ENVIRONMENTAL FACTORS AFFECTING GREEN FOXTAIL (*Setaria viridis*) COMPETITION IN SPRING WHEAT

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ENVIRONMENTAL FACTORS AFFECTING GREEN FOXTAIL

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ROBERT EARL BLACKSHAW

A dissertation submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF FIGURES

ABSTRACT

Blackshaw, Robert Earl. M.Sc., The University of Manitoba, 1979. Environmental Factors Affecting Green Foxtail (Setaria viridis) Competition in Spring Wheat. Major Professor: E. H. Stobbe

The effect of green foxtail competition on the growth and yield of semi-dwarf (c.v. Norquay) and normal height (c.v. Sinton) spring wheat was studied in 1977 and 1978.

Green foxtail competition was found to suppress wheat growth as well as final grain yield. Tiller number, leaf area, and dry weight of wheat were reduced due to competition by green foxtail.

Competition for available soil moisture and soil nutrients were the major ways in which green foxtail competed with wheat.

The intensity of green foxtail competition was higher in the semi-dwarf Norquay wheat variety than in the normal height Sinton wheat variety. At comparable infestation densities, grain yield reductions and the amount of green foxtail seed produced were greater in Norquay than in Sinton wheat.

The intensity of green foxtail competition could not be determined by density alone. The environmental conditions at seeding and early growth were important in determining the competitive ability of green foxtail. Soil moisture and soil temperature were critical parameters affecting the time of emergence of green foxtail relative to that of

wheat. When the soil was moist (0 to -4 bars ψ) and the soil temperature was warm (20 to 25°C) during the emergence period, green foxtail emerged 3 to 5 days after wheat. However, when the soil was dry (-4.0 to -6.5 bars ψ) and the soil temperature was cool (15 to 20°C), green foxtail emerged 10 to 14 days after wheat. If the soil moisture was less than -6.5 bars water potential green foxtail emergence was completely inhibited.

When green foxtail infestation of 200 to 400 plants per m^2 emerged within a week of wheat the potential competitive ability of green foxtail was great. Herbicidial control should occur by the two- to three-leaf stage of green foxtail to minimize wheat yield losses. When green foxtail emerged 2 weeks after wheat, grain losses were usually small. However, these suppressed green foxtail plants were capable of producing large quantities of viable seed.

Seeding of wheat should be done early to maximize yields. This practice lengthens the growing season and more efficient use is made of the long hours of sunlight in June and July. Where green foxtail is a problem, seeding early in May when soil temperatures are normally cool, will reduce the intensity of green foxtail competition by giving wheat the competitive advantage of emerging several days before green foxtail.

INTRODUCTION

Green foxtail, Setaria viridis (L.) Beauv., is a summer annual grass categorized as one of the world's most common weeds. It is thought to have originated in Europe; being present in Canada as early as 1821 and was found to be reasonably widely distributed by 1883 (Alex et al., 1972).

Although distributed throughout Canada, green foxtail occurred in prairie fields in only limited areas (Groh and Frankton, 1948). They found green foxtail present in 15.6, 15.4 and 10.6% of fields surveyed in Manitoba, Saskatchewan, and Alberta, respectively. Friesen and Shebeski (1960) found green foxtail to be the second most prevalent weed in Manitoba, being present in 48% of fields surveyed. Beck (1968) reported widespread distribution of green foxtail in Saskatchewan, with the largest densities being present on sandy textured soils. Alex et al., (1972) reported green foxtail present in 84, 32, and 28% of fields surveyed in Manitoba, Saskatchewan, and Alberta, respectively. In recent surveys, green foxtail has been found to be the most common weed in Manitoba and Saskatchewan, with the average density in Manitoba being 396 green foxtail plants per square meter (Donaghy, personal communication).

Only in the last decade has green foxtail been recognized as a serious weed in Manitoba grain fields. A contributing factor of green foxtail awareness coincided with the widespread use of selective herbicides for control of broadleaf weeds and wild oats. Green foxtail increased in distribution and density, until the point where it has become a serious competitor in wheat.

Green foxtail is capable of producing large quantities of seed and because it requires warm soil temperatures for germination, it usually escapes spring cultivation intended for weed control. This combination enables green foxtail to become established in large enough infestations to reduce wheat yields.

Sturko (1978) found that green foxtail can cause wheat yield reductions at relatively low infestation densities, but that the degree of competition varied with the environmental conditions present at the time of seeding and early plant growth.

The objectives of this study were to determine a) the critical environmental factors affecting green foxtail competition, b) the density of green foxtail required to reduce wheat yields under several environmental conditions, and c) the effect of green foxtail competition on wheat growth.

LITERATURE REVIEW

Introduction

Pavlychenko and Harrington (1935) defined plant competition as a natural phenomenon, in which certain plants of the same or unrelated species growing in close proximity, develop at the expense of their weaker rivals. Competition for water and nutrients commence under the soil surface when the plant root systems overlap. Competition immediately manifests itself in the retarded development of the top growth and is intensified by competition for light after shading of one plant by another takes place.

Supremacy in competition was attained by the species or variety which was best able, by virtue of greater physiological activity and morphological adaptability, to exploit the environment most efficiently (Pavlychenko and Harrington, 1934). Cereals initially had a more extensive root system than did wild oats. However, 21 days after emergence the wild oat plants had the more developed root system. Competitive efficiency was due to the distribution rather than the size of the root system. Of cereal crops, barley had the most extensive root system and was the most successful competitor with weeds, followed by rye, wheat, and oats.

Competition by weeds reduced root development in cereals (Pavlychenko and Harrington, 1934). Wheat grown in competition with wild oats had only one-half the root development of wheat grown alone. In the Canadian prairies, where light is plentiful and soil fertility is reasonably high, moisture was generally the limiting factor.

Blackman and Templeman (1938) studied competition of annual weeds in cereals. They found weed competition was variable from year to year. Weeds often had a greater depressing effect on crop yields following a wet spring than a dry spring. Their studies indicated weeds were competing for soil nutrients, primarily nitrogen. Competition for water and light also occurred, depending upon the weed species and density present.

The degree of weed competition was correlated to the density of the weed infestation present. As the density of the weed increased, the yield of the cereal crop decreased (Blackman and Templeman, 1938). The critical period of plant competition occurred in the early stages of growth, since weeds that developed rapidly reduced crop yields to the greatest extent.

Knake and Slife (1965) found that giant foxtail emerging with the crop reduced the yield of corn and soybean by 13 and 27%, respectively. However, giant foxtail seeded three weeks after the crop did not cause a yield reduction in either corn or soybean.

Williams (1969) found that competitive interaction between crop and weed depended upon when and how fast each started to grow in relation to the other. Relative speed of germination, establishment, and early growth were very important in determining the degree of weed competition.

Godel (1935) stated that the reduction in size of spikes or panicles was the most important factor in weed competition with cereal crops. Second in importance was the decrease in tillering, and third was the reduction in the weight of kernels. Pavlychenko and Harrington (1934) similarly noted that weed competition reduced the number of tillers per plant in cereals. Blackman and Templeman (1938) found crop yields could be depressed by weeds through a decrease in the number of fertile shoots and/or seed head size. Addition of nitrogen to a weedy crop increased the number of tillers as well as the grain yield.

Bowden and Friesen (1967) found that as few as 10 wild oat plants per square meter were sufficient to reduce flax yields. However, 40 wild oat plants per square meter were required to cause similar reductions in wheat yield. With 190 wild oat plants per square meter, tillering of wheat was negligible.

Many researchers concluded that the intensity of weed competition depends on the weed species and the crop involved (Pavlychenko and Harrington, 1934; Blackman and Templeman, 1938; Bowden and Friesen, 1967).

Green Foxtail Competition

Friesen and Shebeski (1960) studied yield losses due to weed competition in Manitoba grain fields from 1956 through 1958. Green foxtail competition in wheat resulted in yield reductions ranging from 2 to 25%. Green foxtail was not as competitive in cereal crops as were comparable densities of wild oats or wild mustard. Barley and oats were more tolerant to green foxtail infestations than wheat, with flax being less tolerant than wheat. Dryden and Whitehead (1963) similarly found that barley and oats competed better against green foxtail than did wheat. In barley, 400 green foxtail plants per square meter were necessary to reduce crop yields (Friesen, 1965).

Corn yield reductions were not always positively related with the density of green foxtail present (Jorge and Staniforth, 1961). Competition by green foxtail was not as easily predicted as if the weed present was wild oats or wild mustard, where density usually dictates the degree of competition offered. Green foxtail competed primarily for soil moisture and soil nutrients, especially nitrogen.

Stobbe (1970) found that as few as 50 green foxtail plants per square meter reduced corn yields when moisture was ample. Under dry soil conditions, green foxtail did not tiller as well as greater densities were required to reduce corn yields.

Staniforth (1964) noted green foxtail infestations of 500 to 600 plants per square meter reduced soybean yields by 24%.

Alex (1967) found green foxtail competed well with wheat for soil nitrogen. Sowing wheat at higher rates was ineffective in reducing green foxtail dry weight. Wheat yields were reduced by 35% with a density of 1575 green foxtail plants per square meter.

Rahman and Ashford (1972) reported that green foxtail competition in flax was variable from year to year. Flax was sown on May 7, 1969, and temperatures were cool during May. The result was no significant reductions in flax yields due to the presence of green foxtail. In 1970, flax was sown on May 22. May temperatures were warmer than in the previous year; with the result that flax yields were reduced by green foxtail infestations.

Green foxtail was sown in pure stands at three dates in 1970. The final stand of green foxtail varied with the date of seeding, even though the seeding rate was the same each time. There were 1140, 2830, and 2390 green foxtail plants per square meter when green foxtail was sown on May 6, May 20, and June 3, respectively. It was suggested that the lower emergence on May 6 was due to low temperatures and limited moisture in the surface soil.

Wheat yields were reduced to a greater extent by the presence of green foxtail infestations when wheat was sown in late May or early June than if seeding operations occurred in early May (Rahman and Ashford, 1972). Early sowing of wheat suppressed green foxtail competition and the result was wheat yields were not reduced by green foxtail infestations. However, these suppressed green foxtail plants still produced large quantities of viable seed, causing the green foxtail population to be increased two- to three-fold in the following year.

A significant factor of green foxtail competition with wheat was the ability of green foxtail to compete for and respond to nitrogen fertilizer additions (Moyer and Dryden, 1976). Green foxtail growing in the wheat crop lowered the nitrogen content of the wheat. Green foxtail seed yields increased with nitrogen additions, creating more dense infestations the following year.

Sturko (1978) studied green foxtail competition in normal height and semi-dwarf spring wheats in 1975 through 1976. As few as 100 green foxtail plants per square meter reduced the yield of both semi-dwarf and normal height wheat varieties. The normal height wheat was found to be more competitive with green foxtail than the semi-dwarf wheat, possibly through a greater shading effect by the normal height wheat on green foxtail plants.

The intensity of green foxtail competition increased when the seeding date was delayed from mid-May to early June. The climatic conditions at the time of seeding and early growth were very important as affecting the resulting competition of green foxtail. Cool temperatures during germination, emergence, and early growth reduced the intensity of green foxtail competition.

Wheat sown early in May, when on the average, temperatures are lower, reduced the intensity of green foxtail competition by giving the wheat a competitive advantage.

In a study to evaluate the effect of the stage of green foxtail removal on wheat yields, it was found that green foxtail should be killed by the one to four leaf stage of the weed to minimize wheat yield losses due to green foxtail competition.

Ecological Factors Affecting Green Foxtail Competition

Green foxtail seed collected at harvest was found to be completely dormant. However, in 85 to 90% of the seed, this primary dormancy was easily overcome by moist storage at 6°C within six weeks (Vanden Born, 1971; Banting *et al*., 1973).

Longevity of green foxtail seeds in the soil increased with the depth of burial (Toole and Brown, 1946; Banting *et al*., 1973; Canada Department of Agriculture, Research Report, 1974; Dawson and Bruns, 1975). A small percentage (5 to 10%) of green foxtail seeds were still viable after 8 to 10 years burial in the surface 15 cm of soil. These seeds would provide a source for future infestations.

Green foxtail emergence was greatest at soil depths of 1 to 5 cm; a greater depth in the soil markedly reduced green foxtail emergence. At a depth of 10 cm, green foxtail emergence was completely inhibited (Dawson and Bruns, 1962; Vanden Born, 1971; Alex *et al*., 1972; Dawson and Bruns, 1975).

Chepil (1946) suggested soil temperature affected green foxtail emergence. He noted that although many weed seeds germinated in April and early May, those of green foxtail did not germinate in large numbers until late May or early June. Molberg (1970,1971) similarly reported that the largest flushes of green foxtail emerged during the first 2 weeks of June.

Vanden Born (1971) studied the effect of temperature on green foxtail germination and emergence. Germination was severely depressed below 15°C, while emergence was markedly reduced below 20°C. The optimum range for green foxtail germination and emergence was 20 to 30°C.

Banting _et al_., (1973) found optimum temperatures for green foxtail germination and emergence were 21.1 to 26.5°C.

The requirements of soil moisture for green foxtail germination have not been clearly determined. Studies on other species have shown large differential moisture requirements for seed germination among species (Hunter and Erickson, 1952; Collin-George and Sands, 1959; Hoveland and Buchanan, 1973).

The importance of the level of soil moisture for seed germination as affecting weed competition was studied by Pavlychenko and Harrington (1934). The majority of weed seeds required more moisture for germination than did seeds of cereals.

Hunter and Erickson (1952) found differential moisture requirements for germination among species. For germination to occur, the soil should not have a water potential of less than -12.5 atm. for corn, -7.9 atm. for rice, -6.6 atm. for soybeans, and -3.5 atm. for sugar beet seeds.

The rate of germination of three _Medicago_ species and of _Juncus vaginatus_ decreased as water potential was lowered; at -10.0 atm., germination ceased completely (Collis-George and Sands, 1959).

McGinnis (1960) studied the germination of six range grasses at water potentials of -1/3 to -15 atm.; using temperatures of 10, 20, and 30°C. He found that as moisture stress increased, both the germination rate and final percentage germination were decreased. At 30°C, germination occurred at a faster rate but the final percentage germination was less than at 20°C. At 10°C, germination started substantially later but the final germination percentage was similar to that at 20°C. A strong temperature-moisture interaction was noted; all species were able to germinate more easily under high moisture stress at 20°C, as compared to higher or lower temperatures.

Parmar and Moore (1966,1968) found that polyethylene glycol 6000 was very effective in creating osmotic solutions to simulate moisture stress conditions, and had no direct effects on germination. Germination of corn was progressively delayed and reduced with decreasing water potentials to -10 atm., where germination ceased.

Pawloski and Shaykewich (1972) studied spring wheat germination under simulated moisture stress using polyethylene glycol 6000. Over a range of -0.8 to -15.3 bars water potential, wheat germination was progressively delayed with decreasing water potential, but final germination remained 100% over the entire range of water potentials used. Differences in the rate of wheat germination in moisture stress conditions were noted with spring, winter, and durum wheat varieties (Woodbury, unpublished data).

Hoveland and Buchanan (1973) studied germination of five crops and 17 weed species under simulated drought conditions. The majority of weed species were more sensitive than crop species to moisture during germination.

Air temperature and light intensity were found to be important parameters affecting the competitive ability of green foxtail (Vanden Born, 1971). At low temperatures (13 to 15°C) and low light intensities of a greenhouse during winter, green foxtail grew at a height of 14 cm. Plants grown under higher light intensities of 17,000 lux and a 22/10°C day/night temperature regime reached a height of 90 cm. Dry matter production, tiller number, and panicle production of green foxtail increased with higher temperatures of 20 to 30°C and reasonably high light intensities of 15,000 to 20,000 lux (Vanden Born, 1971; Duke and Hunt, 1975).

In green foxtail, photosynthetic carbon fixation is by the Hatch and Slack (C4) pathway (Chen et al., 1970); while in wheat the process occurs via the Calvin (C3) pathway (Moss et al., 1969). In C4 species, the photosynthetic rate is maximum between 30 and 40°C (Downton, 1971). With C3 species, the temperature optimum for photosynthesis is between 10 and 25°C. C3 species continue photosynthesis at temperatures as low as 5 to 10°C. With C4 species growing at temperatures below 16°C, the chlorophyll is subjected to photodecomposition and developing leaves become chlorotic. Chen et al., (1970) found that photosynthesis in C4 species did not become light saturated up to intensities of full sunlight or above, while C3 species saturated at 20 to 30% full sunlight.

The adaptation of C4 species to warmer temperatures and higher light intensities would affect the degree of competition of green foxtail with wheat. Green foxtail would have a competitive advantage over wheat at higher temperatures when the more efficient C4 photosynthesis would take full advantage of higher light intensities. At low temperatures, C3 photosynthesis and growth of wheat would be favored. Photosynthetic rates of green foxtail would be depressed by low temperatures and photodecomposition of chlorophyll. These statements were borne out of studies of Chen et al., (1970). Under optimum light intensity and temperature conditions, C4 species attained net photosynthetic rates of 60 to 100 mg of CO_2 assimilated per dm^2 hr^{-1} while

C3 species had net photosynthetic rates of 10 to 35 mg of CO_2 assimilated per dm^2 hr^{-1}. Thus, C4 green foxtail would have a competitive advantage over C3 wheat at higher temperatures and light intensities.

MATERIALS AND METHODS

General Procedures

Field experiments were performed at the University's Weed Research Station at Carman, Manitoba, in 1977 and 1978. The soil is classified as an Almasippi very fine sandy loam: 79% sand, 7% silt, 14% clay, and 3.6% organic matter. Soil fertility was determined from a soil test[1] for each of the plot areas. Fertilizer was applied at rates recommended by the soil test.

The green foxtail seed used in all experiments was collected at the research station the previous fall. The germination percentage was determined by placing 10 100-seed samples on moist filter paper on 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 1000-seed weight, seed samples were then weighed to give predetermined densities for each plot.

The plot areas were double disced and harrowed twice before seeding. Normal height spring wheat (c.v. Sinton) and semi-dwarf spring wheat (c.v. Norquay) were sown at a rate of 90 Kg/ha with a

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

double disc press drill at a depth of 6 cm with a row spacing of 15 cm. Immediately after seeding, the green foxtail seed was broadcast by hand and fertilizer was applied using a Gandy fertilizer spreader. The entire plot area was harrowed with a spike toothed harrow to incorporate the green foxtail seed and the fertilizer.

The green foxtail-free plots were attained using trifluralin[2], a post-plant incorporated herbicide. In plots where the soil was not sterilized with methyl bromide, bromoxynil[3] and a Carbyne-Endaven[4] mixture were applied for control of broadleaf weeds and wild oats, respectively.

After emergence, green foxtail plant counts were taken in two 1/16 m^2 quadrants, randomly placed within each plot. Green foxtail emerged at the predetermined densities ($\pm$ 10%).

Moisture was monitored in the soil to a depth of 75 cm. Soil core samples were taken and the moisture percentage was determined gravimetrically. Soil moisture was then determined on a volume basis by multiplying the gravimetric values by the bulk density of the soil.

The leaf area of wheat was measured using six randomly selected plants per plot at each sampling time throughout the summer. The leaf area per plant was determined using a leaf area meter[5].

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[2]Trifluralin was applied at .7 Kg/ha (active ingredient) in 110 l/ha water, a product of Elanco Products.

[3]Bromoxynil was applied at .28 Kg/ha (active ingredient) in 110 l/ha water, a product of Allied Chemical Services Ltd.

[4]Carbyne (.14 Kg/ha)-Endaven (.56 Kg/ha) tank mixture was applied in 110 l/ha water, products of Gulf Agriculture Chemicals and Shell Canada Ltd., respectively.

[5]Portable Area Meter, Model L1-3000, Lambda Instruments Corporation.

The number of tillers for six randomly selected wheat plants per plot were counted several times throughout the growing season.

Dry weight values of wheat were determined throughout the growing season by harvesting two drill rows of 50 cm in length. The plants were cut off at ground level, and oven-dried at 80°C for a minimum of 48 hours. The wheat dry weights were then determined.

At harvest time, wheat was straight-combined using a Hege plot combine. Sieve and wind speed adjustments were made to allow the greatest possible collection of green foxtail seed in the harvesting operation. Green foxtail seed was screened from the wheat and the weights of green foxtail and wheat per plot were recorded. The seed weight per plot was then converted to Kg/ha for yields of both green foxtail and wheat.

All data taken was analyzed statistically and Tukey's honestly significant difference test was used as the test of significance. Only differences at the 5% level of significance were considered meaningful.

Experiment 1. The effect of soil temperature and soil moisture on the emergence of green foxtail and wheat.

Sinton wheat, overseeded with green foxtail, was sown at three seeding dates in 1977 and 1978. The seeding dates were May 24, June 2, and June 17, 1977; and May 28, June 5, and June 11, 1978.

Soil temperature was monitored for 6 weeks at each seeding date with the use of thermocouples buried at soil depths of 0.5, 2.5, 5.0, and 8.0 cm. The temperature values were recorded four times per day.

Soil moisture was determined gravimetrically. Samples were taken at 2.5 cm intervals from the soil surface to a 15 cm depth. The initial sampling time was the date of seeding, with sampling occurring weekly for a 3 week period after seeding. Soil water potential was calculated from the known water potential - moisture % relationship (Appendix Figure 1).

Experiment 2. The effect of soil temperature on emergence of green foxtail at optimum soil moisture levels.

Green foxtail was sown in pure stands on May 30, June 3, June 7, June 12, June 16, and June 22, 1978. Soil moisture was maintained at a constant -0.5 bars potential by manual watering of the plots. Soil temperature was monitored during the emergence period of each seeding date with the use of thermocouples buried at depths of 1, 3, and 6 cm. The temperature values were recorded four times per day.

Experiment 3. The effect of controlled temperature and moisture on the germination of green foxtail and wheat.

Studies were performed in a controlled environment using an apparatus shown in Figure 1. A thin lens of soil was placed on the top surface of the membrane. The soil was saturated with water and then allowed to equilibriate for a period of 2 weeks with the solution below the membrane. The desired water potential of the soil was attained by using polyethylene glycol (P.E.G.) 6000 to create an osmotic solution of known water potential. Previous calculations (Pawloski and Shaykewich, 1972) using a thermocouple pychrometer and varying concentrations of P.E.G. 6000 in water, allowed the preparation of a concentration of P.E.G. 6000 versus water potential curve. Using this relationship the desired water potential of the equilibriating solution was prepared. With the soil lens in good contact with the membrane, the solution created suction on the soil lens, bringing it to the desired water potential. After the 2 week equilibriation period, known viable seeds were placed on the soil surface and gently pushed partially into

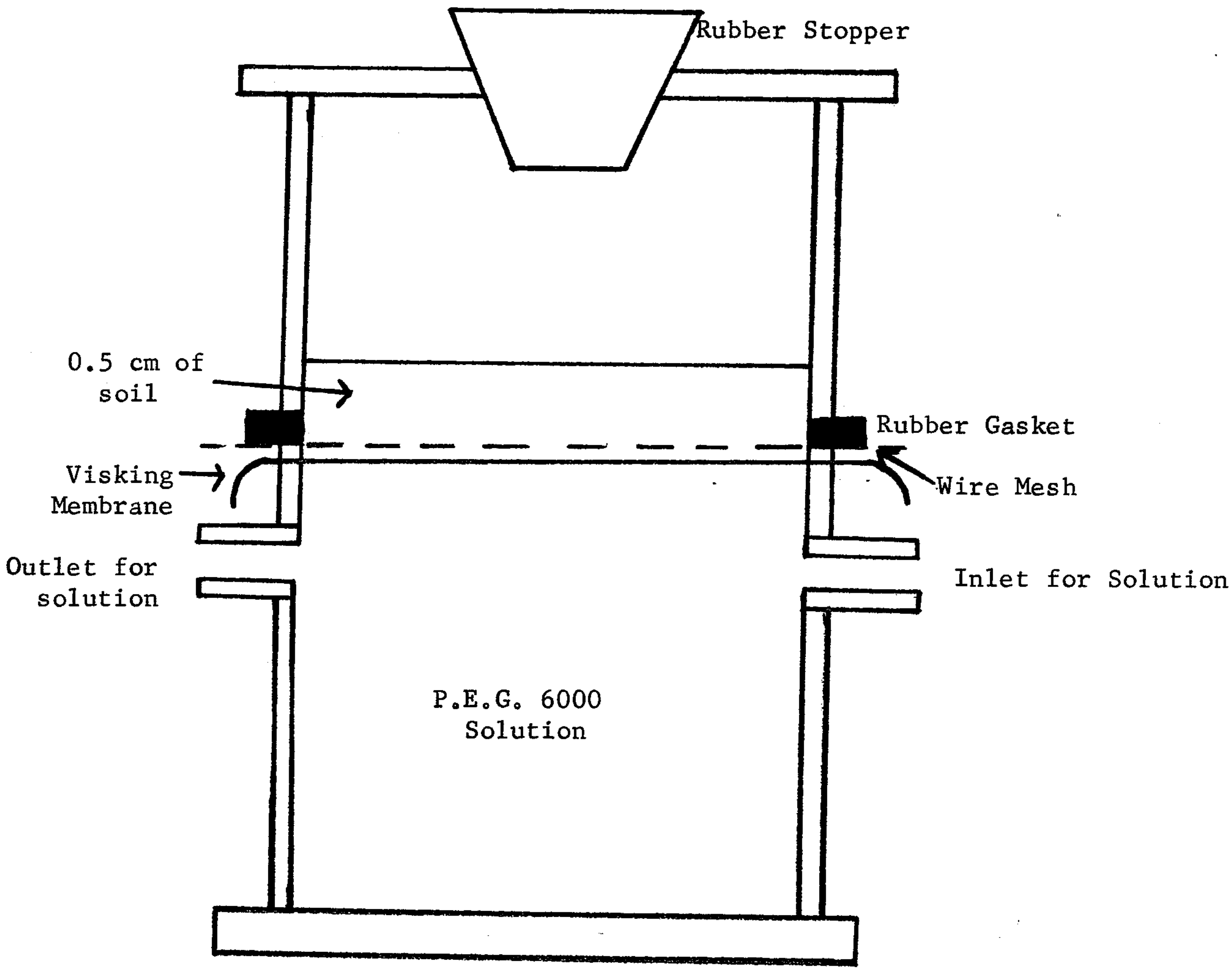

FIGURE 1. Apparatus used to determine the effect of temperature and moisture on the germination of green foxtail and wheat in a controlled environment.

the soil layer to ensure good seed-soil contact. Germination counts were made twice daily for a period of 25 days. Seeds were considered to have germinated when the radicle emerged 3 mm in length.

The water potentials used in the study were 0, -2.8, -5.3, -6.5, -7.8, and -15.3 bars. The temperatures used with green foxtail were 15, 20, and 25 ± 1°C, while the temperatures with wheat were 15 and 25 ± 1°C. The constant temperatures were accomplished by placing the whole germination apparatus in a controlled temperature cabinet.

Experiment 4. The effect of green foxtail removal at various stages on the yield of spring wheat.

The experiment was conducted as a randomized complete block design with six replications. Separate studies were conducted with Sinton and Norquay wheat. The treatments were the varying stages of green foxtail growth at the time of its removal. For each removal stage green foxtail was established at infestations of 100 and 600 plants per square meter. The green foxtail was controlled at planting using trifluralin; at the one- to three-leaf, four- to five-leaf, six- to seven-leaf, and heading stage of the weed using diclofop[6]. A treatment was included in which green foxtail was not removed (weedy check). Wheat was sown on May 30 and harvested on September 12.

Experiment 5. The effect of varying densities of green foxtail the growth and yield of spring wheat.

The experiment was conducted as a randomized complete block design with six replications in 1977 and five replications in 1978. The treatments were the varying densities of the green foxtail

[6]Diclofop was applied at .7 Kg/ha (active ingredient) in 110 l/ha water, a product of Canadian Hoechst Limited.

infestations. The plot area was fumigated using methyl bromide[7] to inactivate all weeds and weed seeds prior to seeding. Sinton wheat was sown in both years on May 30.

In 1977, the green foxtail densities used in the study were 0, 100, 200, 400, 800, and 1600 plants per square meter; while in 1978, the densities were 0, 100, 200, 400, 800, and 1200 green foxtail plants per square meter.

The plots were harvested on September 12, 1977 and September 3, 1978.

Wheat and green foxtail seed yields were determined in both years of the study. In 1978, tiller number, leaf area, and dry weight values of wheat were also determined.

Experiment 6. The effect of seeding date on the ability of green foxtail to reduce the growth and yield of spring wheat.

Separate studies were conducted for Sinton and Norquay wheat, in both 1977 and 1978. The experimental design was a split-plot, with the main plots being the seeding dates and the sub-plots being varying green foxtail densities. In 1977, the treatments were replicated four times; and in 1978, they were replicated six times.

In 1977, wheat was sown on May 24, June 2, and June 17. With each seeding date the green foxtail infestation densities were established at 0, 100, and 600 plants per square meter.

In 1978, wheat was sown on May 17, May 28, June 5, and June 11.

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

Densities of 0, 200, 400, and 600 green foxtail plants per square meter were established within each seeding date.

The plots were harvested as they matured. Harvesting was on September 11, September 12, and September 27, 1977; and August 25, September 3, September 9, and September 23, 1978, respectively.

Tiller number, leaf area, and dry weight of wheat, plus soil moisture, were determined in weed-free and green foxtail-infested wheat plots during both years.

SECTION 1

RESULTS

Experiment 1. The effect of soil temperature and soil moisture on the emergence of green foxtail and wheat.

Green foxtail emerged within 7 to 21 days after seeding depending upon the date of seeding in 1977 and 1978, while wheat emerged within 6 to 8 days at all seeding dates (Table 1). Soil temperature and soil moisture were monitored in the field during the period of green foxtail and wheat emergence. The emergence of green foxtail was found to be more dependent than that of wheat on the environmental conditions at the time of seeding.

Soil temperature and soil moisture were found to be critical parameters affecting the emergence of green foxtail. At low soil temperatures and low water potential the rate of green foxtail emergence was decreased. In 1977, a temperature decrease from 26 to 22^{o}C and a moisture decrease from -5.0 to -11.0 bars accounted for an 8 day delay in the time to 50% emergence of green foxtail. The importance of soil moisture was shown with the June 2 and June 17 seeding dates. With both these seeding dates the soil temperature was 22^{o}C during the period of green foxtail emergence, however, green foxtail emerged within 16 and 7 days after seeding, at the June 2 and June 17 seeding dates, respectively. The difference between the times of emergence was due to soil moisture. Adequate soil moisture (-1.0 bars ψ) was

TABLE 1. The effect of soil temperature and soil moisture on the emergence of green foxtail and wheat in 1977 and 1978

Seeding date	Water potential (Bars) (0-8 cm)	Temp. (°C)[1]	Days to 50% emergence	
			Green foxtail	Wheat
a) 1977				
May 24	-5.0	26	8	6
June 2	-11.0	22	16	8
June 17	-1.0	22	7	7
b) 1978				
May 28	-2.0	17	13	7
June 5	-6.0	20	15-21[2]	7
June 11	-4.5	24	16	6

[1]Thermocouple readings at .5, 2.5, 5.0, and 8.0 cm were grouped to give the average daily soil temperature during green foxtail emergence.

[2]The first flush of green foxtail (25%) emerged within 15 days. On June 10, 12 cm of rain was received, which allowed a second flush of green foxtail to emerge within 21 days.

present on the June 17 seeding date while soil moisture was much more limiting (-11.0 bars ψ) on the June 2 seeding date.

A similar trend of decreased rates of green foxtail emergence with low soil temperature and moisture conditions was noted in 1978. Soil moisture appeared to be the more critical factor. Although soil temperature was increased from 17 to 24^{o}C, the time to 50% emergence of green foxtail did not decrease. In fact, it occurred 3 days later. This can be explained by noting that more moisture (-2.0 bars ψ) was present on the May 28 seeding date as compared to that of the June 11 seeding date (-4.5 bars ψ).

<u>Experiment 2</u>. The effect of soil temperature on the emergence of green foxtail at optimum soil moisture levels.

The effect of soil temperature on green foxtail emergence was studied while the soil moisture was maintained at -0.5 to -1.0 bars water potential, during six seeding dates in the spring of 1978 (Table 2). A difference in the average daily soil temperature of 8^{o}C accounted for a variation of 6 days in the time to emergence of green foxtail. In the temperature range studied, the rate of green foxtail emergence appeared to be directly related to average daily soil temperatures during the period from seeding to emergence (Figure 2).

<u>Experiment 3</u>. The effect of controlled temperature and moisture on the germination of green foxtail and wheat.

Soil temperature was found to affect the rate of green foxtail germination over the range of 15 to 20^{o}C (Table 3). Altering the temperature from 15 to 20^{o}C was more critical in increasing the rate of green foxtail germination than the alteration of temperature from 20 to 25^{o}C. At a water potential of 0 bars, it took 88, 35, and 33

TABLE 2. The effect of soil temperature during emergence of green foxtail at optimum soil moisture conditions in 1978

Seeding date	Temperature (°C)[1]	Days to 50% emergence
May 30	14	13
June 3	16	11
June 7	17	10
June 12	20	8
June 16	20	8
June 22	22	7

[1]Thermocouple readings at 1, 3, and 6 cm were grouped to give the average daily soil temperature during green foxtail emergence.

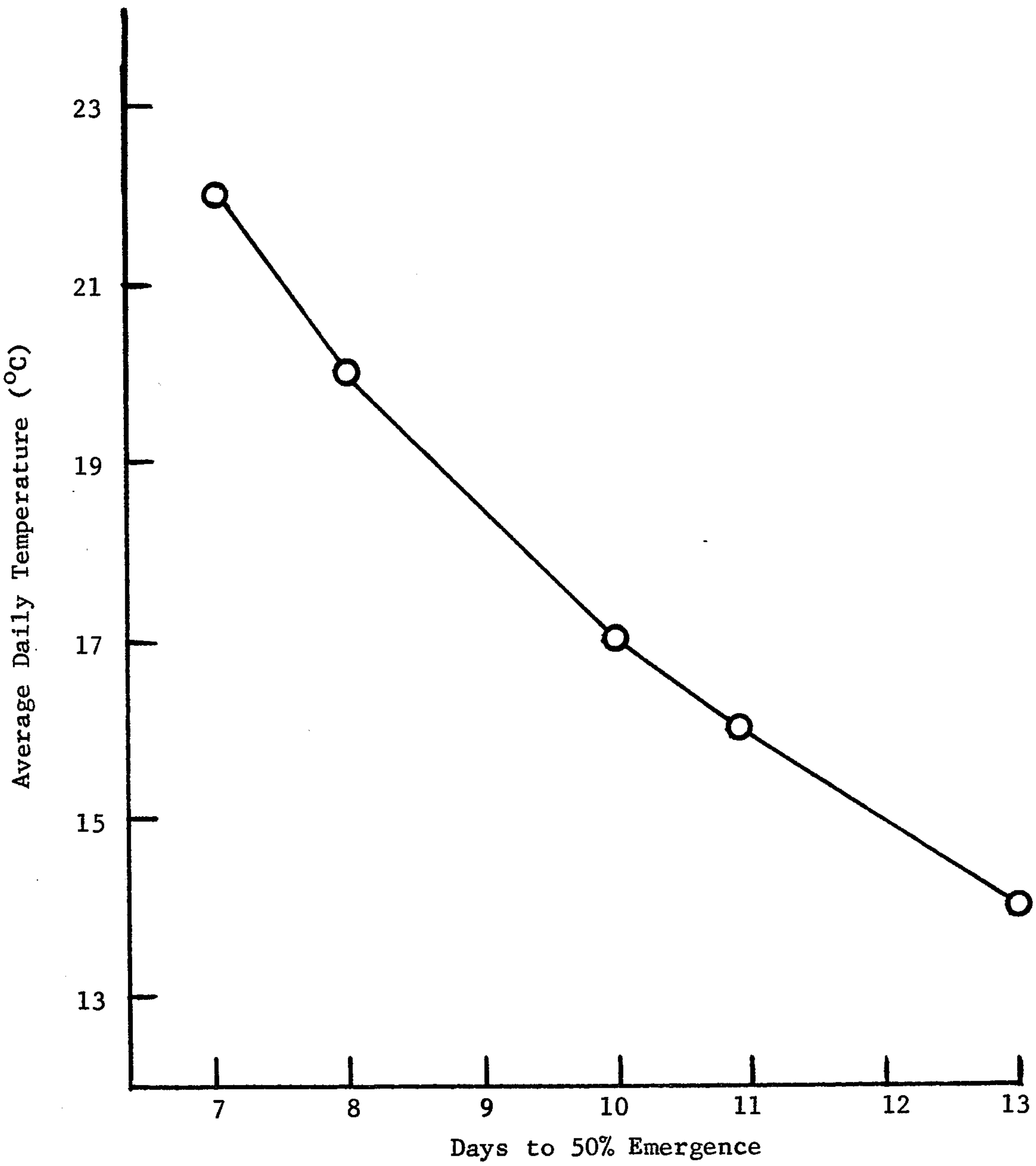

FIGURE 2. The effect of soil temperature on green foxtail emergence under optimum moisture conditions in 1978

TABLE 3. The effect of temperature and moisture on the germination of green foxtail in a controlled environment

Water potential (bars)	15°C			20°C			25°C		
	Hrs to 50% germ.	Final % germ.	Hrs to final germ.	Hrs to 50% germ.	Final % germ.	Hrs to final germ.	Hrs to 50% germ.	Final % germ.	Hrs to final germ.
0	88	100	292	35	100	112	33	100	125
- 2.8	138	100	300	105	100	210	52	100	136
- 5.3	312	69	416	240	75	384	84	88	196
- 6.5	-	-	-	-	8	384	-	-	-
- 7.8	-	-	-	-	-	-	-	-	-
-15.3	-	-	-	-	-	-	-	-	-

hours to reach 50% germination of green foxtail, at temperatures of 15, 20, and 25°C, respectively.

Soil moisture had a greater affect than soil temperature on green foxtail germination (Table 3). By decreasing the water potential, the rate of germination was decreased at all temperatures of the study. At 20°C, 50% germination of green foxtail occurred in 35, 105, and 240 hours, at water potential of 0, -2.8, and -5.3 bars, respectively.

At a water potential of -5.3 bars, green foxtail germination was inhibited drastically. The final percentage germination never reached 100 over the 25 days that germination counts were recorded (Table 3). At this water potential, the final germination was 69, 75, and 88%, at 15, 20, and 25°C, respectively.

At a water potential of -6.5 bars, green foxtail germination was reduced to zero at 15 and 25°C, while at 20°C, final germination was only 8% (Table 3). Germination of green foxtail was completely inhibited at all temperatures with a water potential of -7.8 or -15.3 bars.

Temperature and moisture were found to interact with each other. At 0 bars water potential, the time to 50% germination of green foxtail was similar at 20 and 25°C (Table 3). However, with a decrease in water potential the temperature increment from 20 to 25°C became more important. Water availability for germination of green foxtail was increased with a temperature increase. At -5.3 bars, water potential, the time to 50% germination of green foxtail was 240 and 84 hours, at 20 and 25°C. The final percentage germination at this water potential was also affected by the increase in temperature, being 75 and 88%, at 20 and 25°, respectively.

Soil temperature and soil moisture had an effect on wheat germination, but not to the same degree as with green foxtail. An increase in soil temperature slightly increased the rate of wheat germination. At a water potential of 0 bars, an increase of 16 hours in the time to 50% germination of wheat was found with a temperature increase from 15 to 25°C (Table 4). The same temperature increment with green foxtail caused an increase to 50% germination of 55 hours (Table 3). At a water potential of -5.3 bars, an increase in temperature from 15 to 25° caused an increase of 228 hours in the time to 50% germination of green foxtail while with wheat the increase was only 38 hours (Tables 3 and 4).

The soil moisture requirement for germination of wheat was markedly different than that of green foxtail. Wheat attained 100% germination over the entire range from 0 to -15.3 bars water potential, at 15 and 25°C (Table 4). Not only did wheat attain 100% germination at the low water potential of -15.3 bars, but the rate delay to 50% germination as compared to 0 bars, was only 82 and 72 hours, at 15 and 25°C, respectively.

The combined effect of soil temperature and soil moisture on the germination of green foxtail in relation to that of wheat can be clearly shown. At a water potential of -5.3 bars and a temperature of 25°C, the difference in the time to 50% germination of wheat and green foxtail was small, being only 19 hours (Figure 3). However, the lag in germination was accentuated by a temperature decrease from 25 to 15°C. At -5.3 bars water potential and 15°C, the time to 50% germination of green foxtail lagged behind that of wheat by 199 hours, a difference of over 8 days (Figure 4).

TABLE 4. The effect of temperature and moisture on germination of wheat in a controlled environment

Water potential (bars)	15°C Hrs to 50% germ.	15°C Final % germ.	15°C Hrs to final germ.	25°C Hrs to 50% germ.	25°C Final % germ.	25°C Hrs to final germ.
0	48	100	92	32	100	68
- 2.8	68	100	115	39	100	70
- 5.3	103	100	140	65	100	100
- 6.5	100	100	140	72	100	102
- 7.8	115	100	140	94	100	117
-15.3	130	100	190	104	100	160

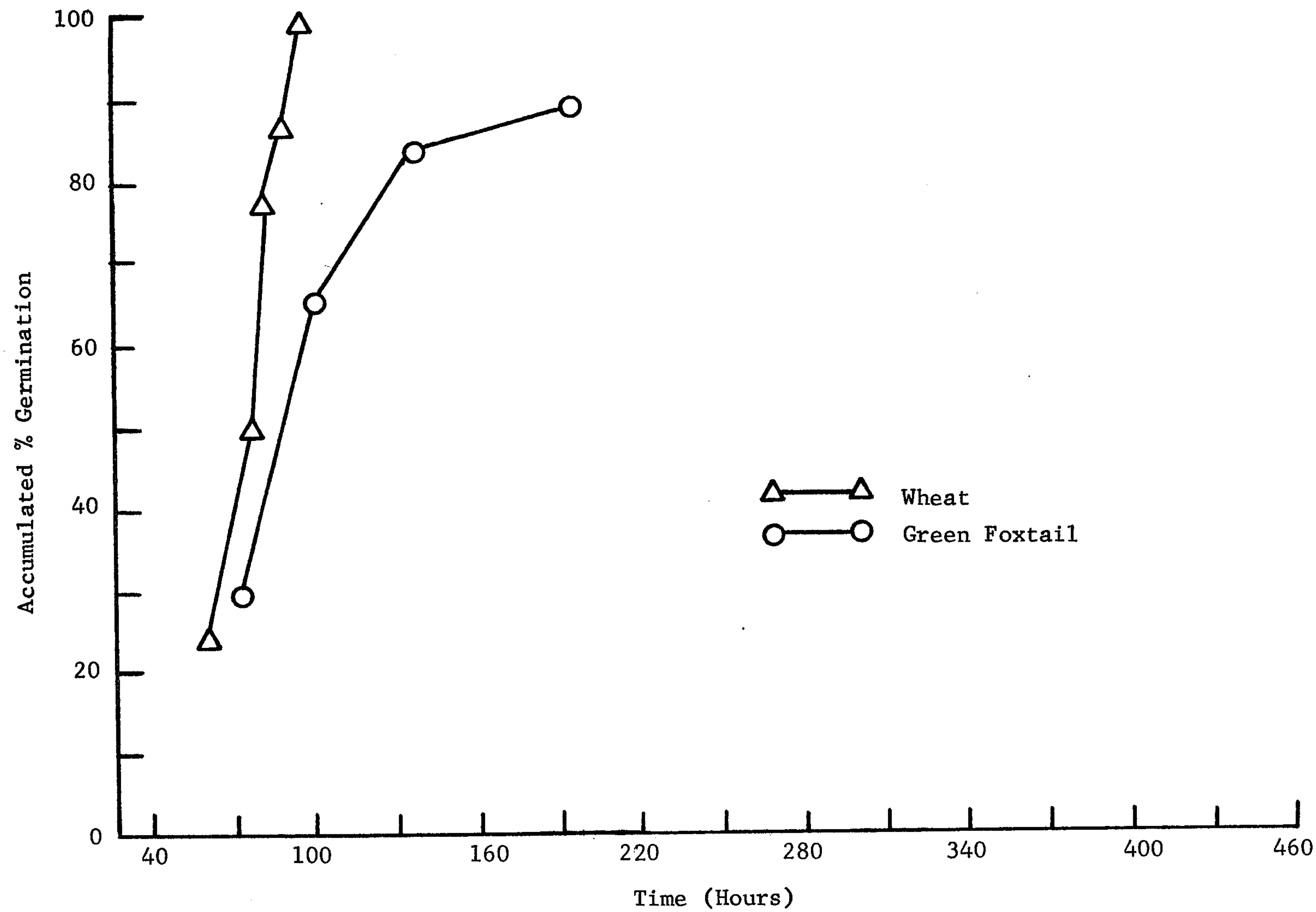

FIGURE 3. Wheat and green foxtail germination at a water potential of -5.3 bars and a temperature of 15°C

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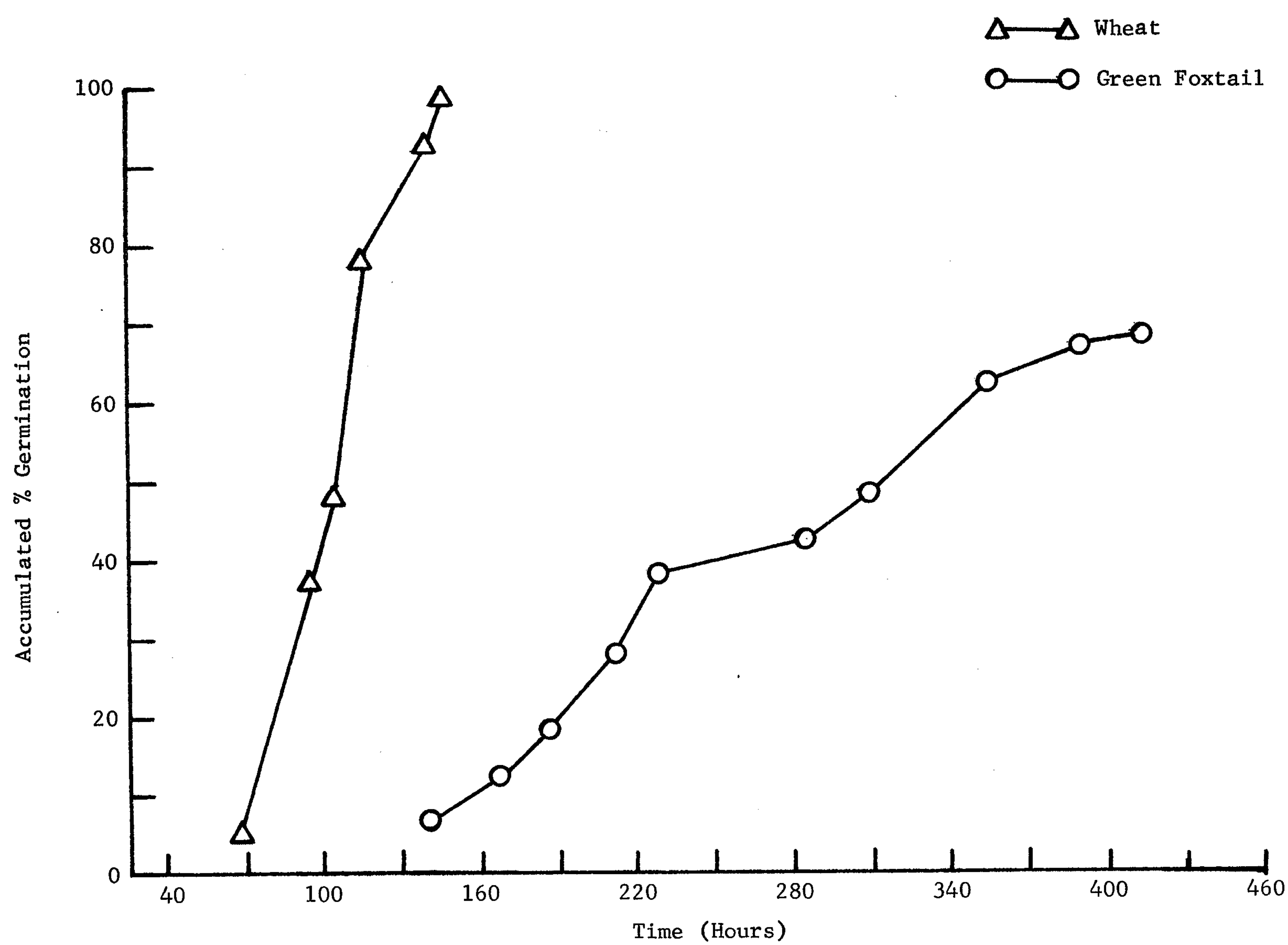

FIGURE 4. Wheat and green foxtail germination at a water potential of -5.3 bars and a temperature of 15°C

DISCUSSION

In the present study, germination and emergence of green foxtail were found to be dependent on soil temperature. A decrease from 25 to 15°C was found to cause large delays in the time to reach 50% germination of green foxtail. While the germination rate was markedly reduced, the final percentage germination was 100% over the temperature range of 15 to 25°C. These results are in agreement with the studies of Vanden Born (1971) and Banting _et al._, (1973), who noted in addition that at temperatures below 10°C, the germination percentage of green foxtail was severely or completely inhibited.

Field studies showed that a temperature decrease of 8°C accounted for a 6 day delay in the time to 50% emergence of green foxtail in the field (Table 2). However, in the controlled environment studies, a similar temperature decrease delayed the time to 50% germination of green foxtail by only 2 days (Table 3). Thus, the process of the emergence of green foxtail would appear to be more dependent than germination on soil temperature. Vanden Born (1971) found large decreases in the rate of emergence of green foxtail over similar temperature ranges. However, he found that the final percentage emergence was markedly reduced at a low temperature of 15°C, while in the present study, the final percentage emergence was similar at all temperatures studied in the field.

The results presented here suggest that soil moisture could have a potentially greater influence than soil temperature on the establishment of green foxtail infestations. With decreasing water potential, the rate of green foxtail germination was markedly decreased. At -5.3 bars water potential, the percentage germination of green foxtail was less than 100% and with a further decrease to -6.5 bars, germination was reduced to nearly zero. Decreasing rates of germination and finally complete inhibition brought about by decreasing water potential, have been noted with several other species (Hunter and Erickson, 1952; Collis-George and Sands, 1959; McGinnis, 1960; Parmar and Moore, 1966, 1968; Pawloski and Shaykewich, 1972; and Hoveland and Buchanan, 1973). The extent of the rate reduction of germination with decreasing water potential and the level where germination is completely inhibited, was variable from species to species.

At a water potential of -6.5 bars, green foxtail germination was completely inhibited at 15 and 25°C. However, at 20°C, green foxtail reached a final germination of 8% (Table 3). Similarly, McGinnis (1960) found with six range grasses, that germination occurred at a higher percentage under high moisture stress at a temperature of 20°C, compared to higher or lower temperatures. Although minimal germination at -6.5 bars and 20°C may seem inconsequential, these green foxtail plants could produce enough viable seed to infest the field the following year.

Field studies in 1977 and 1978 showed that the effects of soil temperature and soil moisture on the germination and emergence of wheat were not as great as those for green foxtail. Laboratory studies, under controlled temperature and moisture conditions, further substantiate the relative insensitivity of wheat germination to soil temperature and soil moisture. Decreases in soil temperature and soil moisture caused slight delays in the rate of germination and emergence, but the final percentage germination and emergence remained high. Pawloski and Shaykewich (1972) also found that wheat germination was delayed with decreasing water potential, but the final percentage germination remained 100% at the extreme moisture stress value of -15.3 bars. Thus, decreases in temperature and/or water potential from optimum conditions would be of far greater severity in establishment of green foxtail compared to wheat.

The large differences in germination and emergence of green foxtail and wheat relative to soil temperature and soil moisture may cause great differences between the time of emergence of green foxtail and wheat in grain fields. At low soil temperatures of 10 to 15^{o}C, wheat would continue to emerge within 7 to 8 days after seeding while green foxtail emergence would be appreciably delayed or completely inhibited. Similarly, if soil water potential were in the range of -5.3 to -6.5 bars, green foxtail germination would be delayed by several days or perhaps inhibited completely, while wheat germination would continue at nearly optimum rates. Thus, in the situation where low soil temperature and/or soil moisture conditions are present during the germination and emergence period, wheat is capable of emerging several days before green foxtail.

The degree of competitiveness of a weed is influenced by the relative time of emergence of the weed and crop (Blackman and Templeman, 1938; Knafe and Slife, 1965; and Williams, 1969). Therefore, if wheat were able to emerge several days before green foxtail, the potential competitive ability of the green foxtail infestations would be severely decreased. However, if the soil was moist (0 to -4 bars) and the soil temperature was moderately high (20 to 25°C) during germination and emergence, then green foxtail would emerge 3 to 5 days after wheat. In this situation, the green foxtail infestations would have the opportunity to exert their full competitive potential.

Farmers should consider planting early in May, when soil temperatures are normally low. This would give wheat a competitive advantage over green foxtail, since the germination and emergence of wheat is not nearly as dependent as that of green foxtail on soil temperature.

Soil moisture values at seeding must also be considered. There must be enough moisture present for uniform germination of wheat, but if the surface 0 to 4 cm of soil is dry, then green foxtail may not readily germinate, giving wheat a competitive advantage through earlier emergence. Thus, such practices as harrowing and pulling packers behind the seeding equipment, which pack the soil and conserve surface soil moisture, may contribute to early emergence of dense infestations of green foxtail. This would allow green foxtail to become severely competitive with wheat, depending upon the environmental conditions during the remainder of the growing season.

Soil temperature and moisture could be monitored during the emergence period of wheat. By knowing these values an estimate of when green foxtail would emerge relative to the wheat crop could be obtained. This knowledge would enable farmers to judge the necessity of using herbicides for control of the green foxtail infestations. If dense infestations of green foxtail emerged within a week of wheat, then control would be advisable. However, if the green foxtail infestations emerged 2 weeks after wheat, then the severity of green foxtail competition would likely be decreased. Rahman and Ashford (1972) found that suppressed green foxtail plants produced enough viable seed for the green foxtail population to be increased two- to three-fold in the following year. Thus, herbicidial control may still be advisable, depending on the infestation density present and the crop to be grown the following year. Barley and oats have been shown to be better competitors with green foxtail than wheat (Friesen and Shebeski, 1960; and Dryden and Whitehead, 1963). If the field is to be sown to barley or oats the following year or it is to be summer fallowed, then herbicidial control may not be economically justifiable when moderate infestation densities of green foxtail emerge 2 weeks after the wheat crop.

SECTION 2

RESULTS

Experiment 4. The effect of green foxtail removal at various stages on the yield of spring wheat.

There were no significant yield reductions in either Sinton or Norquay wheat with the green foxtail densities established in the study (Table 5). Thus, it was impossible to note any significant effect of the stage of green foxtail removal on wheat yields. However, Figure 5 does illustrate a trend of lower wheat yields at the later stages of green foxtail removal. The trend indicates that wheat yields may be decreased if green foxtail was not killed before the six- to seven-leaf stage. The stage of green foxtail removal appeared to be more critical with 600 green foxtail plants per m^2 than with 100 plants per m^2. Wheat yield depressions observed at the six- to seven-leaf stage and at heading may have been partially due to mechanical damage caused by the spraying operation.

Experiment 5. The effect of varying densities of green foxtail on the growth and yield of spring wheat.

Sinton wheat yields were greater in 1977 than in 1978; however, wheat yield losses due to green foxtail competition were greater in 1978 than in 1977 (Figure 6; Table 6).

In 1977, no significant yield reductions occurred in Sinton wheat due to green foxtail (Table 6). While not significant, there was a

TABLE 5. Removal of green foxtail at varying stages and its effect on the yield of spring wheat in 1977

Green foxtail plants/m^2	Stage of removal	Wheat (kg/ha)
a) Sinton		
0	weed-free	2171
0	weed-free	2236
100	1-3 leaf	2292
100	4-5 leaf	2144
100	6-7 leaf	2258
100	heading	2182
100	weedy check	2111
600	1-3 leaf	2357
600	4-5 leaf	2240
600	6-7 leaf	2445
600	heading	2126
600	weedy check	1980
Tukey's H.S.D. (0.05)		N.S.
b) Norquay		
0	weed-free	3186
0	weed-free	3036
100	1-3 leaf	3005
100	4-5 leaf	3118
100	6-7 leaf	2792
100	heading	2726
100	weedy check	2863
600	1-3 leaf	2946
600	4-5 leaf	3036
600	6-7 leaf	2591
600	heading	2513
600	weedy check	2847
Tukey's H.S.D. (0.05)		593

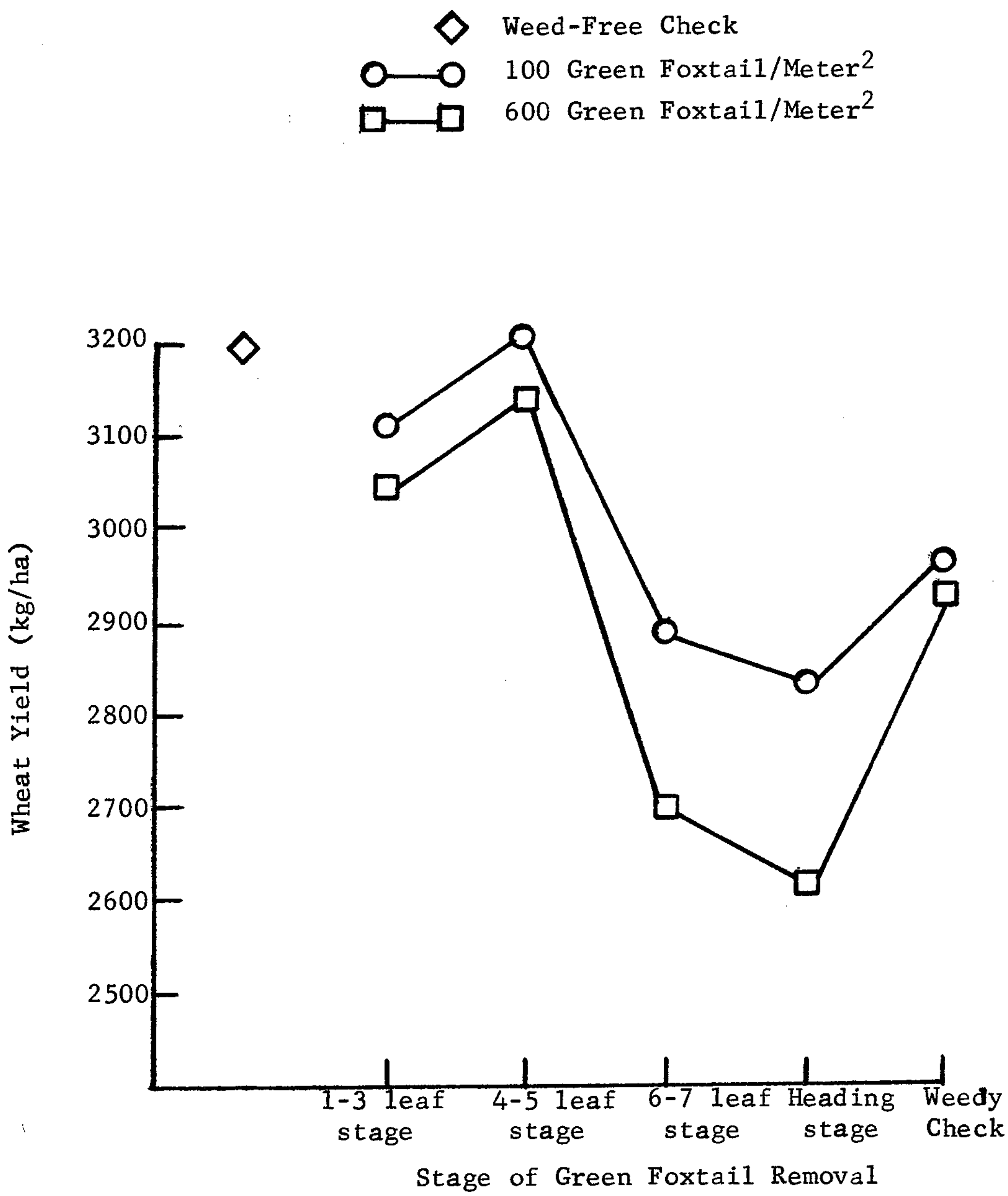

FIGURE 5. The effect of varying stages of green foxtail removal on the yield of Norquay wheat in 1977

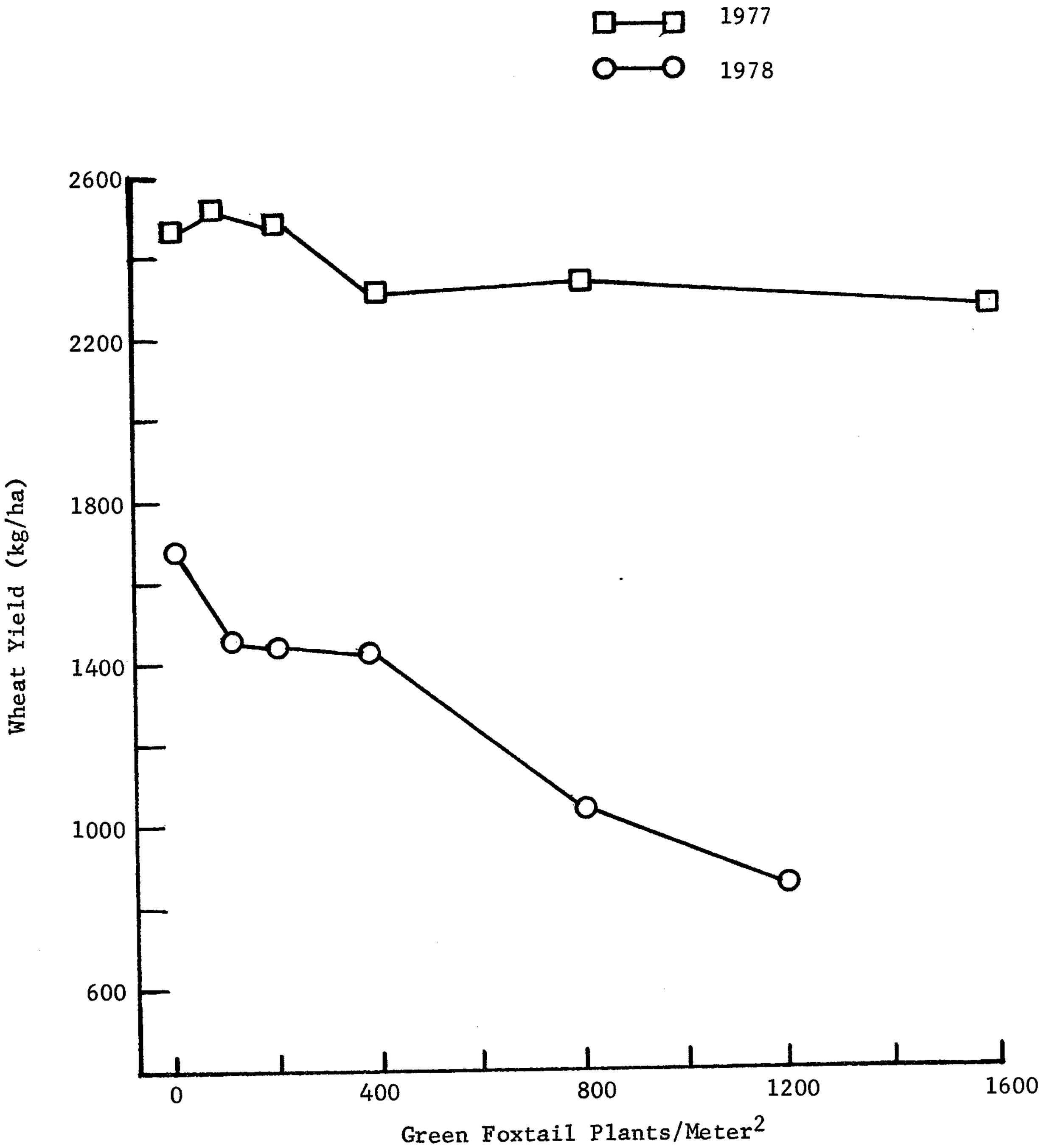

FIGURE 6. The effect of varying densities of green foxtail on the yield of Sinton wheat in 1977 and 1978

TABLE 6. The effect of varying densities of green foxtail on the yield of Sinton wheat in 1977 and 1978

Green foxtail plants/m^2	Yield of wheat (kg/ha)	Green foxtail seed (kg/ha)
a) 1977		
0	2280	-
100	2338	24
200	2292	24
400	2126	109
800	2184	93
1600	2084	127
Tukey's H.S.D. (0.05)	N.S.	76
b) 1978		
0	1476	-
100	1282	237
200	1271	294
400	1224	303
800	838	455
1200	682	594
Tukey's H.S.D. (0.05)	304	103

trend towards lower wheat yields with increasing densities of green foxtail present.

In 1978, Sinton wheat yields were reduced by the presence of green foxtail (Table 6). As the density of the green foxtail increased, wheat yields decreased. At 800 and 1200 green foxtail plants per m^2, wheat yields were reduced by 43.2 and 53.8%, respectively.

The greater degree of green foxtail competition in 1978 was reflected by higher yields of green foxtail seed produced in 1978 than at comparable densities in 1977 (Table 6). Larger quantities of seed were produced with increasing densities of green foxtail infestations in both years. However, a density of 800 green foxtail plants per m^2 produced 93 kg/ha of seed in 1977, while a comparable density in 1978 produced 455 kg/ha of seed, approximately a five-fold increase.

In 1978, the effect of green foxtail competition on the growth of Sinton wheat was studied. It was found that competition offered by green foxtail reduced the tillering ability of the wheat crop (Table 7). A density of 400 green foxtail plants per m^2 reduced the number of tillers per wheat plant by 21%. Increasing the density of the green foxtail infestations caused further reductions in the number of tillers per wheat plant. Wheat tillering was reduced by 42% with the presence of 1200 green foxtail plants per square meter.

Green foxtail competition was found to cause severe reductions in the leaf area of Sinton wheat (Table 8). As few as 100 green foxtail plants per m^2 caused leaf area reductions in the Sinton wheat crop. For example, on the July 26 sampling date, 100 green foxtail plants per m^2 caused a 28% reduction in the leaf area per wheat plant.

TABLE 7. The effect of varying densities of green foxtail on the number of tillers per plant of Sinton wheat in 1978

Green foxtail plants/m^2	Tillers per plant
0	3.4
100	2.9
200	2.9
400	2.7
800	2.3
1200	2.0
Tukey's H.S.D. (0.05)	0.5

TABLE 8. The effect of varying densities of green foxtail on the leaf area of Sinton wheat in 1978

Sampling time	Green foxtail plants/m^2	Leaf area per plant (sq. cm)
July 9	0	191
	100	170
	200	155
	400	154
	800	120
	1200	111
Tukey's H.S.D. (0.05)		24
July 26	0	92
	100	66
	200	48
	400	53
	800	38
	1200	39
Tukey's H.S.D. (0.05)		18
August 21	0	41
	100	34
	200	28
	400	29
	800	22
	1200	19
Tukey's H.S.D. (0.05)		8

Increasing the density of the green foxtail infestation further decreased the leaf area of Sinton wheat.

Sinton dry weight values were decreased by the presence of green foxtail infestations (Table 9). Upon sampling on July 7, approximately 4 weeks of growth, it was found a density 1200 green foxtail plants per m^2 were required to reduce wheat dry weights. However, at the July 20 sampling date, as few as 100 green foxtail plants per m^2 caused a 36% reduction in the dry weight of Sinton wheat. By this date, green foxtail had exerted its full competitive effect. Increasing the density of the green foxtail infestations caused further reductions in the dry weight of wheat. At the July 31 sampling date, a density of 1200 green foxtail plants per m^2 caused a 46% reduction in the dry weight of Sinton wheat.

Experiment 6. The effect of seeding date on the ability of green foxtail to reduce the growth and yield of spring wheat.

Wheat Tillers. In 1977, a density of 600 green foxtail plants per m^2 did not cause a significant reduction in the number of tillers per plant of Sinton wheat at any of the seeding dates (Table 10). However, in Norquay wheat, 600 green foxtail plants per m^2 caused a 34% reduction in the number of tillers per plant with the May 24 seeding date. The ability of Norquay wheat to tiller was not significantly affected by the green foxtail infestations with the June 2 or June 17 seeding dates.

In 1978, the ability of green foxtail to reduce the tillering of wheat was studied in Sinton and Norquay wheat sown at two seeding dates (Table 11). The most striking aspect of the results was the

TABLE 9. The effect of varying densities of green foxtail on the dry weight of Sinton wheat in 1978

Sampling time	Green foxtail plants/m^2	Wheat dry weight (grams)
July 7	0	36.2
	100	32.6
	200	35.3
	400	33.3
	800	28.1
	1200	24.1
Tukey's H.S.D. (0.05)		7.0
July 20	0	70.8
	100	49.9
	200	53.6
	400	47.4
	800	35.0
	1200	30.6
Tukey's H.S.D. (0.05)		8.7
July 31	0	82.3
	100	55.1
	200	49.3
	400	49.4
	800	38.9
	1200	30.0
Tukey's H.S.D. (0.05)		10.2
August 16	0	79.9
	100	66.5
	200	63.6
	400	54.1
	800	37.0
	1200	32.8
Tukey's H.S.D. (0.05)		17.2

TABLE 10. The effect of green foxtail on the tillering of Sinton and Norquay wheats sown at 3 seeding dates in 1977

Seeding date	Green foxtail plants/m^2	Tillers per plant
a) Sinton		
May 24	0	2.4
	100	2.5
	600	2.3
June 2	0	3.0
	100	2.3
	600	2.6
June 17	0	3.0
	100	3.1
	600	2.3
Tukey's H.S.D. (0.05)		N.S.
b) Norquay		
May 24	0	3.2
	100	2.6
	600	2.1
June 2	0	2.6
	100	2.4
	600	2.0
June 17	0	2.3
	100	2.5
	600	2.6
Tukey's H.S.D. (0.05)		0.7

TABLE 11. The effect of green foxtail on the tillering of Sinton and Norquay wheats sown at two seeding dates in 1978

Seeding date	Green foxtail plants/m^2	Tillers per plant
a) Sinton		
May 28	0	3.2
	200	2.0
	400	1.9
	600	1.7
Tukey's H.S.D. (0.05)		1.1
June 5	0	2.8
	200	2.3
	400	2.3
	600	2.4
Tukey's H.S.D. (0.05)		0.7
b) Norquay		
May 28	0	3.3
	200	2.2
	400	2.1
	600	1.7
Tukey's H.S.D. (0.05)		0.8
June 5	0	3.0
	200	2.3
	400	2.2
	600	2.0
Tukey's H.S.D. (0.05)		0.7

large variation in competition offered by green foxtail from the May 28 seeding date to the June 5 seeding date.

With the May 28 seeding date, a green foxtail density of 200 plants per m^2 reduced the tillering of Sinton wheat by 38% (Table 11). Increasing the infestation density to 600 plants per m^2 caused a 47% reduction in Sinton wheat tillering. However, with the June 5 seeding date, 600 green foxtail plants per m^2 did not cause a significant reduction in the number of tillers per Sinton wheat plant.

Similarly, in Norquay wheat the intensity of the green foxtail competition varied from the May 28 to the June 5 seeding date (Table 11). With the May 28 seeding date, 200 green foxtail plants per m^2 reduced Norquay wheat tillering by 33%; while with the June 5 seeding date, a density of 400 green foxtail plants were required to reduce Norquay wheat tillering by 26%.

The depressing effect of green foxtail competition on wheat tillering appeared to be greater with Norquay than with Sinton wheat (Table 11). With the June 5 seeding date, a density of 600 green foxtail plants per m^2 did not cause a significant reduction in tillering of Sinton wheat, while a comparable infestation density in Norquay wheat caused a 33% reduction in the number of tillers per wheat plant.

Leaf Area of Wheat. In 1977, as few as 100 green foxtail plants per m^2 reduced the leaf area of both Sinton and Norquay wheat (Table 12). Increasing the density of the green foxtail infestation to 600 plants per m^2 caused a trend of further decreases in wheat leaf area, although not significantly lower than at the 100 green foxtail plants per m^2 density.

TABLE 12. The effect of green foxtail competition on the leaf area of Sinton and Norquay wheats in 1977

Wheat variety	Green foxtail plants/m^2	Leaf area per plant (sq. cm)
Sinton	0	90
	100	71
	600	58
Tukey's H.S.D. (0.05)		15
Norquay	0	90
	100	73
	600	60
Tukey's H.S.D. (0.05)		14

TABLE 13. The effect of green foxtail competition on the leaf area of Sinton and Norquay wheat in 1978

Sampling time	Seeding date	Green foxtail plants/m^2	Leaf area per plant (sq. cm) Sinton	Leaf area per plant (sq. cm) Norquay
July 15	May 28	0	175	173
		200	113	124
		400	126	105
		600	125	105
	June 5	0	148	142
		200	94	90
		400	97	79
		600	92	66
Tukey's H.S.D. (0.05)			27	29
August 1	May 28	0	99	99
		200	62	52
		400	48	49
		600	48	35
	June 5	0	93	169
		200	75	62
		400	73	66
		600	66	58
Tukey's H.S.D. (0.05)			15	18
August 21	May 28	0	41	44
		200	30	28
		400	23	25
		600	20	21
	June 5	0	36	33
		200	32	29
		400	26	27
		600	29	24
Tukey's H.S.D. (0.05)			6	7

In 1978, 200 green foxtail plants per m^2 effectively reduced the leaf area of Sinton and Norquay wheat (Table 13). Increasing the density of green foxtail to 600 plants per m^2 caused further reductions in the leaf area of Sinton wheat. However, with Norquay wheat the depressing effect of 200 green foxtail plants per m^2 was so great that a further increase in density to 600 green foxtail plants per m^2 did not cause further significant reductions in the leaf area of Norquay wheat.

Leaf area reductions of Sinton and Norquay wheat due to green foxtail competition were of lesser extent with the June 5 seeding date as compared to the May 28 seeding date. Larger infestation densities were needed with the June 5 seeding date to cause reductions in the leaf area of wheat. For example, on the August 21 sampling date, a density of 200 green foxtail plants per m^2 caused a reduction (38%) in Norquay leaf area with the May 28 seeding date; while with the June 5 seeding date, 600 green foxtail plants per m^2 were required to reduce (26%) the leaf area of Norquay wheat.

The leaf area of weed-free Sinton and Norquay wheat were very similar values at corresponding dates throughout the growing season (Table 13). Comparing the extent of the leaf area reduction of Sinton and Norquay wheat at similar green foxtail densities, it was found that the leaf area reductions were greater in Norquay wheat than in Sinton wheat.

Dry Weight of Wheat. In 1977, the dry weight of Sinton wheat was not significantly reduced while growing in association with a green foxtail density of 600 plants per m^2 (Table 14). However, a comparable

TABLE 14. The effect of green foxtail on the dry weight of Sinton and Norquay wheat in 1977

Wheat variety	Green foxtail plants/m^2	Wheat dry weight (grams)
a) Sinton	0	67.1
	100	67.3
	600	58.6
Tukey's H.S.D. (0.05)		11.2
b) Norquay	0	65.3
	100	61.8
	600	52.7
Tukey's H.S.D. (0.05)		11.1

infestation caused an 18% reduction in the dry weight of Norquay wheat (Table 14).

In 1978, it was found that a density of 200 green foxtail plants per m^2 could reduce the dry weight of both Sinton and Norquay wheats (Table 15). Increasing the green foxtail density to 600 plants per m^2 seldom caused further reductions in the dry weight of wheat, however, a greater density occasionally caused the reduction in the dry weight of wheat to occur at an earlier growth stage.

Green foxtail's ability to reduce the dry weight of wheat was found to be greater in Norquay than in Sinton wheat. Competition offered by green foxtail caused dry weight reductions at an earlier growth stage in Norquay as compared to Sinton wheat; approximately at 6 and 8 weeks of growth, respectively. Not only did reductions occur earlier in Norquay wheat, but at comparable infestation densities, the extent of the reductions were greater in Norquay than in Sinton wheat. For example, when sampling was done at 11 weeks of growth with the May 28 seeding date, 600 green foxtail plants per m^2 caused wheat dry weight reductions of 54 and 35% in Norquay and Sinton wheat, respectively (Table 15).

Comparing the degree of green foxtail competition within the four seeding dates of 1978, the results of the June 5 seeding date varied markedly from the other three seeding dates. The severity of competition was found to be much less at this date, in both Sinton and Norquay wheat (Table 15). The largest variation in the degree of green foxtail competition was with the May 28 and June 5 seeding dates, even though there was only 8 days between the seeding dates (Figures 7 and 8). With the June 5 seeding date, the dry weight of wheat was

TABLE 15. The effect of green foxtail on the dry weight of Sinton and Norquay wheat in 1978

Seeding date	Weeks of growth	Green foxtail plants/m^2	Wheat dry weight (grams)	
			Sinton	Norquay
May 17	6	0	68.4	45.5
		200	52.3	21.5
		400	37.1	33.1
		600	45.6	33.2
Tukey's H.S.D. (0.05)			19.6	12.1
	8	0	89.2	67.7
		200	65.1	43.8
		400	63.0	37.0
		600	59.0	37.0
Tukey's H.S.D. (0.05)			19.5	17.6
	10	0	111.0	88.9
		200	67.7	54.6
		400	68.3	41.4
		600	66.4	40.1
Tukey's H.S.D. (0.05)			30.3	28.1
	12	0	96.6	88.9
		200	70.9	50.4
		400	61.2	62.0
		600	60.7	50.5
Tukey's H.S.D. (0.05)			23.7	27.3

(continued)

TABLE 15. (Continued)

Seeding date	Weeks of growth	Green foxtail plants/m^2	Wheat dry weight (grams)	
			Sinton	Norquay
May 28	5	0	39.2	45.7
		200	38.9	29.7
		400	34.6	29.1
		600	44.3	26.2
Tukey's H.S.D. (0.05)			6.1	16.3
	7	0	83.4	83.9
		200	67.3	61.6
		400	53.3	32.4
		600	56.8	43.3
Tukey's H.S.D. (0.05)			20.2	24.4
	9	0	137.6	79.5
		200	77.9	48.4
		400	67.6	60.7
		600	72.4	56.9
Tukey's H.S.D. (0.05)			36.0	16.9
	11	0	126.6	120.0
		200	101.4	90.3
		400	87.6	80.5
		600	82.6	54.5
Tukey's H.S.D. (0.05)			34.5	32.6

(continued)

TABLE 15. (Continued)

Seeding date	Weeks of growth	Green foxtail plants/m^2	Wheat dry weight (grams)	
			Sinton	Norquay
June 5	4	0	26.8	29.4
		200	22.1	19.0
		400	27.9	24.3
		600	29.0	20.2
Tukey's H.S.D. (0.05)			4.2	8.4
	6	0	75.0	64.0
		200	63.5	57.9
		400	66.3	66.4
		600	63.8	59.4
Tukey's H.S.D. (0.05)			16.8	11.3
	8	0	95.6	81.1
		200	90.0	79.6
		400	84.0	75.8
		600	76.2	66.6
Tukey's H.S.D. (0.05)			17.8	21.4
	11	0	122.3	106.2
		200	116.4	85.8
		400	82.2	85.6
		600	101.2	90.9
Tukey's H.S.D. (0.05)			23.4	20.0

(continued)

TABLE 15. (Continued)

Seeding date	Weeks of growth	Green foxtail plants/m^2	Wheat dry weight (grams)	
			Sinton	Norquay
June 11	7	0	40.5	41.2
		200	27.2	24.4
		400	34.5	14.7
		600	24.9	20.7
Tukey's H.S.D. (0.05)			9.1	13.0
	10	0	96.5	69.5
		200	88.8	41.8
		400	73.9	36.5
		600	68.2	45.5
Tukey's H.S.D. (0.05)			19.6	18.9
	12	0	105.8	88.5
		200	72.5	51.0
		400	61.4	47.5
		600	60.0	38.8
Tukey's H.S.D. (0.05)			27.5	25.9

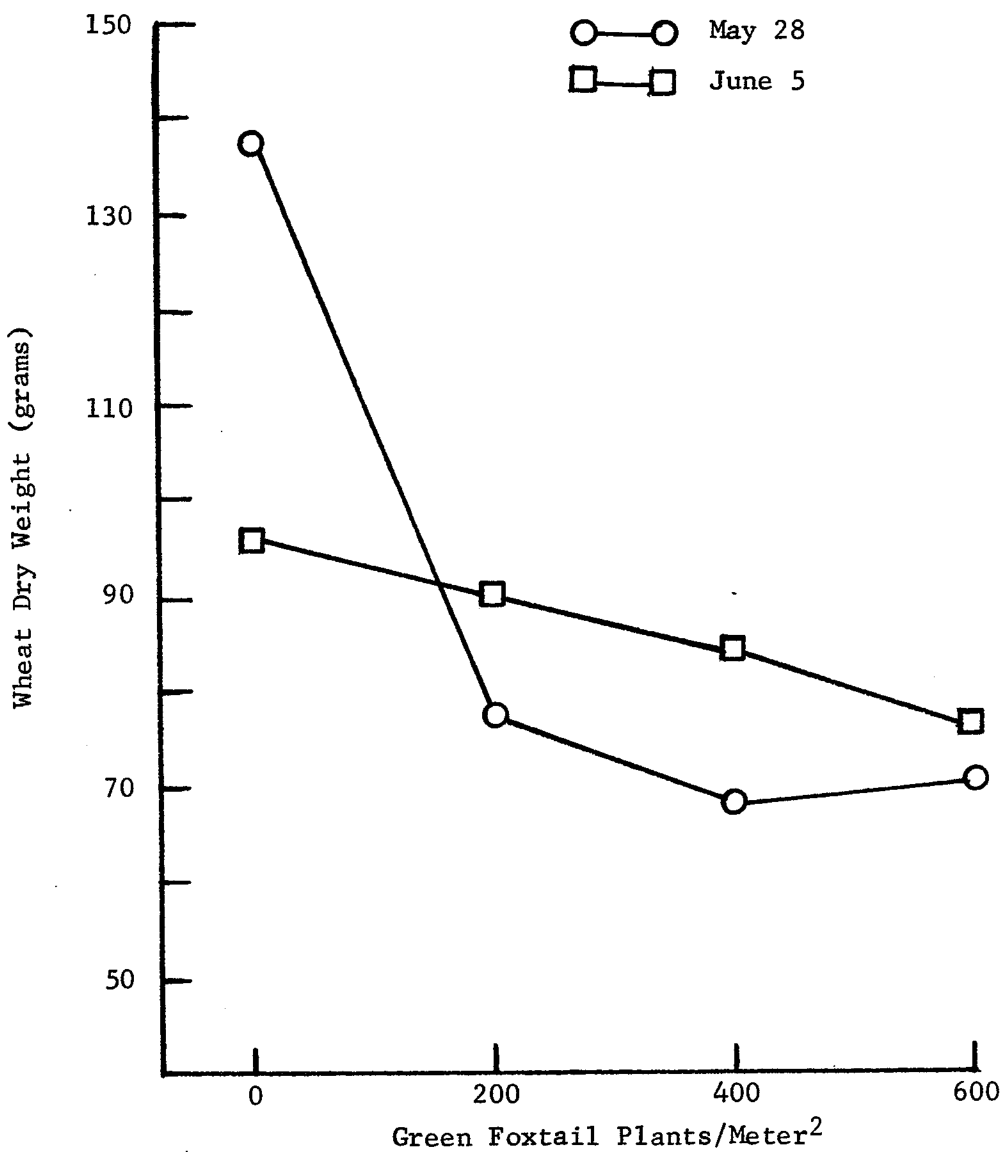

FIGURE 7. Sinton wheat dry weight after 8 weeks of growth with varying green foxtail densities at two seeding dates in 1978

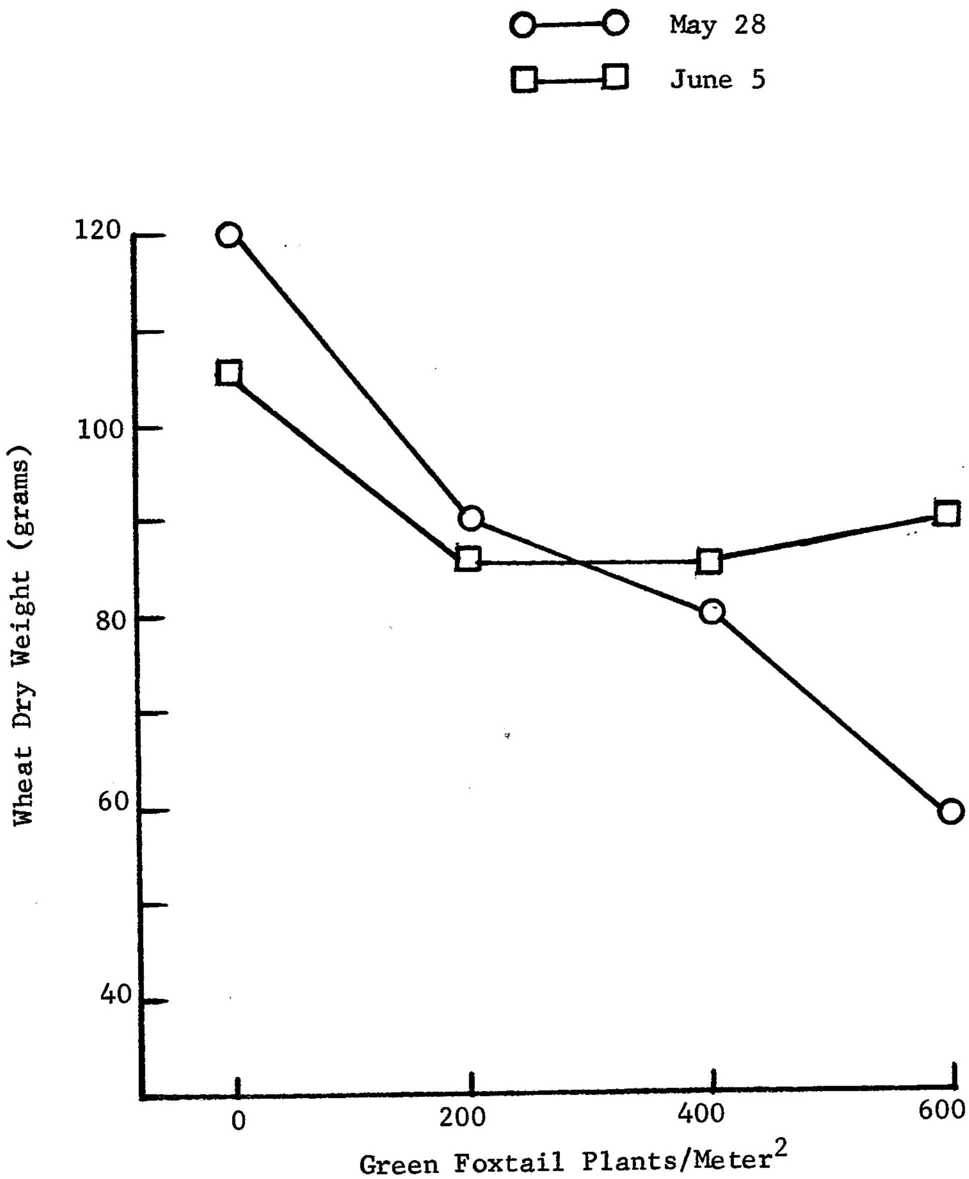

FIGURE 8. Norquay wheat dry weight after 11 weeks of growth with varying green foxtail densities at two seeding dates in 1978

reduced at a later growth stage, and greater densities were required to cause these reductions. The extent of the reduction in the dry weight of wheat was often smaller at 400 or 600 green foxtail plants per m^2 with the June 5 seeding date than 200 green foxtail plants per m^2 at the other three seeding dates.

In weed-free wheat plots, the dry weight of Sinton wheat was greater than that of Norquay wheat at comparable growth stages throughout the growing season.

Grain Yield. The date of seeding was found to affect the yield of both Sinton and Norquay wheat varieties (Figures 9, 10, 11, and 12). In 1977, the greatest yield of Sinton wheat (2688 kg/ha) was attained with the June 2 seeding date (Table 16). The May 24 seeding date had a slightly lower yield (2242 kg/ha) while the yield of the June 17 seeding date (1024 kg/ha) was severely reduced. With Norquay wheat, the May 24 and June 2 seeding dates attained the highest yields, being 2951 and 3088 kg/ha, respectively. The yield of the June 17 seeding date was markedly reduced to 1228 kg/ha.

In 1978, the highest yields of Sinton and Norquay wheat were attained when the seeding dates were May 17 and May 28 (Tables 17 and 18). Although not significantly less, wheat yields tended to be depressed with the June 5 seeding date. A further delay in seeding till June 11 reduced the yield of both wheat varieties.

The yield of green foxtail seed was also affected by the seeding date (Tables 16, 17, and 18). The seed yield tended to be higher at the earlier seeding dates. In 1977, green foxtail competition reduced Sinton wheat yields to a great extent with the June 2 seeding date as compared to the May 24 seeding date (Table 16), however, more

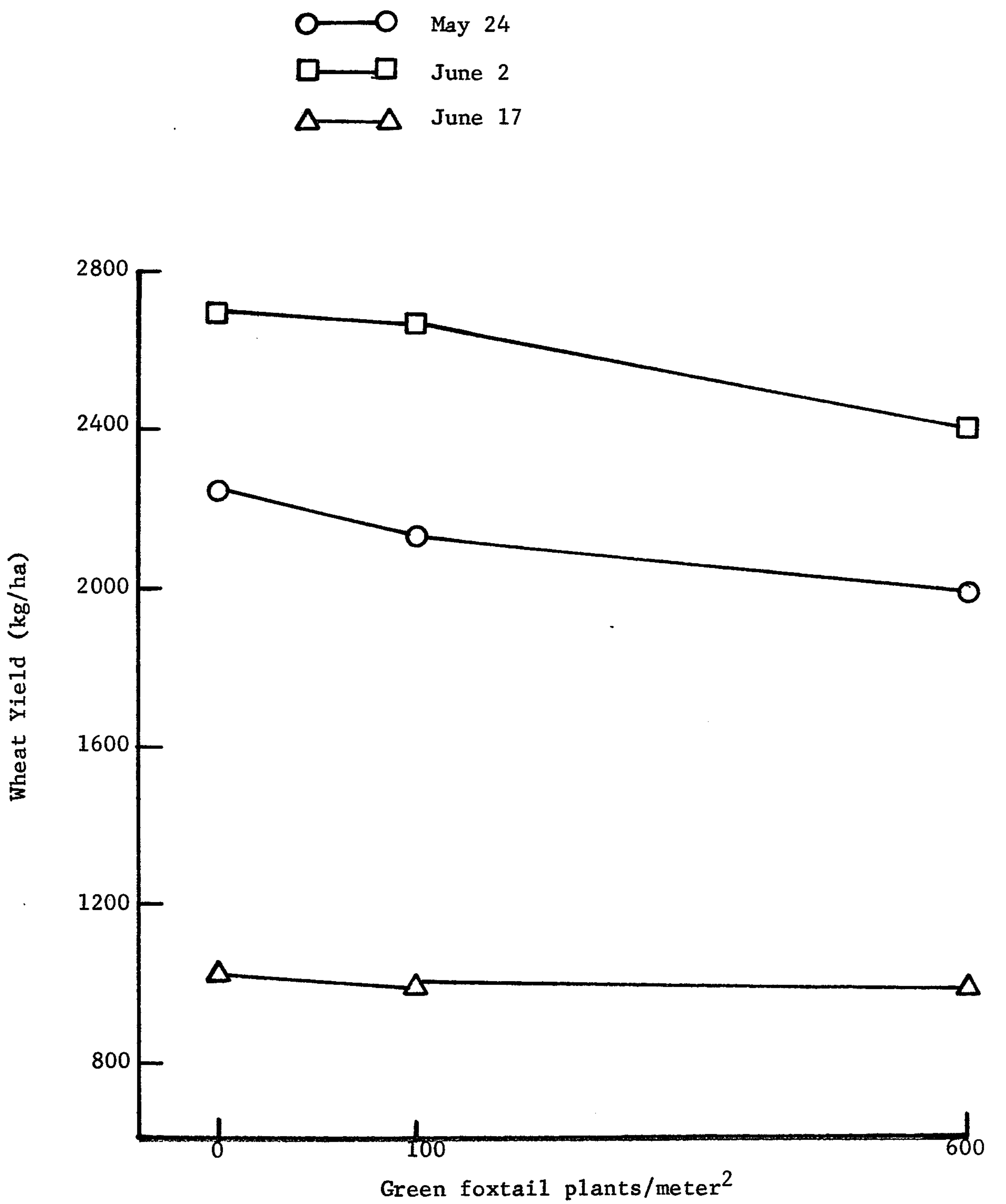

FIGURE 9. The effect of green foxtail on the yield of Sinton wheat sown at three seeding dates in 1977

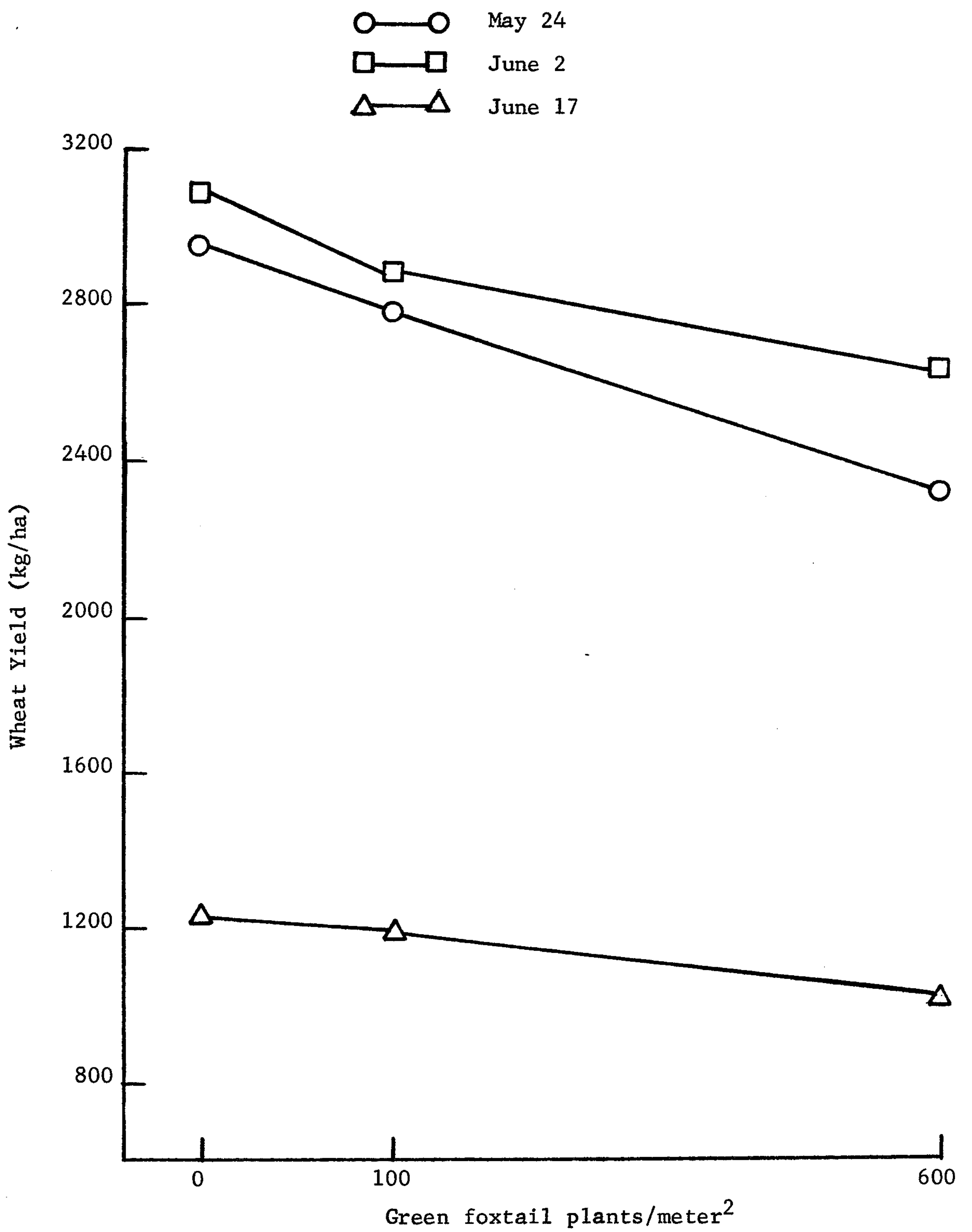

FIGURE 10. The effect of green foxtail on the yield of Norquay wheat sown at three seeding dates in 1977

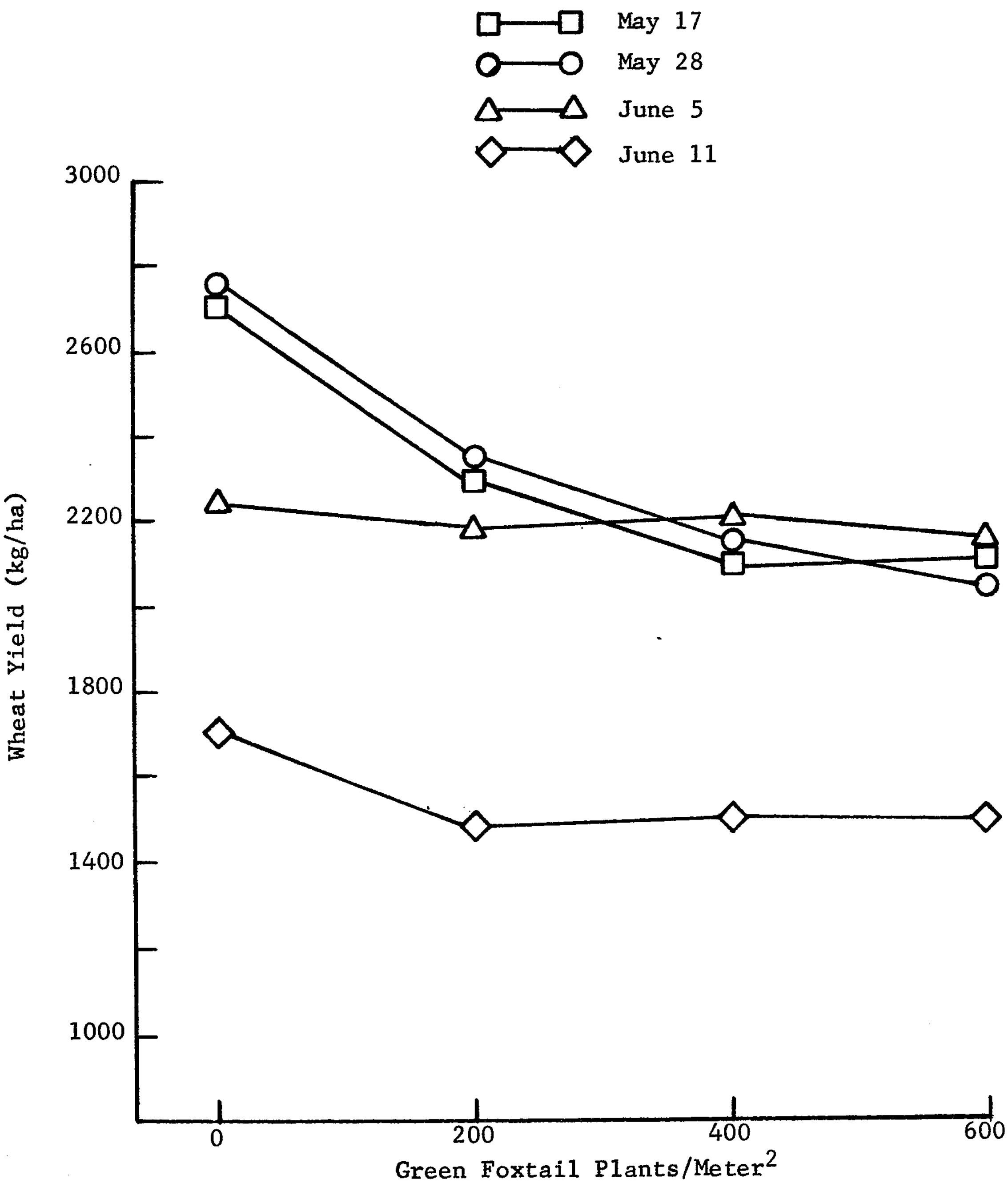

FIGURE 11. The effect of green foxtail on the yield of Sinton wheat sown at four seeding dates in 1978

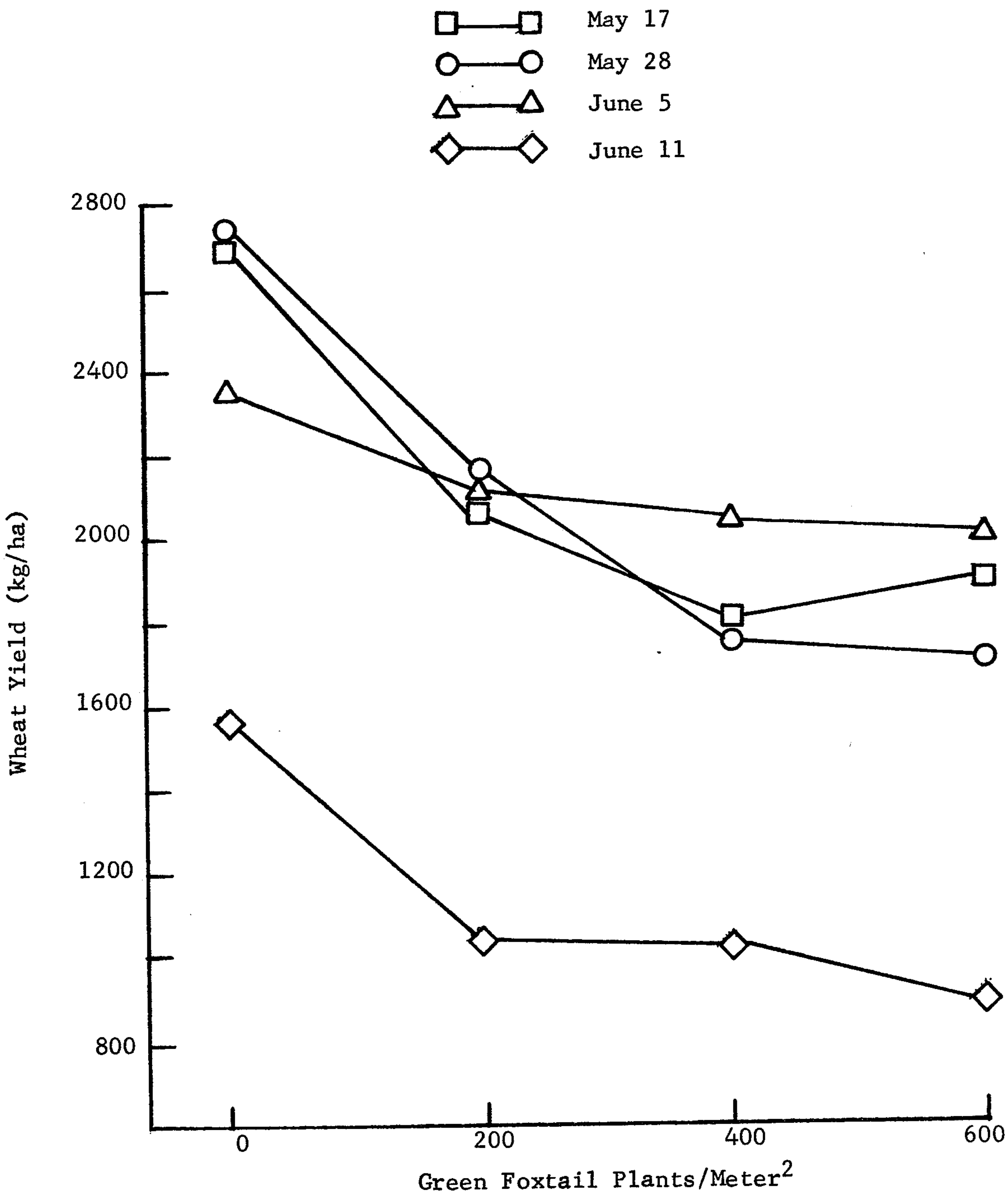

FIGURE 12. The effect of green foxtail on the yield of Norquay wheat sown at four seeding dates in 1978

TABLE 16. The effect of seeding date in the ability of green foxtail to compete with Sinton and Norquay wheat in 1977

Wheat variety	Seeding date	Green foxtail plants/m^2	Wheat yield (kg/ha)	Green foxtail seed yield (kg/ha)
Sinton	May 24	0	2242	-
		100	2135	92
		600	1981	161
	June 2	0	2688	-
		100	2670	44
		600	2386	59
	June 17	0	1024	-
		100	989	33
		600	961	61
Tukey's H.S.D. (0.05)			150	28
Norquay	May 24	0	2951	-
		100	2793	130
		600	2315	273
	June 2	0	3088	-
		100	2894	93
		600	2628	220
	June 17	0	1228	-
		100	1197	25
		600	1002	73
Tukey's H.S.D. (0.05)			436	69

TABLE 17. The effect of seeding date on the ability of green foxtail to compete with Sinton wheat in 1978

Seeding date	Green foxtail plants m^2	Wheat yield (kg/ha)	Green foxtail seed yield (kg/ha)
May 17	0	2685	-
	200	2292	345
	400	2089	426
	600	2132	415
May 28	0	2703	-
	200	2299	307
	400	2116	398
	600	2078	389
June 5	0	2245	-
	200	2163	59
	400	2156	82
	600	2085	103
June 11	0	1697	-
	200	1464	256
	400	1493	294
	600	1544	269
Tukey's H.S.D. (0.05)		367	133

TABLE 18. The effect of seeding date on the ability of green foxtail to compete with Norquay wheat in 1978

Seeding date	Green foxtail plants/m^2	Wheat yield (kg/ha)	Green foxtail seed yield (kg/ha)
May 17	0	2709	-
	200	2031	529
	400	1799	580
	600	1924	763
May 28	0	2746	-
	200	2141	453
	400	1756	560
	600	1720	610
June 5	0	2356	-
	200	2107	116
	400	2055	169
	600	2002	152
June 11	0	1549	-
	200	1036	398
	400	1038	429
	600	905	472
Tukey's H.S.D. (0.05)		318	111

green foxtail seed was produced with the May 24 seeding date. Similarly, in 1978, the amount of green foxtail seed produced was greater with the earlier seeding dates.(Figure 13). The yield of green foxtail seed was markedly less with the June 5 seeding date as compared to the other three seeding dates in both Sinton and Norquay wheat. The lower seed production of the June 5 seeding date indicated that green foxtail was less competitive at that seeding date.

Green foxtail infestations were found to be capable of reducing yields of both Sinton and Norquay wheat varieties. An infestation of 100 green foxtail plants per m^2 did not lower wheat yields in 1977 (Table 16). However, a density of 600 green foxtail plants per m^2 reduced yields of Sinton and Norquay wheat when sown on May 24 and June 2. When wheat was sown on June 17, no significant wheat yield reductions occurred due to the presence of green foxtail.

In 1978, a density of 200 green foxtail plants per m^2 caused reduced yields of both Sinton and Norquay wheat (Tables 17 and 18). Increasing the green foxtail density to 600 plants per m^2 did not cause further significant yield reductions in Sinton wheat. However, with Norquay wheat sown on May 28, an increase in the green foxtail density from 200 to 400 plants per m^2 caused a further yield reduction.

As few as 100 green foxtail plants per m^2 were found to be capable of producing large quantities of seed (Table 16). There was a trend towards higher green foxtail seed yields with increasing infestation densities (Tables 16, 17 and 18). The amount of green foxtail seed produced depended upon the seeding date and the

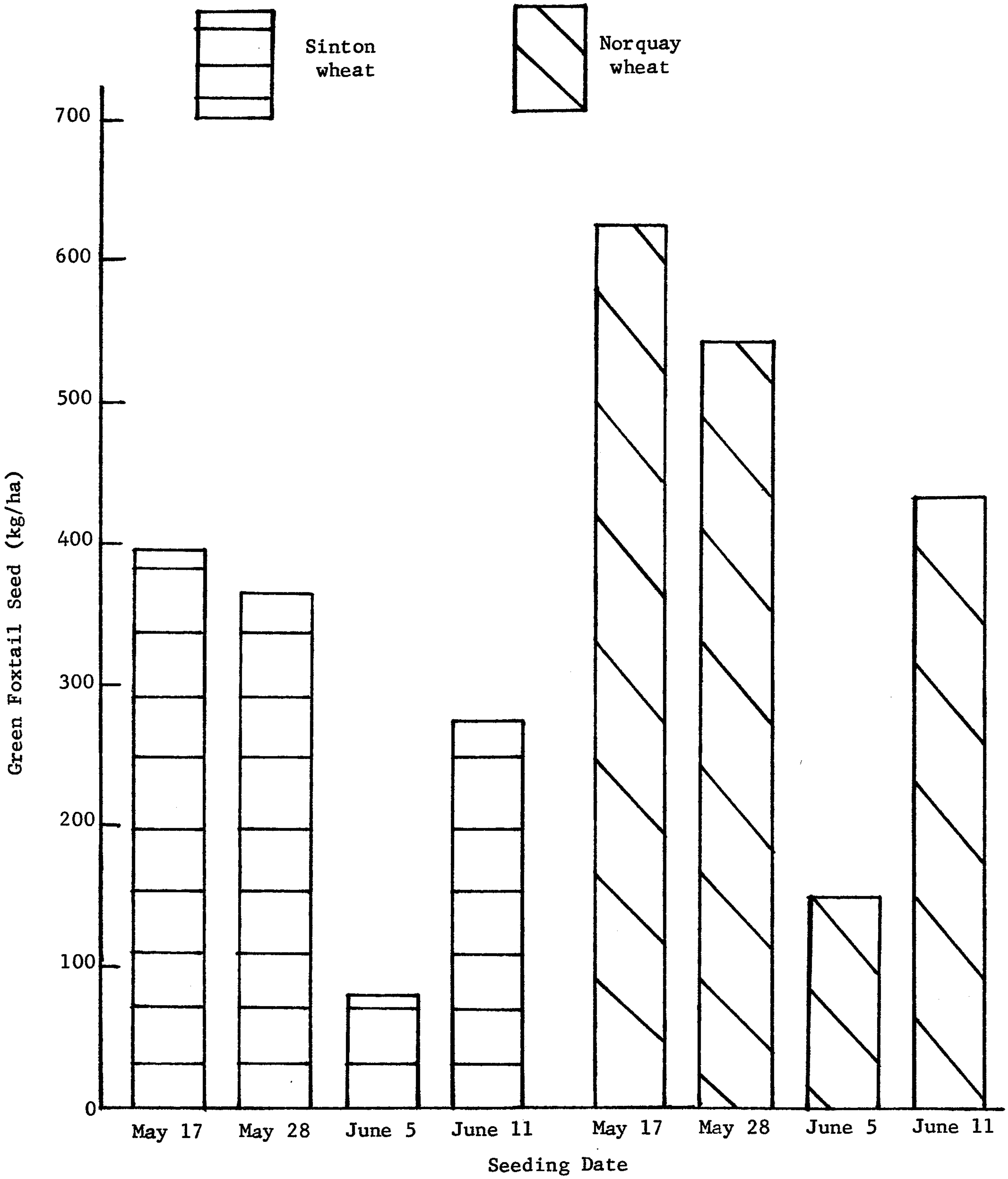

FIGURE 13. The effect of seeding date on green foxtail seed yield in Sinton and Norquay wheat in 1978

competitive ability of green foxtail within that seeding date. For example, with the May 28 seeding date of Norquay, 200 green foxtail plants per m^2 produced 453 kg/ha of seed, while 600 green foxtail plants per m^2 with the June 5 seeding date produced only 152 kg/ha of seed (Table 18).

The degree of green foxtail competition was greater in Norquay wheat than in Sinton wheat. At comparable green foxtail densities, greater yield reductions occurred in Norquay than in Sinton wheat. When wheat was sown on May 28, 1978, a density of 600 green foxtail plants per m^2 reduced the yield of Norquay and Sinton wheat by 37 and 23%, respectively (Tables 17 and 18).

The greater degree of green foxtail competition in Norquay wheat as compared to Sinton wheat was further substantiated by the amount of green foxtail seed produced at comparable infestation densities in the two wheat varieties. For example, when wheat was sown on May 17, 1978, a density of 600 green foxtail plants per m^2 produced 763 and 415 kg/ha of seed, in Norquay and Sinton wheat, respectively (Tables 17 and 18).

The degree of green foxtail competition varied from one seeding date to another. When Sinton wheat was sown on May 28, 1978, a density of 200 green foxtail plants per m^2 reduced the wheat yield by 15%, while the yield of Sinton wheat sown on June 5 was not significantly reduced with any of the green foxtail densities (Figure 11). Similarly, with the June 5 seeding date of Norquay wheat the competitive ability of green foxtail was reduced as compared to the other three seeding dates of 1978 (Figure 12). With the June 5 seeding date, a density of 600 green foxtail plants per m^2 were required to reduce

Norquay wheat yields by 15%, while 200 green foxtail plants per m^2 reduced Norquay wheat yields by 22% when sown on May 28.

Soil Moisture. In 1977, soil moisture studies showed that there was often less soil moisture present in the wheat plots infested with green foxtail as compared to wheat plots without weeds. This soil moisture reduction due to the presence of green foxtail was noted in both Sinton and Norquay wheat varieties (Table 19).

Similarly in 1978, a green foxtail density of 600 plants per m^2 reduced the amount of soil moisture present in wheat plots. These results were found over varying sampling dates of the growing season with two seeding dates of Sinton and Norquay wheat (Table 20).

When the soil moisture was sampled after a recent rainfall, it was impossible to detect differences in the amount of soil moisture in the wheat plots that were infested with green foxtail as compared to the weed-free wheat plots. It was occasionally observed that greater amounts of moisture were present in the wheat stands infested with green foxtail. This may have been due to green foxtail sheltering the surface soil from the drying action of the wind and sun, and if sampling occurred within 2 to 3 days of a rainfall then more moisture might actually be present in the wheat plots infested with green foxtail.

The ability of green foxtail to reduce the soil moisture of wheat stands appeared comparable in the Sinton and Norquay wheat varieties. For example, when soil moisture samples were taken on August 15, 1977, a density of 600 green foxtail plants per m^2 caused a 15% reduction in the amount of moisture present in both Sinton and Norquay wheat (Table 19).

TABLE 19. The effect of green foxtail on soil moisture to a depth of 75 cm in Sinton and Norquay wheats in 1977

Sampling date	Green foxtail plants/m^2	Soil moisture (% by vol.)	
		Sinton	Norquay
July 18	0	20.5	13.6
	600	18.0	13.7
Tukey's H.S.D. (0.05)		1.6	N.S.
July 25	0	12.3	11.1
	600	10.8	9.1
Tukey's H.S.D. (0.05)		1.3	1.4
August 4	0	22.7	18.0
	600	21.6	18.6
Tukey's H.S.D. (0.05)		N.S.	N.S.
August 9	0	19.3	13.5
	600	15.9	13.0
Tukey's H.S.D. (0.05)		2.4	N.S.
August 15	0	17.9	18.7
	600	15.2	15.9
Tukey's H.S.D. (0.05)		1.0	2.1
August 23	0	7.1	6.5
	600	6.8	6.6
Tukey's H.S.D. (0.05)		N.S.	N.S.

TABLE 20. The effect of green foxtail on soil moisture to a depth of 75 cm in Sinton and Norquay wheats in 1978

Sampling time	Seeding date	Green foxtail	Soil moisture % (by vol.)	
		plants/m^2	Sinton	Norquay
July 26	May 28	0	22.0	21.0
		600	19.5	20.6
	June 5	0	22.0	24.4
		600	19.4	21.6
Tukey's H.S.D. (0.05)			1.8	1.6
July 31	May 28	0	19.1	21.2
		600	21.3	22.9
	June 5	0	17.0	21.9
		600	16.5	20.0
Tukey's H.S.D. (0.05)			1.5	1.5
August 15	May 28	0	13.0	16.1
		600	13.5	15.0
	June 5	0	15.8	16.5
		600	13.8	15.9
Tukey's H.S.D. (0.05)			1.3	N.S.
August 25	May 28	0	9.1	9.7
		600	12.1	10.5
	June 5	0	12.2	13.8
		600	9.2	10.3
Tukey's H.S.D. (0.05)			1.0	1.5

DISCUSSION

The seeding date of wheat influenced the yield potential of wheat. Seeding in May gave the higher yields of both Sinton and Norquay wheat. Delaying the seeding date till June resulted in lower wheat yields. The later the date of seeding in June, the lower the wheat yields obtained. Wheat should be sown before the first week of June to maximize the yield potential of the crop.

Early seeding was more critical in Norquay wheat than in Sinton wheat, since late seeding resulted in lower yields of Norquay wheat. This difference in varietal response to the date of seeding has been shown previously (Schmit, 1960; Beard, 1961; and Sturko, 1978).

Norquay, a semi-dwarf wheat, was less tolerant of green foxtail competition than the normal height Sinton wheat. Grain yield reductions at comparable green foxtail densities were greater in Norquay wheat than in Sinton wheat. In addition, green foxtail seed production was greater in plots of Norquay wheat than in plots of Sinton wheat. Sturko (1978) similarly found that green foxtail competition was greater in a semi-dwarf wheat than in a normal height wheat.

Initially, the difference in the competitive ability of Norquay and Sinton wheat may be due to the slower emergence of the semi-dwarf wheat. Liver (1958) and Allan et al., (1962) found that coleoptile growth and seedling emergence was slower with a semi-dwarf as compared to a normal-height winter wheat variety. In the present study, it was observed that Sinton wheat emerged a day before Norquay wheat. Since early emergence and rapid seedling growth result in a more competitive crop, the semi-dwarf wheat, with slower emergence, may not be as competitive with green foxtail as the normal height wheat.

At later growth stages of the crop, the differential shading ability of Sinton and Norquay wheat may have been an important factor in their relative competitive ability with green foxtail. In the present study it was observed that Sinton wheat grew to a height of 85 to 90 cm, while Norquay grew to a maximum height of 60 to 65 cm. Green foxtail grew at a comparable height with Norquay wheat throughout most of the growing season. At heading stage, green foxtail was 10 to 15 cm taller than Norquay wheat. In contrast, at no time during the growing cycle was green foxtail as tall as Sinton wheat. At heading, green foxtail was found to be 20 to 25 cm shorter than Sinton wheat. Green foxtail shaded only the lower leaves of Sinton wheat while with Norquay wheat a large proportion of the leaves were shaded. The photosynthetic capacity of Norquay wheat would be reduced to a greater extend than that of Sinton wheat.

Not only did green foxtail not shade Sinton wheat to a large degree at any stage of the growth cycle, but Sinton wheat severely shaded green foxtail throughout most of the growing season. Vanden Born (1971) and Duke and Hunt (1975) found that green foxtail required high light intensity for optimum growth. When grown under low light intensity, green foxtail vegetative growth was decreased and less seed was produced. The ability of Sinton wheat to shade green foxtail from direct sunlight would limit the growth of green foxtail and thus the intensity of competition offered would be lowered. This is borne out in the field as leaf area, dry weight, and grain yield reductions were greater in Norquay wheat than in Sinton wheat.

Studies were performed to determine how green foxtail competition affected wheat growth and ultimately reduced grain yields. Previous researchers (Pavlychenko and Harrington, 1934; Godel, 1935; and Blackman and Templeman, 1938) found that weeds reduced cereal yields by reducing the number of tillers per plant. In the present study it was determined that green foxtail reduced the number of tillers per wheat plant, in both Sinton and Norquay wheat. The reduction in the number of tillers per wheat plant could be due to green foxtail competition very early in the growth of wheat causing a reduction in the number of axillary buds that are stimulated to develop into tillers. At later stages of the growing cycle green foxtail competition would cause some of the tillers to senesce before reaching maturity. The reduction in the number of tillers that mature means that a lower number of wheat spikes are formed, thereby reducing grain yields.

Green foxtail infestations were found to reduce the leaf area of Sinton and Norquay wheat. The leaf area reductions occurred within 4 to 5 weeks of wheat growth and continued throughout the growth of the wheat crop. Reductions in the dry weight of Sinton and Norquay wheat were also found due to the presence of green foxtail. However, the wheat dry weight reductions were not noted till 6 to 8 weeks of wheat growth. It appears that the reduction in the leaf area of wheat sufficiently reduced the amount of photosynthate produced to cause the dry weight and ultimately the grain yield of wheat to be reduced.

The competititive ability of green foxtail in wheat varied between and within the two years of the study. The degree of green foxtail competition could not be determined by the density of the infestation alone. For example, a density of 800 green foxtail plants per m^2 did not significantly reduce the yield of Sinton wheat when sown on May 30, 1977; however, a comparable density of green foxtail reduced the yield of Sinton wheat by 43% when sown on May 30, 1978 (Table 5). The fact that the intensity of green foxtail competition cannot be solely determined by the infestation density present has been similarly noted (Jorge and Staniforth, 1961; Rahman and Ashford, 1972; and Sturko, 1978).

The competitive ability of green foxtail was found to be dependent on the environmental conditions at the time of seeding and early growth. As previously shown in Experiments 1 to 3, soil temperature and soil moisture conditions during the germination and emergence period were critical to the establishment of green foxtail infestations. Decreases below the optimum soil temperature and/or moisture conditions severely reduced the rate of green foxtail emergence or inhibited it completely. However, over the same range of soil temperature and moisture conditions wheat emergence was only slightly delayed while the percentage emergence remained unchanged. If the soil was moist (0 to -4 bars ψ) and soil temperatures were warm (20 to 25°C), green foxtail emerged within a few days of wheat. However, if the soil was dry (-4.0 to -6.5 bars ψ) and temperatures were low (15 to 20°C), green foxtail would emerge 7 to 14 days after wheat. The time of emergence of green foxtail relative to that of wheat was critical to the potential competitive ability of green foxtail.

Results of the field studies of Experiment 6 show the importance of the time of emergence of green foxtail relative to wheat as it affects the intensity of green foxtail competition. When wheat was sown on May 24, 1977, soil temperature and moisture conditions were favorable for green foxtail (Table 21). These conditions allowed green foxtail to emerge 2 days after wheat. In contrast, with the June 2 seeding date in 1977, soil moisture was limiting for green foxtail germination and green foxtail did not emerge till 8 days after wheat. It would be expected that green foxtail would be more competitive if it emerged a couple of days after wheat than if it emerged 1 to 2 weeks after wheat. This was the situation with the May 24 and June 2 seeding dates. Although 600 green foxtail plants per m^2 reduced the yield of Sinton wheat by 12% with both seeding dates, Norquay wheat yields were reduced by 22 and 15%, with the May 24 and June 2 seeding dates, respectively (Table 21).

With the May 28 seeding date in 1978, the soil was moist but the soil temperature was cool and green foxtail did not emerge till 6 days after wheat (Table 21). With the June 5 seeding date the soil temperature was more favorable but soil moisture was more limiting than with the May 28 seeding date. Under these conditions green foxtail did not emerge till 8 to 14 days after wheat. Strictly on the time of emergence of green foxtail relative to that of wheat it would be expected that green foxtail competition would be greater with the May 28 as compared to the June 5 seeding date. This was confirmed by the wheat yield reductions. With a green foxtail density of 600 plants per m^2 the yield of Sinton wheat was reduced by 23% with the May 28 seeding date, while with the June 5 seeding date no significant yield reductions occurred in Sinton wheat (Table 21). An infestation density of 600

TABLE 21. The influence of soil temperature and soil moisture on the emergence of green foxtail and wheat and the resulting competition of green foxtail with Sinton and Norquay wheat in 1977 and 1978

Seeding date	Water potential (bars) at seeding (0-6 cm)	Temperature (°C) during green foxtail emergence	Days to 50% emergence		% Yield reduction due to 600 green foxtail/m^2	
			Green foxtail	Wheat	Sinton	Norquay
a) 1977						
May 24	-5.0	26	8	6	12[2]	22[2]
June 2	-11.0	22	16	8	12[2]	15[2]
June 17	-1.0	22	7	7	6	18
b) 1978						
May 28	-2.0	17	13	7	23[2]	38[2]
June 5	-6.0	20	15-21[1]	7	7	15[2]
June 11	-4.5	24	16	6	9	42[2]

[1]A first flush of green foxtail (25%) emerged in 15 days. Rain was received on June 10 allowing a second flush of green foxtail to emerge within 21 days after seeding.

[2]Significant at Tukey's H.S.D. (0.05) level.

plants per m^2 reduced the yield of Norquay wheat by 38 and 15%, with the May 28 and June 5 seeding dates, respectively.

With the June 11 seeding date in 1978, the soil temperature was favorable but soil moisture was in the limiting range and green foxtail did not emerge till 10 days after wheat (Table 21). A density of 600 green foxtail plants per m^2 did not cause a significant yield reduction in Sinton wheat, however, the yield of Norquay wheat was reduced by 42% with a comparable infestation density. The large yield reduction in Norquay wheat may be attributable to it being more sensitive to a long growing season for optimum growth and yield than Sinton wheat. When Norquay wheat was sown on the late seeding date of June 11 its yield potential was already severely lowered and green foxtail competition was expressed to a greater extent in this situation, causing large grain yield reductions.

Green foxtail may be expected to be the most competitive when it emerges with or shortly after wheat. However, this is not always true. For example, with the June 17 seeding date of 1977, the soil temperature and moisture conditions were favorable for good emergence of green foxtail (Table 21). Green foxtail emerged on the same day as wheat. In this situation it might be expected that green foxtail would be very competitive. However, this was not borne out as 600 green foxtail plants per m^2 did not cause significant yield reductions in either Sinton or Norquay wheat. This may be partially explained by the fact that a period of cool, cloudy weather followed the emergence of green foxtail and wheat. Wheat would have a competitive advantage over green foxtail in those conditions.

Although not always the case, the intensity of green foxtail competition with wheat was higher when green foxtail emerged within a week of wheat, than if green foxtail emerged 2 weeks after wheat. It cannot always be predicted that green foxtail will reduce wheat yields if it emerges within a week of wheat, however, it can be predicted with a great degree of certainty that green foxtail will not reduce wheat yields if it does not emerge till 2 weeks after wheat.

The time of green foxtail emergence relative to wheat is not the sole factor determining the intensity of green foxtail competition. After green foxtail has emerged, air temperature and light intensity become critical factors affecting green foxtail competition. In green foxtail, photosynthesis occurs by the Hatch and Slack or C_4 pathway (Chen et al., 1970), whereas in wheat photosynthesis occurs via the Calvin cycle or C_3 pathway (Moss et al., 1969). C_4 species require temperatures of 30 to 40°C and light intensities of full sunlight for maximum photosynthetic rates to occur (Downton, 1971; Vanden Born, 1971; and Duke and Hunt, 1975). Maximum photosynthetic rates of C_3 species occur at temperatures of 15 to 25°C and light intensities of 20 to 30% full sunlight (Chen et al., 1970). Under optimum light intensity and temperature conditions for each species, C_4 species attained net photosynthetic rates of 60 to 100 mg of CO_2 assimulated per dm^2 hr^{-1} while C_3 species had net photosynthetic rates of 10 to 35 mg of CO_2 assimulated per dm^2 hr^{-1} (Chen et al., 1970). From these considerations, it could be predicted that green foxtail would be the most competitive with wheat at high temperatures when the more efficient C_4 photosynthesis would take full advantage of high light intensity. More vigorous growth of green foxtail would increase competition with wheat through shading and the development of a more extensive root system. At low temperatures, wheat would have a competitive advantage over green foxtail. The photosynthetic rate of wheat would remain close to optimum while that of green foxtail would be depressed. This would induce shading of green foxtail. Light intensities striking green foxtail would be decreased and photosynthetic rates would be depressed further, causing the intensity of green foxtail competition to be decreased.

Green foxtail infestations reduced the yield of both wheat varieties, therefore, green foxtail competition was limiting one or more of the basic growth requirements.

Competition for light accounted for part of the yield reductions in wheat. Green foxtail was 10 to 15 cm taller than Norquay at heading, causing partial shading of wheat during a critical period when large amounts of photosynthate were required. However, the normal-height Sinton wheat was 20 to 25 cm taller than green foxtail at the grain filling stage. Green foxtail would shade only the lower leaves of wheat and since the majority of the photosynthate for kernel development is produced by the flag leaf and the spike itself, competition for light was probably not as important in a normal height wheat as compared to a semi-dwarf wheat.

Green foxtail could be reducing wheat yields through competition for soil nutrients. By reducing one or more nutrients to a level below that required for optimum wheat growth, grain yields could be severely reduced. Green foxtail has been found to be a good competitor with wheat for available soil nitrogen (Alex, 1967; Moyer and Dryden, 1976; and Sturko, unpublished data). The importance of green foxtail competition for essential nutrients becomes more critical in soils of low fertility.

Green foxtail also competes with wheat for soil moisture. In the present study it was often found that there was less soil moisture present in the green foxtail-infested wheat as compared to the weed-free wheat stands. These results indicate that green foxtail competition reduced the amount of available soil moisture present for wheat growth. Wheat growth may or may not be severely suppressed depending on when in the growing cycle soil moisture becomes limiting. Dense growth of green foxtail and wheat may use most of the available moisture to produce vegetative growth leaving little moisture during the critical grain filling period, thereby reducing wheat yields. Competition for soil moisture would be accentuated with increasing densities and vigorous top growth of green foxtail. Green foxtail competition for soil moisture becomes more critical with increasing aridity of the growing season.

Green foxtail competition was not severe when wheat was sown on May 30, 1977, as significant yield reductions were not noted in Sinton or Norquay wheat of Experiment 4. However, there was trend of lower wheat yields when green foxtail was not killed before the six- to seven-leaf stage. The stage of green foxtail removal was more critical at the larger infestation densities. Sturko (1978) reported that when green foxtail competition was severe, the weed had to be removed by the one- to three-leaf stage to minimize wheat yield losses. When green foxtail competition was of moderate intensity, it was possible to leave green foxtail till the four- to five-leaf stage before control without observing wheat yield losses.

Green foxtail competition was found to be most intense when the infestations emerged within 7 to 10 days after the emergence of wheat. Thus, if green foxtail densities of 200 to 400 plants per m^2 emerged shortly after wheat, control of the infestations should occur by the two- to three-leaf stage of the weed. This action would minimize grain losses due to green foxtail competition.

SUMMARY AND CONCLUSIONS

Competition from green foxtail reduced the yield of Sinton and Norquay wheat. The intensity of green foxtail competition was higher in the semi-dwarf wheat (Norquay) than in the normal height wheat (Sinton). Grain yield losses occurred at lower green foxtail densities in Norquay wheat. At comparable infestation densities, grain yield reductions and the amount of green foxtail seed produced were greater in Norquay than in Sinton wheat.

Green foxtail competition was found to severely suppress wheat growth as well as final grain yields. Tiller number, leaf area, and dry weight of wheat were reduced due to competition offered by green foxtail infestations.

Green foxtail competed more effectively for light in Norquay wheat than in Sinton wheat. Green foxtail competed with wheat most effectively for available soil moisture and soil nutrients.

The intensity of green foxtail competition could not be determined by density alone. The environmental conditions, at the time of seeding and early growth were critical in determining the competitive ability of green foxtail with wheat. When the soil was moist (0 to -4 bars ψ) and the soil temperature was warm (20 to 25°C) during germination and emergence, green foxtail emerged 3 to 5 days after wheat. In this situation, green foxtail densities of 200 plants per m^2 severely reduced wheat yields. However, when the soil was dry (-4.0 to -6.5 bars) and soil temperature was cool (15 to 20°C), green foxtail did not emerge till 10 to 14 days after wheat. Under these conditions the potential competitive ability of green foxtail was reduced, so that even at the high infestation of 800 plants per m^2, yield reductions were small.

Seeding of wheat should be done early to maximize wheat yields. This was true of both weed-free and green foxtail-infested wheat crops. By sowing early, the growing season was lengthened and more efficient use was made of the long hours of sunlight of June and July. Where green foxtail is a problem, seeding early in May when soil temperatures are normally cool, will reduce the intensity of green foxtail competition by giving wheat the competitive advantage of emerging several days before green foxtail.

When green foxtail infestations of 200 to 400 plants per m^2 emerge within a week of wheat, herbicidial control should be done by the two- to three-leaf stage of green foxtail. Control this early will minimize wheat yield losses due to green foxtail competition. When green foxtail infestations do not emerge till 2 weeks after that of wheat, grain losses will usually be small. However, even suppressed green foxtail plants produce large quantities of seed from which infestations may develop in future years. In this situation, the necessity of green foxtail control depends on the infestation density present and the crop to be grown the following year. At infestation densities of over 1000 plants per m^2, control would be advisable in that it reduces the soil seed population. At moderate infestation densities of 400 to 600 green foxtail plants per m^2, the crop to be grown the following year should be taken into consideration. If the crop is a good competitor with green foxtail, like barley or oats, then control may not be advisable. However, if the crop to be grown is a poor competitor, like wheat or flax, then control may be advisable.

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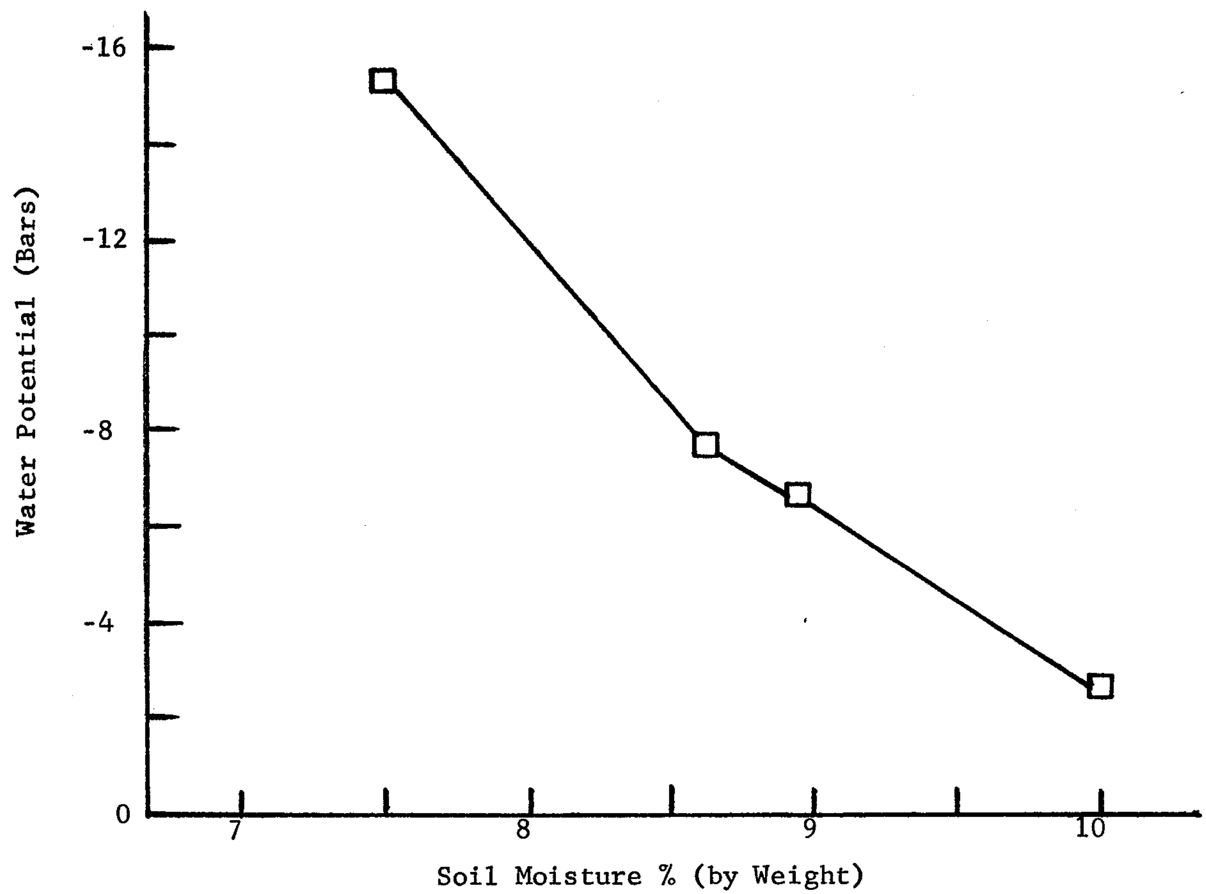

APPENDIX FIGURE 1. Soil water potential-soil moisture relationship of an Almasippi very fine sandy loam (79% sand, 7% silt, 14% clay, and 3.6% organic matter)

APPENDIX TABLE 1. Precipitation and temperature recorded at Graysville Meterological Station, 1977

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		15.6	1.7		16.7	12.8		24.4	10.0	.3	22.1	12.6	1.5	18.5	6.0
2	3.0	22.2	1.7		25.6	5.0	4.3	30.6	7.8	2.6	23.2	11.3		19.5	7.5
3	15.2	26.7	5.0		23.9	8.3		27.8	12.8	4.2	21.4	10.0	1.6	19.5	6.5
4	34.8	18.3	9.4	0.8	25.6	8.9	0.5	30.0	12.8		22.5	9.0	15.2	16.5	8.0
5	0.8	15.0	13.3	0.5	23.9	10.0	3.8	30.0	15.0		21.0	10.0	16.4	16.5	9.0
6		11.7	1.7		27.2	7.2		30.0	17.8	6.3	26.5	8.5		18.5	9.0
7		20.0	1.7		27.2	11.1		27.2	15.0	2.0	26.5	7.5	6.2	24.0	8.0
8		27.8	0.0		21.7	7.8		21.7	10.6		26.5	7.0	37.0	24.0	8.0
9		28.9	11.1		25.0	8.9		24.4	5.6	18.8	30.0	8.0		19.0	10.0
10		32.8	12.2	6.4	20.0	11.1	5.8	27.8	6.1	1.2	30.0	7.0		22.0	7.5
11		32.8	15.0	0.3	15.0	8.9	11.4	22.2	12.2		26.0	6.5		22.0	7.0
12		33.3	15.0	20.8	14.4	8.9		26.1	12.2	16.4	25.5	7.5	1.2	20.5	5.5
13	8.4	33.9	13.3		17.9	8.3	15.0	18.9	13.3		19.0	6.0		20.5	5.5
14	13.7	31.1	15.0		17.2	8.9		22.8	13.9		23.0	5.0		28.0	6.0
15		31.1	14.4	0.5	24.4	11.1		27.8	9.4		23.5	7.0		29.0	9.5
16		23.9	14.4		24.4	15.6	5.1	27.8	11.1	16.3	23.5	6.0		29.0	10.0
17	43.7	24.4	10.0	29.0	16.7	13.9	1.5	33.3	12.2		20.5	6.0		26.5	10.5
18	8.9	24.4	11.1	0.8	22.8	12.2		32.2	15.6		24.0	4.5		15.0	6.0
19	5.8	23.9	12.2	0.5	20.0	12.2		24.4	15.6	1.2	26.5	6.5		15.0	8.0
20		20.6	11.1		25.6	10.0		25.6	9.4		26.5	7.5	1.0	19.5	8.5
21		25.0	8.3		25.6	9.4		27.2	10.6		25.0	10.0		20.0	8.0
22		18.3	11.7		23.3	8.9		34.4	11.7		24.0	7.0	2.7	14.0	10.0
23		26.1	11.1	5.1	29.4	11.1	2.5	28.9	12.8		18.0	4.0	34.0	14.5	10.0
24		31.7	12.2		27.2	14.4		26.7	13.3		23.5	4.0	25.6	12.0	10.0
25		32.8	15.0	3.8	33.3	15.0		25.6	8.3	2.5	26.5	7.0	5.0	12.0	9.0
26	3.0	26.7	18.3		27.2	16.1		30.0	10.0		26.5	8.5		12.5	8.5
27	5.8	26.7	15.0	3.0	25.6	9.4		25.6	10.0	.6	22.5	7.5		16.5	7.5
28		24.4	15.0		24.4	10.0	1.8	29.4	12.8		22.0	10.0		16.5	5.0
29	0.5	26.7	9.4	1.5	25.0	8.9	11.2	24.4	6.3	15.6	23.5	4.0		16.0	1.5
30		25.6	15.6	2.3	17.8	10.6	5.1	23.3	9.4		23.0	5.0		15.5	1.5
31		26.7	13.9				5.3	24.4	11.2	12.6	22.0	9.5		15.5	1.0
	143.6	25.5	10.7	75.3	23.1	10.5	73.3	26.9	11.5	100.6	22.0	7.5	147.4	18.0	7.0

APPENDIX TABLE 2. Precipitation and temperature recorded at Graysville Research Station, 1978

Date	May			June			July			August			September		
	Rain mm	Temp. °C Max.	Temp. °C Min.	Rain mm	Temp. °C Max.	Temp. °C Min.	Rain mm	Temp. °C Max.	Temp. °C Min.	Rain mm	Temp. °C Max.	Temp. °C Min.	Rain mm	Temp. °C Max.	Temp. °C Min.
1		18.5	4.0	19.2	14.0	5.5					23.0	14.0		34.0	10.0
2		22.0	2.5		21.5	3.5				0.2	17.0	8.5			
3		21.5	3.5								33.0	6.0			
4		23.0	4.0				2.6	26.0	14.5						
5				1.5	30.0	4.0	23.6	28.5	17.0					32.0	10.5
6					15.0	12.0	8.0	25.0	14.5					24.0	15.0
7		24.0	5.0		22.0	5.0		21.0	10.0		23.0	6.5		22.0	11.0
8	6.7	16.0	5.0		14.5	7.5					22.0	7.0	0.5	30.0	12.5
9	10.0	18.0	1.0		28.0	6.0				0.2	25.5	14.0			
10		15.0	6.0				12.5	22.0	6.5		28.5	16.5			
11	1.3	16.0	6.0					30.0	11.0		33.0	17.5	4.4	14.0	8.0
12		17.5	2.0		26.0	2.0		28.0	14.0				12.5	10.0	8.0
13					24.0	5.0	8.0	26.0	9.0				57.5	12.0	6.0
14					27.0	12.5		30.0	12.0	4.0	22.5	14.0	4.8	20.0	6.5
15		26.5	0.0		27.0	15.0					22.5	13.0			
16		28.0	9.0		31.0	12.5					22.0	6.5			
17		28.5	13.0				56.3	29.0	12.0		28.0	11.0			
18	12.0	24.0	10.0		21.5	5.0	5.0	24.0	15.5		22.0	11.0	10.2	16.0	5.5
19		20.5	5.5	10.0	19.5	8.5	2.0	21.5	14.0				3.8	13.5	7.5
20					25.0	8.0		25.5	11.0					14.5	0.0
21					26.5	8.5		21.5	11.0		17.5	3.5		18.5	1.0
22					30.0	12.0				0.2	17.0	2.5		24.0	4.0
23		30.0	2.0							0.1	17.0	6.5			
24	15.0	27.5	2.5				5.0	32.0	8.5		30.0	11.5			
25	11.3	26.0	3.0					30.5	14.5		29.5	19.0		22.5	4.0
26	15.0	26.5	11.0	7.4	20.0	13.0		23.0	12.5				0.3	22.5	7.5
27					26.5	11.0		24.5	5.0					23.5	1.0
28					31.0	12.0				13.0	24.5	11.5		18.5	2.0
29		27.5	9.0		31.0	12.5				7.0	18.5	10.5			
30		23.0	7.0		30.0	16.0					23.0	2.0			
31	2.2	10.0	7.0				7.5	25.5	10.0	2.0	25.0	4.0			
	73.5	22.3	5.4	38.1	23.4	9.0	130.5	26.0	11.7	26.7	22.8	9.8	94.0	20.6	6.7