AN EVALUATION OF COMPETITION BETWEEN WEEDS AND SUGAR BEETS (BETA VULGARIS L.)

Thesis for the Degree of Ph. D.

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Gerald R. Miller

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By

Gerald R. Miller

A THESIS

Submitted to
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ABSTRACT

AN EVALUATION OF COMPETITION BETWEEN WEEDS AND SUGAR BEETS

by Gerald R. Miller

Field and greenhouse experiments were conducted for three years to determine the earliest period at which weed competition resulted in permanently restricted growth and reduced yields of sugar beets and to study certain factors involved in interspecific competition. Controlled variables in the field experiments were durations and densities of weeds and fertility level. Early growth, chemical content of sugar beet leaves, yields and sucrose content of mature sugar beets were determined.

Growth curves of sugar beet leaf areas were established in greenhouse experiments in which sugar beets were grown at different intensities of competition in a vermiculite-nutrient solution culture. Additional greenhouse experiments were designed to determine the roles of root competition and nitrogen as factors in plant competition.

Results of these investigations showed that yields of mature sugar beets were reduced if weeds remained more than four weeks. Weed competition for less than 24 to 28 days had no effect on yields.

In the presence of over-all weed stands, all densities of weeds caused reductions in yield compared with weed-free sugar beets. Differences in density tended to be overcome by increased growth of the remaining weeds.

Where weeds were restricted to the sugar beet row, 1/2, 1 and 2 weeds per sugar beet reduced yields 6 to 11 percent. Four and eight weeds per

sugar beet reduced yields 15 percent.

Increasing the fertility level resulted in higher yields, more weed growth and a greater percent reduction in yields due to competition than at the low fertility level.

The amount of nitrogen, phosphorus, potassium and iron in leaves was lower in the presence of weed competition. There were no differences in calcium, magnesium, manganese, copper, boron, zinc or molybdenum in the leaves associated with different intensities of competition.

The percent sucrose of mature sugar beets was not affected by weed competition.

Relative dates of emergence of the sugar beets and weeds and moisture supply were critical factors in determining the amount of competition.

Leaf area and number of leaves on sugar beets grown in the greenhouse were significantly reduced by competition for more than 25 days. After removal of the aerial portion of weeds, sugar beets which had been restricted in growth resumed a rate of growth equivalent to sugar beets of comparable size growing in weed-free conditions.

There was no competition between weeds and sugar beets for nitrogen under greenhouse conditions. Competition was partially alleviated by partitions between the roots of the sugar beets and weeds.

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INTRODUCTION

Losses due to the presence of weeds in crops have been recognized since man first cultured desirable species. These losses may occur in the form of reduced yields; poor quality products; increased insects and diseases; additional production, processing and marketing costs and reduced land values (3, 31).

The economic loss due to weed damage on agricultural lands in the United States has been estimated at 3 3/4 billion dollars annually (29). This amounts to about 33 percent of the major agricultural losses including insects, crop and livestock diseases and soil losses.

Accurate information regarding the extent, nature and causes of losses under particular crop situations is needed. Such information is a necessary prerequisite for evaluating cultural and chemical control procedures, for educating agriculturists as to the value of effective weed control practices and for understanding the mechanisms of competition.

The problem of weed competition in sugar beets (*Beta vulgaris* L.) has become imminent with the development of monogerm seed, mechanization in sugar beet production and the use of herbicides. Monogerm seed and mechanization have made possible space planting and the elimination of hand thinning. Hence, removal of weeds is the only remaining task demanding hand labor in the field work of sugar beet production. Herbicides have generally given a degree of control, but not complete eradication of weeds. The results have varied with differences in soil, moisture and temperature (1). It is therefore necessary to describe and analyze the competitive situation in sugar beets as a basis for developing more effective weed control programs and to determine if expected yield increases will justify additional weed control practices.

Considering the needs stated above, field experiments were conducted in Michigan for three years to evaluate the effects of weeds on sugar beets. Objectives of the experiments were to determine:

a. The critical period of competition in the development of the crop.

b. The yields and sucrose content of sugar beets grown under various intensities of competition.

c. The degree of competition which can be tolerated during the early growth of sugar beets.

d. The effects of competition on the chemical content of sugar beet leaves.

e. The influence of fertility level on competition effects.

Greenhouse experiments were conducted to:

a. Develop techniques for evaluating factors of competition under greenhouse conditions.

b. Characterize the growth of weeds under greenhouse conditions.

c. Establish the growth curves of sugar beets grown with various intensities of competition.

d. Evaluate root competition and nutrient competition between weeds and sugar beets.

REVIEW OF LITERATURE

General

Competition effect has been defined as that restriction in growth of a plant which arises from association with other plants (2). Harper (27) points out that higher plants normally remain rooted and fixed in position after establishment. Therefore, a plant demands its sustenance from a relatively small environment, as compared with mobile organisms. Because the position of plants is fixed, density and spacing of individuals play a significant role in determining the stresses which develop on plants in a particular environment.

It is the purpose of this review to describe the effects and significance of competitive stress resulting from the presence of weeds in crops and the factors which may be involved in competition as determined in previous experiments.

Agronomic methods designed to overcome the effects of undesirable species were in existence in 1832, when De Candolle developed a theory of crop rotation based on the idea that succeeding species should be those not inhibited by toxic substances left by the preceding crop (7). Systematic studies on plant competition were initiated by Clements *et al.* (11, 12, 13, 14). These studies indicated that competition is a physical process occurring only when plants demand the same things at the same time and place from an inadequate supply. Water, light, humidity and temperature were listed as factors involved in competition.

Losses due to different durations and densities of weeds.

Recent workers have evaluated the yield losses due to the presence of various durations and densities of weeds in specific crops.

Sugar beets: Burtch *et al.* (10) reported yield reductions in sugar beets of 2 to 14 tons per acre depending on the degree of infestation of water grass (*Echinochloa crusgalli* (L.) Beauv.). Under conditions of severe infestations, 88 and 20 percent control gave yields of 28.4 and 16.3 tons per acre. Yields were 26.2 and 19.9 tons per acre where moderate infestations had 90 and 40 percent control, respectively. Sparse infestations had no effect on yields.

Sugar beet yields were decreased ten percent by residual stands of weeds left in the crop for six weeks in experiments reported by Hogaboam *et al.* (29). Competition in the first six weeks gave a negative correlation of -.48 with the final yield over a range of fertility levels. The correlation was -.975 where no fertilizer was added.

Haddock (26) studied the influence of plant population, soil moisture and nitrogen on the yield of sugar beets. He concluded that for maximum yields, sugar beets must be kept growing vigorously from emergence until shortly before harvest. Limited moisture during the first few weeks of growth reduced final yields, even though moisture was ample the remainder of the season.

Vegetable crops: Shadbolt and Holm (50, 51) found that a 15 percent stand of weeds for 3 1/2 weeks reduced the weight of carrots 30 percent and 55 percent if left for 5 1/2 weeks. Increase in injury during the 3 1/2 to

4 1/2-week interval was greater than for any other comparable time. Red beets showed a greater ability to recover from competition during the early stages of growth. Onions were injured more severely than carrots and showed less ability to recover.

Yields of peas were reduced 26 percent if three mustard (Brassica hirta Moenck.) plants per square foot were left for five weeks and 58 percent if left the full ten-week season (46). Yield reductions varied from 0 to 64 percent. Variations were attributed to differences in the relative time of weed and pea emergence, differences in maturity of peas at harvest and differences in rainfall. One mustard plant per square foot had no effect on growth and yield of peas.

Results of experiments in which the weeds were removed at three different dates from potatoes showed only slight reductions in relative growth rate and net assimilation rate of the potatoes in the month following the removal of the weeds (43).

Corn: Several workers indicated the marked effects of weeds on corn yields. Staniforth (55) reported reduced yields of seven to eight bushels per acre due to residual stands of annual weeds. Yields were severely reduced if weeds remained more than six weeks in one year but not until after tasseling in another year (54). Reductions in yield averaged six to eight bushels per acre in four years of studies with relatively small infestations of foxtail, even when weeds were removed prior to tasseling (53). In an early experiment, Mosier and Gustafson (42) obtained yields of 46 bushels per acre where weeds were controlled by scraping, but only seven bushels per acre where weeds grew the full season.

Hackbarth's (25) experiments showed the importance of early season weed control in corn. Corn was cultivated, one, two or three times. Omission of the first cultivation resulted in increased weed yields and decreased corn yields. Omission of the second or third cultivations had little or no effects. Corn yields were reduced in these experiments by uncontrolled *Setaria* spp. from 111.9 to 9.8 bushels per acre and by *Amaranthus* spp. from 100.3 to 31.8 bushels per acre.

Li (34) reported reductions in corn yields if weeds remained for more than two to five weeks depending on moisture, temperature and fertility conditions. Weed-free bands of 12 and 24 inches did not eliminate early competition in 36-inch rows (16, 34).

Average results of three years of tests by Knake (32) with *Setaria faberii* in corn showed insignificant reductions from one plant every 24 inches of row. One foxtail plant per foot caused a seven percent yield reduction. Further reductions occurred from dense weed stands up to 54 foxtail plants per foot of row which reduced yields 24.5 percent. Collins (16) observed no reductions in corn yields due to the presence of weeds for only a portion of the growing season. Weed growth in these experiments was below normal because of limited moisture. Where weeds remained the full season, dicotyledonous weeds were more competitive with corn than monocotyledonous weeds on a dry weight and a per plant basis.

Soybeans: From a series of experiments in which controlled annual weed populations grew with soybeans, Staniforth *et al.* (55, 56, 57) measured yield reductions of 5 to 15 percent depending on moisture conditions.

Dry matter yields of above ground parts of soybeans and weeds approximated that of weed-free beans alone. A four-inch band of giant foxtail left in the row of soybeans caused 28 percent lower yields in three years of experiments (32). One weed per foot of row in these experiments reduced yields 4.5 percent. Staniforth (56) removed weeds at several stages of growth. In seasons when rainfall was ample early in the season, yields were reduced if weeds remained up to the four-trifoliate-leaf stage of soybeans. In other years, when rainfall was limiting, yields were not reduced significantly by weeds remaining for any duration up to maturity.

Small grains: Friesen and Shebeski (22, 52) evaluated yield losses in small grains due to weeds on 142 farms in Manitoba, Canada. Results of this work showed an average of 224 weeds per square yard, 28 different weed species present and average yield losses of 15.25 percent in three years of study. Reductions in yield ranged from 0 to 61.5 percent and weed counts from 0 to 2143 weeds per square yard. Weed competition was found to commence early in the growing season of spring wheat. Yields of winter wheat were reduced ten bushels per acre due to one fiddleneck (*Amsinckia intermedia* Fisch and May) plant per square foot when the weeds emerged the same time as the wheat and remained the full season (58). Weed populations of two and three plants per square foot did not further decrease yields. Fiddleneck did not reduce yields if it emerged after the wheat. Yields were lower where the heavier populations prevailed up to the time the wheat was five to eight inches tall. Lower populations had no effect on yields at this early stage. Burrows and Olson (9) observed that yields of spring wheat were reduced if wild mustard

Brassica arvensis L.) Rabenh.) remained longer than the four-leaf stage of wheat.

Li (34) evaluated the critical period of weed competition in oats. Yields were reduced if weeds remained longer than one to three weeks, depending on the moisture and temperatures during the early growing season. Cool temperatures and excessive rainfall resulted in less competition effect.

In a series of pot experiments with different weed species in competition with barley, Mann and Barnes (37, 38, 39, 40, 41) found that increased barley densities reduced weed effects. The relative time of emergence of weeds and wheat was a major factor determining the effects of weeds on barley. Fresh weight yield reductions varied from 0 to 80 percent with different species of weeds. A given volume of soil was found to produce a constant weight of plant material regardless of the number of plants present.

Competition effects on plant characters

In an effort to determine the specific effects of competition which result in lower yields, various plant characters have been measured. Clements (12) determined that more densely planted sunflowers had smaller stems, fewer leaves, less leaf surface area, less dry matter, smaller flower heads and fewer and smaller seeds. Leaf area of carrots was reduced 20 to 75 percent and root diameter was 50 percent less due to early competition (50). Competition in peas during the first four weeks reduced leaf areas 28 to 43 percent (46).

With increasing densities of giant foxtail, decreases were observed in yields of grain, cobs, stalks, stalk diameter and ear weight of corn (32). Percent moisture, shelling percent and height of corn were unaffected. Collins (16) observed that competitive stands of pigweeds in corn delayed the emergence of ears, silks, tassels and mature pollen. Corn grain showed no differences in mineral content due to competition.

Weeds in soybeans delayed maturity one day, decreased height two inches and increased lodging two to six percent (57). Knake (32) observed a decrease in the number of soybean pods per plant and in straw weight. There were no differences in the oil or protein content of beans, weight per bean or number of beans per pod due to the presence of weeds.

Oats in competition with weeds produced less grain yield, less dry matter, fewer tillers and fewer seeds per panicle than weed-free oats (34). Persicaria (Polygonum lapathifolium L.) at low densities had little effect on the addition of dry matter by barley, but it did reduce tillering (2). Yellow charlock, (Brassica arvensis) in competition with spring barley reduced the number of tillers and fertile shoots (4). Wild radish (Raphanus raphanistrum) reduced the number of tillers, fertile shoots and spike size.

Donald (18, 19) studied the influence of a wide range of densities on flowering, seed production and growth in Trifolium subterraneum L. and Lolium rigidum Gaud. Dry matter reached a maximum at moderate densities and remained constant at higher densities. Seed production was maximum at moderate densities and progressively declined at higher densities. The greatest number of inflorescences occurred at densities exceeding those of peak seed production. The most widely spaced plants had the greatest number of inflorescences and seeds per plant, but had smaller seeds and fewer seeds per inflorescence than denser swards.

Factors involved in competition

Yield reductions due to weeds have been attributed generally to competition for nutrients, water, light and carbon dioxide (12, 31, 36). Various authors rank the factors differently as to their significance. Pavlychenko and Harrington (49) stated that competition is not known to take place where the root systems do not meet underground and that severe competition may occur before tops are large enough to shade each other. Nutrients: Vengris *et al.* (60, 61) reported that several common weeds were able to accumulate considerable amounts of the essential elements and apparently were able to readily compete with cultured plants for these elements. From their studies, the possibility of overcoming competition in corn by fertilizing was questioned. At high rates of fertilization with nitrogen, phosphorus and potassium, weeds competed strongly for essential nutrients, suppressed the growth of corn and resulted in decreased yields. Corn yields were higher at low phosphorus levels where pigweeds and lambsquarters did not grow vigorously. In greenhouse studies, Hackbarth (25) found that higher fertility increased the yields of both corn and weeds where moisture was not limiting. Staniforth (53, 54) indicated that competition in corn was more severe in fields low in fertility. Corn yield reductions from mature yellow foxtail were 20, 10 and 5 percent, respectively with 0, 70 and 140 pounds per acre of nitrogen. Corn yields were increased two to three times as much as foxtail by nitrogen fertilization.

Kurtz et al. (33) concluded that competition between corn and intercrops was primarily for water and nitrogen. They reasoned that a level of fertility of the relatively immobile nutrients like phosphorus and potassium which is sufficient for maximum corn yields is a level high enough to support an intercrop also. Water and nitrogen, which are mobile in the soil, limited yields in an absolute way. A sufficiency of nitrogen and water, however, did not completely eliminate competition between corn and the intercrop.

Common weeds were found to contain 2 times as much nitrogen, 1.6 times as much phosphorus, 3.5 times as much potassium, 7.6 times as much calcium and 3.3 times as much magnesium as corn (31, 60).

Li (34) observed that competition was more severe in corn and oats at lower fertility levels. The possibility of eliminating early competition by increasing the rate of fertilization was suggested under conditions where moisture was not limiting. The content of nitrogen, phosphorus, potassium and calcium content in the plants was reduced by competition, although the effects were not consistent.

Welbank (62), in greenhouse studies, lessened competition between sugar beets and Agropyron repens by adding nitrogen but not potassium during the early stages of growth. However, the uptake of both nitrogen and potassium by the sugar beets was increased. Welbank concluded that competition was acting solely through its effects on uptake rates of nitrogen and potassium with competition for nitrogen having more effect than competition for potassium. It was indicated that competition may decrease uptake of a nutrient in ways other than by diminishing the amount.

in the soil; e.g. by depleting another nutrient that interacts with it.

Mann and Barnes (37) found that added nitrogen did not increase the growth of barley competing with certain weeds, but only increased the percent nitrogen in the plants. Barley was able to obtain over 75 percent of the nitrogen present even when weeds were present in greater numbers than the barley. Competition between cereal crops and annual weeds resulted in lower content of nitrogen and potassium in the cereals in experiments of Blackman and Templeman (4). The presence of weeds did not influence phosphorus content of the cereals. Hawkins and Black (28) obtained a greater response to nitrogen fertilizer by weed-infested wheat than by weed-free wheat, indicating competition for nitrogen. Significant increases in protein content were obtained in experiments by Friesen _et al._ (23) following weed removal from cereal crops suggesting competition for nitrogen. Fertilization of wheat growing in competition with weeds resulted in higher yields but lower protein content (45).

Myers and Lipsett (44) found that nitrogen was the major factor limiting yields of wheat and oats in competition with skeleton weed. Early weed control increased yields. Late weed control increased nitrogen in the grain.

Experiments with forage crops indicate that competition is intensified at lower fertility (18). Legume-grass mixture experiments showed the effects of interactions of nutrients on competition (5). Added nitrogen resulted in luxury feeding for potassium by grasses. This resulted in potassium deficiency in ladino clover. Clover yields were increased by addition of potassium.

Yields of sugar beets were reduced more by competition during the first six weeks of growth at lower than at higher fertility levels (29).

Water: Water has been shown to be a limiting growth factor of plants in competition. Klingman (31) cites experiments in which a common ragweed required three times as much water as a corn plant. Li (34) found that yield reduction of corn and oats were less in seasons of limited rainfall. Early competition was less severe in seasons of excess rainfall and cool temperatures. Yield reductions of soybeans were greater in years of high June - July rainfall (32). Similarly, Staniforth (56, 57) determined that yields of soybeans were reduced when weeds were removed as early as when the soybeans had 4 trifoliate leaves if rainfall was adequate early in the season. In other years, when rainfall was limiting early in the season, yields were not reduced significantly if the weeds were removed at any stage. Moisture supply was considered the principal environmental factor for which soybeans and weeds compete. Greater weed growth was associated with higher early season moisture. Other researchers attributed seasonal differences in competition and differences which could not be overcome by fertilizing to moisture, although this factor was not specifically measured (5, 28, 46). In greenhouse studies, (25) corn growth and weed growth were increased by higher moisture at either high or low fertility levels. On the other hand, higher fertility at low moisture levels did not increase yields.

Light: Light has been shown to be a limiting factor for which plants compete. Donald (20) states that under conditions of high fertility and rainfall, light may be the only factor for which there is competition.

Even where water or nutrients imposed some limit on the rate of growth, competition for light was still a factor of importance. Furthermore, light competition could occur relatively early in the growth of the plant. Pasture swards were observed to intercept all measurable light in as little as 40 days after growth commences. Buckwheat reduced light intensity at ground level to two percent of daylight 37 days after sowing. Shadbolt and Holm (50) found that light reduction in carrots was greatest 3 1/2 to 4 1/2 weeks after emergence. Light intensity was reduced by weed competition up to 85 percent four weeks after emergence.

Aspinall and Milthorpe (2) attributed reduced tillering of barley in the presence of white persicaria to shading of the lower portion of the barley culms.

Donald (18) stated that competition for light varied with leaf area index, leaf arrangement, orientation, efficiency and transmissibility, height of plants, relative rates of growth, planting arrangements and the light environment of the region.

Toxic substances: The literature on toxic substances has been reviewed by several writers (7, 24, 33, 46). These reviews indicate that toxic substances formed in the plant and excreted to the surrounding media may play an ecologically significant role. Toxic effects between species have been observed between only a few plant species under field conditions. Plant tissue leachates have been demonstrated to reduce subsequent plant growth in many greenhouse and laboratory experiments. These effects have not been apparent under most agronomic conditions. It is generally concluded that under field conditions, toxic substances may play a role in competition under conditions of stress such as limited aeration, excess moisture or organic matter accumulations; but under normally good growing conditions, they are probably not a limiting factor except in the case of a few isolated species. Welbank (62) studied competition between quackgrass and sugar beets. Results of these experiments gave no support for the formation of toxic substances from living roots or rhizomes. Toxic effects resulted only under conditions of limited aeration and high concentrations of plant residues.

MATERIALS AND METHODS

Field Experiments

Field experiments were conducted in Michigan in 1960, 1961 and 1962 to evaluate the effects of density and duration of weed competition on sugar beets at different fertility levels.

Location description

Sugar beets were grown on tile-drained Conover silt loam soil at the Michigan State University Experimental Farm at East Lansing in 1960 and 1961. These areas were fallowed in the summer prior to use for these experiments and planted in previous years to alfalfa. Experiments were established in Bay County, Michigan in 1962 on tiled Kawkawlin loam soil. The field was in field beans in 1960 and wheat underseeded with red clover in 1961. Monthly precipitation values for the different years are presented in Table 1. Supplemental irrigation with an overhead sprinkler system was used in 1960.

Seed and planting

Monogerm seed, variety SL 122 MS X SP 5460-0 commercial, was space planted in all of the experiments. The sugar beets were thinned to eight to ten-inch spacings. Planting dates were May 24, 1960; May 10, 1961; April 24, 1962.

Fertility

The area used in 1960 and 1961 was limed according to soil tests and fertilized with 400 pounds per acre of 0-25-25 broadcast in 1959.

Table 1. Monthly precipitation and deviation from normal at the experimental sites*

Month	Precipitation, inches 1960	1961	1962	Deviation, inches 1960	1961	1962
April	2.80	3.45	3.31	-.03	.62	1.09
May	3.05	1.00	2.29	-.70	-2.75	-.64
June	2.95	2.97	3.57	-.42	- .40	.34
July	2.25	2.28	2.88	-.03	.00	.69
August	2.98	3.33	2.74	.30	.65	.06
September	1.39	4.61	2.44	-1.66	1.56	-.40

*Climatological data. 1960, 1961, 1962. Weather Bureau. U.S. Dept. Comm.

An additional area used in 1961 was broadcast fertilized with 850 pounds per acre of 6-24-12 before planting. The field used in 1962 was fall plowed at which time 550 pounds per acre of 8-16-16 fertilizer were plowed down. At the time of planting, 500 pounds per acre of 12-12-12 fertilizer were applied in a band below and to the side of the row.

Controlled variables

Fertility level, weed density and duration of weed competition were controlled variables in these experiments. In the 1960 experiment, these variables were:

2 fertility levels - 600 and 3,000 pounds per acre of 6-24-12 broadcast prior to planting.

2 durations - 27 and 35 days after emergence of the sugar beets. Weeds emerged 1 week later than the sugar beets.

4 densities - no weeds, 1/3, 2/3 and a full natural density of over-all stands of weeds.

In 1961, the following variables were applied to the same area as in the above experiment:

2 fertility levels - 450 and 1,300 pounds per acre of 6-24-12 broadcast on the low and high fertility main plots, respectively, of the 1960 experiment.

2 densities - 1/4 and the full natural density of over-all weed stands.

8 durations - 0, 9, 12, 15, 18, 21, 24 and 27 days after weed emergence.

The second experiment conducted in 1961, involved variation of the density and duration of weeds limited to a six-inch strip along the row.

Treatments were:

6 densities - 0, 1/2, 1, 2, 4 and 8 weeds per sugar beet.

5 durations - 1, 2, 4, 8 and 20 weeks after weed emergence. Sugar beets emerged 2 weeks earlier than the weeds.

In 1962, the controlled variables were:

6 densities - 0, 1/2, 1, 2, 4 and 8 weeds per sugar beet within a 6-inch strip along the row.

5 durations - 1, 2, 4, 6 and 12 weeks after weed emergence. Sugar beets emerged at the same time.

A second experiment in 1962 involved the removal of over-all weed stands at weekly intervals 1, 2, 3, 4, and 5 weeks after sugar beet and weed emergence.

Comparative development of sugar beets and weeds

The relative densities and sizes of weeds at 27 days after emergence in 1960 are indicated in Figure 1. Figures 2, 3 and 4 show the stage of development of the sugar beets and weeds at the different durations in 1962.

In the 1961 experiment involving over-all stands of weeds, the sugar beets and weeds were less than one inch tall and had one to two true leaves at the time the densities and zero duration were established. At the nine-day duration, the sugar beets were three to four inches tall with four to six leaves and the weeds varied in height up to four inches. The beets were 10 to 12 inches tall and the weeds 8 to 18 inches tall at the 27-day duration.

The sugar beets were generally taller than the weeds in the experiment involving pigweeds in the row only. At the time the weed densities were established, the sugar beets had four to six leaves and were six to eight inches tall. The weeds were still in the cotyledon stage. The sugar beets and weeds were the following sizes at the different durations:

	Height, inches	
Duration, weeks	Sugar beets	Weeds
1	8-10	1-2
2	10-12	2-4
4	12-15	3-10
8	18-22	15-24
20 (Mature)	18-24	15-30

Stages of development were as follows in the 1962 experiments:

	Over-all weed stands		
	Sugar beets		Weeds
Duration, weeks	No. leaves	Height, in.	Height, in.
0	0-1	<1	<1
1	2	1	1
2	3-4	1 - 1 1/2	1-2
3	5-6	4-6	2-4
4	8-10	8-10	6-8
5	10-12	10-14	8-12

	Weeds in the sugar beet row		
	Sugar beets		Weeds
Duration, weeks	No. leaves	Height, in.	Height, in.
0	0-1	1	1
1	1-2	1-2	1-2
2	6-10	3-5	2-6
4	10-12	6-8	6-10
6	16-20	15-18	24-36
12	20 +	18-24	36-42

Figure 1. A portion of the 1960 experiment showing the relative densities and growth of weeds and sugar beets at 27 days after emergence. Plots were four rows wide. The range in the foreground shows from left to right 0, 1/3, 2/3 and a full natural stand.

Figure 2. Stage of development of the sugar beets and weeds at the time the densities were established (upper photograph) and one week later (lower photograph). 1962.

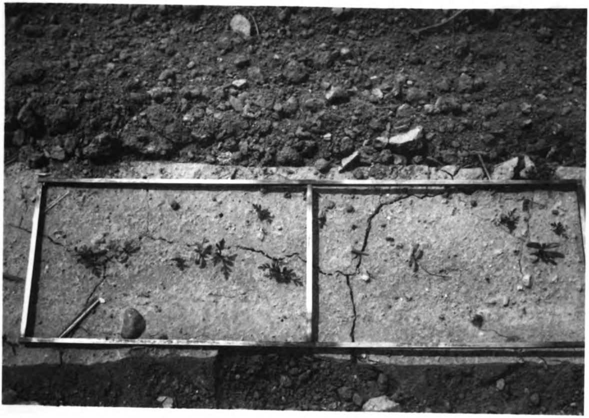


Figure 3. Stage of development of the sugar beets and weeds at two weeks (upper photograph) and at four weeks (lower photograph). 1962.

Figure 4. Stage of development of the sugar beets and weeds at six weeks (upper photograph) and twelve weeks (lower photograph). 1962.

Weed species

The experiments involving over-all weed populations included several species. In 1960 the weeds were predominantly lambsquarters (Chenopodium album L.) and rough pigweed (Amaranthus retroflexus L.). Also present were purslane (Portulaca oleracea L.), common ragweed (Ambrosia artemisiifolia L.), wood sorrel (Oxalis stricta L.), crabgrass (Digitaria sanguinalis (L.) Scop.) and yellow foxtail (Setaria lutescens L.).

In 1961, all plots were sprayed pre-emergence with 7.2 pounds per acre of trichloroacetic acid to control grasses and thus give some control over the species spectrum. The resulting weeds were predominantly lambsquarters with some rough pigweed and wormseed mustard (Erysimum cheiranthoides L.) in certain areas. The natural infestation of weeds in the 1962 experiment involving over-all infestations consisted primarily of common ragweed with smaller numbers of lambsquarters, rough pigweed and yellow foxtail.

In those experiments involving weeds only in the rows, the weeds were limited to one species. Scarified rough pigweed seeds were planted in bands along the row at the same time the sugar beets were planted in 1961. The different densities were established by thinning the rough pigweed to the desired numbers. All other species were removed by clipping.

In 1962, common ragweed seedlings emerged uniformly over the experimental area at the same time as the sugar beets. There were sufficient numbers of this species to establish the desired densities in all but those plots of highest weed density (eight weeds per beet plant). In these plots, it was necessary to supplement the ragweed with lambsquarter, rough pigweed, yellow foxtail or barnyard grass (Echinochloa crusgalli (L.) Beau.) plants to attain the desired densities.

Weed removal

Weeds were removed to establish the various densities and durations by cutting the weeds at the soil surface with razor blades or hand clippers in a manner that avoided disturbing the soil. After removal of the weeds at the specified durations, the plots were kept weed-free the remainder of the season by clipping as necessary or by uniform cultivation in those experiments where all the plots could be cultivated at the same time. In experiments where weeds were restricted to the sugar beet row, the areas between the rows were kept weed-free by cultivation. A six-inch strip was left undistrubed along the row in these experiments. Soil compaction resulting from working in the plots could have been an influential factor in the 1960 experiment. In subsequent experiments, the plot design facilitated working from the border areas of the plot. Differential soil compaction was therefore avoided.

Experimental designs and plot techniques

Split-split plot designs were used in the 1960 and 1961 experiments involving over-all weed populations. In 1960, the main plots were fertility levels, sub-plots were durations of weed competition and sub-sub plots were weed densities. Main plots in 1961 were fertility levels, sub-plots were weed densities and sub-sub plots were weed durations.

Randomized complete block designs with factorially arranged treatments were used in the other experiments. Each experiment consisted of four replications, except the 1962 experiment involving five durations of over-all weed stands which had six replications. Analysis of variance and multiple range tests were calculated for the data (15, 21, 47).

Plots were four rows wide (28-inch spacing) and 25, 30 or 35 feet long in different experiments. Treatments were applied to all four rows in 1960. In subsequent experiments, treatments were imposed on the two center rows. The outside rows of the plots were kept weed-free by cultivating and spraying pre-emergence with endothal and trichloroacetic acid at 4 and 7.2 pounds per acre, respectively.

Criteria of measurement

Weed growth was characterized in the experiments by dry weight yields, plant densities and height of plants. In the 1960 and 1961 experiments involving over-all weed populations, dry weight yields of weeds and sugar beets were determined at the time of weed removal for each duration. Samples were obtained from one square yard located one foot from the end of each plot and centered over the two middle rows. The above ground portions of the weeds and sugar beets and the enlarged tap root portion of the sugar beets were dried and weighed. In these same experiments samples of sugar beet leaves were taken for chemical analysis. Thirty recently matured and fully expanded leaves were randomly picked from the entire plot in accordance with sampling techniques described by Ulrich *et al.* (59). Leaf samples were obtained at each date of weed removal in 1960. In 1961, samples were taken from all the plots on August 1, four weeks after the weeds had been removed from the last duration. The samples were dried at 80° C, ground in a Wiley mill to pass through a one millimeter screen and stored in glass bottles until analyzed. Quantitative analyses for K, P, Ca, Mg, Mn, Fe, Cu, B, Zn and Mo were accomplished with a self-recording photoelectric spectrometer (30). Nitrogen content was determined using Kjehldahl procedures.

Yields of mature sugar beets and percent sucrose were determined in all the experiments. Harvest dates were October 15, 1960; October 14 and 19, 1961; October 5 and 6, 1962. Twenty feet in 1960 and 1961, and 30 feet in 1962 from each of the two center rows were lifted with a tractor-mounted lifter, topped with hand knives at the lowest leaf scars and weighed to determine yields of mature beets. Ten beets were randomly selected from each plot for sucrose percentage analysis.

Greenhouse Experiments

Greenhouse experiments were designed to describe the effects of weed competition on the growth of sugar beets during the first few weeks of development and to analyze certain possible causes of the competitive effects.

Techniques for studying competition in the greenhouse have been described by Aspinall and Milthorpe (47). Their studies resulted in the establishment of growth curves of barley grown either alone or mixed with various densities of white persicaria (*Polygonum lapathifolium* L.). Growth measurements were based on dry weight yields of plants grown in a sand-nutrient solution culture in ten-inch pots.

Techniques used in this study were based on the needs for a simplified growing medium in which environmental variables could be defined and controlled, a system which could be duplicated and a measurement of growth which could be repeated on the same plants at various time intervals in order to avoid the introduction of additional variability that might result from measuring different plants each time.

Controlled variables in the various experiments were as follows:

Experiment 1. 6 weed densities - 0, 2 1/2, 5, 10, 20 and 40 weeds per sugar beet

Experiment 2. 2 weed densities - 5 and 20 weeds per sugar beet

3 durations of weeds - 25, 50 and 65 days after emergence weed-free check

Experiment 3. 2 weed densities - no weeds and 20 weeds per sugar beet

2 nitrogen levels - .005 and .018 molar nitrogen nutrient solutions given in Table 2.

Experiment 4. 2 weed densities - no weeds and 20 weeds per sugar beet

2 patterns of root growth - roots of weeds and beets growing together or roots separated by aluminum cylinders

Plants were grown in vermiculite in wood flats having inside dimensions of 14 X 20 1/2 X 3 1/2 inches. Lambsquarters were seeded randomly in the flats. These were then kept moist with tap water until the weeds emerged. As soon as sufficient numbers of weeds had emerged, they were thinned to the desired densities.

Sugar beets, variety 59B18-0, were planted eight days after the weeds were seeded to compensate for the slow germination of the weeds

Table 2. Nutrient solutions used in greenhouse experiments*

Salt	Formula	Concentration, mg/l .012 M N Standard	.005 M N Low N	.018 M N High N
Calcium nitrate	$Ca\ (NO_3)_2 \cdot 4H_2O$	472.26	472.26	628.89
Potassium nitrate	KNO_3	404.34	______	404.34
Ammonium nitrate	NH_4NO_3	79.26	______	320.38
Monobasic potassium phosphate	KH_2PO_4	68.11	68.11	68.11
Monobasic ammonium phosphate	$NH_4H_2PO_4$	230.19	230.19	230.19
Magnesium sulfate	$Mg\ SO_4 \cdot 7H_2O$	369.62	369.62	369.62
Potassium chloride	KCl	298.11	596.22	298.11
Boric acid	H_3BO_3	.75	.75	.75
Manganous sulfate	$Mn\ SO_4 \cdot 2H_2O$	.75	.75	.75
Zinc sulfate	$Zn\ SO_4 \cdot 7H_2O$	.09	.09	.09
Copper sulfate	$Cu\ SO_4 \cdot 5H_2O$	.03	.03	.03
Ammonium molybdate	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	.08	.08	.08
Ferrous sulfate	$Fe\ SO_4 \cdot H_2O$	9.00	9.00	9.00

*From F. W. Snyder, Plant Physiologist, Tobacco and Sugar Crops Research Branch, ARS, USDA. East Lansing, Michigan.

and give nearly simultaneous emergence. The sugar beets were thinned as soon as they emerged to four or six plants per flat arranged in two rows of two or three plants each as shown in Figure 5.

Nutrient solution was added uniformly to the flats. The vermiculite was leached weekly with tap water to remove accumulated salts. Nutrient solutions used are given in Table 2. The standard solution was used in all experiments except the one involving different nitrogen levels.

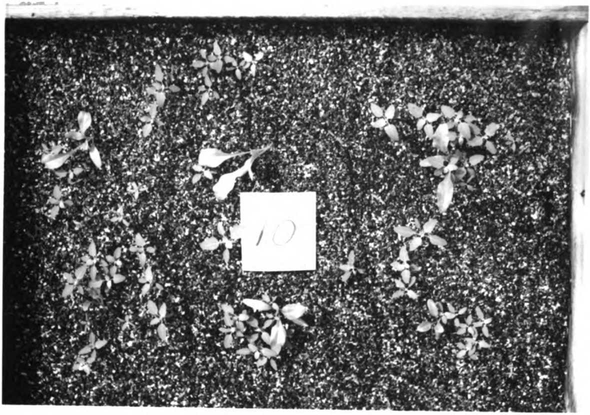
Temperatures ranged from 65 to 75°F except on some warm sunny days when the greenhouse temperature was 90 to 95°F. Three hundred-watt incandescent lights were used to maintain a 16-hour photoperiod.

Partitions between roots were made by placing four aluminum cylinders 3 3/4 inches high by 3 1/2 inches in diameter in each flat. The cylinders were secured with waterproof plastic tape and placed in a uniform rectangular pattern in each flat. Sugar beet seed was planted in each cylinder and the weeds were seeded around the cylinder. A similar pattern of sugar beets and weeds was used for comparison where there were no partitions.

Weeds were removed at the various dates indicated in the tables in the results or allowed to remain the duration of the experiment. The weeds were removed by clipping at the surface of the vermiculite. Dry weight yields of the weeds were determined. The relative growth of the weeds and sugar beets is indicated in Figures 5 and 6.

Growth of the sugar beets was described by measuring the leaf areas of the plants at various time intervals. Leaf areas were determined by three different techniques depending on the size of the plants. When

Figure 5. Growth of sugar beets and weeds 15 days after emergence (upper photograph) and 27 days after emergence (lower photograph) in the greenhouse. Density is ten weeds per sugar beet with six sugar beets per flat.


10


10

Figure 6. Growth of sugar beets and weeds 37 days after emergence (upper photograph) and the condition of the sugar beets after weed removal at 37 days (lower photograph). Figures in photograph indicate the density of weeds in number per sugar beet.


10


0
2½
5
10
20
40

the plants were small, areas were determined by placing a piece of acetate on which was drawn a grid square over the leaf and counting the number of squares within the leaf area. Larger leaves were traced by placing an acetate folder over the leaf and drawing the leaf outline on tracing paper. The areas were then measured with a planimeter. At the termination of an experiment, the dry weights of the plants were determined. These weights were converted to leaf areas according to a conversion factor obtained by comparing the dry weight of the leaves of six plants with the leaf areas of these plants.

A randomized complete block design with four replications was used in each experiment. An individual flat with six sugar beet plants was the unit of treatment. Thus, the mean values per plant reported in the results are the average of 24 plants, i.e. four flats with six plants each. An exception to this is the root partition experiment which had four sugar beets per flat.

RESULTS AND DISCUSSION

Weed Growth

Growth of weeds in the field and greenhouse has been described in terms of height and density in the materials and methods section. The amount of weed growth obtained is further described by the dry weight yields at the time of weed removal in Tables 3, 4 and 5.

Yields of weeds in the field experiment in 1960, Table 3, show that weed growth was greater at the higher fertility level and at the later duration as compared with lower fertility and the earlier duration, respectively. The weed-free plots in this experiment were established 17 days after emergence of the sugar beets. Density comparisons at each duration and fertility level show that all values were significantly different from weed-free plots. Significant differences between the 1/3 and 2/3 densities occurred only at the lower fertility level and 35-day duration. The lack of consistent differences between the 1/3 and 2/3 densities reflects the variability in weed growth and the increased growth per plant in the thinner stands. The intensity of competition is therefore not necessarily reflected by weed density alone. Weed growth was significantly greater at the full density than from less dense stands except at the higher fertility level and 27-day duration at which the difference between 2/3 and a full stand was not significant. From the above results, more severe competition would be expected with higher fertility, longer duration and increased density, but differences in density may be nullified by increased growth of individual plants in thinner stands.

Table 3. Dry weight yields of weeds at the time of removal. East Lansing, Michigan. 1960.

Fertilizer lb/A	Duration of competition, days	Yield, g/sq. yd. Density of weeds, fraction of natural density			
		0	1/3	2/3	1
600	27	0 a[1]	33 b	58 b	107 c
	35	0 a	98 b	135 c	183 d
3,000	27	0 a	34 b	67 bc	87 c
	35	0 a	164 b	154 b	216 c

[1] Yields in same row with the same letter are not different at 5% level. Analysis of variance in Table I of appendix.

Table 4. Dry weight yields of lambsquarters grown at different densities in the greenhouse.

Density, weeds per sugar beet	Yield, g/flat
0	0 a[1]
2 1/2	9.8 b
5	15.4 c
10	21.9 d
20	29.5 e
40	37.3 f

[1] Means with the same letter are not different at the 5% level.

Table 5. Dry weight yields of lambsquarters grown at two densities for three durations in the greenhouse.

Density, weeds per sugar beet	Duration, days 25	50	65
		yield, g/flat	
5	.78	8.22	19.94
20	2.58	15.70	36.36

Weed growth in the greenhouse was closely related to the density and duration as shown in Tables 4 and 5. The yields showed little variability. Growth increased with increasing density and duration and each value was significantly different from all other values.

Early Growth of Sugar Beets

Competition effects were reflected by the differences in dry weight, leaf area and number of leaves per plant during the first few weeks of growth.

The dry weight yields of sugar beet tops at the time of weed removal, presented graphically in Figure 9, indicate there was little competition effect at 27 days. At the 35-day duration of weed competition, growth was reduced 27 to 48 percent by the various densities of weeds as compared with the weed-free growth. Yields were greater at the higher fertility level, but the percent reduction in growth was practically the same at both fertility levels as compared with weed-free plots at the respective fertility levels. At the 27-day duration, yields were greater at the higher than at the lower fertility level by about the same amount at all weed densities. At the 35-day duration, growth was increased by the higher fertility level most in the weed-free plots and less with increasing weed density. Thus, although large amounts of nutrients were present in the soil, the sugar beets were still limited in growth by competition. This indicates the importance of factors in addition to soil nutrient level in early competition.

Yields of sugar beet tops and roots at the time of weed removal in 1961 were extremely variable showing no conclusive effects attributable to the presence of weeds.

Leaf areas of sugar beets grown with different durations and densities of lambsquarters in the greenhouse indicate that competitive effects occur early in the growth of sugar beets. However, sugar beets had considerable capacity for overcoming early growth limitations as indicated by the increased rate of growth when the above ground portions of the weeds were removed.

The data presented in Figure 7 compare the leaf areas of sugar beets grown at six different weed densities and measured at intervals up to 68 days after emergence. The weeds were removed from all flats 37 days after emergence. By this time, the growth of the sugar beets was decreased at all intensities of competition as compared with weed-free plots and growth was practically nil at the greatest density. After the weeds were removed, all sugar beets resumed a rate of increase in size equivalent to that of beets of comparable size which had grown under weed-free conditions; e.g. those sugar beets which grew in the presence of

10 weeds per sugar beet, increased in size from 147 g/plant to 782 g/plant, a 5.3 fold increase during the last 31 days of the experiment. This growth rate is comparable to that of the sugar beets growing under weed-free conditions from 27 to 54 days during which time these plants increased from 124 g/plant to 723 g/plant, a 5.8 fold increase.

The results presented in Figure 9 from a greenhouse experiment indicate that growth was not affected by competition for 25 days after emergence, but was severely limited by competition for 50 or 65 days. Removal of the above ground portions of the weeds at 50 days again resulted in a resumption of the growth at a rate equivalent to sugar beets of comparable size growing in weed-free conditions. Competition was less severe at the lower density of weeds.

The competition effects are indicated also in the dry weight yields of sugar beet tops and roots at the termination of the experiments which are presented in Tables 6 and 7. Weights of beet roots were decreased more than leaf weights by increasing densities of weeds up to 40 weeds per beet. Percent reduction in the other greenhouse experiment was about the same for both leaves and roots.

The number of leaves per sugar beet closely follows the pattern of competition as shown by the data in Tables 8 and 9. It is apparent that leaf numbers were most different at the time when the weeds were removed. After weed removal, the number of leaves became less variable. Leaf initiation or development is apparently a factor that is highly responsive to competition.

It should be recalled that the effects in the greenhouse experiments

Table 6. Dry weight yields of sugar beets grown with various densities of lambsquarters for 37 days and harvested 31 days after weed removal.

Weed density, number of weeds/sugar beet	Yield - g/plant	
	Tops	Roots
0	39 a[1]	49 a
2 1/2	36 a	38 b
5	31 ab	30 b
10	28 ab	18 c
20	20 b	11 cd
40	19 b	9 d

[1]Means in the same column with the same letter are not different at the 5% level.

Table 7. Dry weight yields of sugar beets grown with various densities and durations ot lambsquarters and harvested 65 days after emergence.

Density, weeds/ sugar beet	Duration, days after emergence	Yield, g/plant	
		Tops	Roots
0		2.4 a[1]	.33 a
5	25	2.5 a	.38 a
	50	1.9 ab	.27 ab
	65	1.7 bc	.26 ab
20	25	2.5 a	.39 a
	50	1.2 c	.16 bc
	65	.4 d	.06 c

[1]Means in the same column with the same letter are not different at the 5% level.

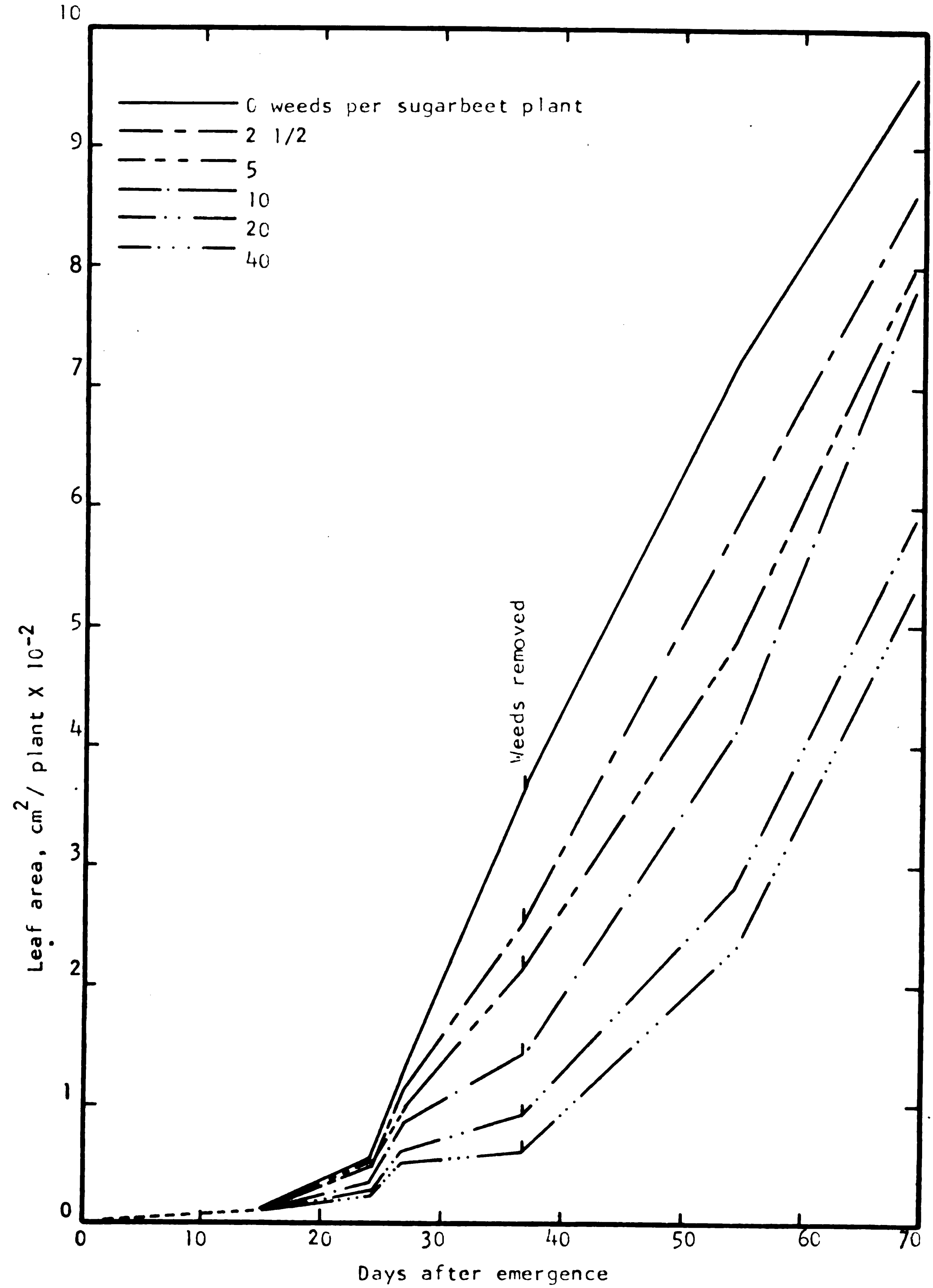


Figure 7. Leaf areas of sugar beets grown with different densities of lambsquarters in the greenhouse. Data and statistical analysis in Tables II and X of appendix.

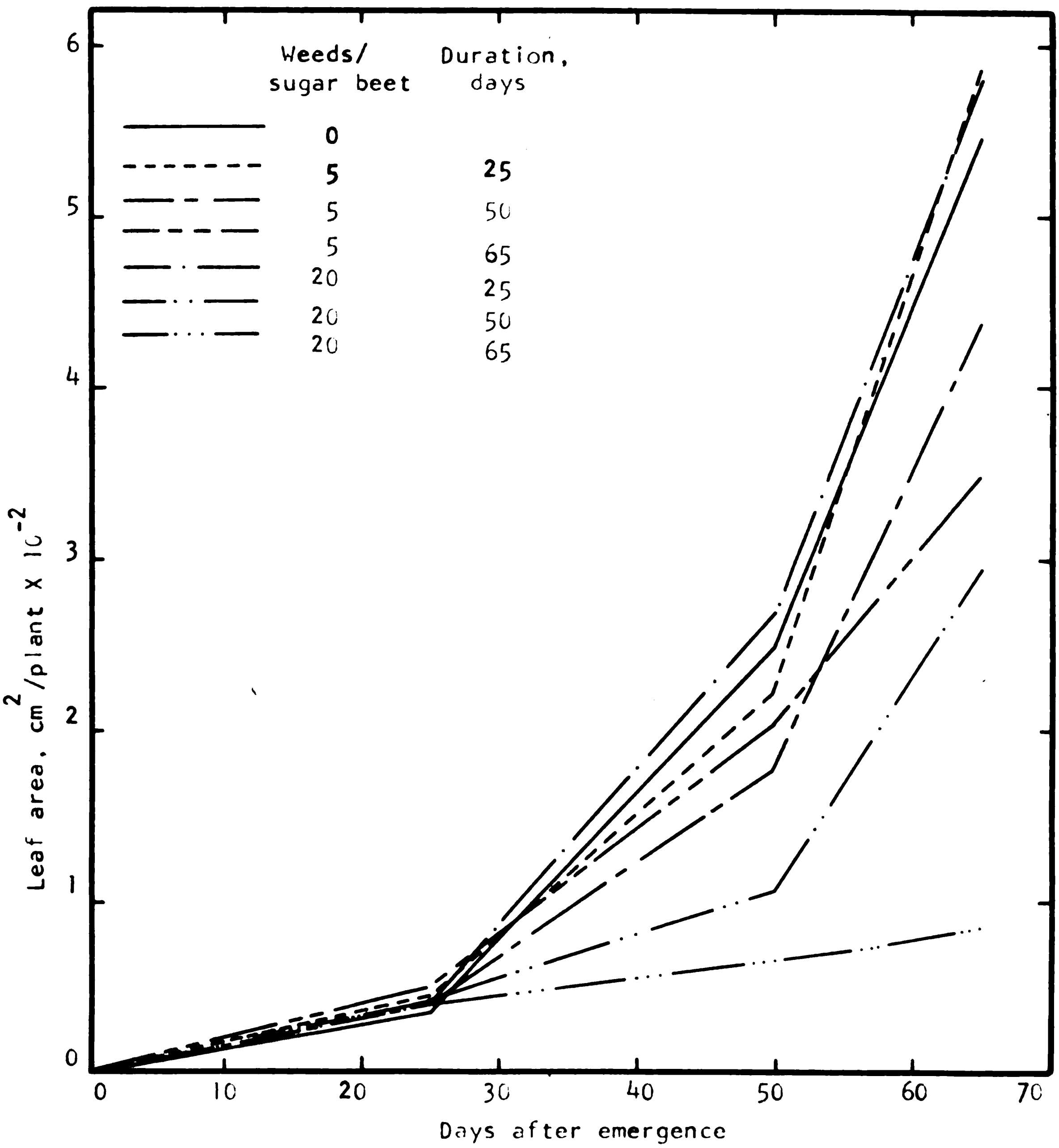


Figure 8. Leaf area of sugar beets grown with different durations and densities of lambsquarters in the greenhouse. Data and statistical analysis in Tables III and XI of appendix.

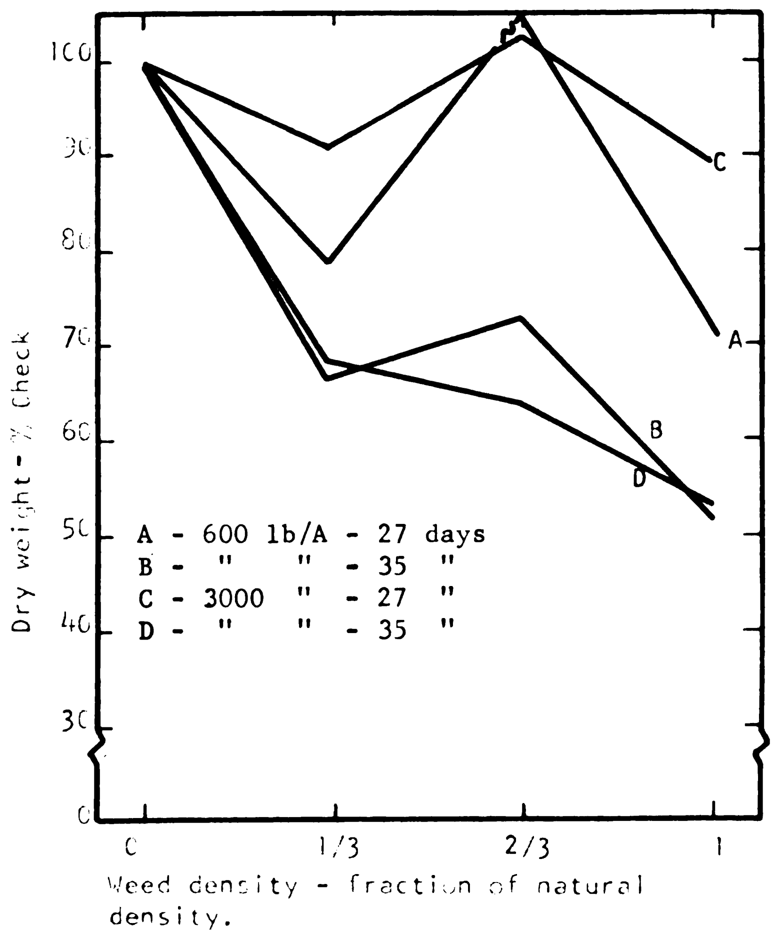


Fig. 9. Relative dry weight yields of sugar beet tops at the time of weed removal. Data and statistical analysis in Tables I and XII of appendix.

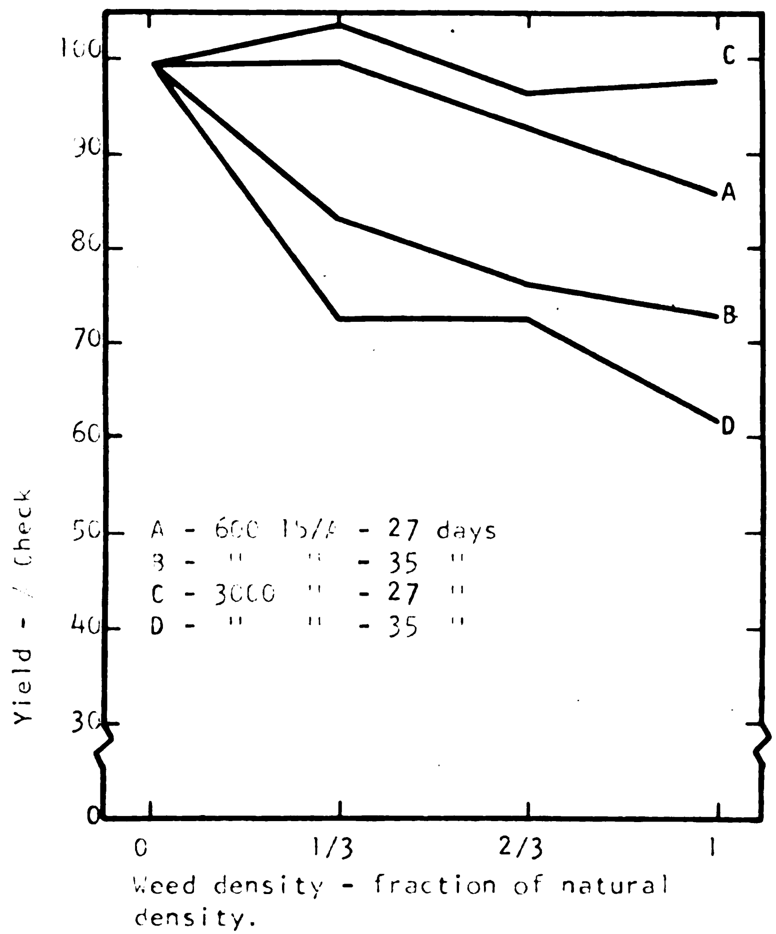


Fig. 10. Relative yields of sugar beets as affected by weed competition for two durations at two fertility levels. Data and statistical analysis in Tables IV and XII of appendix.

Table 8. Number of leaves on sugar beets grown with different densities of lambsquarters in the greenhouse.

Density, weeds/ sugar beet	Days after emergence 15	24	27	37[1]	54	68
0	2.2 a[2]	5.0 a	6.3 a	9.7 a	13.2 a	17.1 a
2 1/2	2.2 a	4.8 ab	6.1 a	9.3 a	12.1 ab	16.7 a
5	2.1 a	4.7 ab	6.0 ab	8.0 b	11.6 b	15.6 ab
10	2.2 a	4.5 ab	5.6 abc	6.8 c	11.3 bc	16.2 ab
20	2.2 a	4.3 ab	5.2 bc	6.2 cd	10.2 cd	14.6 b
40	2.0 a	4.1 b	4.8 bc	5.3 d	9.8 d	14.7 b

[1]Weeds were removed at 37 days.

[2]Means in the same column with the same letter are not different at the 5% level.

Table 9. Number of leaves on sugar beet plants grown at different durations and densities of lambsquarters in the greenhouse.

Density of weeds, No. per sugar beet	Duration of weeds, days	Number of leaves per sugar beet plant 25 days	50 days	65 days
0		3.6 a[1]	8.7 a	10.5 a
5	25	3.8 a	8.7 a	10.4 a
	50	3.6 a	7.4 b	9.8 ab
	65	3.8 a	7.6 b	9.0 ab
20	25	3.7 a	9.0 a	10.6 a
	50	3.5 a	5.6 c	8.2 b
	65	3.7 a	4.9 c	5.8 c

[1]Means in the same column with the same letter are not different at the 5% level.

occurred under conditions in which the plants were growing in vermiculite and that nutrient solution was added frequently. Under these conditions, it was expected that decomposition of root material remaining after weed removal would be slower than in soil. Also, the tie-up of nutrients in the weeds would likely be less important than if the plants were growing in soil.

Yields of Mature Sugar Beets

Yields of mature sugar beets as affected by various durations and densities of weed populations at different fertility levels are presented in Tables 10 through 14. The data for 1960 are presented graphically in Figure 10. Results of the 1961 tests were inconclusive due to the variability in stands and relative time of emergence of weeds and sugar beets as a result of limited rainfall during the early part of the growing season. In one experiment, weeds which emerged 15 days ater emergence of the sugar beets did not reduce yields, even though there were present in the row up to eight weeds per sugar beet remaining in the field until maturity of the sugar beets.

Duration effects: In the presence of over-all weed stands, significant yield reductions of 16-38 percent occurred when weeds remained for 35 days in 1960, 14 percent for 27 days in 1961 and 13.5 percent for 5 weeks in 1962. Yields were not reduced if weeds were removed prior to these durations. Weed populations which were restricted to a six inch strip along the row in 1962, caused no yield reductions if the weeds were removed by four weeks after emergence. If the weeds remained for 6 or 12 weeks, yields were significantly reduced by any of the densities of weeds as compared with yields kept weed-free from emergence.

Density: Yields were markedly reduced by any number of weeds as compared with weed-free plots if the weeds remained as long as the critical periods mentioned above. In 1960, differences between 1/3, 2/3 and a full natural density of weeds were slight, being significant only between 2/3 and a full natural density at the 35-day duration and 3,000 pounds per acre fertility level. Results of the 1962 experiment in which various densities of common ragweeds were allowed to grow only in the row show that yields were reduced by any number of weeds as compared with sugar beets kept weed-free from emergence. One weed every 20 inches, i.e. 1/2 weed per sugar beet, reduced yields 0.9 and 3.7 tons per acre if left for 6 or 12 weeks, respectively. Yields were reduced more by greater weed densities, with the maximum yield reduction of 3.6 tons per acre at the six weeks duration resulting from eight weeds per sugar beet. The greatest yield reductions at 12 weeks were 10 tons per acre resulting from four weeds per sugar beet and 9.7 tons per acre caused by eight weeds per sugar beet. Yields associated with 1/2, 1, and 2 weeds were not significantly different from each other; nor were the yields obtained in the presence of 2, 4 or 8 weeds significantly different from each other. Yield reductions were more severe when 4 or 8 weeds per sugar beet remained than if only 1/2 or 1 weed per sugar beet was present.

Fertility effects: Yields were greater at the higher fertility, but the percent reduction in yields due to weeds was also greater at the higher rate of fertilizer application. There was a trend toward lower yields at 27 days at the lower fertility which did not occur at the higher fertility level indicating that increasing the level of fertility may

Table 10. Yields of sugar beets as affected by various durations and densities of weeds at two fertility levels. 1961.

Duration of competition, days	Fertility: 450 lb/A — Density, fraction of natural stand 1/4	450 lb/A 1	1300 lb/A 1/4	1300 lb/A 1	Duration means
0	18.2 T/A	15.7	23.0	25.8	20.7 a[1]b
9	19.3	21.0	23.5	24.1	22.0 a
12	17.0	16.2	19.7	22.5	18.9 bc
15	15.3	19.5	25.2	23.7	20.9 a b
18	14.8	17.6	21.7	19.8	18.5 bc
21	18.3	15.2	21.3	21.5	19.1 bc
24	16.7	15.8	21.7	21.4	18.9 bc
27	15.6	14.3	21.1	20.0	17.7 c

Fertility means 450 lb/A - 16.9 T/A* Density means 1/4 - 19.5 T/A
1300 lb/A - 22.3 " 1 - 19.6 T/A

*Different at the 5% level.

[1]Duration means with the same letter are not different at the 5% level. Statistical analysis in Table XIII of appendix.

Table 11. Yields and sucrose content of sugar beets as affected by density of weeds. East Lansing, Michigan. 1961.

Density, weeds per beet	Yield T/A	Sucrose %
0	18.7[1]	11.5[1]
1/2	19.3	11.9
1	18.7	12.1
2	18.5	12.0
4	19.1	11.6
8	18.9	11.2

[1]No difference at 5% level.

Statistical analyses in Table XIV of appendix.

Table 12. Yields and sucrose content of sugar beets as affected by duration of competition. East Lansing, Michigan. 1961.

Duration of weeds, weeks after emergence	Yield T/A	Sucrose %
1	19.7[1]	11.8[1]
2	19.0	11.5
4	18.6	12.1
8	18.0	11.9
20	19.2	11.2

[1]No difference at 5% level.

Statistical analyses in Tables XIV of appendix.

Table 13. Effect of duration of competition from overall weed stands on sugar beet yields and percent sucrose. Bay County, Michigan. 1962.

Duration, weeks after emergence	Yield T/A	Sucrose percent
1	15.12 a[1]	19.2 a
2	15.25 a	18.5 a
3	14.65 a	18.1 a
4	14.90 a	18.6 a
5	13.08 b	18.4 a

[1]Means in the same column with the same letter are not different at the 5% level. Statistical analyses in Table XV of appendix.

Table 14. Effect of various densities and durations of competition from common ragweed (Ambrosia artemisiifolia L.) on sugar beet yields. 1962.

Density, weeds per sugar beet	Yield, T/A — Duration, weeks after emergence 1	2	4	6	12	Density means
0	18.8	18.7	18.9	18.6	18.6	18.7 a[1]
1/2	18.4	19.9	18.4	17.7	14.9	17.5 b
1	18.6	18.9	18.4	16.6	13.0	17.5 b
2	19.4	18.6	18.2	16.3	11.1	16.6 bc
4	18.4	18.0	18.4	15.9	8.6	15.9 c
8	19.5	17.7	18.6	15.0	8.9	15.9 c
Duration means	18.9[1]a	18.6 a	18.5 a	16.7 b	12.5 c	

[1]Means with the same letter are not different at the 5% level. Statistical analysis in Table XVI of appendix.

slightly delay the critical period of competition. Yields were increased more by increasing the level of fertility where no weeds were present than where there were weeds. It should be recalled that the growth of weeds was considerably greater at the higher fertility level. Whether the reduced yields in the presence of weeds are the result of direct competition for specific nutrients or an indirect effect which limits the capacity for utilization of the nutrients was not determined in this experiment.

Sucrose content

The percentages of sucrose in mature sugar beets as affected by various durations and densities of weeds at different fertility levels are given in Tables 11, 12, 13, 15 and 16. Competition had no effect on percent sucrose in any of the experiments.

Table 15. Sucrose content in sugar beets as affected by weed competition. 1960.

Fertilizer lb/A	Duration of competition, days	Sucrose, % Density of weeds, fraction of natural density 0	1/3	2/3	1
600	27	16.5[1]	16.2	16.4	16.6
	35	16.8	16.8	17.4	17.2
3,000	27	16.0	15.4	16.2	16.2
	35	15.2	15.8	16.0	16.0

[1]No differences at the 5% level.

Statistical analysis in Table XII of appendix.

Table 16. Effect of various densities and durations of common ragweed (Ambrosia artemisiifolia L.) on sucrose content. 1962.

Density, weeds per sugar beet	Sucrose, % Duration, weeks after emergence 1	2	4	6	12	Density means*
0	18.2	18.0	17.8	17.6	17.6	17.8
1/2	17.8	17.7	18.1	18.0	17.7	17.8
1	17.6	18.3	18.4	18.8	18.2	18.3
2	18.2	18.9	18.3	18.1	18.2	18.3
4	17.9	18.3	18.3	19.0	17.9	18.3
8	18.4	18.8	18.3	18.4	18.6	18.5
Duration means*	18.0	18.3	18.2	18.3	18.0	

* No differences at the 5% level.

Statistical analysis in Table XVI of appendix.

Chemical content of sugar beet leaves

Quantitative analyses showed no differences in the content of Ca, Mg, Mn, Cu, B, Zn or Mo in sugar beet leaves taken at the time of weed removal in 1960. The amounts of N, P, K and Fe were significantly reduced by competition as indicated in Figures 11, 12, 13 and 14.

Nitrogen content of the sugar beet leaves was reduced zero to six percent by the various densities of competition at the 27-day duration. After 35 days of competition, the nitrogen content of leaves was 7 to 18 percent lower at the various densities of weeds as compared with weed-free plots. Nitrogen content was reduced three to six percent more at the lower than at the higher fertility level after 35 days of competition.

Phosphorus in the sugar beet leaves was reduced 7 to 30 percent by competition as indicated in Figure 12. At the higher fertility level there was no reduction in phosphorus content due to weeds at the 27-day duration and 1/3 density. Significant reductions occurred at all other levels of competition with greater reductions occurring at the 35-day than at the 27-day duration. The actual content of phosphorus in the sugar beets was greater at all levels of competition where the higher rate of fertilizer was applied, but the percent reduction in phosphorus was as great at the higher as at lower fertility level.

The pattern of effects on potassium content in sugar beet leaves was similar to that for phosphorus, but the percent reduction was less. The content of potassium was not significantly lower than the weed-free check at the 3,000 pounds per acre fertility level and 1/3 density.

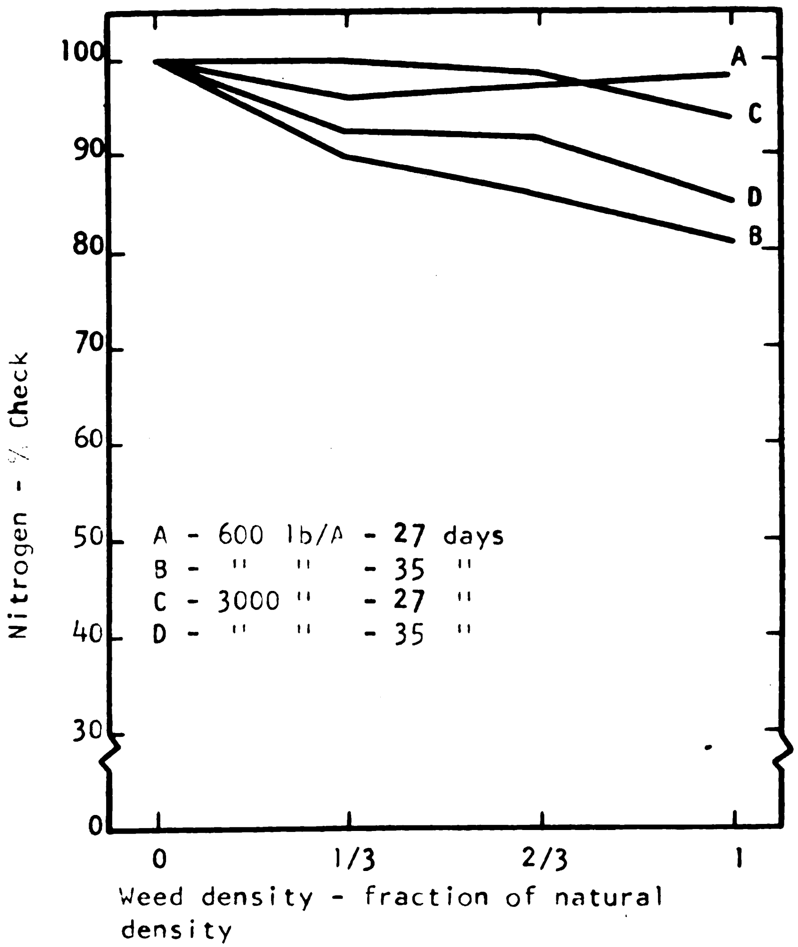


Fig. 11. Relative nitrogen content of sugar beet leaves as affected by weed competition for two durations at two fertility levels. Data and statistical analysis in Tables V and XII of appendix.

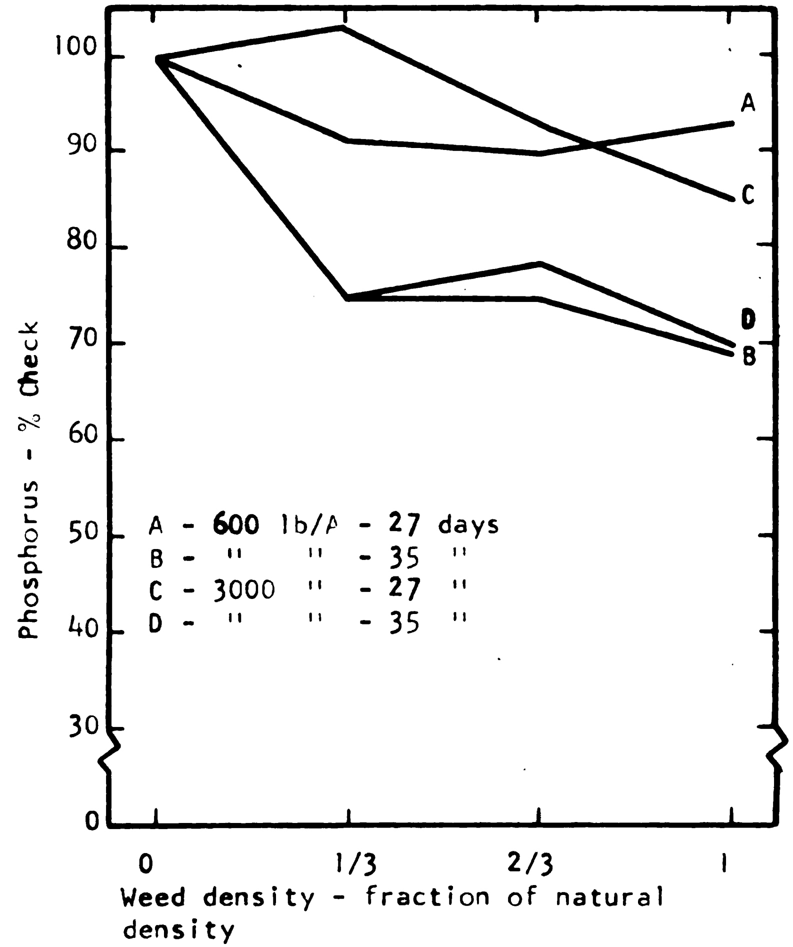


Fig. 12. Relative phosphorus content of sugar beet leaves as affected by weed competition for two durations at two fertility levels. Data and statistical analysis in Tables VI and XII of appendix.

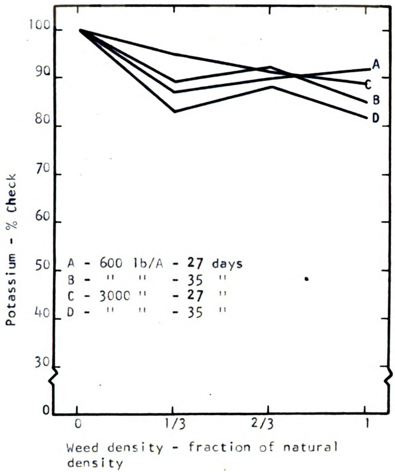


Fig. 13. Relative potassium content of sugar beet leaves as affected by weed competition for two durations at two fertility levels. Data and statistical analysis in Tables VII and XII of appendix.

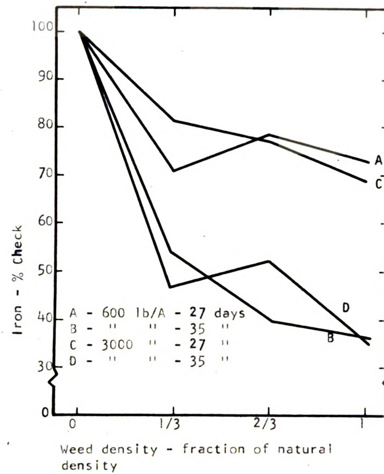


Fig. 14. Relative iron content of sugar beet leaves as affected by weed competition for two durations at two fertility levels. Data and statistical analysis in Tables VIII and XII of appendix.

Significant reductions occurred at all other intensities of competition, with reductions varying from 8 to 18 percent. Reductions were greater at the 35-day than at the 27-day duration. The higher fertility level resulted in a greater amount of potassium in the leaves, but the percent reduction was greater at the higher fertility level.

The amount of iron in sugar beet leaves was lower at all levels of competition as compared with the weed-free plots. Reductions varied from 19 to 65 percent. The actual content of iron was generally lower at the high than at the lower fertility level. There were no apparent differences in the percent reduction at the different fertility levels. Reductions were greater at the 35-day duration than at the 27-day duration.

In 1961, results of analyses of sugar beet leaves taken later in the season showed no differences in chemical content associated with the various competition treatments.

The above results suggest that uptake of certain nutrients may be a more critical factor than the concentration of the nutrients in the soil. It may be that the weeds present were able to obtain more of the nutrients than the sugar beets. Other factors, such as light or water may have limited the capacity of the sugar beets to obtain and utilize nutrients. Further experimentation is needed to clarify these relationships and to determine if the actual concentrations of the nutrients in the plants were low enough to restrict the rate of growth. Although the concentrations of N, P, K and Fe were lower under the various levels of competition as compared with the weed-free plots, it may be that the concentrations were not below a level which would restrict growth.

Factors involved in competition in the greenhouse

Nitrogen: Results of the experiment in which sugar beets were grown with weeds or weed-free at two nitrogen levels are given in Table 17. Leaf areas of the sugar beets were significantly greater at the higher nitrogen level at each of the dates when measurements were made. There was no effect due to the presence of weeds 25 days after emergence. At the two later dates on which the sugar beets were measured, the presence of weeds was associated with significant reductions in the size of the sugar beets.

There was no significant interaction between nitrogen level and weeds. The increase in leaf area of the sugar beets was the same in the presence of weeds as under weed-free conditions. It appears there was no competition for nitrogen under these conditions. Apparently some factor other than nitrogen is limiting growth at both fertility levels when weeds are present.

Root partitions: The leaf areas of sugar beets grown either weed-free or in the presence of lambsquarters and with the roots of the sugar beets growing together or separated by a partition are given in Table 18. There were no significant effects at 25 days after emergence. Ten days later there was a significant decrease in the growth of the sugar beets due to the presence of weeds as compared with no weeds.

Growth was depressed by the presence of a partition around the sugar beet roots where there were no weeds present. But, in the presence of weeds growth was greater where the weed and sugar beet roots were separated by the partition. This effect is most apparent at 45 days after

Table 17. Leaf area of sugar beets grown at two nitrogen levels and two densities of lambsquarters in the greenhouse.

Nitrogen	Weeds per sugar beet	Leaf area, sq cm/plant Days after emergence		
		25	35	45
Low	0	20 b[1]	86 b	216 b
	20	25 b	66 b	96 c
High	0	33 a	142 a	330 a
	20	35 a	118 a	209 b

[1]Means in the same column with the same letter are not different at the 5% level. Statistical analysis in Table XVII of appendix.

Table 18. Leaf area of sugar beets grown at two densities of lambsquarters and with the roots of the sugar beets and weeds either together or separated by an aluminum partition.

Roots	Weeds per sugar beet	Leaf area, sq cm/plant Days after emergence		
		25	35	45
Separate	0	19 a[1]	78 a b	193 b
	20	21 a	67 b	116 c
Together	0	25 a	108 a	267 a
	20	18 a	54 b	93 c

[1]Means in the same column without the same postscript are different at the 5% level. Statistical analysis in Table XVIII of appendix.

emergence, at which time there was a significant root zone X weed interaction. The growth of the sugar beets in the presence of weeds which have their roots separated by a partition was the resultant of the partition effect and the weed effect. The partition itself depresses growth, but apparently also alleviates a part of the competitive effect of the weeds. If it is assumed that the effect due to the partition itself is the same in the presence of weeds as in the absence of weeds and that the effect of the weeds is only that in addition to the partition effect, then it is tenable that a significant reduction in competition occurred where the roots of the weeds and sugar beets were separated. To illustrate, considering the values at the 45-day measurement, if 74 cm^2 (267-193) is attributed to the presence of the partitions, then in the presence of partitions the weeds further reduced growth only 77 cm^2 (193-116). But, in the absence of partitions, the size of the sugar beet leaves was reduced 174 cm^2 (267-93) which is attributable to the presence of weeds.

Competition appears to have been partially eliminated by keeping the root zones of the weeds and sugar beets separated. As in previously discussed experiments factors other than nutrient competition and root competition play a significant role. Relative heights of the sugar beets and weeds in both the greenhouse and field and the etiolated condition of the sugar beets at the critical competition period suggest the importance of light as a limiting factor. Competition prior to the time the sugar beets appeared etiolated did not seem to cause reductions in the yields of sugar beets under field conditions.

SUMMARY

Investigations were conducted to determine the earliest time at which competition resulted in permanently restricted growth and reduced yields of sugar beets. Field and greenhouse experiments were carried out in three successive years. Sugar beets were grown with various durations and densities of weeds at different fertility levels. Early growth, chemical content of sugar beet leaves, yields and sucrose content of mature sugar beets were determined.

Growth curves of sugar beet leaf areas were established in greenhouse experiments in which sugar beets were grown at different intensities of competition. Additional greenhouse experiments were designed to determine the roles of root competition and nitrogen as factors in plant competition.

These studies provided the following conclusions:

1. Yields of mature sugar beets were reduced if weeds remained more than four weeks. Weed competition for less than 24 to 28 days had no effect on yields.
2. Where over-all weed stands remained in sugar beets, all densities of weeds caused reductions in yield as compared with weed-free sugar beets. Differences in density tended to be overcome by increased growth of the remaining weeds.
3. Where weeds were restricted to the sugar beet row, 1/2, 1 and 2 weeds per sugar beet reduced yields 6 to 11 percent. Four and eight weeds per sugar beet reduced yields 15 percent.

4. Increasing the fertility level resulted in higher yields, more weed growth and a greater percent reduction in yields due to competition than at the lower fertility level.

5. The amount of nitrogen phosphorus, potassium and iron in leaves was lower in presence of weed competition. There were no differences in calcium, manganese copper, boron, zinc or molybdenum in the leaves associated with different intensities of competition.

6. The percent sucrose of mature sugar beets was not affected by weed competition.

7. Relative dates of emergence of the sugar beets and weeds and moisture supply were critical factors in determining the amount of competition.

8. Leaf area and number of leaves of sugar beets grown in the greenhouse were significantly reduced by competition for more than 25 days after emergence. After removal of the aerial portion of weeds, sugar beets which had been restricted in growth resumed a rate of growth equivalent to that of sugar beets of comparable size growing in weed-free conditions.

9. There was no competition for nitrogen when plants were grown in a vermiculite-nutrient solution culture in the greenhouse.

10. Competition was partially alleviated by partitions between the roots of sugar beets and weeds.

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APPENDIX A

Tables of data

Table I. Dry weight yields of sugar beet tops at the time of weed removal. 1960.

Fertilizer lb/A	Duration of competition, days	Yield, g/sq. yd. Density of weeds, fraction of natural density			
		0	1/3	2/3	1
600	27	18 a[1]	14 b	22 a	13 b
	35	96 a	64 b	70 b	50 b
3,000	27	35 a	32 a	36 a	31 a
	35	154 a	104 b	98 b	82 b
Density means		76 a	54 b	57 b	44 c

Means: 600 lb/A - 43* 27 days - 25**
3,000 " - 71 35 " - 90

[1]Means in the same row with the same letter are not different at the 5% level. Statistical analysis in Table XII.

** Significant at the 1% level.

* Significant at the 5% level.

Table II. Leaf areas of sugar beets at six dates grown with different densities of lambsquarters in the greenhouse.

Days after emergence	Weed density, weeds per sugar beet: 0	2 1/2	5	10	20	40
	Leaf area, sq cm/plant					
15	10.2 a[1]	9.0 a	9.7 a	9.0 a	8.7 a	8.3 a
24	56 a	51 ab	52 ab	44 ab	38 ab	34 b
27	124 a	107 ab	101 ab	85 abc	65 abc	53 c
37[2]	364 a	252 b	219 bc	147 cd	95 d	67 d
54	723 a	585 b	484 c	416 c	282 d	235 d
68	961 a	867 ab	799 ab	782 ab	590 bc	531 c

[1]Means in the same row with the same letter are not different at the 5% level. Statistical analysis in Table X.

[2]Weeds were removed at 37 days.

Table III. Leaf areas (sq cm/plant) of sugar beets grown with different durations and densities of lambsquarters in the greenhouse.

Days after emergence	Density, weeds per sugar beet: 0	5			20		
		Duration of weeds, days after emergence					
		25	50	65	25	50	65
25	40 a[1]	45 a	41 a	49 a	43 a	43 a	40 a
50	252 a	225 a	180 ab	204 a	271 a	107 bc	67 c
65	546 a	586 a	438 abc	352 bc	581 a	295 c	94 d

[1]Means in the same row with the same letter are not different at the 5% level. Statistical analysis in Table XI.

Table IV. Yields of sugar beets as affected by weed competition. 1960.

Fertilizer lb/A	Duration of competition, days	Yield, T/A Density of weeds, fraction of natural density 0	1/3	2/3	1	Duration means
600	27	18.4 a[1]	18.4 a	17.3 a	15.9 a	17.5*
	35	18.4 a	15.4 b	14.2 b	13.5 b	15.4
3,000	27	21.5 a	22.4 a	20.8 a	21.0 a	21.5*
	35	25.7 a	18.7 b	18.7 b	15.9 c	19.7
Density means @ 600 lb/A		18.4 a	16.9 ab	15.8 bc	14.7 c	
" " " 3,000 "		23.6 a	20.5 a	19.7 bc	18.4 c	
" "		21.0 a	18.7 b	17.7 bc	16.6 c	
Duration means	27 days	19.4*	Fertility means 600 lb/A			16.3**
	35 "	17.5	3,000 lb/A			20.5

*Different at the 5% level

**Different at the 1% level

[1]Yields in the same row with the same letter are not different at the 5% level. Analysis of variancein Table XII.

Table V. Nitrogen in sugar beet leaves as affected by weed competition. 1960.

Fertilizer lb/A	Duration of competition, days	Nitrogen, % Density of weeds, fraction of natural density 0	1/3	2/3	1	Duration means
600	27	5.28 a[1]	5.07 b	5.14 ab	5.17 ab	5.16*
	35	5.26 a	4.72 b	4.50 c	4.33 c	4.70
3,000	27	5.44 a	5.44 a	5.31 ab	5.14 b	5.33*
	35	5.24 a	4.86 b	4.82 b	4.44 c	4.84
Density means @ 600 lb/A		5.27 a	4.90 b	4.82 b	4.75 c	
" " " 3,000 "		5.34 a	5.15 b	4.06 b	4.79 c	
" "		5.30 a	5.02 b	4.94 b	4.77 c	
Duration means	27 days	5.25**	Fertility means 600 lb/A			4.93*
	35 days	4.77	3,000 lb/A			5.09

** Significant at the 1% level.

* Significant at the 5% level.

[1]Values in the same row with the same letter are not different at the 5% level. Statistical analysisin Table XII.

Table VI. Phosphorus in sugar beet leaves as affected by weed competition. 1960.

Fertilizer lb/A	Duration of competition, days	Phosphorus, %				
		Density of weeds, fraction of natural density				Duration means
		0	1/3	2/3	1	
600	27	.483 a[1]	.446 b	.437 b	.451 b	.454*
	35	.493 a	.368 b	.370 b	.340 b	.393
3,000	27	.598 a	.615 a	.554 b	.508 c	.569*
	35	.538 a	.406 b	.419 b	.375 c	.434
Density means @ 600 lb/A		.488 a	.407 b	.404 b	.396 b	
" " " 3,000 "		.568 a	.510 b	.486 c	.442 d	
" "		.528 a	.459 b	.445 b	.418 c	
Duration means	27 days	.512	Fertility means 600 lb/A			.424**
	35 days	.414	3,000 lb/A			.502

** Significant at the 1% level.

* Significant at the 5% level.

[1]Values in the same row with the same letter are not different at the 5% level. Statistical analysis in Table XII.

Table VII. Potassium in sugar beet leaves as affected by weed competition. 1960.

Fertilizer lb/A	Duration of competition, days	Potassium, %				
		Density of weeds fraction of natural density				Duration means
		0	1/3	2/3	1	
600	27	1.53 a[1]	1.33 b	1.38 b	1.40 b	1.41**
	35	1.17 a	1.04 b	1.08 b	1.00 b	1.07
3,000	27	1.86 a	1.77 ab	1.68 b	1.66 b	1.74**
	35	1.44 a	1.20 b	1.27 b	1.18 b	1.27
Density means @	600 lb/A	1.35 a	1.18 b	1.23 b	1.20 b	
" "	" 3,000 "	1.65 a	1.48 b	1.48 b	1.42 b	
" "		1.50 a	1.33 b	1.35 b	1.31 b	
Duration means	27 days	1.58**	Fertility means		600 lb/A	1.24**
	35 "	1.17			3,000 lb/A	1.51

** Significant at the 1% level.

[1]Values in the same row with the same letter are not different at the 5% level. Statistical analysis in Table XII.

Table VIII. Iron in sugar beet leaves as affected by weed competition. 1960.

Fertilizer lb/A	Duration of competition, days	Iron, ppm — Density of weeds fraction of natural density 0	1/3	2/3	1	Duration means
600	27	379 a[1]	268 b	296 b	277 c	305
	35	596 a	320 b	240 c	214 c	342
3,000	27	310 a	252 b	240 b	215 b	254*
	35	581 a	271 bc	300 b	206 c	340
Density means @ 600 lb/A		488 a	294 b	268 b	246 b	
" " " 3,000 "		446 a	262 b	270 b	210 c	
" "		466 a	278 b	269 b	228 c	
Duration means	27 days	280*	Fertility means	600 lb/A		324
	35 "	341		3,000 lb/A		297

* Significant at the 1% level.

[1]Values in the same row with the same letter are not different at the 5% level. Statistical analysis in Table XII.

APPENDIX B

Tables of analysis of variance

Table IX. Dry weight yields of weeds at the time of removal. 1960.

Source	DF	MS
Replication	3	3,765
Fertilizer (A)	1	3,835
Error (a)	3	2,670
Duration (B)	1	105,938**
AB	1	5,228
Error (b)	6	1,094
Density (C)	2	18,218**
AC	2	856
BC	2	445
ABC	2	803
Error (c)	24	461

** Significant at the 1% level.

* Significant at the 5% level.

Table X. Leaf areas of sugar beets grown with different densities of lambsquarters in the greenhouse.

		Mean squares						
		Days after emergence						
Source	DF	15	24	27	37	54	DF	68
Replications	3	12.9	544**	2,263**	5,879*	11,076*	2	7,054
Density	5	1.6	287**	2,896**	48,942**	135,769**	5	81,028**
Error	15	2.6	50	302	1,264	2,304	10	8,246

** Significant at the 1% level

* Significant at the 5% level

Table XI. Leaf areas of sugar beets grown with different durations and densities of lambsquarters in the greenhouse.

		Mean square		
Source	DF	25 days	50 days	65 days
Replication	3	56	767	3,136
No weeds vs weeds	1	53	19,850**	82,674**
Density	1	41	18,104**	109,958**
Duration	2	23	31,338**	263,904**
Density X duration	2	44	17,205**	32,132*
Error	18	77	1,878	8,107

** Significant at the 1% level

* Significant at the 5% level

Table XII. Effects of weed duration and density at two fertility levels on sugar beets. 1960.

		Mean squares			Chemical content of leaves			
Source	DF	Dry wt. of tops	Yield of mature sugar beets	Percent sucrose	N	P	K	Fe
Replication	3	341	6.0	.68	.12	.00531*	.05	7,198
Fertilizer (A)	1	12,572*	273.0**	12.50*	.36	.09781**	1.13**	11,718
Error (a)	3	2,153	2.6	1.14	.02	.00049	.03	22,715
Duration (B)	1	67,275**	56.7*	.78	3.59**	.15308**	2.61**	60,148*
AB	1	2,059	.6	2.72	.00	.02095*	.07	9,168
Error (b)	6	402	8.7	.62	.05	.00341	.02	5,704
Density (C)	3	2,783**	54.9**	1.02	.80**	.03492**	.117**	181,217**
AC	3	193	1.9	.01	.53**	.00232*	.003	1,512
BC	3	2,162**	29.1**	.46	.32**	.01075**	.000	62,966**
ABC	3	157	8.8	.24	.04	.00194	.023	3,779
Error (c)	36	244	3.9	.53	.02	.00075	.007	2,249

** Significant at the 1% level

* Significant at the 5% level

Table XIII. Yields of sugar beets as affected by various durations and densities of weeds at two fertility levels. 1961.

Source	DF	MS
Replications	3	82.1
Fertilizers	1	929.2*
Error (a)	3	63.4
Densities	1	.1
Fertilizer X density	1	.1
Error (b)	6	22.5
Durations	7	32.7*
Fertilizer X duration	7	6.7
Density X duration	7	43.4**
Fertilizer X density X duration	7	14.6
Error (c)	84	13.6

** Significant at the 1% level

* Significant at the 5% level

Table XIV. Yields and percent sucrose of sugar beets as affected by duration and density of weeds in the row. 1961.

Source	DF	Mean square Yield	% Sucrose
Replication	3	100.54**	9.50*
Duration (A)	4	8.45	2.60
Density (B)	5	1.31	2.20
AB	20	9.70	2.80
Error	87	6.98	2.85

** Significant at the 1% level

* Significant at the 5% level

Table XV. Effect of durations of over-all weed stands on yield and percent sucrose of sugar beets. 1962.

		Mean square	
Source	DF	Yield	% Sucrose
Replication	5	527**	4.52
Duration	4	194**	1.02
Error	20	36	4.25

** Significant at the 1% level

Table XVI. Effect of density and duration of common ragweed on yield and sucrose content of sugar beets. 1962.

Source	DF	Yield	% Sucrose
Replication	3	1197**	8.90**
Duration (A)	4	2923**	.50
Density (B)	5	394**	1.51
AB	20	195**	.41
Error	87	50	1.01

** Significant at the 1% level

* Significant at the 5% level

Table XVII. Leaf area of sugar beets grown at two nitrogen levels and two densities of lambsquarters in the greenhouse.

		Mean squares for each date of measurement		
			Days after emergence	
Source	DF	25	35	45
Replication	3	19	54	305
Nitrogen	1	518**	11,342**	51,189**
Weeds	1	51	1,980	57,961**
Nitrogen X weeds	1	6	13	35
Error	9	14	248	1,288

Table XVIII. Leaf areas of sugar beets grown at two densities of lambsquarters and with the roots of the sugar beets and weeds either together or separated by a partition.

		Mean squares at each date of measurement		
			Days after emergence	
Source	DF	25	35	45
Replication	3	854	529	1760
Root zones	1	169	281	2550
Weeds	1	420	4,258*	62,750**
Root zones X weeds	1	1,765	1,870	9,507*
Error	9	467	377	1,330

LY

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