to be similar in the two trials with green foxtail consistently heading 2 to 3 weeks before yellow foxtail which did not produce heads until the 9th week in both trials.

The shoot:root ratios, shown in Table 12, integrate the results of the root and shoot dry weights. As was expected, green foxtail had a greater shoot:root ratio than yellow foxtail at all dates in the two trials. However, some variation existed between the two trials since in

Figure 12. Shoot dry weight per plant of green foxtail (GF) and yellow foxtail (YF) over 9 weeks in two trials.



TRIAL 1
LSD (0.05)
GF
YF
TRIAL 2
LSD (0.05)
SHOOT DRY WEIGHT PER PLANT (g)
SAMPLING DATE (WEEKS)
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1 2 3 4 5 6 7 8 9

TABLE 12. Shoot:root ratio of green foxtail (GF) and yellow foxtail (YF) over 9 weeks in two trials.[1]

Sampling date (weeks)	Shoot:Root Ratio			
	Trial 1		Trial 2	
	GF	YF	GF	YF
1	1.59	1.11	3.91*	2.41
2	2.77	1.49	4.45	3.41
3	4.79	3.13	6.12*	3.55
4	7.54*	5.19	5.79*	4.14
5	7.92*	3.67	7.77*	5.15
6	7.21*	3.33	6.23	4.84
7	7.03*	4.31	8.21*	4.52
9	6.93*	2.34	12.00*	2.39

[1]Asterisk indicates that mean is significantly greater than comparable species mean at the same date, in the same trial ($p = 0.05$).

the first one green foxtail had a significantly greater ratio only from week 4 to the end of sampling, while in the second trial green foxtail had a significantly greater ratio at all dates except weeks 2 and 6. In both trials, yellow foxtail had an increase in root dry weight at the end of the growing period which caused a corresponding decrease in the shoot: root ratio. Green foxtail also had a small increase in root dry weight at the end of trial 1 which similarly caused the shoot:root ratio to decrease while in trial 2 the decline in root dry weight at the end of the season resulted in the ratio increasing markedly.

Yellow Foxtail Biotypes Study

Final measurements of most of the growth parameters examined failed to show any major differences between the three yellow foxtail biotypes (Table 13). Dry weight determinations differed slightly in the 2 years since in 1979 there was no significant difference between the three biotypes while in 1980 the Winnipeg and Carman biotypes had significantly higher final dry weights than the Ontario biotype. Measurements throughout both seasons showed a similar pattern with no difference between dry weights of the three biotypes until mid-season when the Carman and Winnipeg biotypes had greater dry matter accumulations than the Ontario biotype. By the end of sampling in 1979, the dry weight of the Ontario biotype was equal to that of the other two biotypes. Since in 1980, emergence and maturity of the Ontario biotype was delayed to a greater extent than either the Carman or Winnipeg biotypes, it is probable that the Ontario biotype would have reached a comparable dry weight had sampling continued.

Insofar as height and tiller number are concerned, in neither year were there any significant differences between the three biotypes by the final sampling date. However, differences between the biotypes were evident in both of these parameters early in the season. The Carman biotype was significantly taller than the Ontario biotype until the 5th sampling week, while the Winnipeg biotype did not differ in height from either biotype. Similarly, tiller number showed significant differences between all three biotypes until near the end of the season with the Carman biotype having the greatest number of tillers in contrast to the Ontario biotype with the least number of tillers.

The greatest difference between the biotypes was seen in head number since the Ontario biotype did not begin heading until at least 2 weeks

TABLE 13. Final measurements of four growth parameters of three yellow foxtail biotypes in 1979 and 1980.

Yellow foxtail biotype	Growth Parameter			
	Dry Weight		Height	
	1979	1980	1979	1980
	(g)		(cm)	
Ontario	21.7	7.9	100.1	60.5
Winnipeg	23.2	9.8	106.7	63.5
Carman	21.3	10.6	109.4	64.7
LSD (0.05)	7.2	1.4	16.8	6.4
	Tiller Number		Head Number	
	1979	1980	1979	1980
	(No./plant)		(No./plant)	
Ontario	27.3	24.1	16.8	4.8
Winnipeg	33.7	24.8	30.8	23.2
Carman	29.7	26.5	26.5	23.3
LSD (0.05)	7.0	4.5	8.5	2.0

after the other two biotypes. Consequently, there were large differences between the Manitoba biotypes and the biotype from Ontario in total heads emerged by the end of sampling. Once again it is felt that had the growing season been longer and sampling continued until the Ontario biotype fully matured, which was approximately 1 month after the other biotypes, similar final head numbers would have been recorded.

DISCUSSION

Shade Experiment

An examination of the results of the shade experiment showed that the two foxtail species responded differently in the 2 years and therefore much of the data does not lead to obvious conclusions and in some instances may even appear to be conflicting. There are several possible explanations for the variable results, one of which is the divergent weather conditions which occurred in the 2 years (Appendix Tables 1 and 2). After the extremely wet spring in 1979, a moderate amount of rain fell compared to the spring drought of 1980 which was followed by a relatively wet summer. Although this rainfall data helps to explain the difference in overall plant vigour in the 2 years, it does not satisfactorily explain why trends were often dissimilar.

Another possible explanation might lie in the fact that although the stands were quite uniform within each treatment, the final densities differed in the 2 years. The reason for the lower than expected emergence of yellow foxtail in some plots in 1979 is not known but may be related to differences in soil moisture content. Reduced emergence of yellow foxtail in wet soil has been reported by Dawson and Bruns (1975) who found a 15% decrease in emergence on irrigated soil as compared to non-irrigated soil. Their results showed opposite results for green foxtail with 30% increases in emergence on the irrigated soil. Blackshaw (1979) also noted green foxtail emergence to be very dependent on soil moisture with optimum emergence occurring at higher water potentials. In 1980, although plots were hand-watered to overcome dry soil conditions, final plot densities of green foxtail were lower than in 1979. The reason for this was because a substantial number of plants in the first flush were injured after application of bromoxynil/MCPA to control broadleaf weeds. Yellow foxtail, which emerged 1 week later than the green foxtail did not suffer comparable reductions in plant populations and attained higher final densities. The only exception occurred within the wheat plots where the slower emergence of the yellow foxtail allowed the wheat to compete more strongly than with the green foxtail.

Regardless of the reason for the varying densities between the foxtail species and over the 2 years, it is evident that these differences are at least partially responsible for the inconsistencies in the data for the 2 years, especially for the control plots. In 1979, not only were yellow foxtail densities low but plant to plant spacing was non-uniform which resulted in uneven growth within the plot. Work by Santelmann et al. (1963) emphasized that spacing of plants greatly affects tiller and subsequent head formation of yellow foxtail with plants spaced 30.5 cm apart having a mean of 56 tillers compared to a mean of two tillers for plants spaced 5 cm apart. Consequently, the lower, non-uniform plot densities of 1979 allowed development of some abnormally large yellow foxtail plants which was reflected in the data. A similar response was noted with green foxtail in 1980 with lower plot densities resulting in less crowding and the production of plants with greater numbers of tillers than in 1979.

The data collected in 1980 is generally considered to be more reliable. The greater reliability is reflected in the lower coefficients of variation (C.V.) which are a measure of the relative variation within a set of data. For most parameters the C.V. values were twice as high in 1979 as in 1980 and ranged from 30 to 50%.

The lower variability of the 1980 data may be attributed to several factors. Since the plots were initially seeded to higher densities and then carefully thinned out, the result was more uniform plant growth within stands. Secondly, because the sampled plants were marked with coloured rings, it was assured that all plants which were sampled were of the same age. Also, measurements of height, tiller and head number were based on a larger sample size. Finally, the addition of flaps to the south end of each tent ensured that all of the plants sampled experienced the same level of shade throughout the season. Therefore, the reduced sampling variability in 1980 supports the conclusion that the second year data is the more accurate of the 2 years and consequently more emphasis will be placed on these results in the remainder of this section of the Discussion.

Despite the differences observed in the 2 years of the study, certain general trends of green and yellow foxtail growth under varying shade levels can be discerned. It is important to note that only comparisons between foxtail growth under the 0, 55 and 73% shade levels can be made. It is not possible to directly compare growth at 55 and 73% shade to growth within the crop, since in the latter situation it is impossible to attribute the existing competition to shade alone. The data seem to indicate that the increased height of the yellow foxtail combined with the decreased tillering ability of the green foxtail under shaded conditions yields plants which are very similar in dry matter and total leaf area.

Height of green foxtail was little affected by 55% shade while there was a significant reduction in height under the 73% shade level compared to control plots (Figure 5). This response was very similar to that seen by Knake (1972) working with giant foxtail. He found that shade levels of 70 and 80% were necessary to cause significant height decreases. In the present study, a very different response was seen for the yellow foxtail in 1980, in that 55% shade caused an increase in height in comparison to the control plots. At the 73% shade level, a reduction in height from plants under 55% shade was apparent, but only to the level of the unshaded plants. These results are contrary to those of Santelmann et al. (1963) who found that 60% shade caused a 17% decrease in yellow foxtail height compared to plants grown under full light. However, the data are similar to the findings of Patterson (1979b) who noted that low levels of shade stimulated elongation in itchgrass while higher shade levels limited overall growth and caused height reductions.

The effect of density on tiller formation noted by Santelmann et al. (1963) for yellow foxtail was well illustrated with both species in the 2 years. In 1980, growth of green foxtail, particularly in the control plots, was abnormally vigorous and produced plants at the end of the season with a mean of 73 tillers (Figure 7). In contrast, Vanden Born (1971) found that tiller number of green foxtail growing near Edmonton could range from 10 to a maximum of 35 tillers under good growing conditions with limited crowding.

Notwithstanding the very lush growth of green foxtail in 1980, it is apparent that this species had significantly more tillers per plant than yellow foxtail by the end of the season regardless of the shade level. Although both species showed decreased tiller numbers under shade, it is evident that of the two species, the tillering ability of green foxtail is more affected by shade, with higher levels of shade causing proportionately greater reductions in tiller number than in yellow foxtail. These data agree closely with the results of Vanden Born (1971) who showed that tillering and overall dry matter productions of green foxtail was almost directly proportional to light intensity with the low light intensity producing plants with the fewest tillers.

The trend for head numbers per plant was similar to that of tiller number, with green foxtail having the greater number of heads. Green foxtail heads appeared 1 week earlier than those of yellow foxtail regardless of the shade level. Perhaps the major effect of shade was to uniformly delay the production of heads in the two foxtail species by approximately 1 and 1.5 weeks under 55 and 73% shade, respectively. A delay in heading under shade was also found by Vengris and Damon (1976) in witchgrass where 51 and 76% shade caused a significant 3 and 6 day delay, respectively, in the production of the first head compared to control plots.

Dry weight measurements from 1980 indicated that under unshaded conditions, green foxtail had a higher dry weight than yellow foxtail which was growing under slightly more crowded conditions. This significant difference in dry weight between the two species ceased to be evident at either 55 or 73% shade. The two species showed a similar reaction to the shade in that both experienced similar reductions in dry weight, with the greatest decreases occurring under 73% shade. The rate of dry matter accumulation or relative growth rate was also found to show no consistent difference between the two species, regardless of the shade level. Therefore, although yellow foxtail is slower to germinate and emerge than green foxtail, there are no appreciable differences in either rate, pattern or quantity of dry matter produced under shaded conditions.

Studies of the total leaf area per plant failed to show any consistent trend of differences between green and yellow foxtail in the unshaded control plots. However, results from both years showed that regardless of how the species grew in full sunlight, under either the 55 or 73% shade level they reacted similarly with no significant differences in leaf area. Friend et al. (1962) reported a linear response of increasing leaf area with decreasing irradiance in wheat. In their studies, leaf area increased as light intensity decreased from 200 to 45 watt m^{-2}. At lower irradiance, leaf production and expansion was restricted. In the present study, a similar trend was seen in 1979 but in 1980 a different response was noted whereby the 0% shade plots had greater total leaf area than at either shade level at all four sampling dates. On the basis of these data, it is not possible to determine whether or not the leaf area of C_4 species like foxtail show a similar response to decreasing light intensity as do C_3 species like wheat.

In two of the parameters studied, there appeared to be an inherent difference between the two species under shade. Although dry weight of the species under 55 and 73% shade was almost the same, yellow foxtail had a comparatively greater fresh weight than green foxtail indicating that it is the more succulent of the two species. Also, measurements of the extended length of the fourth leaf indicated that yellow foxtail has a longer fourth leaf than green foxtail regardless of the shade level. Both green and yellow foxtail showed an inverse relationship between leaf length and light intensity which is similar to the results of Friend et al. (1962) for wheat. However, an increase from 55 to 73% shade did not cause significant increases in leaf length in either green or yellow foxtail indicating that the response is not linear (Figure 3). It would appear that of the two species, leaf length of yellow foxtail is more responsive to increasing shade.

Overall, it seems that there is a difference between the two species in what parameters are the most sensitive to the varying shade levels. With green foxtail, characteristics of reproductive growth such as tiller and head number are more affected, while with yellow foxtail vegetative characters including fresh weight, leaf length and height are affected more by reductions in light intensity.

The within crop treatment was included in this study as a means of determining what levels of shade are experienced by green and yellow foxtail growing within a wheat stand and the possible effects on growth. From the light integrator information, it is apparent that in order for either green or yellow foxtail to provide adequate competition to the wheat, they must emerge very close to the time of wheat, as was the case in 1979, since available light levels within the stand decline very rapidly once the wheat starts to develop. In 1980, emergence of both foxtail species was delayed with green foxtail emerging at least 1 week later than the wheat and 1 week ahead of yellow foxtail. The late emergence of yellow foxtail resulted in very low densities and severe competition from the wheat.

Insofar as the weekly light readings were concerned, there are conflicting arguments as to which sensor should be used in this type of study. According to Patterson (1979a) in studies of the effect of light on plant growth such as shading or light competition experiments, total irradiance should be measured with a pyranometer (radiometric) sensor.

However, information in the Licor "Light Sensors and Accessories" Pamphlet[10] specifies that this sensor should not be used within plant canopies. Therefore, discussion will first center on the pyranometer readings which will be compared to the data obtained with the quantum sensor.

In week 3, 50% light reductions were found at the 30 cm height with the pyranometer sensor (Table 7). Since on this date, green and yellow foxtail in the crop were a mean of 46 and 48 cm tall, respectively, it seems probable that they were experiencing shade levels similar to those found under the 55% shade treatment. By the 4th week, the light reduction at this same height was 76%. Thus, according to the pyranometer sensor, the artificial shade levels chosen closely approximated the shade conditions encountered by foxtail growing within the crop. Results from the quantum sensor showed levels of photosynthetically active radiation (PAR) to be much lower at 0 and 30 cm heights within the crop than levels of total irradiance measured by the pyranometer. These data indicate that later emerging foxtail within the crop may have even less utilizable light available for growth than was detected by the pyranometer. Also, this data points out that in years when wheat is able to emerge earlier than the foxtail, shade levels within the crop during early foxtail growth stages may be much higher than the artificial shade levels chosen.

Although it is not possible to attribute characteristics of foxtail growth within the crop to competition for light only, there can be no doubt that the low levels of light occurring within the crop canopy do

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[10] Brochure R51-279, Licor Inc., Lincoln Nebraska.

have some effect on development of both green and yellow foxtail. Height measurements showed that not only was yellow foxtail consistently taller than green foxtail, but by the end of the season it achieved heights greater than that of the wheat which had a mean final height of 95 cm. In both 1979 and 1980, yellow foxtail grew taller than 95 cm, while green foxtail never reached a height of 90 cm and was hidden within the wheat canopy (Figures 4 and 5). Sturko (1978) noted that at no time during the growing season did green foxtail become as tall as Napayo wheat and, in fact, green foxtail heads were 10 to 15 cm shorter than the wheat spikes. As well, Blackshaw (1979) found that Sinton wheat also severely shaded green foxtail throughout most of the growing season.

Both tiller and head number of the two foxtail species were greatly depressed which probably was a result of not only the increased shade, but of far greater crowding than in the control plots. Although green foxtail had a larger number of tillers and heads than yellow foxtail, this species also experienced larger reductions in tiller number compared to control plants. Under the heavily shaded conditions, yellow foxtail had greater numbers of tillers arising from the main stem than did green foxtail. This phenomenon in yellow foxtail is similar to the findings of Knake (1972) for giant foxtail wherein 80% shade caused over 50% of the total culms to be produced along the main stem.

In terms of fresh and dry weight, both species were reduced in comparison to the control to an equal extent by the end of the season. The relative growth rate was also similar in the two species although it differed from the control plants.

Leaf area values were very inconsistent over the 2 years. In general, yellow foxtail initially had a greater leaf area than green foxtail but by the 4th week, there was no difference between the species (Table 5). There was also some indication that yellow foxtail within the crop had greater leaf areas than comparable control plants on some dates. The probable explanation for this occurrence is in the greatly increased leaf lengths of both species within the crop. Both green and yellow foxtail had fourth leaves that were at least twice as long as those in the control plots with yellow foxtail having the longer leaves of the two species.

The characteristic growth of green and yellow foxtail within the crop seems to indicate that superior height growth of yellow foxtail may give this species an advantage over green foxtail which could make it the more serious weed, at least where competition for light is involved. As well, the proportionately greater reduction in tiller number experienced by green foxtail under heavy shade and in the crop suggests that the reproductive growth of this species is more seriously harmed by competition with wheat than it is with yellow foxtail. Consequently, it would appear that the implementation of management practices such as heavier seeding that would increase the shading potential within the crop, might be beneficial in reducing the vigour and competitive ability of green foxtail to a greater extent than yellow foxtail.

Fertility Experiment

Results from the 2 years of the field trial looking at the effect of varying levels of fertility on green and yellow foxtail competition in wheat were also very inconsistent and did not conform to expectations based on previous studies. The fact that in neither year were the two foxtail species able to successfully compete with the wheat for any level of soil nitrogen is contrary to most of the previous results reported in the Literature Review. Numerous researchers have found that green foxtail is able to respond to additions of nitrogen fertilizer and compete aggressively with wheat, especially at high rates of nitrogen (Alex 1967; Moyer and Dryden 1976; Sturko 1978). Although less information is available about yellow foxtail competition in wheat under varying nitrogen levels, work by Huemoeller (1967) indicated that this species is competitive with wheat at low soil nitrogen levels.

The unexpected results of the field studies may be related to the relative time of emergence of the two foxtail species and the wheat. Banting et al. (1973) emphasized that for best survival, green foxtail should emerge at the same time as the crop or even a little ahead of it. In both years of the present study, wheat emerged at least 2 weeks earlier than either foxtail species. Emergence of green foxtail has been found to be very dependent on the soil temperature and moisture conditions at the time of seeding, whereas wheat is only slightly affected by similar conditions (Blackshaw et al. 1981). Blackshaw (1979) also noted that soil moisture had a greater effect than soil temperature on green foxtail germination and emergence. Similarly, Banting et al. (1973) found that peaks in green foxtail emergence occurred after periods of high rainfall. In 1979, soil moisture levels were much higher early in the season than in 1980, but by the time of seeding in the 1st week of June surface soil conditions were quite dry in both years. There was no major rainfall until approximately 1 week after seeding in 1979 and 3 weeks after seeding in 1980, although in the latter year the plots were irrigated 2 weeks after seeding. However, in 1980 air temperatures were sufficiently warm to cause extensive drying of the soil surface after irrigation which probably led to reduced germination of the foxtail seeds near the soil surface. Similar results were noted by Dawson and Bruns (1962) with low germination of both green and yellow foxtail seeds on the soil surface after irrigation. The wheat was seeded much deeper than the foxtail and probably was able to germinate more readily in the presence of existing subsurface moisture as well as the irrigation water which percolated through the upper soil layer.

The results of the fertility studies illustrated quite clearly that regardless of soil fertility levels, in years when environmental conditions at the time of seeding are suboptimal for either green or yellow foxtail emergence, competition to the wheat crop may not be sufficient to cause yield reductions. These results lend support to the hypothesis proposed by Blackshaw (1979) that soil temperature and moisture conditions should be monitored during the emergence period of wheat to gain an estimate of when the foxtail would emerge relative to the wheat crop. In years when environmental conditions cause foxtail emergence to be delayed at least 2 weeks after the wheat so that competition is greatly decreased, it may not be necessary or economically practical to implement herbicidal control of foxtail infestations.

To augment the field studies, a more precisely controlled growth room experiment was carried out to determine specific effects of varying nitrogen levels on foxtail root and shoot growth. Unfortunately, it proved impossible to accurately separate the roots of the foxtail from the Almasippi very fine sandy loam soil which was collected from Graysville and was used to more closely simulate the field conditions. Consequently, only measurements of shoot growth could be taken. For all of the growth characteristics examined, significant differences between green and yellow foxtail were apparent only at the low and high nitrogen levels while at intermediate levels the response of the two species was very similar. The differences between the two species at low and high nitrogen regimes may be a direct consequence of their inherent abilities to take up and utilize this nutrient. It is also important to emphasize that since the volume of soil per pot available for five developing foxtail plants was limited, nutrient depletion almost certainly occurred, especially at the low nitrogen levels, before termination of the study. Therefore, the results for these treatments may be slightly misleading and reflect a greater deprivation and stress on the two foxtail species than would occur under more natural field conditions.

Nevertheless, according to the nutrient analysis report, green foxtail utilized as much or more nitrogen than yellow foxtail at the two lowest levels of 0 and 50 ppm (Table 8). However, when shoot dry matter accumulation is taken into account, yellow foxtail produced an equal or greater amount of top growth than green foxtail. At the two low levels of nitrogen, it would appear that yellow foxtail had the higher nitrogen use efficiency of the two species, at least in terms of dry matter produced per unit of applied nitrogen. Schreiber and Orwick (1978) similarly found that yellow foxtail produced equal amounts of shoot dry matter at "normal" and "below normal" nitrogen fertility levels which further substantiates its efficiency under low nitrogen status.

At the highest applied nitrogen level (400 ppm) green foxtail utilized more nitrogen which was manifested in significantly greater dry matter production than for yellow foxtail. The data indicate that while yellow foxtail may use nitrogen more efficiently at low levels, green foxtail is better able to utilize additional increments of nitrogen at higher levels in the production of dry matter. In light of the hypothesis that

C_4 grasses have a higher nitrogen use efficiency than C_3 grasses (Brown 1978), it is interesting to speculate on the basis of the work presented here that marked differences exist between closely related species of C_4 grasses as well.

Two of the growth parameters examined, namely plant height and head length, reflect the greater efficiency of yellow foxtail compared to green foxtail at low nitrogen levels. Maximum height of yellow foxtail occurred at low levels of nitrogen, whereas green foxtail required higher levels of nitrogen to reach maximum height. Even at 300 or 400 ppm nitrogen, the green foxtail still did not attain the height of comparable yellow foxtail plants (Figure 9). An examination of head length revealed that yellow foxtail not only had significantly longer heads under conditions of low fertility than green foxtail but head length of yellow foxtail was relatively unresponsive to changes in nitrogen over the fertility range studied. In contrast, green foxtail showed a distinct increase in head length as nitrogen was increased except at the highest level. It would appear that head length of green foxtail is much more sensitive to variations in nitrogen level than is head length of yellow foxtail and is consequently affected to a much greater extent under low nitrogen conditions. The facts that yellow foxtail reaches maximum height at low fertility levels and that head length is relatively unresponsive to increasing nitrogen lends credibility to the proposition that this species is better able to maximize its growth potential under nutrient stress than green foxtail.

However, it is clearly evident from the other parameters measured including both tiller and head number that under high nitrogen status, green foxtail is more responsive to added nitrogen and is better able to exploit additional amounts than yellow foxtail. Not only was green foxtail able to produce significantly more tillers than yellow foxtail at high fertility levels, but the difference between the two species were almost twice as great as at low levels. This difference in ability of the two foxtail species to produce tillers at high nitrogen levels is not surprising in view of the fact that variation in rate of initiation and maximum number of tillers produced has been shown to vary between cultivars of wheat and is known to be influenced by the availability of mineral nutrients (Milthorpe and Moorby 1974). Both species appear to have the ability to utilize increasing increments of nitrogen to produce increasing numbers of tillers up to a maximum at 300 ppm. However, since the magnitude of the response is much less in yellow foxtail, green foxtail showed a greater efficiency in total number of tillers produced per increment of nitrogen.

Head number was expected to follow a similar trend as tiller number with green foxtail having more heads than yellow foxtail at high nitrogen levels. While this was the case in trial 1, the results from trial 2 showed that only one-half of the green foxtail tillers produced heads (Table 10). A possible explanation for this anomaly is that toward the end of the second trial there was a short period when the plants suffered a water deficit. Consequently, many of the green foxtail plants, which were generally less succulent than yellow foxtail and had more herbage at high nitrogen levels, wilted badly. Milthorpe and Moorby (1974) reported that a water deficit which occurs late in the developmental period of wheat, may cause a reduction in both the number and size of spikelets produced. It is likely that green foxtail responds similarly although this has not been confirmed.

Head emergence of both green and yellow foxtail was delayed uniformly at high levels of nitrogen which is consistent with the general observation that high nitrogen levels delay maturity in many species. Although both species showed a positive response of head number to increasing nitrogen level, green foxtail was able to respond to higher levels of nitrogen than yellow foxtail which once again indicates its greater efficiency at high nitrogen.

With regard to percent protein content of green and yellow foxtail, it was difficult to find any consistent significant differences between the two species. A very general trend may be extrapolated from the data wherein it would appear that green foxtail had a higher percent protein content than yellow foxtail at low nitrogen values while the reverse is true at high nitrogen values. Furthermore, it was found that there was no difference between the two species with respect to total protein production except at the very highest nitrogen level where green foxtail produced more total protein than yellow foxtail. It would appear that growth of yellow foxtail reaches a maximum level at 300 ppm after which further additions of nitrogen do not result in greater amounts of nitrogen taken up or increased production of protein (Table 11). A similar result was noted by Bosemark (1954) in wheat. He found that plants with a high level of nitrogen showed a pronounced inhibition in root growth which was manifested in a reduction in total plant growth.

In summary, it would appear that there are distinct differences in the ability of the two species of foxtail in the uptake of nitrogen and in the utilization of nitrogen in the production of top growth. In comparing relative efficiencies of shoot dry matter produced per unit nitrogen taken up, yellow foxtail seems to have an advantage over green foxtail on low fertility soils whereas the opposite situation exists under high fertility conditions. Schreiber (1977) similarly observed that the foxtail species with high nitrogen requirements such as robust white and robust purple foxtail did not compete as well on soils of low fertility as did yellow foxtail.

The greater efficiency of yellow foxtail at low nitrogen was due mainly to increased dry matter production and culm elongation. Also, no change in head length ensured that the reproductive capacity of this species was not harmed seriously. In contrast, the greater efficiency of green foxtail at high nitrogen was manifested by enhanced reproductive growth mainly in the production of more tillers and heads than yellow foxtail. Perhaps these differences between green and yellow foxtail may ultimately mean that the two foxtail species will not always occupy exactly the same niche in Manitoba. Yellow foxtail may be able to outcompete green foxtail on low nitrogen soils and be more prevalent in areas like ditches and fencerows while green foxtail may be the more successful competitor and main inhabitant of highly nitrogen fertilized areas like cropland.

Growth Curves Experiment

In order to gain information on the comparative growth patterns of green and yellow foxtail under conditions with no environmental stress, a study was undertaken which measured root and shoot growth at weekly intervals throughout the growing period. It was found that there is a significant difference between green and yellow foxtail in root growth but not in shoot growth. The difference in root growth between the two species was not evident until the end of both trials at which time yellow foxtail responded with dramatic increases in root dry weight. These results are similar to those reported by Schreiber and Orwick (1978) who found that yellow foxtail had a significantly greater root mass than four other Setaria taxa including giant foxtail, giant green foxtail, robust white and robust purple foxtail. However, since visual observation revealed that the root system of yellow foxtail is much coarser than that of green foxtail, it is possible that the higher root dry weight of yellow foxtail does not necessarily reflect an increased root surface area, but instead is merely a consequence of a larger root diameter. It may even be that green foxtail roots actually have a greater absorptive area but due to their finer texture, weigh less than that of yellow foxtail.

Regardless of whether or not the root dry weight of yellow foxtail is necessarily indicative of a greater absorptive capacity, it is interesting that this species experienced a large increase in root weight just prior to heading which was not similarly observed in green foxtail. Research done by Hackett (1969, 1973) in sorghum and barley indicated that although there may be large differences in root dimensions between varieties of a species, within a variety, constant relationships are maintained between the total number, length, surface area and volume of the root members. Therefore, if this same phenomenon exists in foxtail, it is unlikely that the late increase in overall yellow foxtail dry weight is due to an increase in any one of the aforementioned parameters.

A possible explanation for the increased root dry weight of yellow foxtail at the end of the season may be, as proposed by Hackett (1973), that the age of the plant has an effect on overall root dimensions. Huemoeller (1967) outlined a general theory whereby the shoot, which receives light first, tends to satisfy its own demands before transferring organic nutrients to the root. Perhaps this mechanism occurs in yellow foxtail whereby transfer of assimilates to the root is restricted until the end of the season when shoot growth is close to maturity. It is also conceivable that root growth of green foxtail may act in a similar manner but not have been able to experience late season increases due to restrictions from the pot. On the basis of these dry weight data alone, it is very difficult to assess and interpret the root performance of these two foxtail species and more specific morphological root growth analyses, including root length, diameter, volume, surface area and elongation are necessary.

It is somewhat surprising that no difference in shoot growth exists between the species since Evetts and Burnside (1973) found that vigorous root growth was positively correlated with vigorous shoot growth. Therefore, it would be expected that yellow foxtail, with the higher root dry weight, would also have a significantly greater shoot dry weight than green foxtail, at least at the end of the season. Although this was the case in trial 2, it is felt that the loss of vigour in shoot growth experienced by the green foxtail in comparison to trial 1 is abnormal and due to drought stress for a short period as well as an infestation of spider mites (Figure 12). The yellow foxtail appeared to suffer to a lesser extent from both the lack of water and the spider mites which is evidenced by the fact that, at the end of the experiment, yellow foxtail had a greater number of tillers. Since under field conditions, green foxtail normally has a higher shoot dry weight than yellow foxtail (see Table 3, 1980 results), the fact that there was no difference in shoot growth between the species in this experiment may be significant. Perhaps it is possible that the improved shoot dry weight of the yellow foxtail relative to green foxtail was due to the increased root growth of the former species.

The higher shoot:root ratio of green foxtail emphasized that there is less root material present in this species than in yellow foxtail to support an equivalent amount of shoot growth. Depending on whether or not this lower root dry weight necessarily is indicative of a lower absorptive capacity, it may be that green foxtail would be less able to withstand the restricted water and nutrient supply incurred through severe competition.

Yellow Foxtail Biotype Study

The 2 year field study of the comparative growth of three yellow foxtail biotypes failed to show any major differences between the biotypes at the end of the season. Differences in growth found earlier in the season were mainly between the two Manitoba and the Ontario biotypes and are attributed to the later emergence and slower development of the Ontario biotype. The effect of the slower development was especially evident in final head number wherein the Ontario biotype had significantly fewer heads than both of the Manitoba biotypes at the end of the sampling season. Since the Ontario biotype continued to produce heads and set seed long after the Manitoba biotypes had begun to senesce, it is felt that this later maturity reflects the comparatively longer growing season which occurs in its native habitat of southern Ontario. This finding is similar to the results of Schoner et al. (1978) who found that three California biotypes studied were similar in all respects except in time to heading and this difference was a direct result of variations in latitude between the collection sites. However, in the shorter growing season in southern Manitoba, the early maturity of the Carman and Winnipeg biotypes would ensure the production of viable seed to maintain and increase the population. Since the Ontario biotype had not fully matured until the end of September, it is possible that plants located within the crop would be harvested before seed set and thus severely restrict population growth. The requirement for the longer growing season would limit the spread of this biotype in Manitoba.

Although in most respects the growth of the three biotypes was similar, the lower densities in some plots in 1979 showed that under low levels of intraspecific competition, the Ontario biotype assumed a more prostrate growth habit which was not seen for the Manitoba biotypes in comparable densities. However, as the density increased, the Ontario biotype developed the more erect habit of the other two biotypes. The prostrate habit of the Ontario biotype might be indicative of an adaptation to a low growing crop. In Manitoba, tall field crops dictate a necessity for an erect habit for survival of yellow foxtail. However, if the Ontario biotype withstands competition throughout the season, the prostrate habit might ensure survival of enough heads to propagate the biotype, which otherwise would be clipped during harvest. Similarly, Schoner et al. (1978) have noted that in California, yellow foxtail which largely occurs in alfalfa, has a distinct prostrate growth habit which protects the biotype from excessive defoliation by alfalfa harvesting equipment.

On the basis of these data, it would appear that the morphological differences between the three yellow foxtail biotypes is small and there is potential for spread in Manitoba. However, the extent of spread of the Ontario biotype especially would be limited by the length of growing season as well as temperature and moisture levels which could have an effect not only on growth and development but may influence seed dormancy and germination requirements. Experiments are currently being conducted to determine if differences in germination behaviour between biotypes grown at the same site do, in fact, occur.

SUMMARY AND CONCLUSIONS

Green and yellow foxtail differed in their relative ability to respond to and utilize varying levels of shade and fertility. In full sunlight, green foxtail was more productive than yellow foxtail both in terms of dry matter accumulation and tiller number. However, under both 55 and 73% shade, dry matter production and total leaf area was similar for the two species. This response was found to be due to increased plant height and leaf length of yellow foxtail under 55% shade compared to plants grown in full sunlight. Green foxtail did not show a similar response to the shade regime. In this species, both 55 and 73% shade levels caused a large reduction in tiller number which was proportionately greater than the decreases seen in yellow foxtail.

Within the crop, the combination of decreased light availability and crop competition caused similar but more pronounced effects on foxtail growth. Green foxtail experienced huge reductions in tiller number compared to plants in full sunlight. Yellow foxtail, which did not suffer as great a decrease in tiller number also had large increases in height which enabled its heads and upper leaves to grow above the crop canopy. Light measurements revealed that available light levels within the stand decline rapidly once the wheat begins to develop so that late emerging foxtail plants have little chance of survival.

The amount of nitrogen utilized by both species was similar at the low and intermediate levels while green foxtail utilized more nitrogen than yellow foxtail at the high levels. At the low nitrogen levels, yellow foxtail produced an equal or greater amount of top growth than green foxtail which indicated that it was the more efficient of the two species under these conditions. Conversely, green foxtail had a greater dry matter production at the highest nitrogen level than yellow foxtail. This species is better able to efficiently utilize additional increments of nitrogen. At the intermediate nitrogen levels the two species acted similarly.

The greater dry matter production of yellow foxtail over green foxtail at low nitrogen levels was due to greatly increased plant height. Head length was not only longer in yellow foxtail than in green foxtail at low nitrogen but also was much less affected by variations in nitrogen level. At higher nutrient status, green foxtail utilized the additional nitrogen in the production of greater numbers of tillers than yellow foxtail. Despite the different relative efficiency of nitrogen use between the two species, no difference in total protein content was found except at the highest nitrogen level. Unlike green foxtail, it appears that yellow foxtail was not able to utilize this level of nitrogen in increased production of protein.

Under greenhouse conditions there was no difference in shoot dry weight between the two foxtail species throughout the season. However, significant differences between root dry weight of green and yellow foxtail were evident by the end of the study. Just prior to heading, the root dry weight of yellow foxtail increased dramatically compared to the root dry weight of green foxtail. Visual observations of root appearance noted that the root system of yellow foxtail was much coarser than the more finely textured root system of green foxtail.

The small study examining three biotypes of yellow foxtail failed to show any significant differences between the two Manitoba biotypes.

The Ontario biotype was also similar in most respects except that it did not begin to produce heads until after both the Carman and Winnipeg biotypes and begun to senesce. The inherent ability to assume a prostrate growth habit may aid in the spread of the Ontario biotype into Manitoba should it adapt to the shorter growing season.

Thus, it would seem that yellow foxtail has the potential to be a more serious competitor than green foxtail under conditions such as moderate shade and low nutrient status which would be expected to occur within crop stands. Since this species can increase in height to above the crop canopy, it can utilize light that would not be available to the shorter growing green foxtail. Since increases in height are also stimulated by low nitrogen levels, yellow foxtail should be able to survive and reproduce efficiently even when the available nutrient levels are depleted by crop competition. Green foxtail, on the other hand, requires more light and high levels of nitrogen to grow most efficiently. Depending on water availability, it would seem that a decrease in either one or both of these essential growth factors through crop competition would harm the growth and reproductive potential of green foxtail to a greater extent than yellow foxtail.

Since it is apparent that differences in growth response exist between the two foxtail species, it is interesting to speculate as to the reasons for these differences. Although it is impossible to arrive at any definite conclusions after so preliminary a study, it would seem that the difference in shoot fresh weight seen in the two species under shade may be a factor. But perhaps the real difference lies in the root systems of the two foxtail species. It is possible that the larger root mass of yellow foxtail compared to green foxtail may also give this species an advantage under competitive conditions when water and nutrient availability is restricted. However, further study is required to determine whether or not the larger root mass of yellow foxtail is necessarily indicative of a greater absorptive capacity.

The biotype study emphasized that yellow foxtail is a highly adaptive species since the Ontario biotype was not only able to survive in southern Manitoba, but in most respects had similar growth characteristics as the two Manitoba biotypes. It would seem that there is a good potential for spread of yellow foxtail across southern Manitoba. The combination of this potential for spread and the high competitive efficiency under crop conditions theoretically may make yellow foxtail an even more serious threat to crop production than is green foxtail at the present time.

From this study it would appear that several avenues lie open for further research. In the area of shade studies, it is known that not only do changes in light intensity occur as light passes through the crop canopy, but changes in light quality happen as well which also affect growth. Taylorson and Borthwick (1969) determined that light which is filtered through green leaves has its spectral quality altered so that much more of the incident far-red is transmitted than the incident red. Since only very preliminary work has been done thus far, it is important to know the exact implications of such spectral light changes on weed seed germination, growth and competitive ability.

From a more practical viewpoint, since this study indicated that the vigour and competitive ability of green foxtail may be decreased under shade, it is important to explore more specifically the levels of shade required to suppress this species. Also, research should be done on the effect of varied rates and methods of seeding on the incident shade levels within the crop to determine if cultural practices could aid in green foxtail control. At the same time, it would be interesting to find out the effect of more than one competitive factor on both species of foxtail within a crop situation. It seems likely that several competitive factors acting together would exert a greater effect on weed growth so that less shade might be needed to control green foxtail.

There also appears to be a need for greater definition of root growth within the two foxtail species. It may well be, as Pavlychenko and Harrington (1934) outlined, that roots are the key to the proper interpretation of above ground development. Not only is further study needed in the area of general root relations such as root length, volume, diameter and elongation but more specific research should be done on how these root parameters are affected by nutrient and water stresses. It is possible that the greater efficiency of yellow foxtail over green foxtail at low nitrogen levels is directly related to root growth under these conditions.

In summary, there is a great need for further study of the biological nature of both of these two foxtail species in Manitoba. Not only is this type of research essential to our understanding of how and why these weeds cause crop losses, but it may prove helpful in defining cultural practices which could be used to augment or supersede costly chemical control methods.

BIBLIOGRAPHY

ALEX, J.F. 1967. Competition between Setaria viridis (green foxtail) and wheat at two fertility levels. Res. Rep. Nat. Weed Comm. (West Sect.) Canada. pp. 286.

ALEX, J.F., J.D. BANTING and J.P. GEBHARDT. 1972. Distribution of Setaria viridis in western Canada. Can. J. Plant Sci. 52: 129-138.

BANTING, J.D., E.S. MOLBERG and J.P. GEBHARDT. 1973. Seasonal emergence and persistence of green foxtail. Can. J. Plant Sci. 53: 369-376.

BLACK, C.A. 1968. Soil-plant relationships. John Wiley and Sons, New York.

BLACK, C.C., T.M. CHEN and R.H. BROWN. 1969. Biochemical basis for plant competition. Weed Sci. 17: 338-344.

BLACKSHAW, R.E. 1979. Environmental factors affecting green foxtail (Setaria viridis) competition in spring wheat. M.Sc. Thesis, University of Manitoba, Winnipeg, Manitoba.

BLACKSHAW, R.E., E.H. STOBBE, C.F. SHAYKEWICH and W. WOODBURY. 1981. Influence of soil temperature and soil moisture on green foxtail (Setaria viridis) establishment in wheat (Triticum aestivum). Weed Sci. 29: 179-184.

BOARDMAN, N.K. 1977. Comparative photosynthesis of sun and shade plants. Ann. Rev. Plant Physiol. 28: 355-377.

BOSEMARK, N.O. 1954. The influence of nitrogen on root development. Physiol. Plant. 7: 497-501.

BROWN, R.H. 1978. A difference in N use efficiency in C_3 and C_4 plants and its implications in adaptation and evolution. Crop Sci. 18: 93-98.

CHEN, T.M., R.H. BROWN and C.C. BLACK. 1970. CO_2 compensation concentration, rate of photosynthesis, and carbonic anhydrase activity of plants. Weed Sci. 18: 399-403.

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.

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

DITTMER, H.J. 1948. A comparative study of the number and length of roots produced in nineteen angiosperm species. Bot. Gaz. 109: 354-358.

DRYDEN, R.D. and C.W. WHITEHEAD. 1963. The effect of TCA on green foxtail in competition with cereals. Can. J. Plant Sci. 43: 451-456.

EVETTS, L.L. and O.C. BURNSIDE. 1973. Early root and shoot development of nine plant species. Weed Sci. 21: 289-291.

FELTNER, K.C., H.R. HURST and L.E. ANDERSON. 1969. Yellow foxtail competition in grain sorghum. Weed Sci. 17(2): 211-213.

FRIEND, D.J.C., V.A. HELSON and J.E. FISHER. 1962. Leaf growth in Marquis wheat as regulated by temperature, light intensity and daylength. Can. J. Bot. 40: 1299-1311.

FRIESEN, G. and L.H. SHEBESKI. 1960. Economic losses caused by weed competition in Manitoba grain fields. I. Weed species, their relative abundance and their effect on crop yields. Can. J. Plant Sci. 40: 459-467.

HACKETT, C. 1969. A study of the root system of barley. II. Relationships between root dimensions and nutrient uptake. New Phytol. 68: 1023-1030.

HACKETT, C. 1973. A growth analysis of the young sorghum root system. Aust. J. Biol. Sci. 26: 1211-1214.

HARPER, J.L. 1977. The population biology of plants. Academic Press, New York.

HUEMOELLER, W.A. 1967. The nature of the competition between Chris wheat (*Triticum aestivum* L.) and yellow foxtail (*Setaria glauca* L. Beauv.). M.Sc. Thesis, North Dakota State University, Fargo, North Dakota.

KEELEY, P.E. and R.J. THULLEN. 1978. Light requirements of yellow nutsedge (*Cyperus esculentus*) and light interception by crops. Weed Sci. 26: 10-16.

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

McWHORTER, C.G. and T.N. JORDAN. 1976. Comparative morphological development of six Johnsongrass ecotypes. Weed Sci. 24: 270-275.

MILTHORPE, F.L. and J. MOORBY. 1974. An introduction to crop physiology. Cambridge University Press, London.

MOYER, J.R. and R.D. DRYDEN. 1976. Effects of combined applications of triallate or trifluralin with solution nitrogen on wheat, wild oats and green foxtail. Can. J. Plant Sci. 57: 479-484.

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

ORWICK, P.L. and M.M. SCHREIBER. 1975. Differential root growth of four Setaria taxa. Weed Sci. 23: 364-367.

PAVLYCHENKO, T.K. and J.B. HARRINGTON. 1934. Competitive efficiency of weeds and cereal crops. Can. J. Res. 10: 77-93.

PAVLYCHENKO, T.K. and J.B. HARRINGTON. 1935. Root development of weeds and crops in competition with dry farming. Sci. Agric. 16: 151-159.

PATTERSON, D.T. 1979a. Methodology and terminology for the measurement of light in weed studies - a review. Weed Sci. 27: 437-443.

PATTERSON, D.T. 1979b. The effects of shading on the growth and photosynthetic capacity of itchgrass (Rottboellia exaltata). Weed Sci. 27: 549-553.

PETERS, R.A., J.A. MEADE and P.W. SANTELMANN. 1963. Life history studies as related to weed control in the northeast. 2. Yellow foxtail and giant foxtail. Rhode Island Ag. Exp. Stn., Bull. No. 369.

RADFORD, P.J. 1967. Growth analysis formulae - their use and abuse. Crop Sci. 7: 171-175.

RAHMAN, A. and R. ASHFORD. 1972. Control of green foxtail in wheat with trifluralin. Weed Sci. 20: 23-27.

ROCHE, B.F., Jr. and T.J. MUZIK. 1964. Ecological and physiological study of Echinochloa crusgalli (L.) Beauv. and the response of its biotypes to sodium 2,2-dichloropropionate. Agron. J. 56: 155-160.

RYLE, G.J.A. 1961. Effects of light intensity on reproduction in S.48 timothy (Phleum pratense L.). Nature:191: 196-197.

SANTELMANN, P.W., J.A. MEADE and R.A. PETERS. 1963. Growth and development of yellow foxtail and giant foxtail. Weeds 11: 139-142.

SCHONER, R.F., R.F. NORRIS and W. CHILCOTE. 1978. Yellow foxtail (Setaria lutescens) biotype studies. Growth and morphological characters. Weed Sci. 26: 632-636.

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

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

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

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

STEEL, R.G.D. and J.H. TORRIE. 1960. Principles and procedures of statistics. McGraw Hill Inc., New York.

STURKO, A.R.W. 1978. Green foxtail (Setaria viridis) competition in semidwarf and normal height spring wheat. M.Sc. Thesis, University of Manitoba, Winnipeg, Manitoba.

TAYLORSON, R.B. and H.A. BORTHWICK. 1969. Light filtration by foliar canopies: Significance of light controlled weed seed germination. Weed Sci. 17: 48-51.

TERRELL, E.E. 1976. The correct names for pearl millet and yellow foxtail. Taxon 25: 297-304.

THOMAS, A.G. 1979. The 1979 weed survey of cultivated land in Manitoba. Agric. Can. Res. Stn., Regina, Sask. and Man. Dept. Agric., Winnipeg, Manitoba.

VANDEN BORN, W.H. 1971. Green foxtail: Seed dormancy, germination and growth. Can. J. Plant Sci. 51: 53-59.

VENGRIS, J. 1963. The effect of time of seeding on growth and development of rough pigweed and yellow foxtail. Weeds 11: 48-50.

VENGRIS, J., A.E. KACPERSKA-PALACZ and R.B. LIVINGSTON. 1966. Growth and development of barnyardgrass and grass in Massachusetts. Weeds 14: 299-301.

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

WILLIAMS, R.D. and M.M. SCHREIBER. 1976. Numerical and chemotaxonomy of the green foxtail complex. Weed Sci. 24: 331-335.

APPENDIX

APPENDIX TABLE 1. 1979 Weather data.

Date	May			June			July			August			September		
	Rain	Temp. °C		Rain	Temp. °C		Rain	Temp. °C		Rain	Temp. °C		Rain	Temp. °C	
	mm	Max.	Min.	mm	Max.	Min.	mm	Max.	Min.	mm	Max.	Min.	mm	Max.	Min.
1		12.0	- 1.5		17.0	3.0		27.0	12.0		30.0	10.5		23.0	15.0
2		6.0	- 2.0		22.5	5.0		26.5	14.0		26.0	15.0		16.0	12.0
3		5.5	- 4.5		26.0	8.0	2.8	26.5	14.5		24.0	10.0	0.8	21.0	11.0
4		5.0	- 5.0	7.6	19.0	7.0		30.5	7.5		22.0	10.0		22.5	12.0
5		6.5	- 4.5		25.0	6.0		29.0	9.5		22.0	8.0		25.0	
6		6.0	- 4.0	1.8	25.0	7.0		29.0	11.0	26.4	27.0	10.5		15.5	6.0
7		7.0	0.0		16.0	5.0		24.0	10.5		27.0	13.5		18.0	2.5
8		6.0	- 1.5		20.0	4.5		33.0	12.0		25.0	8.0		25.0	3.0
9		6.5	- 3.0		22.0	6.0		32.0	14.0		24.5	9.0		19.5	6.0
10		6.0	- 2.5		23.0	7.0		33.0	15.0		22.0	11.0		16.0	8.0
11		6.0	- 3.5	6.6	26.0	4.0		33.0	14.5		26.0	7.0		20.0	9.0
12		16.0	- 3.0		30.0	6.0		32.0	17.0	0.2	24.0	9.0		15.0	8.0
13		13.5	- 2.0		38.0	10.5	1.0	28.5	15.0	trace	15.5	6.5		14.0	5.0
14		14.0	0.0	0.2	29.0	13.0		25.0	12.0		19.0	4.5		22.5	0.0
15		18.5	- 3.0		24.5	7.0		21.5	12.5		23.0	2.0		26.5	2.5
16		29.0	- 1.0		25.0	5.0	2.5	25.5	10.0		25.0	3.5		35.0	8.5
17		20.0	5.0		26.5	3.0		29.5	11.0		29.0	9.0		23.5	16.0
18		11.0	2.5		28.0	5.0		32.0	15.0		30.0	11.5		16.0	7.0
19		10.0	- 3.0		22.0	7.0		30.5	16.0		30.0	12.0		26.0	6.0
20		5.5	- 1.5	33.0	17.0	11.0		34.0	16.0		30.0	10.5		16.5	6.0
21		20.0	2.5	12.7	12.0	7.5		29.0	17.0		22.0	11.0		20.0	1.5
22		19.5	4.0		19.0	6.0		31.5	13.0		23.0	12.5		15.0	7.5
23		16.0	3.0		23.0	4.5	15.2	27.5	15.0	trace	17.0	11.0	12.7	18.5	3.0
24		26.0	2.0		27.5	5.0	1.3	27.0	12.5	2.8	25.0	16.0		20.0	4.0
25	10.2	24.0	3.5		24.0	4.0	10.9	24.0	13.0		23.0	6.0		22.5	8.0
26		26.0	10.0		26.0	11.0		24.0	10.0		24.5	7.0	3.0	23.5	5.0
27		23.5	5.0		29.0	9.0		27.0	11.5		28.0	6.0		15.5	6.0
28		29.0	6.0	4.8	27.5	10.5		29.5	14.0	0.2	29.5	7.0		14.0	5.0
29	4.8	19.0	9.0		30.0	14.0		26.0	12.0	0.2	21.0	11.5		17.5	5.0
30	5.6	11.0	6.0		29.5	12.0		22.0	15.0		25.0	4.0		20.5	1.5
31		16.0	3.0					26.0	9.0	5.1	25.0	5.0			
	20.6	14.3	0.5	66.7	24.4	7.1	33.7	28.2	12.9	34.9	24.7	8.7	16.5	20.1	6.6

APPENDIX TABLE 2. 1980 Weather data.

Date	May			June			July			August			September		
	Rain mm	Temp. °C Max.	Min.	Rain mm	Temp. °C Max.	Min.	Rain mm	Temp. °C Max.	Min.	Rain mm	Temp. °C Max.	Min.	Rain mm	Temp. °C Max.	Min.
1		29.5	3.0		17.5	6.0		23.0	8.0		28.0	14.0		21.2	7.2
2		30.5	5.0		20.5	1.0		31.0	11.0		25.2	8.5	0.25	24.5	6.0
3		33.0	8.0		25.0	3.0		30.0	12.0	16.7	25.0	7.0	1.22	26.5	14.5
4		27.0	9.0	3.0	28.2	6.2	1.0	20.0	13.0	3.5	20.2	9.8	0.12	21.0	11.5
5		22.0	7.0		27.8	14.5		27.0	9.0	3.2	23.5	12.0		25.0	8.0
6		9.5	- 1.0		23.0	11.0		29.2	11.2		24.5	10.0		32.0	6.0
7		10.0	- 0.5		18.0	5.0	4.7	26.0	15.0		25.4	12.5	3.00	36.0	8.0
8		17.0	- 3.0		24.8	6.0		29.0	20.0		23.2	12.0	3.50	23.0	15.4
9		19.0	- 2.5		27.8	8.5		34.0	13.4		22.5	8.2		20.5	7.5
10		10.5	- 0.5		29.4	6.0		33.2	17.6	3.0	22.8	10.4		27.4	7.5
11		14.5	1.0		36.0	6.0	5.0	30.8	18.0	0.5	24.0	9.0		22.4	4.5
12		10.0	4.0	0.7	26.0	14.5		30.2	16.0		26.5	10.2	7.00	13.8	6.2
13		11.0	- 1.5	1.0	27.0	12.0	6.0	36.0	16.2	0.5	24.5	13.5		19.5	5.8
14		17.0	- 1.5		22.0	9.0	2.2	25.5	17.0		26.0	11.0		20.5	2.0
15		23.0	- 5.0		23.0	3.0		26.0	14.6		26.4	8.2		18.0	5.2
16		27.4	0.0		27.0	3.5	8.5	26.2	16.0		16.5	8.8	2.50	13.0	4.0
17		27.0	4.2	0.7	22.0	7.0	0.7	26.5	14.0		30.5	11.5	8.00	6.0	3.0
18		27.0	8.5		22.2	8.0		26.0	13.5	9.7	27.2	8.2	8.00	11.5	-2.0
19		34.0	8.0		25.0	4.5		23.0	11.0		31.2	9.0	7.00	7.0	-2.0
20		33.5	11.2		29.0	8.0		23.0	11.2	6.7	22.2	16.0		13.4	2.0
21		37.2	14.5		30.2	12.5	2.5	22.5	13.5	6.0	22.4	15.0	16.00	14.5	4.5
22		39.5	15.0		36.0	13.0		28.5	11.5		22.5	9.4		10.5	5.0
23		36.0	20.0	1.0	26.2	14.8		33.0	12.8		24.0	10.0	3.0	8.2	1.0
24		34.4	13.0		30.5	15.0		28.0	14.0		31.0	10.0		10.0	4.0
25	5.0	34.5	11.5		26.0	2.4		23.4	7.0		20.0	12.4		8.5	3.0
26		33.0	14.0		19.0	8.0		28.0	8.2		20.0	5.0			
27	0.2	33.0	14.4	1.0	19.0	8.5		28.5	10.0		22.5	2.0			
28	2.0	29.8	14.6	0.7	18.8	10.0		28.6	13.0	1.2	22.5	2.5			
29		26.0	14.5	11.0	24.2	10.4		32.5	10.0	3.2	21.0	11.0			
30		21.0	6.0	44.0	28.0	12.0		29.0	13.0		22.0	9.0			
31	1.5	22.0	5.0				1.0	28.8	14.5		21.0	5.0			
	8.7	25.1	6.3	63.1	25.3	8.3	31.6	27.9		51.2	24.0	9.7	59.6	18.1	5.5

APPENDIX TABLE 3. Weekly temperatures at three shade levels in 1979 and 1980.

Date	Temperature		
	% Shade Level		
	0	55	73
	(C)		
1979			
July 12	24.0	24.0	23.5
July 20	35.5	33.5	33.5
July 24	28.5	26.0	25.5
July 26	22.0	23.0	22.0
July 31	25.0	24.0	23.5
Aug 14	14.0	14.5	13.5
1980			
July 9	32.5	32.0	33.5
July 14	23.0	22.0	22.5
July 23	32.0	32.0	33.0
July 30	27.0	26.0	27.5
Aug 6	25.0	24.0	25.0
Aug 13	22.5	21.0	22.0
Aug 27	22.0	21.5	22.0