THESIS

INTERFERENCE OF APPLE SEEDLING GROWTH BY GREEN FOXTAIL

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY OMEZINE ABDESSATAR ENTITLED INTERFERENCE OF APPLE SEEDLING GROWTH BY GREEN FOXTAIL BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT

INTERFERENCE OF APPLE SEEDLING GROWTH BY GREEN FOXTAIL

Because of the documented benefits of cover crops in orchards, the interactions of one potential candidate—green foxtail (*Setaria viridis* L. Beauv.)—with apple seedlings (*Malus domestica* L.) have been investigated. Two possible interference mechanisms have been studied under greenhouse conditions: competition and allelopathic effects of green foxtail on apple seedling growth.

Inhibition of apple seedling growth by green foxtail was recorded only in interference experiments where competition for water or nutrients was a present factor. No inhibition was detected when competition was removed or minimized in an hydroponic system. The incorporation of green foxtail root debris into soil mixture did not result in inhibition of apple growth. Thus, competition for water was the most likely reason for inhibition of apple seedling growth by green foxtail.

The presence of green foxtail did not affect dry matter distribution in apple seedlings when water and nutrients were equally available to both plants. Studies of allometric parameters anatomical indices suggested that green foxtail roots did not release any allelopathic chemicals.

Green foxtail might be used as cover crop in apple orchards when competition for water and nutrients is minimized. Elimination of competition is a difficult and expensive task and is often impossible in the field. However, the reduction of competition can be made by using strip herbicidal treatment in the tree rows.

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INTRODUCTION

For centuries, animal manures and leguminous cover crops and crop rotation have been the principal methods of maintaining soil fertility. In recent years, manure has not been extensively utilized in many places in the world because of scarcity and cost. Under such conditions, deterioration of the soil structure has been observed and leaf symptoms indicate deficient nutritional status (Rogers and Raptopoulos, 1945). Some of the nutritional and structural soil problems can be minimized by utilizing organic matter and a balanced inorganic fertilizer program.

Organic matter content plays a critical role in providing an optimum soil environment for plants. Organic matter is of particular importance in relation to soil structure. The breakdown of soil structure is often causally related to organic matter depletion (Haynes, 1980). Organic matter favors microbial activities, mainly because of the high energy supply, and increases soil microbe and earthworm populations, which improve soil stability (Russell, 1973; Oades, 1978). Hence, the incorporation of organic matter results in a friable, stable well-structured and less compact soil, with adequate aeration and improved water retention and infiltration capacities, providing better conditions for plant growth (Rogers et al., 1948; Hardisty, 1966; Childers, 1973).

One of the most interesting sources of organic matter which can partially replace animal manures are cover crops in fruit plantations. Cover crops are widely advocated as a source of organic matter and available nutrients and also as a means to increase water infiltration (Rutherford, 1944) and to reduce soil erosion (Mech, 1959; Kemper and Derpsch, 1981), compaction (Rogers et al., 1948) and leaching of nutrients (Haynes, 1981). Cover crops also influence environment (Rogers et al., 1948; Hamer, 1975) and provide an adequate surface for orchard equipment.

Various cover crop species have been investigated to determine their compatibility with usual orchard operations such as spraying, pruning and harvesting. All cover crops tested caused an increase in the percentage of organic matter in the upper layer of soil when compared with clean cultivation (Rogers and Raptopoulos, 1945).

The effects of cover crops on soil moisture are well known. Cover crops deplete moisture during the growing season, but if killed by fall frosts, they act as a mulch in the late fall and spring to conserve moisture. If the cover crop is not killed by frost, water loss can occur on warm winter days and in early spring; also, a vigorous growth starts in spring and further depletion of moisture may occur. In addition, cover crops protect soil from extreme temperature fluctuations; they may prevent severe freezing of soil, low soil temperatures in the spring (Oskamp, 1920), and reduce the depth of frost penetration (Cooper, 1973).

The cover crop may be beneficial or detrimental according to the species and the growing period. Reported beneficial effects of the cover crop include improvement of fruit color, reduced preharvest fruit drop, correction of certain mineral deficiencies (Rogers and Raptopoulos, 1945) and provision of an adequate floor surface for orchard equipment (Scheer and Juergenson, 1964). The detrimental effect of grass on fruit trees varies with the species and the period in the life cycle of the tree when it is planted. Young trees are more adversely affected than fully mature specimens which contain large quantities of reserves and extensive root systems (Howard, 1925). Autumn or spring cover crops can add significantly to soil organic matter without restricting the growth of mature apple trees. However, summer cover crops are more likely to complete with the trees than autumn and spring cover crops (Rogers and Raptopoulos, 1945); the presence of a cover crop without added nitrogen may restrict tree growth (Hoblyn and Bane, 1934) and it increases water requirement.

Many methods have been used to estimate the growth of fruit trees. The principal method has been the standard measurement of trunk diameter at a marked height. Among other methods, pruning weights, leaf appearance and color, defoliation, time of blossoming, picked and dropped fruit and finally, fruit size, have been used (Rogers et al., 1948). Trunk diameter measurements showed that the trees with grass and grass plus legumes cover crops made less than half the growth of those in clean cultivated plots; those in the legumes plots made about two-thirds the growth of those in the clean cultivated ones. The trees in weedy plots made significantly less growth than in clean cultivated plots but significantly more growth than in the cover crop plots. Grass cover crops caused the greatest growth reduction while the effect of legumes was broader in both respects (Rogers and Raptopoulos, 1945).

The green foxtail exhibits competitive effects, is a summer annual grass, and one of the world's most common weeds. It is thought to have originated in Europe and is prevalent in other parts of the world

(Holm et al., 1977). Seeds exhibit complete or near complete dormancy when freshly harvested. This dormancy can be overcome by storing at 6°C for 3 to 6 weeks. The optimum germination temperature is above 25°C. Although some seedlings emerge later in the season (July), they still produce seeds during the same season (Vanden Born, 1971). Moreover, green foxtail population density increases every year because of the tremendous number of seeds produced/plant (Vanden Born, 1971).

Green foxtail is considered a serious weed in barley (*Hordeum vulgare* L.), corn (*Zea mays* L.), beans (*Phaseolus vulgaris* L.) soybeans (*Glycine max* L.), sugarbeets (*Beta vulgaris* L.), and sunflowers (*Helianthus annuus* L.) in North America; sugarbeets, cotton (*Gossypium hirsutum* L.) and corn in Europe; and carrots (*Daucus carota* L.), sugarbeets, rice (*Oryza sativa* L.) and sunflowers in Asia. Green foxtail is considered a common weed in vineyards, orchards and irrigated crops (Holm et al., 1977).

Green foxtail inteference was estimated to reduce corn yield by 5.6 to 17.6 percent with a density of 20 to 56 plants/m^2, respectively (Sibuga and Baudeen, 1980). Studies conducted by Blackshaw et al. (1981) showed that grain yield losses caused by green foxtail competition were variable, ranging from 21 to 67 percent when the green foxtail density increased from 100 to 1,600 plants/m^2.

This reduction in yield and growth is due to a general phenomenon called interference between species (Harper, 1961). The term interference has two components (Muller, 1969). The first was clearly recognized as competition, in terms which have since been improved: "In the exact sense, two plants, no matter how close, do not compete with each other as long as the water content, the nutrient material, the light and heat are in excess of the needs of both. When the immediate supply of a single necessary factor falls below the combined demands of the plants, competition begins" (Clements, 1907). The second concept was developed from DeCandolle's view of plants at war which is a fitting analogy for secretion of metabolic products into the environment. DeCandolle (1820, 1832) cited in Clements et al. (1929) suspected that plants released toxic materials into soils.

Since that time, more work has been done in order to confirm this second concept. Bedford and Pickering (1919) found an inhibition of apple growth by grass. They hypothesized that an allelopathic effect was the most likely explanation for this phenomenon. Similar effects were described by Grummer in 1961. Moreover, Bonner and Galston (1944) showed that an inhibitor, trans-cinnamic acid, accumulated in the culture medium and interfered with the growth of apple seedlings. Many examples show the secretion and accumulation of metabolic products that are identifiable as specific phytotoxins (Winter, 1961). Although it is true that higher plants do not have to absorb organic substances from the soil for normal development, it cannot be overlooked that some organic substances are taken up, thus plants may show specific responses to these substances (Winter, 1961). Allelopathy has been clearly shown in native habitats and between specific cultivated plants (Winter, 1961).

This study describes experiments to test the suitability and the value of green foxtail as a cover crop in orchards. Based on its physiology and morphology, green foxtail may be a good cover crop for irrigated fruit orchards. It can produce large amounts of organic matter during a short summer period, and provide a mulch during the rest of the year. It has the added advantage of self-reseeding, and is killed by the first fall frost. However, the extent of its competition with, or allelopathic effect upon, orchard trees is not known. So this present study considered the potential inhibitory effect of green foxtail on the growth of apple seedlings.

LITERATURE REVIEW

Many different systems of soil management have been applied in fruit tree production, but three major systems merit special consideration. One of these is sod culture, where the grass grown in the orchard is mowed and left behind as a mulch. A seonc system involves control of weeds over the entire orchard floor either through cultivation or use of herbicides, and consists of keeping the soil as free of weeds as practically possible. The third major system is a combination of the first two. Each method has its advantages and disadvantages, and it is difficult to predict which method, under certain environmental and edaphic conditions, will give the best results.

No one cultural program can be recommended for all orchards. A program that is satisfactory for one orchard under one set of climatic and soil conditions may be unsatisfactory for another under a different set of conditions. For instance, on steep land, it is unwise to perform any type of cultivation, but the use of herbicides about the base of each tree is acceptable. One of the better soil management systems for steep land is in permanent sod culture, or a combination of a cover crop and herbicides.

The effect of clean cultivation, cover crops and herbicides on orchard soils and trees have been investigated (Rogers et al., 1948; Atkinson and White, 1976). The methods of elimination of vegetation from the orchard floor, cultivation and herbicidal treatments, have highly significant effects on soil structure and tree growth.

Cultivation decreased moisture retention properties, water stable aggregates, and habitat for earthworms. One of the major problems with cultivation in orchards is the formation of a hard pan which interferes with water movement and other processes (Arkin and Taylor, 1981). However, cultivation also led to an increase in total porosity, macroporosity and water infiltration capacity. Herbicidal treatments can cause compaction of surface soil, formation of a massive but stable structure with decreased infiltration capacity and moisture retention properties, and provide unfavorable conditions for earthworms (Rogers et al., 1948; Haynes, 1981).

Cover crops provide a well-structured soil with a high density of earthworms (Haynes, 1981). The most stable aggregates, less compact soil with improved aeration and water retention capacity, but the soil under grass loss water more quickly than under cultivation due to competition and transpiration from the grass (Rogers et al., 1948).

As early as 1919, Bedford and Pickering (1919) concluded that grass affected fruit trees and that tree vigor was related to the grass rooting system. Later Rogers et al. (1948) demonstrated that tree performance was inversely related to grass vigor. Trees under sod culture were smaller than those under clean cultivation. This reduction in growth, vigor, and yield was largely due to competition for nutrients (Bolland, 1957) and water (Rogers and Raptopoulos, 1945). In general, herbicidal treatments increase the growth of trees in comparison with sod culture (Atkinson and White, 1976); this increased growth in response to herbicides has been attributed to elimination of grass or weed competition.

The most suitable system of orchard floor management for any particular area depends largely on soil type, amount of precipitation, topography and certain other factors. The goals of any orchard floor management system are to increase or at least maintain the organic matter content of soil, to conserve moisture, prevent water run-off, soil erosion and to maintain adequate fertility. Optimum soil management contributes to maximum production of a large quantity of quality fruit at a minimum cost.

Campbell (1978) pointed out that grass root provide large amounts of dry matter for slow steady decomposition throughout the soil volume which their roots penetrate. Soil management practices influence the moisture availability in two major ways. The first is the effect on the rate at which moisture is absorbed by soil and the capacity of soil to hold absorbed moisture. When irrigation is available, grass sod might increase moisture storage efficiency through decreased run-off (Toenjes, 1941; Kenworthy, 1953). However, water use is increased when a cover crop is present due to grass growth and transpiration.

Norware Berg, Chief of the Soil Conservation Service, said, "Enough soil goes into the Mississippi River in one year to build an island a mile long, a quarter of a mile wide, and 200 feet in length. Such an island would contain the equivalent of 808 railroad carloads of phosphorus, 21.121 carloads of potassium, 291,411 carloads of calcium, and 67,270 carloads of magnesium" (Peterson, 1982). Soil erosion can result in a rapid decline in productivity. Cover crops reduce erosion on slopes subjected to water run-off, especially on sandy soils where wind and water erosion of soil are most severe. Cover crops increase water penetration, thus reducing run-off and their roots tend to increase water holding capacity of these soils (Scheer and Juergenson, 1964).

The improvement of soil fertility by cover crops is well known. It has been established that a legume cover crop can contribute up to 100 lbs of nitrogen per acre (Hardisty, 1966).

Trees from orchards where a permanent sward is established are usually smaller and general tree growth and vigor, trunk increment and fruit yield are reduced (Bollard, 1957; Goode and Hyryez, 1976). This restriction is due to competition for nutrients and water (Rogers and Raptopoulos, 1945; Bollard, 1957; White and Holloway, 1967; Goode and Hyrycz, 1976; Atkinson and Ferre, 1977). However, cover crops are not always detrimental; mowing of cover crops often results in the formation of more fruit spurs (Miles, 1958), there is less tendency to biennial bearing (Rieniazek and Slwik, 1962), there is a marked reduction of pre-harvest drop (Rogers and Raptopoulos, 1945), and highly-colored fruit of good quality results (Hardisty, 1966). Fisher et al. (1961) and Toenjes (1941) found that over a long term the trees under grass sod were as large as those from other treatments.

Moreover, the presence or absence of a cover drop may affect temperatures above and below the soil surface. Soil temperature at ten centimeters was consistently different under a ground cover from bare ground. The differences varied as a function of weather and direct exposure to sun ranging from no difference to as much as 12°C higher than ambient temperature (Eakes and Dawson, 1979). During summer, soil temperatures were generally lower under cover crop and mulch than in the arable treaments. Cover crops reduce the depth of frost penetration in comparison with arable treatments (Toenjes, 1941).

Agricultural activities modify the distribution of soil microbes, earthworms, and roots. Generally, the density of earthworms has been shown to be higher in grassed than in cultivated apple orchards (Satchell, 1967; Tisdall, 1978). The root growth of a fruit tree may be modified by soil management practices. Coker (1959) showed that under cultivation apple roots growing upward had been pruned; however, trees in grass had a more branched root habit and more fibrous roots. In addition, Bini (1963) found that mowing favored the superficial development of a more finely ramified peach root system. Weller (1966) showed a similar trend in the vertical distribution of the roots of apple varieties under cultivation or grass.

Although the beneficial effect of mowing on the growth of the tree root is apparent, root growth in the upper 20 cm of soil is inhibited by a cover crop (Atkinson and White, 1976). The influence of higher plants upon one another cannot be attributed only to competition for nutrients, water, and light. Biochemical interaction between plants may result from metabolic products which are exceeded or remain in the soil as residues of decaying material.

DeCandolle (1832) suggested that root exudates of certain weeds cause injury to some crop plants and that the "soil sickness" might be due to exudates of crop plants. Livingston (1905) indicated that the failure of non-bog plants to grow in peat bogs is due to chemical substances that act as inhibitors. Moreover, early experiments of Bedford and Pickering (1919) indicated that the inhibiting effect of grass on tree growth was due to some toxic influence of grass on the trees. Lyon and Wilson (1921) demonstrated that roots of several crop plants exuded large amounts of organic compounds that were taken up by adjacent plants. Kacaraca (1961) also reported that root exudates of grass decreased growth of forest apple and wild pear (*Pyrus communis* L.) seedlings. Bergamimi (1967) found that the growth, height, and trunk girth increase of peach (*Prunus persica* L.) seedlings in containers was retarded by adding ground roots of clover (*Trifolium incarnatum* L.) to the soil and more markedly with similarly treated alfalfa (*Medicago sativa* L.) roots. Bell and Koeppe (1972) indicated that exudates of mature giant foxtail (*Setaria faberii* Herrm.) roots and leachates of giant foxtail whole plant residue significantly inhibited growth in height, accumulation of dry weight and fresh weight of corn. Croak (1972) showed that ferulic acid affects the rate of depletion of four micronutrients and three macronutrients from a medium containing suspension cultures of Paul's scarlet rose (*Rasa hybrida* Bailey) cells.

Green foxtail is an annual grass that produces abundant seeds and is a native of Europe. Primarily a weed of the temperate zone, it is sometimes found in the cooler subtropics, usually at higher elevations. It may be seen that green foxtail is a major weed of the world's temperate zones. This species is a major weed of cereals and vegetables (Holm et al., 1977). In addition to competing directly with crop plants, green foxtail also causes abnormal or disrupted growth in cabbage (*Brassica oleracea* L.) and tomato (*Lycopersicon esculentum* Miu.) roots (Retig et al., 1972). They postulated that the effect was caused by diffusible compounds from green foxtail seedlings.

METHODS AND MATERIALS

The objective of this study was to clarify the interactions between apple seedlings and green foxtail when grown together. The primary purpose of these experiments was to determine the degree of interference or allelopathy between these two plants under greenhouse conditions. For that, three types of experiments were conducted. The first was designed to study the degree of interference between green foxtail and apple seedlings. The second involved leaching of dried green foxtail root samples spread over the soil surface in pots containing apple seedlings. In the third, the dead green foxtail roots were incorporated into the soil and growth of apple seedlings in this soil was investigated. The fourth experiment involved the use of a hydroponic system to eliminate competition for water and minimize competition for nutrients between green foxtail and apple seedlings.

A. Interference Experiments

These experiments were initiated in the greenhouse in the fall of 1982. Seeds of green foxtail were collected from an apple orchard located in Rogers Mesa one year before and were stored dry at room temperature and chilled at 4°C prior to planting. Chilled at 4°C Red King Delicious apple seeds were used in these experiment. These apple seeds were stratified for approximately three months in the refrigerator prior to planting.

Germinated apple seeds were grown in small pots (5 cm diameter, 5 cm depth) containing an equal volume of steamed peat moss and vermiculite. N.P.K. fertilizer (5 grams/pots of 14-14-14) was added one week after planting. Seedlings were transplanted into 20x20x20 cm root view boxes after they reached 35 cm in height. Each box contained four equally spaced apple seedlings. The soil medium was an equal volume of peat moss and vermiculite mixed with the same fertilizer cited above; the amount was about 83 grams/box.

When the apple seedlings were well established, green foxtail seeds were planted at a density of approximately 200 seeds/box. The boxes were irrigated weekly using the same amount of water for the treatments before green foxtail establishment. This amount was equal to four liters; additional water (four liters/week) was added after green foxtail establishment. Control of insects, fungi and weeds was practiced. Measurements of shoot length were begun on February 14, 1982 and taken weekly for 13 weeks. At the end of the experiment, leaf area, stem diameter, stem fresh and dry weight and root fresh and dry weight were taken.

Two other experiments were done in small pots (10 cm diameter) to test the validity of the results and to complete the data missed in the first experiment (leaf area, root weight, stem diameter increment). Green foxtail seeds were planted at a density of 20 seeds/pot. Five grams of 14-14-14 fertilizer were added to each pot. The pots were irrigated weekly using the same amount of water for both treatments. This amount was equal to half of a liter.

The three experiments were in a randomized complete block design with two treatments and with six replications for the first experiment and five replications for the other two treatments.

B. Allelopathy Experiments

1. Incorporation of green foxtail roots

In the first experiment, competition for water was minimized and the possible allelopathic effect of green foxtail examined. Green foxtail was grown in 20x20 cm pots containing an equal volume of peat moss and vermiculite. Five grams of 14-14-14 fertilizer and mist irrigation practices were used. After the plants reached maturity, green foxtail was frozen (in the pots) at -20°C for two days to avoid the water deficit encountered during drying. Roots were dried in an oven at 70°C until they reached a constant weight and were then ground to a fine powder. Dried, ground roots (6.5 g) were incorporated into the soil medium (peat moss and vermiculite); ten grams of 14-14-14 fertilizer were added to each pot. The apple seedlings were transplanted, watered, and kept under intermittent mist irrigation. After establishment of apple seedlings, shoot length measurements were taken weekly for 13 weeks.

Another experiment was done in smaller pots (10 cm diameter) to test the validity of the results obtained in the first experiment and to minimize the effect of organic matter on adsorption of root exudate. A sandy soil was used instead of peat non-vermiculite and 2.5 grams of 14-14-14 fertilizer were used instead of ten grams. Alto two grams of green foxtail roots were used for each pot; the experiment was continued for six weeks. The experimental design was a completely randomized block with five replications and two treatments.

2. Leaching

The second type of experiment consisted of transplanting apple seedlings to pots containing a sandy soil covered by green foxtail roots for the green foxtail treatments.

Green foxtail roots were handled (drying and grinding) in the same way as in the incorporation experiment. Two grams of dried ground green foxtail roots were used per pot (10 cm diameter) to mulch the soil; 2.5 grams of 14-14-14 fertilizer were added to each pot; after initial watering, the plants were placed under intermittent mist irrigation. The experimental design was a completely randomized block with five replications and two treatments. After the apple seedlings were established, shoot length measurements were taken weekly for six weeks.

C. Hydroponic Experiments

The third type of experiment involved a hydroponic system: the main objective was to eliminate competition for water and minimize competition for nutrients.

Apple seedlings were grown for approximately four months in pots containing peat moss and vermiculite. Uniform plants were selected and cut off at about ten centimeter height; roots were rinsed free of the growing medium. The stems were inserted into slits cut in a stryofoam cover which covered the container. Each container (15x15x20 cm) contained one apple seedling. The experimental design was a completely randomized block with five replications and two treatments.

The experiment was carried out with the nutrient solution used by Gergely et al. in 1980 (Table 1). The nutrient solutions were aerated continuously and changed weekly to avoid water, nutrient deficiency and microbial effects. Water was replenished as needed to replace that lost by evapotranspiration.

Green foxtail was seeded in pots (5 cm diameter) which were placed on the styrofoam cover; about 20 green foxtail seeds were placed

Table 1. Nutrient solution used in hydroponic system to grow apple seedlings and green foxtail under greenhouse conditions during the spring of 1983.

	Stock solution (g/L)	mM/L	g/100L	mℓ Sol*/100L
A. Macronutrients				
KNO_3	101.1	1.3	12.6	125.0
KH_2PO_4	136.0	1.3	17.0	125.0
$Ca(NO_3)_2$	182.1	2.5	45.5	250.0
$CaCl_2$	111.0	1.4	15.3	137.5
$MgSO_4$	120.4	1.9	22.6	187.5

	Stock Solution	ppm	mℓ Sol*/100L
B. Micronutrients			
Fe(NaFeEDTA)	32.8	5.8	116.0
$B(H_3BO_3)$	6.7	0.6	50.0
$Cu(CuSO_4 \cdot 5H_2O)$	1.9	0.2	50.0
$Zn(ZnSO_4 \cdot 7H_2O)$	4.4	0.5	50.0
$Mn(MnSO_4 \cdot H_2O)$	3.1	0.5	50.0
$Mo(H_2MoO_4)$	1.5	0.5	50.0

*mℓSol = milliliters of stock solution.

in each pot. Thus, each replication contained one apple seedling and about 120 green foxtail seeds for green foxtail treatments and one apple seedling alone for the other treatments.

D. Measurements

1. Apple seedling vigor

The vigor of a tree can be estimated in several ways. Hoblyn and Bane (1934) as well as others, concluded that no single measure is ever sufficient to describe the vigor of a particular seedling. For these reasons, the following measurements were used to evaluate the vigor of apple seedlings in these experiments.

a. Stem diameter

Stem diameter measurements are of value, but have inherent limitations because of stem eccentricity. However, trunk diameter of mature trees is considered to be one of the best estimates of vigor of fruit trees under orchard conditions (Rogers and Raptopoulos, 1945). The measurements of stem diameter were taken at three centimeters above the soil surface.

b. Stem length

The best measure of vegetative growth of apple seedlings is generally considered to be stem length. Moreover, it is considered the easiest measurement with minimal errors, at least in these experiments, because all secondary shoots from the principal axis were suppressed (Blake et al., 1937). The length of each apple seedling stem was measured weekly.

c. Weight of stems, leaves and roots

Fresh and dry weight of tissue produced are also considered to be good measurements of growth (Evans, 1972). At the end of the experiment, the roots were washed, surface dried and weighed after a constant weight was obtained in an oven at 70°C. The dry weight of leaves and stems were obtained in the same manner. The fresh weight of leaves and stems were also recorded.

d. Leaf area

At the end of each experiment, the total leaf area was measured using a leaf area meter (LAMBDA Inst. Corp., Model LI-3100).

e. Root development

The length of apple seedling roots either with or without green foxtail and green foxtail root was estimated. Test equipment consisted of hand tally counter and transparencies of 1x1 cm grid squares. For length estimates the grid was placed on the side of the box. The roots were drawn on that transparency. Counts of the intercepts of the roots with the vertical and horizontal grid lines were made and accumulated on the hand tally counter, then converted to length measurements using the modified formula inclusive of the grid unit (Tennant, 1975).

f. Allometric parameters

The allometric parameters used for this study were specific leaf area, leaf weight ratio and leaf area ratio. The specific leaf area was obtained by dividing the total leaf surface area by its dry weight. The leaf area ratio was calculated by dividing the total leaf surface area by the total plant dry weight.

g. Anatomical indices

The determination of fresh weight of the various organs of apple seedlings grown under different experimental conditions as a function of dry weight could yield much interesting information, relevant to problems of plant development, suggesting convections with the morphological and anatomical state of these various organs. The determination of these anatomical indices was calculated by dividing the organ fresh weight by its dry weight.

2. Elemental analysis

The nutritional effect of green foxtail on apple seedlings was evaluated by leaf analysis and soil analysis.

a. Leaf analysis

The five upper mature and the five lower leaves of each plant from both treatments were taken from apple seedlings; these were washed to remove accumulated pesticide residue. Clean leaves were dried in an oven at 70°C and four composite samples were transferred to the CSU Soil Testing Laboratory and analyzed for nutrient content (N, P, K, Mg, Zn, Ca, Mn, Cu, B, Na, Fe) in May 1982. The total nitrogen content was determined using Kjeldahl digestion and the ammonium in the digest was determined using an automated salicylate calorimetric method (Nelson and Sommers, 1980). The other elements were determined using a nitric acid plant tissue digest method for use with inductively coupled plasma spectrometry (Havlin and Soltanpour, 1980).

b. Soil analysis

Soil samples were taken with an ordinary soil auger in May 1982 from each box. All samples were mixed into three representative composite samples. The samples were dried and brought to the CSU Soil Testing Laboratory and analyzed for nutrient content (N, P, K, Zn, Mn, Cu, Fe), pH, organic matter and type of soil. The method used to evaluate the fertility of soil was routine test (Soltanpour and Workman, 1981).

RESULTS AND DISCUSSION

A. Interference Experiments

1. Apple seedling vigor

The measurements shown in Tables 2a, 2b and 2c represent the response of apple seedlings to green foxtail. Tables 2a, 2b and 2c indicate that green foxtail significantly depressed vigor of apple seedlings. The magnitude of this effect varied with the density and time of green foxtail seeding relative to the time of apple seedling transplanting density. Apple seedlings grown in association with green foxtail had shorter shoots, less stem diameter increment, less stem weight and less root weight than when grown alone (Tables 2a, 2b, 2c; Figure 1; Table 10). This poor growth of apple seedlings when grown with green foxtail, coupled with the appearance of yellow and purple colored leaves, indicated that they might be suffering from nitrogen or phosphorus deficiency. If this were the case, green foxtail was more efficient than apple seedlings in removal of relatively immobile phosphorus or perhaps phosphorus uptake was blocked by an allelopathic substance released by green foxtail roots. The purple color could also have been the result of arrested metabolism in young apple leaves. It has been shown that when growth is arrested, phenols may accumulate in young leaves, giving them a purple color (Siegelman, 1964; Sarapuu, 1964; Thimann and Edmondsen, 1948). So visual symptoms are not usually a reliable indication of mineral deficiencies as

Table 2a. The effect of green foxtail on apple seedling growth under greenhouse conditions during the spring of 1982.

Growth Parameters	Treatment* With green foxtail	Without green foxtail	Reduction** (%)
Length (cm)	59.8a	81.1b	26.2
Stem fresh weight (g)	123.5a	164.8b	25.0
Stem dry weight (g)	46.8a	74.4b	37.1
Root fresh weight (g)	199.9a	221.7b	9.8
Root dry weight (g)	49.1a	61.3b	19.9

*Means in a row followed by the same letter were not significantly different at p = 0.05.

**Reduction % = $\frac{\text{Without green foxtail-with green foxtail}}{\text{Without green foxtail}}$ X 100

Table 2b. The effect of green foxtail on apple seedling growth under greenhouse conditions during the spring of 1982.

Growth Parameters	Treatment* With green foxtail	Treatment* Without green foxtail	Reduction (%)
Leaf area (cm^2)	106.2a	303.2b	64.9
Length (cm)	14.0a	22.8b	38.5
Stem fresh weight (g)	1.8a	6.1b	70.4
Stem dry weight (g)	0.6a	2.0b	70.0
Root fresh weight (g)	1.4a	4.5b	68.8
Root dry weight (g)	0.7a	2.9b	75.8

*Means in a row followed by the same letter were not significantly different at $p = 0.05$.

Table 2c. The effect of green foxtail on apple seedling growth under greenhouse conditions during the spring of 1983.

Growth Parameters	Treatment* With green foxtail	Without green foxtail	Reduction (%)
Length (cm)	28.5a	49.4b	42
Diameter increase (mm)	1.0a	2.3b	56
Leaf area (cm^2)	325.6a	619.9b	47
Leaf fresh weight (g)	5.8a	12.2b	52
Leaf dry weight (g)	1.8a	4.4b	59
Stem fresh weight (g)	4.2a	10.0b	58
Stem dry weight (g)	1.7a	3.8b	55

*Means in a row followed by the same letter were not significantly different at $p = 0.05$.

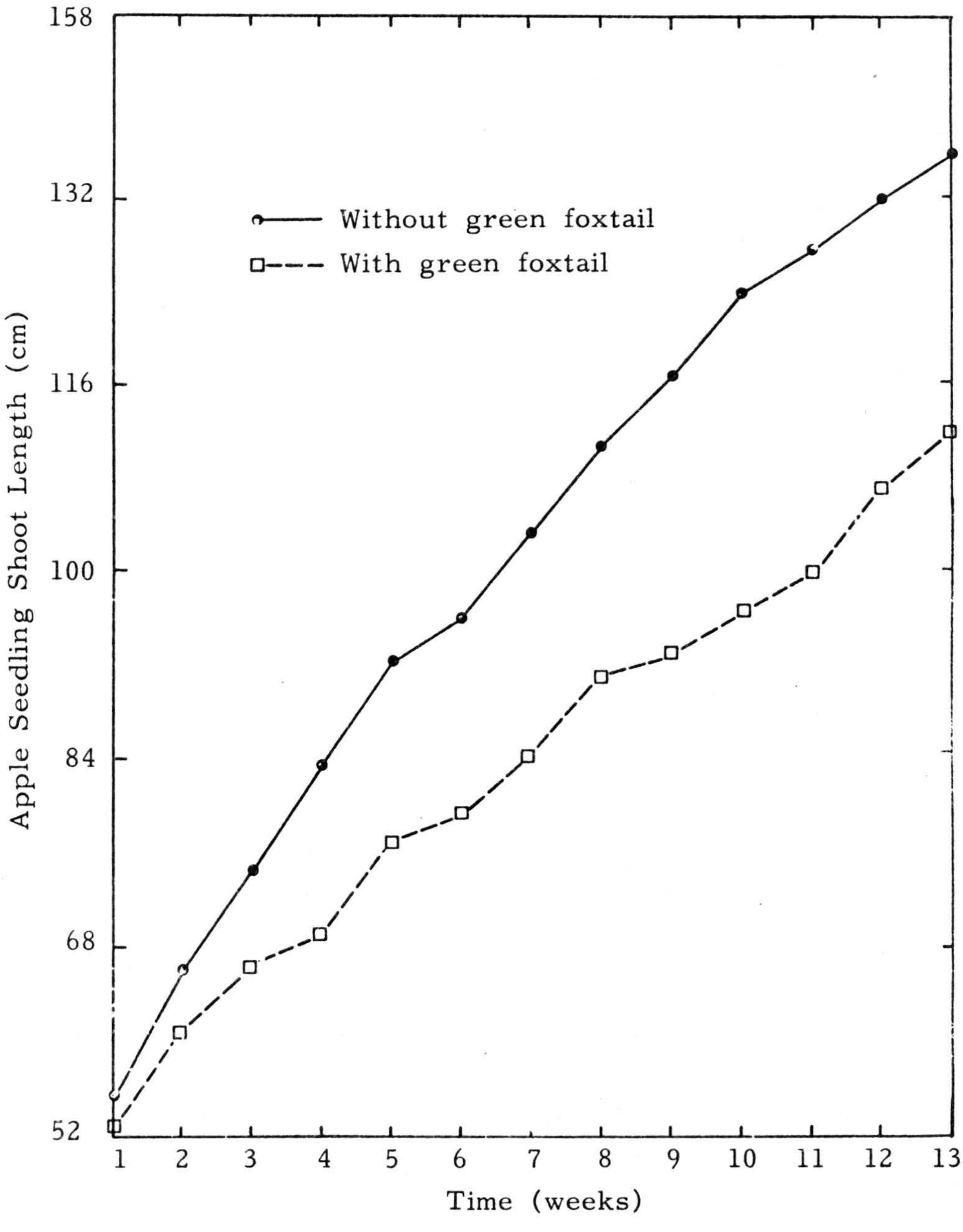

Fig. 1. Effect of green foxtail on apple seedling shoot growth (interference).

their expression is affected by environmental factors. Soil and plant tissue analysis are more reliable indicators of the mineral status of plants.

2. Soil analysis

Soil analysis showed an increase in pH and phosphorus and potassium content when green foxtail was associated with apple seedlings (Table 3). The data for nitrogen showed that soil from pots with green foxtail had a higher nitrogen level than that containing apple seedlings alone (Table 3). The high level of phosphorus and potassium might be due to the recycling effect of these elements by grass (Wallace, 1953; Montgomery and Wilkinson, 1962). The high nitrogen level might be due to a lower requirement of green foxtail for this element.

Soil analysis indicated two important characteristics: low pH (5.2) and high organic matter content (35%) (Table 3). Bailey and White (1964) found that adsorption of organic molecules from soil increased as pH decreased. Also, organic matter fixes organic molecules (Burs, 1972). Thus, even if green foxtail roots were exuding allelopathic compounds, they were not likely to be phytotoxic because of inactivation by adsorption.

3. Leaf analysis

The nitrogen content of mature apple seedling leaves, grown with green foxtail was almost similar to the leaves from other treatments (Table 4). The nitrogen content of young apple leaves grown with green foxtail was higher than the leaves from other treatments (Table 4). The presence of green foxtail did not affect the phosphorus content of the young apple seedling leaves. There was no effect on

Table 3. Analysis* of soil from the boxes in which apple seedlings and green foxtail were grown together or alone in the greenhouse during the spring of 1982 (composite samples).

Element	Treatment: Apple alone	Treatment: Green foxtail alone	Treatment: Apple with green foxtail
Nitrogen-NO_3	928.6	1496.6	1248.6
Nitrogen-NH_4	566.6	1160.0	533.3
Phosphorus	458.3	625.7	499.0
Potassium	1536.6	2232.0	1746.0
Zinc	14.9	9.7	12.0
Iron	235.6	227.6	167.0
Manganese	32.2	29.8	36.5
Copper	3.0	2.6	2.7
pH	4.8	4.8	5.2
Organic matter	36	39	35

*Analyzed at CSU Soil Testing Laboratory. The statistical analysis was not possible because of one composite sample.

Table 4. Analysis*of apple seedling leaves from the lower and the upper part of the seedlings grown under greenhouse conditions during the spring of 1982 (composite samples).

	Apple alone		Apple with green foxtail	
Elements	Old leaves	Young leaves	Old leaves	Young leaves
Nitrogen (%)	2.7	3.6	2.9	4.3
Phosphorus (%)	0.3	0.3	0.3	0.4
Potassium (%)	2.0	2.0	2.0	2.0
Magnesium (%)	0.3	0.2	0.4	0.2
Zinc (ppm)	38.6	26.3	34.0	34.6
Manganese (ppm)	281.0	66.6	282.0	78.6
Copper (ppm)	2.3	2.6	3.0	1.0
Boron (ppm)	29.0	34.0	29.0	36.0
Iron (ppm)	144.6	68.3	177.3	54.0

*Analyzed at CSU Soil Testing Laboratory.

apple leaf potassium content (Table 4). Since the leaf mineral status of apple seedlings grown with green foxtail was equal or superior to that of apple seedlings grown without green foxtail, the observed discoloration was not caused by mineral deficiencies; it might be due to other factors not detectable by this analysis.

B. Allelopathy Experiments

Green foxtail used either as a mulch or incorporated into the soil did not affect apple growth (Tables 5, 6 and 7; Figures 2, 3 and 4). The previous interference experiments were not specifically designed to test for possible allelopathic effects of green foxtail on apple seedlings because of high soil organic matter content. On the other hand, the allelopathy experiments involving leaching or mixing of green foxtail roots were designed to minimize adsorption or inactivation of any potential allelopathic compounds. Also, competition for water between living green foxtail and apple seedlings was eliminated by the use of dead green foxtail root debris. Leachate or root debris in soil did not inhibit growth of apple seedlings indicating that either the green foxtail debris did not release phytotoxic compounds to the soil, or these compounds were ineffective or inactivated.

C. Hydroponic Experiments

Green foxtail did not affect apple growth (Table 8; Figure 5). However, the yellow and purple color of upper new growing leaves indicated a possible effect on apple nutrition. Although the same visual symptoms were observed in these experiments as in the interference study, no inhibition of apple seedling vigor was shown. Also, leaf analysis showed that apple leaves for both treatments did not have any

Table 5. The effect of dead green foxtail root used as a mulch on apple seedling growth parameters under greenhouse conditions during the summer of 1983.

Growth Parameters	Treatment*	
	With leaching	Without leaching
Length (cm)	45.9a	45.3a
Diameter (mm)	2.3a	2.1a
Leaf area (cm^2)	535.8a	539.4a
Stem fresh weight (g)	7.2a	7.5a
Leaf fresh weight (g)	9.8a	10.3a
Root fresh weight (g)	4.1a	5.1a
Stem dry weight (g)	2.7a	2.7a
Leaf dry weight (g)	3.7a	3.6a
Root dry weight (g)	1.6a	1.5a

*Means in a row followed by the same letter were not significantly different at $p = 0.05$.

Table 6. The effect of dead green foxtail roots mixed with peat soil on apple seedling growth.

Growth Parameters	Treatment*	
	With green foxtail	Without green foxtail
Leaf area (cm^2)	2738.9a	2242.6a
Leaf fresh weight (g)	55.9a	44.6a
Leaf dry weight (g)	25.3a	20.8a
Stem fresh weight (g)	70.3a	57.5a
Stem dry weight (g)	24.1a	28.3a
Root fresh weight (g)	35.0a	40.4a
Root dry weight (g)	21.0a	23.6a
Seedling length growth (cm)	85.0a	84.1a
Stem diameter increment (mm)	4.9a	4.3a

*Means in a row followed by the same letter were not significantly different at p = 0.05.

Table 7. The effect of dead green foxtail root mixed with sandy soil on apple seedling growth.

Growth Parameters	Treatment* With green foxtail	Treatment* Without green foxtail
Length (cm)	39.0a	45.3a
Diameter increment (mm)	1.7a	2.1a
Leaf area (cm^2)	516.6a	539.4a
Stem fresh weight (g)	5.8a	7.5a
Leaf fresh weight (g)	9.2a	10.3a
Root fresh weight (g)	3.1a	5.1b
Stem dry weight (g)	2.7a	2.2a
Leaf dry weight (g)	3.5a	3.6a
Root dry weight (g)	1.3a	1.5a

*Means in a row followed by the same letter were not significantly different at $p = 0.05$.

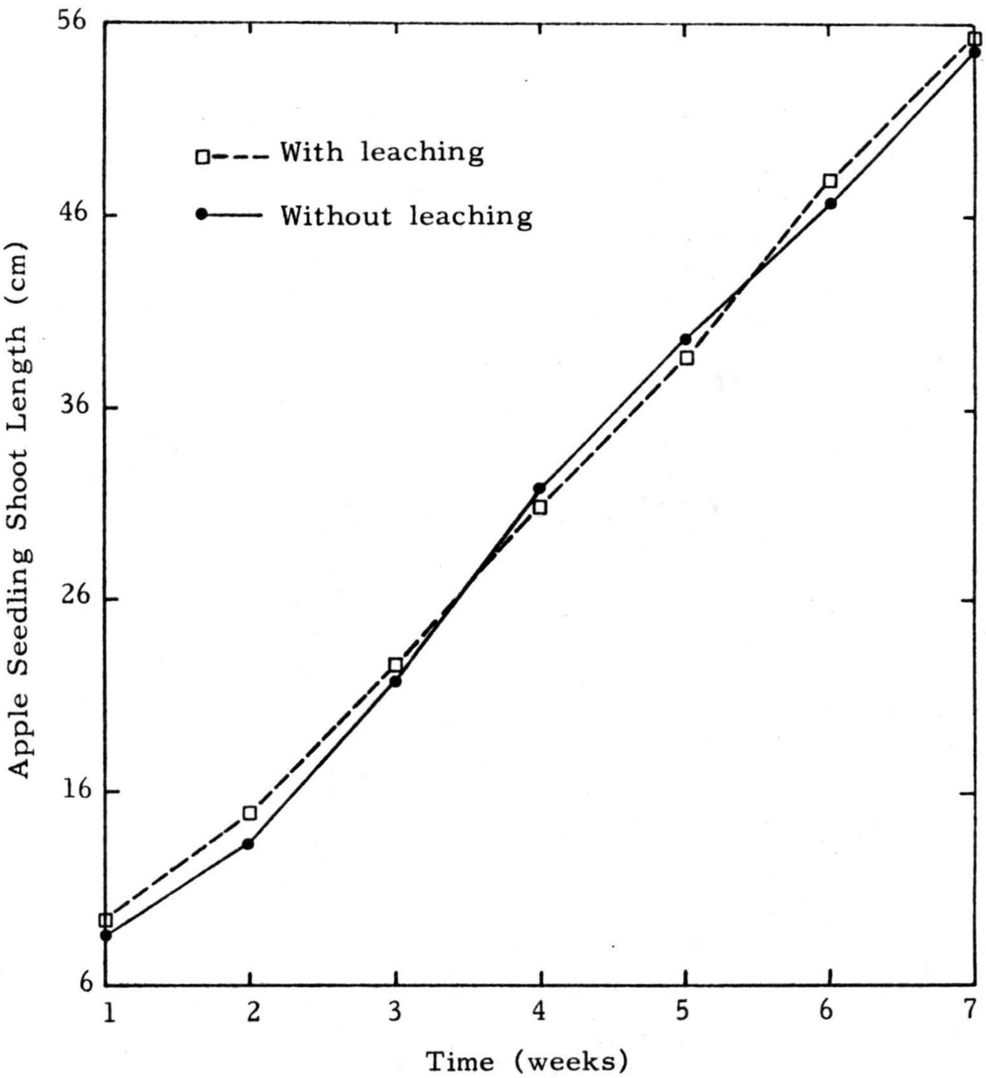

Fig. 2. Effect of green foxtail on apple seedling shoot growth (leaching).

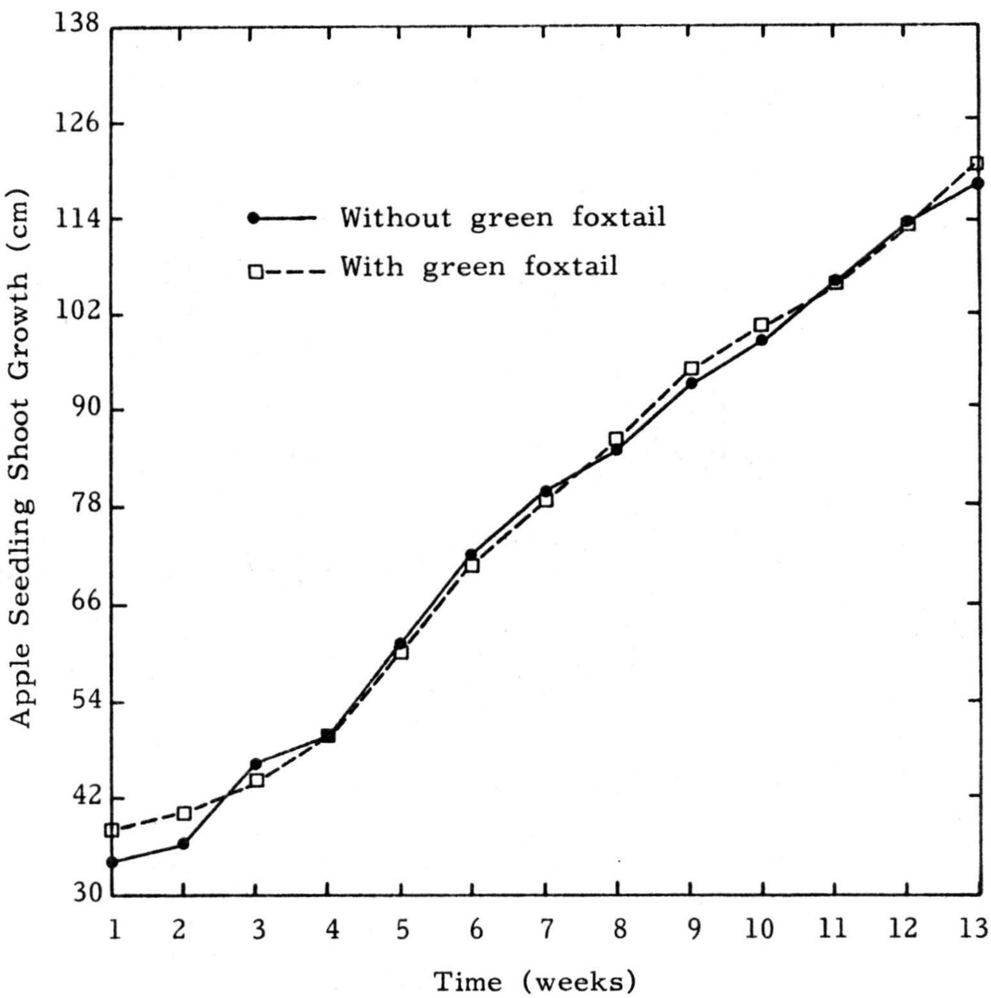

Fig. 3. Effect of green foxtail on apple seedling shoot growth.

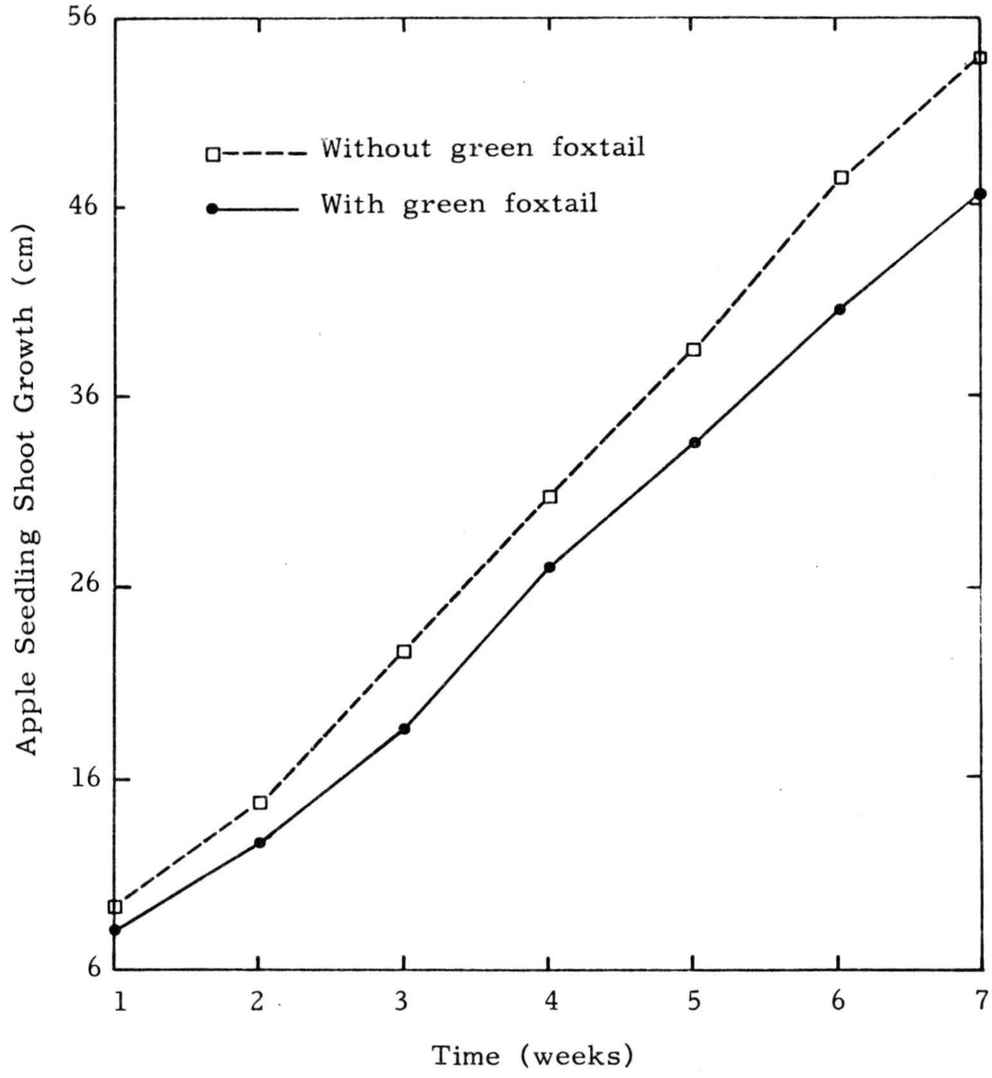

Fig. 4. Effect of green foxtail on apple seedling shoot growth.

Table 8. The effect of green foxtail on apple seedling growth.

Growth Parameters	Treatment* With green foxtail	Treatment* Without green foxtail
Leaf area (cm^2)	2825.0	2797.7
Leaf fresh weight (g)	58.9	60.0
Stem fresh weight (g)	52.1	56.4
Root fresh weight (g)	44.2	52.0
Leaf dry weight (g)	27.8	27.0
Stem dry weight (g)	25.2	25.7
Root dry weight (g)	6.9	8.5
Leaf area growth (cm^2)	52.0	51.3
Stem increment (mm)	4.6	4.5
Seedling length (cm)	100.1	103.7

*Means in a row are not significantly different at $p = 0.05$.

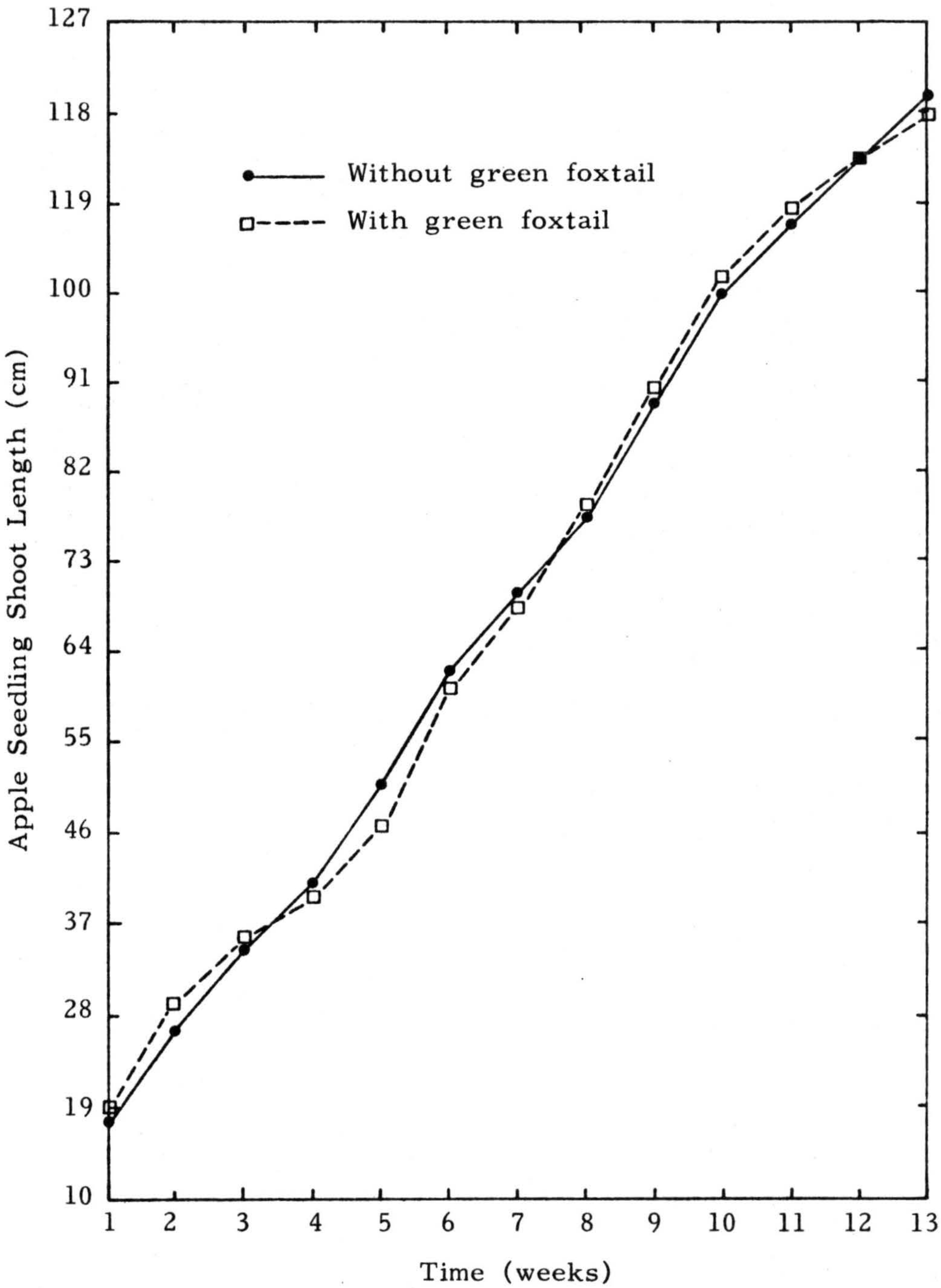

Fig. 5. Effect of green foxtail on apple seedling shoot growth.

nutrient deficiency (Table 9). So, this discoloration could have been due to decreased metabolism, phenol accumulation, or other environmental factors not detectable by this analysis.

D. Root Development

1. Root study

Plant roots may influence the distribution of neighboring root systems and their spatial relationships. These interactions may reflect and influence the intensity of other forms of interference. The present work deals with the problem of the natural relationship between root systems and their pattern of distribution in soil. This relationship may vary with environmental conditions and involves random mixing dependent on environmental conditions (Litav and Harper, 1967). Within this framework, the lengths of apple and green foxtail roots either planted alone or together, were measured using a square centimeter grid (Newman, 1965; Tennant, 1975).

The root systems were distributed randomly with respect to each other within the same soil volume. However, the root length of apple seedlings showed a reduction of 41.3 percent in the presence of green foxtail (Table 10). The root length of green foxtail was not modified by the presence of apple seedlings; green foxtail showed an extensive root system presumably capable of drawing water and nutrients from the soil more effectively than apple seedlings. It is likely that the smaller root system of the apple seedlings made more susceptible to stress. The reduction of the apple seedling root system may have decreased the growth factors supplied to the above ground portion of the plant and competition may result from more rapid growth of green foxtail roots.

Table 9. Analysis* of apple seedling leaves grown in hydroponic system under greenhouse conditions (composite samples).

	Young leaves		Old leaves	
Element	With green foxtail	Without green foxtail	With green foxtail	Without green foxtail
Nitrogen (%)	3.5	4.6	1.8	2.5
Phosphorus (%)	0.3	0.4	0.2	0.2
Potassium (%)	1.4	1.5	1.2	1.8
Calcium (%)	0.3	0.5	1.0	1.0
Magnesium (%)	0.2	0.2	0.1	0.2
Zinc (ppm)	23.0	42.0	39.0	47.0
Iron (ppm)	28.0	57.0	37.0	60.0
Manganese (ppm)	43.0	77.0	92.0	93.0
Copper (ppm)	7.0	10.0	6.0	6.0
Boron (ppm)	17.0	18.0	22.0	25.0
Ash (%)	4.9	5.6	4.1	5.5

*Analyzed at CSU Soil Testing Laboratory. The statistical analysis was not possible because of one composite sample.

Table 10. The length* of apple seedling roots measured using a one cm^2 grid at the end of the first interference experiment.

Treatment	Root length (cm)
Foxtail root	177.0
Apple root	109.0
Apple root (with foxtail)	45.0
Foxtail root (with apple)	186.0

*The statistical analysis was not possible because of one replication.

2. Root/shoot ratio

Roots are adapted for absorption and anchorage, and shoots for photosynthesis. The correlation between them is achieved by making one dependent on the other, for supplies of basic food materials required for growth and for some of the hormonal substances that control the utilization of these materials.

The various physiological ties between the root and shoot systems form a complex and highly sensitive control system by which the plant is able to adjust its root to shoot ratio according to the environment in which it is growing. The three major environmental factors influencing the root to shoot ratio are soil moisture, nutrients and light. For apple trees this ratio tends to be remarkably constant for a given set of conditions (Barlow, 1960). This constancy is brought about by a uniform distribution in weight between the shoot and root (Knight, 1934) and implies that the two systems grow at the same rate (Barlow, 1960).

These physiological ties between root and shoot are indicated in Table 11 and show no significant difference between the control and treated plant for all four experiments. Table 11 indicates that the dry weight of roots and shoots was similar for all treatments, so green foxtail did not influence the distribution of photosynthates between the organs. Therefore, green foxtail will not affect the yield of apple trees when competition for water and nutrients is eliminated.

E. Allometric Parameters

1. Specific leaf area

The specific leaf area is the ratio of leaf surface area to the leaf dry weight and represents leaf density. The specific leaf area

Table 11. Root dry weight/shoot dry weight ratio of apple seedlings grown under different experimental conditions with or without green foxtail.

	Treatment*	
Experiment	With green foxtail	Without green foxtail
Interference**	0.8a	1.1a
Leaching	0.2a	0.2a
Mixing	0.2a	0.2a
Hydroponics	0.2a	0.2a

*Means in a row followed by the same letter were not significantly different at $p = 0.05$.

**From Table 2a.

describes the two dimensional dispersion of leaf dry matter which may vary for different reasons.

Leaves grown under different environmental conditions will differ anatomically. Cells may increase differently in size and they may disperse to different degrees with consequent changes in the proportion of air space in the leaf. Varying amounts of material can be deposited in cell walls, or stored within cells, and of course, new cells which have been subjected to the same processes may differ anatomically. It is possible to identify some of these changes by comparing the trends in specific leaf area measurements.

The data showed that green foxtail did not influence the specific leaf area of apple seedlings (Table 12). Since there was no change in leaf density, there was probably no extra accumulation of substances into cells, thus, cell composition was not modified by the presence of green foxtail.

2. Leaf area ratio

The leaf area ratio is the ratio of leaf surface area to the plant dry weight and represents the relative size of the plant's assimilatory apparatus. In a broad sense, the leaf area ratio represents the ratio of photosynthesizing to respiring material within the plant. The leaf area ratio can be obtained directly from the surface area and plant dry weight or indirectly from the product of leaf weight ratio and specific leaf area. Leaf area ratios for apple were calculated with green foxtail and without green foxtail.

Green foxtail did not affect the leaf area ratios of apple seedlings (Table 13). Thus, green foxtail did not interfere with photosynthesis and respiration, as allelopathic agents often do (Rice, 1974).

Table 12. Specific leaf area of apple seedlings grown under different experimental conditions with or without green foxtail.

Experiment	Treatment*	
	With green foxtail	Without green foxtail
Interference**	137.8a	142.1a
Leaching	148.8a	148.6a
Mixing	150.4a	148.6a
Hydroponics	100.9a	103.3a

*Means in a row followed by the same letter were not significantly different at $p = 0.05$.

**From Table 2c.

Table 13. The leaf area ratio of apple seedlings grown under different experimental conditions with or without green foxtail.

Experiment	Treatment*	
	With green foxtail	Without green foxtail
Interference**	81.7a	76.1a
Leaching	69.8a	68.8a
Mixing	75.0a	68.8a
Hydroponic	46.7a	45.2a

*Means in a row followed by the same letter were not significantly different at $p = 0.05$.

**From Table 2c.

3. Leaf weight ratio

The leaf weight ratio is the ratio of leaf dry weight to the plant dry weight and is a measure of plant leafiness. There was no difference between the two treatments, i.e., with or without green foxtail (Table 14). This implies that the photosynthetic organs of apple seedlings, which provide the major part of the production of dry weight, were not influenced by the presence of green foxtail.

F. Anatomical Indices

The vacuolate nature of most plant cells makes the ratio of fresh weight at full turgor a valuable anatomical index. Tissue water content may vary widely depending on the environment in which apple seedlings grow. Green foxtail (as whole living plants or as dried roots) did not influence apple tissue moisture since the anatomical indices were not significantly different at the 5 percent level (Table 15). However, there were some effects on roots (Table 16). This difference was probably due to free water attached to the root system during weighing.

Since the tissue water content was not influenced by the presence of green foxtail, it did not modify apple cell structure, e.g., by making the cell vacuoles bigger or smaller. Thus, growth inhibition observed in the interference experiment was most likely due to water stress.

Table 14. The leaf weight ratio of apple seedlings grown under different experimental conditions with or without green foxtail.

	Treatment*	
Experiment	With green foxtail	Without green foxtail
Interference**	0.6a	0.5a
Leaching	0.5a	0.5a
Mixing	0.5a	0.5a
Hydroponics	0.5a	0.5a

*Means in a row followed by the same letter were not significantly different at $p = 0.05$.

**From Table 2c.

Table 15. Stem fresh weight/dry weight ratio of apple seedlings grown under different experimental conditions with or without green foxtail.

	Treatment*	
Experiment	With green foxtail	Without green foxtail
Interference**	2.5a	2.7a
Leaching	2.7a	2.8a
Mixing	2.7a	2.8a
Hydroponics	2.1a	2.2a

*Means in a row followed by the same letter were not significantly different at $p = 0.05$.

**From Table 2c.

Table 16. Root fresh weight/dry weight ratio of apple seedlings grown under different experimental conditions with or without green foxtail.

	Treatment*	
Experiment	With green foxtail	Without green foxtail
Interference**	4.1a	3.6a
Leaching	2.5a	3.3b
Mixing	2.4a	3.3b
Hydroponics	6.4a	6.5a

*Means in a row followed by the same letter were not significantly different at $p = 0.05$.

**From Table 2a.

CONCLUSION

Growth inhibition of apple seedlings by green foxtail occurred only in experiments where water was limiting. When water stress was eliminated in the hydroponic system, no inhibition of apple seedling growth was observed. This indicates that allelopathy was not responsible for the observed inhibitory effects. Also, leaf and soil analyses did not point to any major mineral deficiencies, so mineral nutrients were probably not limiting.

The evidence obtained from the experiments conducted on the interactions between green foxtail and apple seedlings indicated that competition for water may be responsible for the inhibition of apple growth. Competition for nutrients may have also been involved but it is less likely to be a major factor as mineral indicated high nutritional status of the plants and the soil mix. In areas where water is limiting, the use of green foxtail as a cover crop on the entire orchard floor is not advocated.

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