Evaluation of intercropped sugar beets Beta vulgaris L. with emphasis on competition for light
by Muammer Ozkan

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in Crop and Soil Science
Montana State University

Abstract:
Sugar beets were grown with beans, barley, or corn in alternate single rows in 1969 and 1970 using four different spaeings. Alternate paired plantings were also studied in 1968 and 1969. Turnips were used as an intercrop in 1968 only. Sugar beets were also grown under four levels of light intensity at the Montana State University Experiment Station located at Huntley, Montana in 1969 and 1970.

Objectives were (1) to determine the competitive effects of other crops on the yield and sugar content of sugar beets, (2) to determine the effect of reduced light intensity on the yield, sugar content and nutrient composition of sugar beefs, (3) to compare the gross returns per acre from growing two crops in a mixed culture with returns from growing one crop in a monoculture, (4) to compare the yield and sugar content of intercropped sugar beets planted in alternate single versus alternate paired rows and (5) to determine the effects of a companion crop on the micro-climate of sugar beets.

Corn had the greatest and beans the least competitive effects on sugar beef yields. Barley was nearly as competitive as corn. The taller intercrops had a competitive advantage for light interception over beefs or beans. Corn reduced light intensities on the canopies of intercropped sugar beets by 94% and 74% for 11 and 22-inch spacings respectively. Barley reduced light intensities for sugar beets 11% and 6% in 11" and 22" spaeings respectively. Beans and turnips did not. reduce light intensities in the sugar beet canopies when planted in alternate rows. Increased air temperature in canopies of intercropped sugar beets may also have contributed to the reduction of sugar beef yields and sugar content.

Artificial shading of the sugar beet canopy decreased the overall growth and root weights, but caused an increase in the nitrogen and phosphorus content (percentage) of the leaves and roots.

Narrow spacing (11") of pure stand sugar beets gave a higher sugar content in 1969 and higher yield in 1970 than wide rows (33"). Growing sugar beefs in alternate rows with beans resulted in the largest gross return per acre.

EVALUATION OF INTERCROPPED SUGAR BEETS *BETA VULGARIS L.* WITH EMPHASIS ON COMPETITION FOR LIGHT

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DOCTOR OF PHILOSOPHY

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Crop and Soil Science

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Bozeman, Montana

June, 1971

ACKNOWLEDGEMENT

The author would like to express his sincere gratitude to Dr. Jarvis H. Brown, Assistant Professor of Plant and Soil Science and Mr. Donald E. Baldridge, Associate Agronomist, Huntley Branch Station for patience, consideration, and their valuable assistance during the course of this work and the preparation of this thesis.

Appreciation is also extended to other committee members: Drs. Glee S. Cooper, James R. Sims, James M. Pickett, Nels Nelson, for their constructive criticism in the preparation of this thesis.

Special thanks to Mr. J. L. Krall, Superintendent and Agronomist, and Mr. Donald M. Erb, Assistant Soil Scientist, and personnel of the Huntley Branch Station for their helpful comments and suggestions and involvement with the fieldwork.

A special thanks to Mrs. Ethel Fleming for typing the thesis and to Dr. Ervin P. Smith for assistance with computer programming.

Thanks also to the Plant and Soil Science Department for the Grant-in-Aid and the use of laboratory facilities throughout this study.

Lastly, the author wishes to express thanks to his patient family.

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ABSTRACT

Sugar beets were grown with beans, barley, or corn in alternate single rows in 1969 and 1970 using four different spacings. Alternate paired plantings were also studied in 1968 and 1969. Turnips were used as an intercrop in 1968 only. Sugar beets were also grown under four levels of light intensity at the Montana State University Experiment Station located at Huntley, Montana in 1969 and 1970.

Objectives were (1) to determine the competitive effects of other crops on the yield and sugar content of sugar beets, (2) to determine the effect of reduced light intensity on the yield, sugar content and nutrient composition of sugar beets, (3) to compare the gross returns per acre from growing two crops in a mixed culture with returns from growing one crop in a monoculture, (4) to compare the yield and sugar content of intercropped sugar beets planted in alternate single versus alternate paired rows and (5) to determine the effects of a companion crop on the micro-climate of sugar beets.

Corn had the greatest and beans the least competitive effects on sugar beet yields. Barley was nearly as competitive as corn. The taller intercrops had a competitive advantage for light interception over beets or beans. Corn reduced light intensities on the canopies of intercropped sugar beets by 94% and 74% for 11 and 22-inch spacings respectively. Barley reduced light intensities for sugar beets 11% and 6% in 11" and 22" spacings respectively. Beans and turnips did not reduce light intensities in the sugar beet canopies when planted in alternate rows. Increased air temperature in canopies of intercropped sugar beets may also have contributed to the reduction of sugar beet yields and sugar content.

Artificial shading of the sugar beet canopy decreased the overall growth and root weights, but caused an increase in the nitrogen and phosphorus content (percentage) of the leaves and roots.

Narrow spacing (11") of pure stand sugar beets gave a higher sugar content in 1969 and higher yield in 1970 than wide rows (33"). Growing sugar beets in alternate rows with beans resulted in the largest gross return per acre.

INTRODUCTION

Variations in the external environment affect not only photosynthesis but also all other physiological processes through the supply of substrate for energy and biosynthesis. Photosynthesis and subsequent plant growth are influenced by the light intensity, the carbon dioxide concentration and the temperature of the external environment in which the plant is growing. Sunlight is the primary energy source of a natural environment and it can be considered as the pre-eminent factor of the environment. Variation in light intensity and quality cause morphological changes in plant growth.

Light is an important factor in intra-plant and/or inter-plant competition. The wide fluctuations which occur in light intensity and quality in different locations and growing seasons suggest that competition for light may affect the competive ability of plants.

The research reported here was set up to study the relationship between competitive ability of different genotypes and availability of light. This study had the following objectives:

(1) to determine the competitive effects of other crops (barley, corn, beans, or turnips) on the yield and sugar content of sugar beets, (2) to determine the effect of reduced light intensity on the yield, sugar content and composition of sugar beets, (3) to compare the gross returns per acre from growing two crops in a mixed-culture with returns from growing one crop in a monoculture, (4) to compare the yield and sugar content of intercropped sugar

beets planted in alternate single versus alternate paired rows, (5) to determine the effects of a companion crop on the micro-climate (We planned to measure light intensity, soil and air temperatures.) and composition of sugar beets.

The information obtained should provide a better understanding of the physiology of sugar beets and information on the economic feasibility of intercropping sugar beets.

LITERATURE REVIEW

Competition may occur among plants for water, nutrients, light, CO_2 and oxygen. The components of the environment for which adjacent plants compete most are light, mineral nutrients, and water (15). Adequate application of fertilizer and timely irrigation can minimize competition for nutrients and water so that production is primarily limited by light (15,4,14,26,). According to Clements et al., cited by Donald (15), two plants do not compete with each other so long as water nutrients, and light 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. It is assumed that in these experiments light is the main factor limiting the yield of intercropped plants. Therefore, this review of literature will emphasize the effect of competition for light upon the yield and sugar content of sugar beets. Since artificial shading of sugar beets affected both temperature and composition of sugar beets the effects of temperature and of sugar beet nitrogen, phosphorus and potassium content on sugar beet yield and sugar content will also be discussed here.

I. The Effect of Competition for Light on Sugar Beet Yield and Sugar Content

Competition for light can occur whenever one plant shades another plant or within a plant, when one leaf shades another leaf. Blackman and Black (3) and Evans and Hughes (17) have measured the effect of artificial shading on growth of several species in the early vegetative phase. They showed that the net assimilation rate was dependent on the amount of light received while the leaf-area ratio (total leaf area/ ground area) rose as the level of shading was increased. They also concluded that during the season of active growth the quantity of light reaching the individual plants was limiting photosynthesis. Blackman and Black (4), in another experiment, found that shading (50% of daylight) reduced the relative growth rate of twenty-one out of twenty-two species, and concluded that the growth rate of many species is restricted even in midsummer by the lack of sufficient light energy.

Thomas and Hill (39) have investigated the photosynthesis of crops in the field where there was a high degree of self-shading as in sugar beets. They established that the net photosynthesis did not attain a maximum value for sugar beets until the intensity reached 4,400 foot-candles. In contrast Went (47) recorded that for seedlings of sugar beets under conditions where there was no self-shading, light saturation in environmental chambers occurred at 1,000 foot-candles. Watson (45) also showed that in normal stands of Beta mantima self-shading depresses photosynthesis.

Davidson and Philip (12), Davidson and Donald (11), and Watson (45) have shown that the degree of mutual shading of leaves which depends on the leaf area per unit area of land (the Leaf-Area Index or LAI) is related to the rate of dry-matter production per unit time (the Crop Growth Rate). Watson and Witts (46) compared wild beets and sugar beets under experimental conditions and found out that early in the season (LAI = 1), the net assimilation rate was equal in wild and cultivated beets. This suggested that "There was no difference in the leaf physiology". When the LAI rose to 2, the net assimilation rate fell for both, but much more steeply for wild beets. They attributed the fall to mutual shading in the wild beet because it has a rosette of horizontally disposed foliage. Cultivated beets have leaves at steeper angles and with less vertical separation between leaves. Therefore, a greater proportion of leaves in cultivated plants received a favorable light intensity. In general, with high solar elevations, light is better utilized by crops with erect leaves than by crops with horizontally placed leaves (14).

Researchers (5, 9, 22, 29, 36) have shown that the reduction in yield and leaf area per plant and the loss of leaf efficiency has been attributed, at least in part, to the reduction of incident light around the lower leaves of the plants.

Rate of photosynthesis in crop plants is highly correlated with light intensity from a low intensity to light saturation of the leaves (22, 29, 38).

Kruger and Wimmer cited by Ulrich (44) found that yields of sugar beets were limited by light rather than by the nutrient deficiencies which restricted growth in direct sunlight. Borden (6) showed that shaded sugar cane plants grown in pots produced less sugar than unshaded plants regardless of the nitrogen or potash treatments used.

II. The Effect of Temperature on the Yield and Sugar Content of Sugar Beets

Ulrich (41) and Went (47) have shown that both day and night temperatures have pronounced effects on sugar beets. But the effect of night temperature is more pronounced. The optimum night temperature for growth lies between 20 and 23 C, whereas the optimal day temperature is 23 C. They also showed that the sugar content of the beets was inversely proportional to the temperature, again night temperature being slightly more important than daytime temperature. According to Ulrich (41) and Went (47) sugar content of sugar beets reached the highest value at 2 C to 4 C (night temperature) whereas at 30 C the sugar content was the lowest. Increasing the day temperatures from 20 to 23 or to 26 C during 8-hour day periods also decreased the sucrose concentration of the beets, but the effects were not nearly as great as for the night temperatures (41).

Ulrich et al. (44) showed that beets grown at a higher temperature gave lower yields and lower sugar percentages than obtained in a cooler climate.

Ulrich (42) found that petioles of sugar beets were high in nitrogen, phosphorus and potassium when night temperatures were kept at a high level.

Loomis (27) showed that the temperature of a leaf exposed to sunlight is often well above that of the air. Under conditions of high insolation and high humidity, leaf temperatures of 10 to 15 C above air temperatures (37) have been recorded (24, 37). Linacre (25) noted that when plants were exposed to the sun but without suffering from water stress, the difference between air and leaf temperatures was usually small. Linacre also reported a tendency for equality of air and leaf temperature at about 33 C (91.5 F). Below that temperature, leaves tended to be warmer than the air; above that temperature, the reverse was observed. According to Priestley (32) the maximum temperature of a plant canopy should be about 92 F. He also concluded that leaves whose surface temperature exceeds 92 F suffer from water deficit. Ansari and Loomis (1) found that leaves shaded from direct sunlight were usually about 1 C warmer than the air temperature.

There is not much information available on the effect of soil temperature on the growth of sugar beets. The percent emergence of sugar beet seedlings at soil temperatures of 13, 18, and 24 C was significantly higher than at 6 C and the speed of emergence increased as the temperature increased (16). Nielsen et al. (30, 31) found that the yield of roots and foliage of lucerne increased with increase in temperature to at least 19.4 C. The phosphorus content of the roots and foliage tended to increase with increasing temperature. Oats produced higher yields (30) of grain and straw when soil temperature was increased from 41 to 67 F (19.4 C). They also showed that there was a trend toward increased concentration of phosphorus in the oat plants with increasing temperature. Low soil temperature depressed the growth and phosphorus percentage of corn seedlings (23).

III. The Effects of Nitrogen, Phosphorus and Potassium on Sucrose Content and Yield of Sugar Beets

Researchers (19, 28, 34, 35) indicated that mineral nutrient content and balance in plant tissue strongly affect yield and quality. Gardner and Robertson (18) analysed petioles of sugar beets and found it useful in determining fertilizer needs as regards nitrate, phosphate and potassium.

Ulrich and Hill (43) and Tolman and Johnson (40) conducted experiments with sugar beets, and studied yield and quality in regard to fertilizer practices. They found a negative relation between levels of nitrate nitrogen in the petioles and percentage sucrose of the roots.

Hoddock et al. (20) found that nitrogen fertilization and nitrogen plant composition are closely associated with sucrose storage in beet roots and sugar recoveries from extract juice.

Baver (2) showed that nitrogen was the major factor affecting the quality of sugar crops both sugar beets and sugar cane.

Ulrich and Hill (43) have proposed and used the theory of "Critical Concentrations" of nitrogen, phosphorus, and potassium in sugar beet petioles as a guide to crop fertilization. They proposed 1,000 ppm of nitrate-nitrogen, 750 ppm phosphorus, and 10,000 ppm potassium as "Critical levels" in sugar beet petioles.

MATERIALS AND METHODS

Experimental Area

The experiments were conducted on the Huntley Branch of the Montana Experiment Station at Huntley, Montana in 1968, 1969 and 1970. The soil texture was silty clay, pH values were 6.9; 7.5; 8.1; 8.1 and 8.3 for soil depths of 0-6; 6-12; 12-24; 24-36 and 36-48 inches respectively. Conductivity was 2.0-4.0 mmhos/cm (slightly salty) for the surface soil but subsoil was 0.0-2.0 mmhos/cm (33). Organic matter was medium in the surface soil but low below 12 inches. Available phosphorus was high in the surface soil but low below 12 inches. Available potassium was high at all soil depths (Appendix Table 26).

A. Interseeding Experiment

Experimental Design and Methods

The design of the interseeding experiment was a randomized split-plot with four replications. Four different row spacings (11", 16½", 22" and 33") were randomly assigned to main plots, 77 feet long and 30 feet wide.

Four pure stand and three interseeding treatments were randomly assigned to subplots, 11 feet wide and 30 feet long within each main plot.

The experimental fields were uniformly fertilized with 500 pounds of 16-20-0 per acre. Plots were irrigated by furrow irrigation between rows in 1968 and 1970, and by sprinkler irrigation in 1969.

Each year spring barley (*Hordeum vulgaris L.*) variety (Vantage), corn (Zea mais L.) variety (Trojan TX68) or beans (Phaseolus vulgaris L.) variety (Pinto UI114) were planted in alternate rows with sugar beets (Beta vulgaris L.) variety (Great Western Hybrid size 3). Turnips (Brassica rapa L.) variety (Purple top white globe) were also planted with sugar beets in 1968. Rows were east-west oriented. Sugar beets were planted with a 6-row John Deere Flexi-planter May 10, 1968, April 23, 1969 and June 4, 1970. In 1968, the other crops were planted at the same time as the sugar beets. In 1969, the other crops were planted at one week intervals in order to give the sugar beets an adequate growing season and to use conventional planting times for barley, corn, and beans. These three crops were planted May 5, 12 and 19, 1969 respectively. In 1970, wet weather delayed seeding until June 4 and 5, and all crops were planted on the same date. Plots were maintained weed free by hand weeding and cultivating.

Measurement of Light

The percent penetration of photosynthetically useful radiation (visible light) through crop canopies of four crops was measured.

Light measurements were determined by the method of Bula et al. (7) in 1969 and by a modification of the method of Daynard et al. (13) in 1970. No light measurements were made in 1968. In 1970, eight selenium photo cells were connected in parallel and mounted on a 33 x 4 x 4 cm wooden block. Photocells were painted with white paint and covered with opal plexiglass which in turn was covered with black paint and black electrician's tape. A slit through the black paint was varied so that all cells gave the same micro ampere output in full sunlight intensity. Each block of eight photo cells was called a station. All stations were connected to a timer and a stepping switch assembly that provided successive readings to a 50 µA Rustrak recorder (Model 288).

Two stations were used in each interseeded plot of one replication. One was at the top of the sugar beet canopy, the other at the bottom of the sugar beet canopy (at ground level). Plots with pure stands had one station at the bottom of the crop canopy. Stations were oriented the same direction as the crop rows. Percent reduction of light intensity was calculated by comparison with another station above the barley, corn and bean canopies. Heights were adjusted as the crops grew. Readings were taken 5 times a day (8 AM, 10 AM, 12:30 PM, 3 PM and 5 PM) in full sunlight every 10 to 15 days. Solar noon was approximately 12:45 PM.

Measurement of Air and Soil Temperatures in Cropped Areas

Thermocouples were used to measure temperatures. Temperatures within intercrop canopies were compared with temperature taken in the canopies of pure stand sugar beets. Thermocouples were connected to a stepping switch assembly and a Rustrak Model 157C amplifier and Model 288 recorder.

Sampling Procedure

Yields were calculated from one 20-foot row sample taken from each plot. Nitrogen was determined by the Macro Kjeldahl method and phosphorus and potassium were determined with a spectrophotometer and atomic absorption spectrophotometer respectively. The Great Western Sugar Company in Billings, Montana determined sugar content of the sugar beets.

B. Shading Experiment

The shading experiment was conducted in 1969 and 1970 in an area immediately adjacent to the experimental area used for the Interseeding Experiment. The design used in the shading experiment was a randomized complete block with four replications. Plots were 22-feet long and 11-feet wide. The sugar beets were planted in 22 inch spaced rows on April 23, 1969 and June 4, 1970. Four shading intensities were created with saran shade cloth that was used by Cooper et al. (10) at Montana State University. Cloths were suspended at a height of 36 inches on July 7, 1969 and July 27, 1970. Intensities of shading were: (a) full sunlight, (b) 51% shade, (c) 76% shade, and (d) 92% shade.

Cultivation and irrigation were done at the same time as Interseeded Experiment.

Air and soil temperatures (4-inch depth) were recorded by thermocouples under the shading cloths in 1970. Temperatures were not measured in 1969.

C. Alternate VS Paired Rows Experiment

This experiment, conducted in another area adjacent to the Interseeded Experiment, compared plantings of barley, corn or beans grown in alternate single rows with sugar beets with alternate double rows (paired rows). The experimental design was a randomized split-plot with four replications. Two different row spacings (11" and 22") were randomly assigned to main plots, 77 feet long and 30 feet wide. Pure sugar beet stand and two different planting patterns (alternate single and alternate paired rows) with three interseeding treatments were randomly assigned to subplots, 11 feet wide and 30 feet long within each main plot.

All plots were planted, cultivated and irrigated at the same time as the Interseeded Experiment.

RESULTS AND DISCUSSION

Weather, experimental designs and planting patterns differed in 1968, 1969 and 1970. In 1969, each crop was planted at the normal planting time but a snowfall and frost occurred on June 12 and 13th, causing light damage to corn. Center rows of beans were covered by plastic to prevent damage. After June 13, temperatures warmed gradually and remained warm through September. Precipitation throughout the growing season was higher than normal (see Appendix Table 27). These conditions resulted in a high yield and sugar content of sugar beets in 1969. A cold and wet spring in 1970 preceded a wet growing season (see Appendix Table 28). The wet spring in 1970 delayed planting and thereby reduced yields. Because of differences in weather and planting dates, each year's results will be discussed separately.

1968 Experiment

One preliminary experiment was conducted in 1968 to study competition between sugar beets and different interseeded crops. Each cultivated crop was planted in alternate single or alternate paired rows. Gross returns per acre, yields, and sugar content were determined. Neither light intensities nor temperatures were measured in 1968.

The data presented in Tables 1 and 2A shows that sugar beets grown alone yielded 19.0 tons per acre compared to 8.1; 9.1; 15.9; or 13.9 tons per acre of sugar beets when grown in alternate single rows (11 inches apart) with barley, corn, beans or turnips, respectively. Barley had the greatest and beans the least competitive effect on sugar beet yields. Corn was nearly as competitive as barley and turnips were only slightly more competitive than beans. Percent reductions in yield of sugar beets were 57.4; 52.1; 16.3; or 26.8 when barley, corn, beans or turnips respectively were grown between 22 inch beet rows resulting in 11" spacings between adjacent rows.

The effects of alternate 22" rows of barley, corn, beans or turnips on sugar beets were essentially identical to 11" rows. Barley had the greatest and beans the least competitive effect as indicated by sugar beet yields.

Yields of sugar beets were 9.9; 8.8; 12.9; or 12.4 tons per acre when grown in alternate paired rows with 22 inches between adjacent rows with barley, corn, beans or turnips respectively. The competitiveness of intercrops on sugar beet yield decreased in the order corn, barley, turnips and beans.

Percent sugar was not significantly affected. Means ranged from 17.7 to 16.4.

Competitive effects of sugar beets upon the other crops can also be observed (Table 2A). The beets had a greater effect upon the yield of beans and barley than on corn and turnips. The percent yield reductions of corn, beans, or turnips were 22.4; 69.7; or 17.9 respectively in alternate single rows with 11" spacing.

The relative competitiveness of the different intercrops was the same for alternate paired 22" rows as for alternate single 22" rows.

Table 1. The effect of the competition of barley, corn, pinto beans, and turnips upon the yield and sugar content of sugar beets at Huntley, Montana in 1968.

Row Spacing	Crops	% Sugar	Root Yield Tons/Acre	% Yield Reduction
		Averages		
22"	Beets alone	17.7	19.0	
11"	Beets in alternate single rows with barley	17.3	8.1	57.4
11"	" " " " " " corn	17.6	9.1	52.1
11"	" " " " " " beans	17.9	15.9	16.3
11"	" " " " " " turnips	17.8	13.9	26.8
22"	" " " " " " barley	17.5	8.1	
22"	" " " " " " corn	16.4	9.7	
22"	" " " " " " beans	16.8	15.6	
22"	" " " " " " turnips	16.9	14.0	
22"	Beets in paired rows with barley	17.1	9.9	
22"	" " " " " corn	17.4	8.8	
22"	" " " " " beans	16.3	12.9	
22"	" " " " " turnips	16.2	12.4	

Table 2A. The yield and gross returns for barley, corn, beans, and turnips grown alone and intercropped with sugar beets at Huntley, Montana, in 1968.

Row Spacings inches	Crops	Yield: Sugar Beets T/A Roots	Yield: Sugar Beets T/A Tops	Yield: Interseeded Crops Barley Cwt./A	Corn T/A	Beans Cwt./A	Turnips T/A	Yield Reduction by Inter-Crop (%)	Gross Return per Acre
22"	Sugar beets alone	19.0	14.2						382.00
11"	Barley alone (grain)			26.0					63.20
22"	Corn alone (silage)				17.0				119.00
22"	Beans alone (seed)					14.5			100.40
22"	Turnips alone (roots)						8.4		63.30
11"*	Beets w/barley	8.1	7.2	10.5					194.50
11"	" w/corn	9.1	5.8		13.2			22.4	271.23
11"	" w/beans	15.9	15.1			4.4		69.7	375.22
11"	" w/turnips	13.9	7.6				6.9	17.9	325.69
22"*	Beets w/barley	8.1	4.2	7.2					173.41
22"	" w/corn	9.7	8.3		10.7				274.33
22"	" w/beans	15.6	14.4			7.3			382.00
22"	" w/turnips	14.0	10.8				4.6		320.83
22"**	Beets w/barley	9.9	6.9	8.0					217.60
22"	" w/corn	8.8	7.7		10.3				253.73
22"	" w/beans	12.9	10.5			7.7			322.18
22"	" w/turnips	12.4	12.5				4.2		299.60

* Planted in alternate single rows.

** Planted in alternate paired rows.

Table 2B. The yield and gross returns for barley, corn and beans grown alone and intercropped sugar beets at Huntley, Montana in 1969.

Treatments	Yield (T/A) Sugar Beets	Beans	Barley	Corn	Gross Crop Value/Acre ($)
Sugar beets 22" spacing alone	25.54				434.18
Sugar beets 22" spacing between rows beans	25.88	.05			440.00 + 6.50 = 446.50
Sugar beets 22" spacing between rows barley	9.76		1.66		165.92 + 69.16 = 235.08
Sugar beets 22" spacing between rows corn	8.94			14.62	151.98 + 102.34 = 254.32
Sugar beets 33" spacing alone	24.58				417.86
Sugar beets 33" spacing between rows beans	15.82	.25			268.94 + 32.50 = 301.44
Sugar beets 33" spacing between rows barley	15.10		1.35		256.70 + 56.25 = 312.95
Sugar beets 33" spacing between rows corn	8.46			19.50	143.82 + 136.50 = 280.32

Corn and barley were almost equally competitive in alternate and paired rows but beans and turnips were less competitive to sugar beets in alternate rows than in paired rows.

Total gross crop values per acre, using local prices at harvest, are presented in Table 2A and Table 2B. Sugar beets grown alone and sugar beets grown in alternate 22-inch rows with beans produced the largest gross of $382 per acre in 1968 (Table 2A) and $446.50 per acre in 1969 (Table 2B). Turnips were not planted in the 1969 and 1970 experiments because no market was available for turnips. Although beets grown with beans produced the same gross return per acre as beets alone, net income with beans as an intercrop should be more than beets grown alone because labor and machinery expenses were reduced when sugar beets were planted with beans in alternate rows.

1969 and 1970 Experiments

Although the same drill, the same planting pattern, and the same seed type were used both years, some results differed. This was partly due to the climatic conditions described above. Therefore, it is impractical to discuss the results from the two years together. The data obtained and calculated "F" values in 1969 and 1970 are presented in Table 3.

I. Interseeded Experiment

A. The Effects of Row Spacing and Intercrops on Sugar Beets:

1. Yield and % Sugar

Row spacing significantly affected yields and sugar content of beets (fresh weight basis) in 1969 but only yields were affected in 1970 (Table 3 and 4). Narrow (11") spacing of pure stand sugar beets gave a higher sugar percentage in 1969 and a higher yield in 1970. The higher yield and sugar content in narrow rows can be attributed to the increased population (smaller beets) and possibly to the more erect leaves that can use light more efficiently than the more horizontal leaves obtained with wider rows. These concepts are supported by other researchers.

Root yields and sugar content were generally lower in 1970 than in 1969 because of the shorter growth period in 1970 (164 days in 1969 vs 144 days in 1970). On the other hand, late planting in 1970 adversely affected the photosynthesis attained in the period from June 1 to July 10. The "Maximum photosynthesis possible" for this period was calculated by Campbell and Viets (8) to be 17.6 tons per hectare (7.3 T/A). Most of this photosynthetic potential was lost since plants were too small to intercept light efficiently.

Growing barley or corn, in alternate rows with beets decreased sugar beet yields in both years (Table 5). Percent reductions in yield of beets were 65 and 62 when corn or barley respectively were grown

Table 3. A summary of the analyses of variance for the intercropped sugar beet experiments at Huntley, Montana in 1969 and 1970.

Source of Variation	DF	Root Yield		Top Yield		% Sugar	
		1969	1970	1969	1970	1969	1970
Reps	3						
Spacing (A)	3	*	**	**	**	*	NS
Error (a)	9						
Interseeded Crops (B)	3	**	**	**	**	*	*
A x B	9	*	**	*	**	NS	**
Error (b)	36						
Total	63						

* Significant at .05 level
** Significant at .01 level

Table continued. . .

Table 3. (continued)

Source of Variation	DF	% N Leaves		% N Roots		% P Leaves		% P Roots		% K Leaves		% K Roots	
		1969	1970	1969	1970	1969	1970	1969	1970	1969	1970	1969	1970
Reps	3												
Spacing (A)	3	NS	NS	**	NS	NS	NS	*	*	NS	NS	NS	*
Error (a)	9												
Interseeded Crops (B)	3	**	**	**	**	**	**	**	NS	NS	NS	**	NS
A x B	9	*	NS	**	NS	**	NS	**	NS	**	NS	*	NS
Error (b)	36												
Total	63												

Table 4. The effect of row spacing and intercrops on sugar beet yield and sugar content at Huntley, Montana in 1969 and 1970.

Row Spacing	Averages — Sugar Beets — Yield (T/A) - (Fresh Wt. Basis)							
	Pure Stand		W/Beans		W/Barley		W/Corn	
	1969	1970	1969	1970	1969	1970	1969	1970
11"	27.37a*	16.36a	25.88a	10.75a	9.76b	6.40b	8.94b	1.23b
16.5"	25.83a	14.50ab	15.82b	11.16a	15.10a	9.65a	8.46b	4.30a
22"	25.54a	14.14ab	22.59a	10.15a	17.78a	9.43a	14.89a	4.84a
33"	24.58a	12.49b	16.22b	8.11a	16.50a	8.60ab	12.02ab	6.81a

Row Spacing	Percent Sugar - (Fresh Roots)							
	Pure Stand		W/Beans		W/Barley		W/Corn	
	1969	1970	1969	1970	1969	1970	1969	1970
11"	16.45a	13.20a	15.47a	12.12a	14.80a	11.95a	15.25a	5.90b
16.5"	15.37ab	12.90a	15.10ab	12.35a	14.25ab	11.70a	13.37b	12.02a
22"	15.00b	12.47a	14.45bc	11.87a	15.40a	12.25a	14.47ab	12.50a
33"	14.87b	11.70a	13.82c	10.92a	12.65b	11.60a	14.12ab	11.52a

* Means in the same column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

between 22-inch beet rows resulting in 11" spacings between adjacent rows in 1969. Beans were not competitive. When beans, barley or corn were grown between 33-inch beet rows resulting in 16.5" spacings between adjacent rows, percent reductions were 36, 39 or 66 respectively in 1969. Corn was most competitive followed by barley and beans (Figure 1, 2). The same trend continued in 1970 with greater reductions in sugar beet yields (Table 5 and Figure 1, 2). Percent sugar was not significantly affected by intercrops.

These results can be partially explained by the greater competition of the taller intercrops for light. Both corn and barley are tall crops. Heights of corn varied from 128 to 163 cm in different row spacings and barley height ranged from 87 to 96 cm, while sugar beets ranged from 30 to 55 cm and bean heights were from 20 to 30 cm. When sugar beets and corn were grown together with 11" or 22" row spacings, light measurements showed that 6% or 26% of full sunlight was falling on the top of the sugar beet canopy while only 4% or 6% of full sunlight penetrated through the canopy in the rows at solar noon (12:45 PM) on August 24, 1970 (Table 6). At this same time when beets and barley were grown in alternate rows at 11" and 22" spacings, light reaching the top of the beet canopy was 89% and 94% while at the bottom canopies penetration was 6% and 10% respectively. Beans planted with sugar beets had little effect on the light reaching the beet canopy. Corn intercepted more light than the barley on every date measured (Table 6).

Table 5. The effect of the competition of beans, barley and corn upon the yield and sugar content of sugar beets at Huntley, Montana, 1969-1970.

Treatments	S. Beet Yield 1969	S. Beet Yield 1970	% Reduction in Yield 1969	% Reduction in Yield 1970	% Sugar 1969	% Sugar 1970
Sugar beets, 22" spacing alone	25.54a*	14.14a			15.00a	12.47a
" " " " beans between rows	25.88a	10.75b	101	24	15.47a	12.12a
" " " " barley " "	9.76b	6.40c	62	55	14.80a	11.95a
" " " " corn " "	8.94b	1.23d	65	91	15.25a	11.80a
Sugar beets, 33" spacing alone	24.58a	12.49a			14.87a	11.70a
" " " " beans between rows	15.82b	11.16a	36	11	15.10a	12.35a
" " " " barley " "	15.10b	9.65a	39	23	14.25a	11.70a
" " " " corn " "	8.46c	4.30b	66	66	13.37a	12.02a

* Means in the same column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

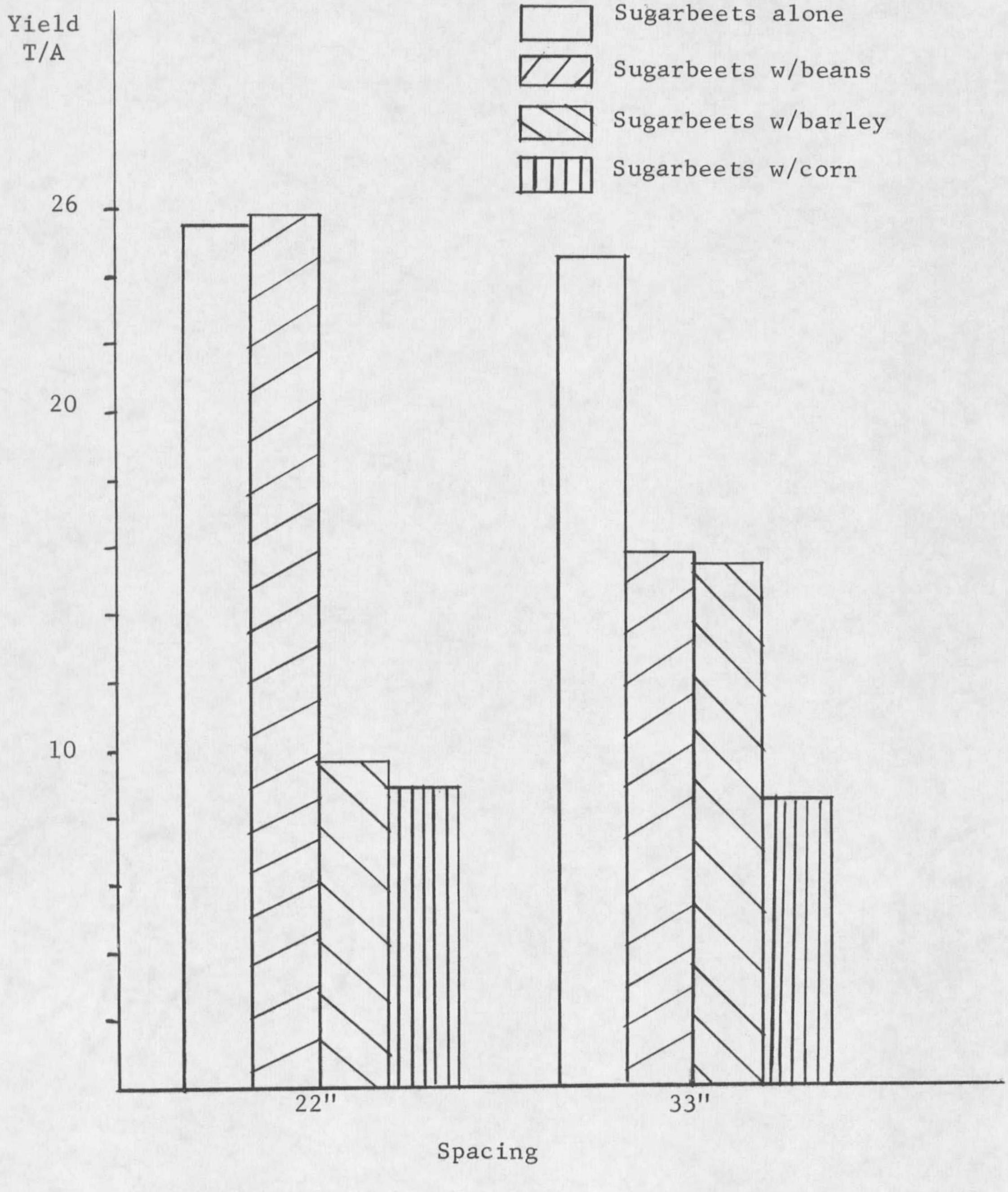

Figure 1. The effects of intercrops on sugar beet yield at Huntley, Montana in 1969.

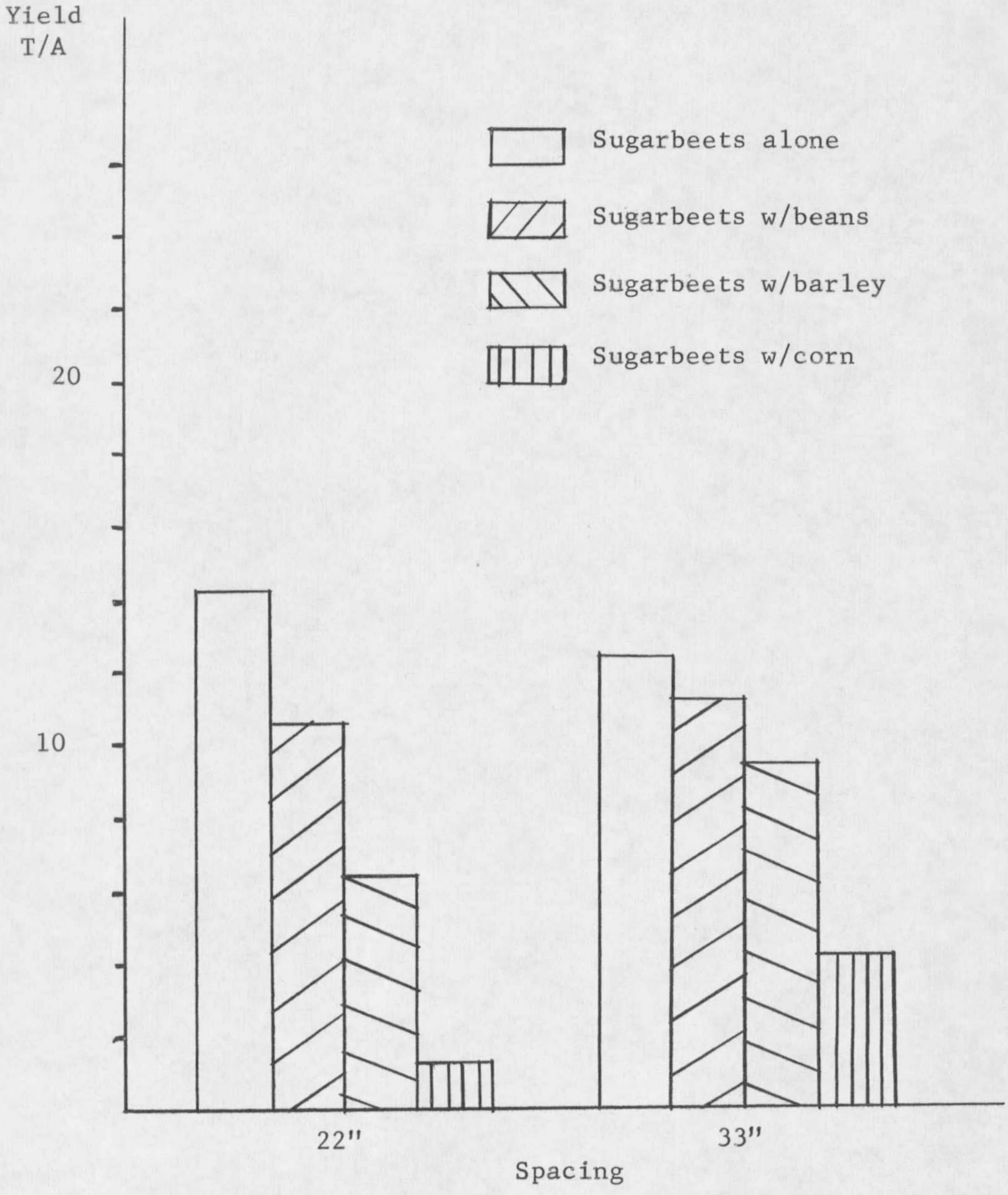

Figure 2. The effects of intercrops on sugar beet yield at Huntley, Montana in 1970.

Table 6. The percentage of incident radiation penetrating to the top and the bottom of the sugar canopy when grown with a companion crop at 2 spacings at Huntley, Montana in 1970.

	% of Light Penetration					
	At the top of canopy					
Dates	Aug. 24		Sept. 3		Sept. 16	
Spacings	11"	22"	11"	22"	11"	22"
Crops						
8:00 AM						
Pure Stand	100	100	100	100	100	100
W/beans	100	100	100	100	100	100
W/barley	47	94	100	100	89	100
W/corn	10	85	14	78	8	31
10:00 AM						
Pure Stand	100	100	100	100	100	100
W/beans	100	100	100	100	100	100
W/barley	89	96	83	100	99	100
W/corn	74	64	7	76	16	58
12:45 PM (Solar Noon)						
Pure Stand	100	100	100	100	100	100
W/beans	100	99	100	100	100	100
W/barley	89	94	91	100	89	100
W/corn	6	26	6	63	7	67
3:00 PM						
Pure Stand	100	100	100	100	100	100
W/beans	94	96	100	100	100	100
W/barley	27	92	63	100	92	100
W/corn	7	59	11	36	11	26
5:00 PM						
Pure Stand	100	100			100	100
W/beans	90	90			100	100
W/barley	68	90			84	100
W/corn	4	79			20	32

Table continued. . .

Table 6. (continued)

Dates / Spacings / Crops	Aug. 24 11"	Aug. 24 22"	Sept. 3 11"	Sept. 3 22"	Sept. 16 11"	Sept. 16 22"
	% of Light Penetration At the bottom of canopy					
8:00 AM						
Pure Stand	4	9	1	10	1	1
W/beans	9	15	5	14	1	8
W/barley	4	13	5	10	4	4
W/corn	3	3	5	5	4	1
10:00 AM						
Pure Stand	3	10	3	5	1	4
W/beans	5	8	16	9	4	8
W/barley	5	14	7	7	6	8
W/corn	4	5	5	3	4	4
12:45 PM (Solar Noon)						
Pure Stand	8	19	4	6	2	6
W/beans	48	49	12	23	2	9
W/barley	6	10	12	27	4	34
W/corn	4	6	4	6	2	4
3:00 PM						
Pure Stand	5	32	3	5	5	5
W/beans	5	9	7	9	5	7
W/barley	5	9	9	13	5	7
W/corn	5	7	7	6	7	3
5:00 PM						
Pure Stand	4	4			1	1
W/beans	4	11			8	7
W/barley	4	8			1	6
W/corn	8	8			2	1

Yield reductions of beets may be explained by the temperature in beet canopies. Air temperatures in canopies of intercropped sugar beets are higher than the air temperature of pure stand beet canopies for both 11 and 22-inch rows (Table 7) at solar noon. As a result, reduction in yield might be explained by reduction of light from the shading of tall crops and by increase in air temperatures of interseeded beets in comparison with pure stand beets.

2. Leaf to Root Ratio

When the light intensity falling on the sugar beet canopy was reduced by intercrops, the overall growth rate decreased but root growth was decreased more than leaf growth, resulting in higher leaf to root ratio: 2.55, 1.97, 1.56 and 1.11 when sugar beets were planted with barley, corn, alone, and with beans respectively in 1969. In 1970 the trend differed slightly from 1969. Sugar beets planted with corn gave a leaf to root ratio of 1.60; with beans 1.44; with barley 1.41 and for sugar beets alone 1.32. The different trends between 1969 and 1970 might be partially explained by weather conditions in 1970 (after planting) which were favorable for the warm season crops corn and beans. Therefore, corn and beans were more competitive than the barley. As a result, sugar beet root growth was slower than the leaf growth giving higher leaf to root ratios in both years.

3. The Effect of Intercrops on the Nitrogen, Phosphorus and Potassium Content of the Leaves and Roots of Sugar Beets

The analysis of variance of the effect of intercropping upon percentages of N, P, and K in the leaves and roots of sugar beets are presented in Table 3.

Shading reduces growth but increases nitrogen and phosphorus content of the leaves and roots of sugar beets. There were no significant differences in potassium content in either leaves or roots in 1969 or in the roots in 1970. N, P, and K levels were higher in leaves than in roots (Table 8).

When intercropped corn or barley reduced the light intensity at the top of the beet canopy, nitrogen and phosphorus content increased in the leaves and roots of beets in 1970. The trend was different in 1969 than in 1970 for percent nitrogen in leaves and roots, and percent potassium in leaves. This was probably due to a significant interaction of spacings with intercrops (Table 9). Nitrogen content of sugar beets intercropped with corn and barley increased as the spacing was increased (Figure 3). Explanation could be that early in the season corn and barley shaded the sugar beets. The accumulation of nitrogen was increased in the sugar beet leaves after corn and barley were harvested, especially in wide rows since they received more light than in narrow rows. Another reason could be such that shading reduced carbohydrate production but mineral uptake was adequate as shown by the

Table 7. Comparison of the temperature in the canopies of interseeded sugar beets with that in the pure stand grown at two row spacings, on three different dates at Huntley, Montana in 1970.

	°C					
	11"			22"		
	8/24	9/3	9/16	8/24	9/3	9/16
9:00 AM						
S. Beets	17	20.5	13	17	20.5	13
W/Beans	23	23	21.5	29	23	14
W/Corn	31	22	18	29	22	11
W/Barley	31	23.5	22	24	21.5	14
11:00 AM						
S. Beets	24	22	23.5	24	22	23.5
W/Beans	24	25	25	28	24	23
W/Corn	28	24.5	25.5	28	21	23
W/Barley	25	24.5	22	29	24.5	23
1:00 PM						
S. Beets	28.5	25	22.5	28.5	25	22.5
W/Beans	30	27	25.5	31	28.5	24
W/Corn	29	25	24	30	24	22
W/Barley	31	26.5	24.5	32	28	24.5
3:00 PM						
S. Beets	29.5	24.5	21	29.5	24.5	21
W/Beans	29.5	24	22	31	32.5	22
W/Corn	28	25	21	31	25.5	22.5
W/Barley	30	26	22	34	26.5	22.5
5:00 PM						
S. Beets	29	24	19	29	24	19
W/Beans	29.5	25	18	31	30	19.5
W/Corn	28	24	20	30	24	19.5
W/Barley	30	25	19	30	25	19

Table 8. The average nitrogen, phosphorus and potassium content in the leaves and roots of interseeded sugar beets at Huntley, Montana, in 1969-1970.

	% N		% P		% K	
	1969	1970	1969	1970	1969	1970
Sugar Beet Leaves						
Sugar Beets alone	2.54a*	3.17c	.25b	.23b	NS	NS
W/Barley	2.04b	3.63a	.29a	.27a	NS	NS
W/Corn	2.55a	3.65a	.28a	.26a	NS	NS
W/Beans	2.42a	3.44b	.29a	.23b	NS	NS
Sugar Beet Roots	% N		% P		% K	
Sugar Beets alone	.72b	1.29c	.13d	NS	.83b	NS
W/Barley	.73b	1.39b	.18b	NS	.93b	NS
W/Corn	.70b	1.59a	.21a	NS	1.04a	NS
W/Beans	.80a	1.42b	.17c	NS	1.11a	NS

* Means in the same column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

higher percentage of N, P and K in the leaves.

Higher nitrogen in the leaves and roots of beets inversely affected the sugar content of beets in 1970 (Table 10). This was less evident in 1969. Decrease in sugar content with increasing nitrogen can be seen when we compare the nitrogen content in 1969 and 1970 with sugar content of these years (Table 10). In 1969 there was a lower plant nitrogen content and higher sugar content than observed in 1970.

B. The Effect of Row Spacing and Sugar Beets on Interseeded Crops

The analysis of variance of the data shows that in both years, highly significant yield differences occurred among spacings for corn and barley. Planting interseeded crops with sugar beets also affected the yield of interseeded crops (Table 11).

Yield of barley or corn planted in alternate rows with sugar beets decreased gradually as the row spacing increased from 11" to 33" (Table 12). Bean yields were not affected by increased row spacing. When sugar beets were planted with barley in alternate rows, barley yields were not affected in 22 and 33" spacings in both years (Table 13). Corn yields were reduced 39% in 1969 and 15% in 1970 by intercropped sugar beets in 22" spacing while 14% and 10% in 33" spacing. Beets reduced bean yields the most (94% in 1969 at 22" spacing, 67% in 1970 at 33" spacing). Bean yield, however, increased in both spacings in 1970. Competition for light could probably explain the relative competitiveness of the different intercrops. Barley and corn were tall enough to

Table 9. The nitrogen content of sugar beets grown with barley, corn and beans at Huntley, Montana in 1970.

	CROPS				
Spacing	S. Beets Alone	S. Beets W/Barley	S. Beets W/Corn	S. Beets W/Beans	Average
11"	2.33	1.84	2.37	2.15	2.17
16.5"	2.61	1.98	2.90	2.39	2.47
22"	2.75	1.67	2.54	2.47	2.36
33"	2.48	2.66	2.39	2.66	2.55
Average	2.54a*	2.04b	2.55a	2.42a	

* Means in the same column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

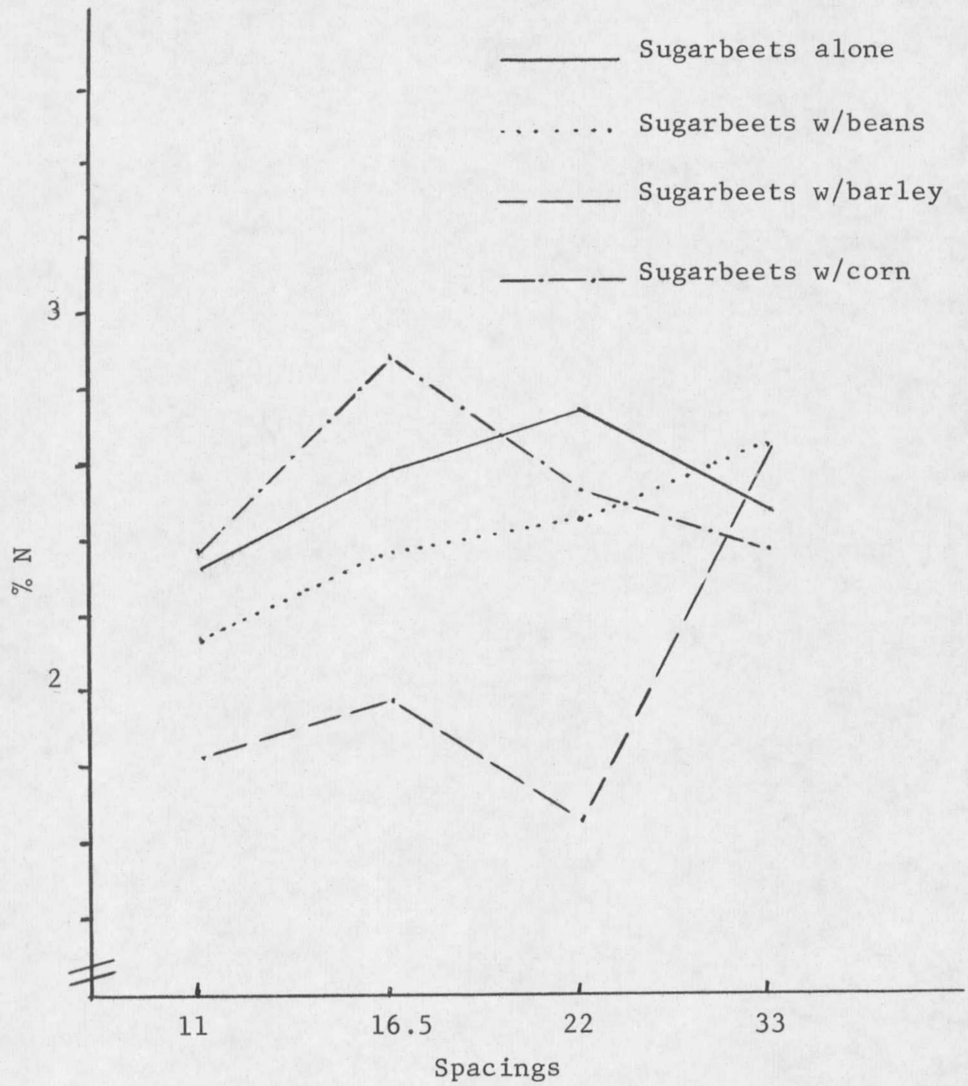

Figure 3. The interacting effects of spacing and intercrops on percent nitrogen of sugarbeets at Huntley, Montana in 1970.

Table 10. The relationship between nitrogen content of sugar beet roots and leaves and sugar content of sugar beets grown at Huntley, Montana in 1969-1970.

	1969			1970		
	% N		% Sugar	% N		% Sugar
	Leaves	Roots		Leaves	Roots	
Sugar Beets alone	2.54a*	.72b	15.42a	3.17c	1.29c	12.57a
W/Barley	2.04b	.73b	14.27b	3.63a	1.39bc	11.87a
W/Corn	2.55a	.70b	14.31b	3.65a	1.59a	10.49b
W/Beans	2.42a	.80a	14.71b	3.44b	1.42b	11.82a

* Means in the same column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

Table 11. A summary of the analyses of variance of sugar beet intercropping experiment at Huntley, Montana, in 1969-1970.

Source	DF	Yield						Percent Nitrogen					
		Barley		Corn		Beans		Barley		Corn		Beans	
		1969	1970	1969	1970	1969	1970	1969	1970	1969	1970	1969	1970
Reps	3												
Spacing (A)	3	**	**	**	**	NS	NS	NS	NS	**	NS	NS	**
Error (a)	9												
Intercrop Competition + or - (B)	1	**	**	**	**	**	**	NS	NS	**	NS	**	NS
A x B	3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Error (b)	12												
Total	31												

Table continued. . .

Table 11. (continued)

Source	DF	Percent Phosphorus						Percent Potassium					
		Barley		Corn		Beans		Barley		Corn		Beans	
		1969	1970	1969	1970	1969	1970	1969	1970	1969	1970	1969	1970
Reps	3												
Spacing (A)	3	NS	NS	*	NS	NS	NS	NS	NS	*	NS	NS	NS
Error (a)	9												
Intercrop Competition + or - (B)	1	**	NS	**	NS	NS	NS	NS	**	**	NS	**	NS
A x B	3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Error (b)	12												
Total	31												

Table 12. The effect of sugar beets on the average yield of barley, corn or beans planted in alternate rows with sugar beets at Huntley, Montana, in 1969-1970.

	Averages T/A					
	Barley		Corn		Beans	
	1969	1970	1969	1970	1969	1970
11"	1.72a*	1.07a	23.70a	19.40a	.45a	.68a
16.5"	1.57a	.78b	23.60b	17.95b	.68a	.41a
22"	1.28b	.65bc	16.80d	16.57c	.50a	.54a
33"	1.05c	.49c	17.17c	12.84d	.55a	.48a

* Means in the same column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

Table 13. The competitive effect of sugar beets upon the yield of barley, corn and beans in 1969-1970, at Huntley, Montana.

Treatment	Yield (T/A) 1969	Yield (T/A) 1970	% Yield Reduction 1969	% Yield Reduction 1970
Barley 22" spacing alone	1.56	.89		
" " " S. beets between rows	1.66	.90		
Corn 22" spacing alone	23.7	20.3		
" " " S. beets between rows	14.62	17.4	39	15
Beans 22" spacing alone	.77	3.5		
" " " S. beets between rows	.05	5.0	94	
Barley 33" spacing alone	1.29	.62		
" " " S. beets between rows	1.35	.62		
Corn 33" spacing alone	22.5	16.5		
" " " S. beets between rows	19.5	15.0	14	10
Beans 33" spacing alone	.74	4.0		
" " " S. beets between rows	.25	6.0	67	

compete for light while beans were shaded more by sugar beets in 1969, while in 1970 the sugar beets and beans were planted on the same date.

The Effect of Sugar Beets on the Composition of Barley, Corn, or Beans

Spacing significantly affected the composition of intercropped corn plants in 1969 (Table 11). But these plant spacings did not affect the % N in barley or the % P in beans. In the 1969 experiment, percent nitrogen in corn increased with increasing spacing and ranged from .97% to 1.18% (Table 14). Table 14 shows that planting sugar beets with corn in alternate rows decreased % N from an "intermediate range" (1.15%) to a "low range" (1.02%) (Hanway 21). Percent N in corn was in the "low range" for 11" and 16.5" spacings and in the "intermediate range" for 22" and 33" in 1969. This suggests that percent yield reduction in corn plants came from a strong competition for nitrogen by the sugar beets. In 1970, with late planting, neither spacing nor intercrop affected the nitrogen composition of corn (Table 15).

Percent phosphorus in corn decreased with increasing spacing in 1969 but when corn was grown with beets in alternate rows, the percent phosphorus in corn increased (Table 14). In 1970, no significant effect was found (Table 15). The same trend was found for the effect of spacing on the percent potassium in corn in 1969 but corn potassium content decreased when beets were planted between the corn rows.

The effect of spacing on the nitrogen content of beans was variable in 1970 and nonexistent in 1969. Nitrogen content decreased from

Table 14. Average nitrogen, phosphorus and potassium content of barley, corn and beans planted with sugar beets in different spacings at Huntley, Montana, in 1969.

	Averages								
	% N (D.M.)			% P (D.M.)			% K (D.M.)		
Spacing	Barley	Corn	Beans	Barley	Corn	Beans	Barley	Corn	Beans
11"	1.94a*	.97d	3.97a	.24a	.21a	.42a	.51a	1.25a	1.89a
16.5"	2.01a	1.06bc	3.94a	.25a	.18b	.40a	.48a	1.13a	1.95a
22"	2.07a	1.12ac	3.94a	.26a	.18b	.40a	.48a	1.08b	1.96a
33"	1.95a	1.18a	3.97a	.29a	.18b	.41a	.54a	.98b	1.95a
Interseeded Crops									
Alone	2.00a	1.15a	4.10a	.27a	.17b	.40a	.50a	1.21a	1.91b
W/ Sugar Beets	1.99a	1.02b	3.81b	.24b	.20a	.41a	.51a	1.01b	1.97a

* Means in the same column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

Table 15. Average nitrogen, phosphorus and potassium content of barley, corn, and beans planted with sugar beets in different spacings at Huntley, Montana, in 1970.

	Averages								
	% N			% P			% K		
Spacings	Barley	Corn	Beans	Barley	Corn	Beans	Barley	Corn	Beans
11"	2.44a*	1.19a	3.92a	.35a	.19a	.36a	.53a	1.27a	1.61a
16.5"	2.53a	1.23a	3.88ab	.37a	.19a	.36a	.59a	1.20a	1.64a
22"	2.52a	1.18a	3.77b	.38a	.20a	.34a	.59a	1.22a	1.63a
33"	2.58a	1.21a	4.00a	.39a	.20a	.36a	.59a	1.20a	1.71a
Crops:									
Alone	2.54a	1.20a	3.94a	.38a	.20a	.35a	.55b	1.24a	1.62a
W/ Sugar Beets	2.50a	1.20a	3.85a	.37a	.20a	.36a	.59a	1.20a	1.68a

* Means in the same column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

4.10 to 3.81 when beets were planted with beans in 1969, but no changes occurred in 1970 (Table 14 and 15).

Explanation of these results would require the use of different fertilizer rates, the calculation of the interactions of N, P, and K, determination of purity, as well as the sugar content of beets, etc. I am interested in pursuing this in order to obtain a better understanding of the physiology of sugar beets.

II. Alternate VS Paired Rows Experiment

The presence of interseeded crops significantly affected sugar beet yields but percent sugar was not affected (Table 16). Spacing, on the other hand, affected percent sugar but not beet yield (Table 16).

Planting corn or barley in alternate rows with beets at 11" spacings decreased beet yield significantly but beans in alternate rows did not affect beet yield (Table 17). Planting intercrops of barley or corn in alternate paired rows also decreased beet yields, but beans had no significant effect (Table 17). Yield reductions of beets planted in alternate single or alternate paired rows with barley or beans were the same (not significantly different) but corn reduced beet yield more in alternate paired rows than in alternate single rows (Table 17). Since corn is taller than barley, reduction in light intensity is more with corn than with barley with a narrow row spacing (11"). With intercropped beets planted in the same arrangement but with 22" row spacings yields were again reduced (Table 17). Corn, in a 22" spacing, reduced

Table 16. Analyses of variance for root yield and sugar content of sugar beets relative to alternate vs paired rows in 1969.

Source	D. F.	Yield	% Sugar
Reps	3		
Spacing (A)	1	NS	**
Error (a)	3		
Crops (B)	6	**	NS
A x B	6	**	NS
Error (b)	36		
Total	55		

Table 17. Yield of sugar beets when planted with beans, corn or barley in alternate single or alternate paired rows in two row spacings at Huntley, Montana in 1969.

	Mean Yields (Tons/Acre)	
	Row Spacing	
Treatment	11"	22"
Sugar beets alone	28.24a*	26.87a
W/beans (alternate single)	25.66a	22.78b
W/corn " "	18.26b	18.22cd
W/barley " "	11.85c	20.20c
W/beans (alternate paired)	25.88a	19.42c
W/corn " "	13.10c	14.40e
W/barley " "	14.38bc	16.63de

* Means in the same column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

Table 18. Sugar content of beets when planted with beans, corn, or barley in alternate single or alternate paired rows in two row spacings at Huntley, Montana, in 1969.

Treatment	Means (% Sugar) Row Spacings 11"	22"
Sugar beets alone	16.38a*	16.62a
W/beans (alternate single)	16.88a	15.40ab
W/corn " "	16.35a	15.13b
W/barley " "	16.08a	15.78ab
W/beans (alternate paired)	16.48a	15.13b
W/corn " "	16.18a	15.80ab
W/barley " "	16.30a	15.35ab

* Means in the same column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

beet yield more than barley and beans in both alternate single and alternate paired rows.

Percent sugar was not affected by intercrops in either alternate or paired rows with 11" row spacing. Some intercrops in 22" row spacings, however, affected sugar content (Table 18). Planting beets in alternate single rows with corn significantly reduced sugar content (Table 18) (16.62% vs 15.13%), but other interseeded crops did not affect sugar content. On the other hand, planting beets in alternate paired rows with beans also reduced sugar content but barley and corn did not affect the sugar content (Table 18). Corn in alternate rows with beets shaded the beets and this probably caused low carbohydrate accumulation in the beets. Percent nitrogen content in the beet roots was highest in beets when planted with beans in 1969 (Table 8). Beans do not compete as vigorously with beets for nitrogen as other intercrops since beans can fix atmospheric nitrogen. This higher nitrogen resulted in lower sugar percentages. This inverse relationship between nitrogen and sugar content has been established by many researchers.

The influence of beets on the yield of barley, corn, and beans is shown in Table 19. The beets had the greatest effect on the yield of beans in 11" spacing. At a 22" spacing, sugar beet competition reduced the yield of beans, corn and barley. In alternate single and alternate paired rows, yield of beans, corn and barley were significantly lower than the pure stand of beans, corn and barley (Table 19). This reduction of yield was more pronounced for beans. The competitive effect of the beets upon the beans could probably be attributed to the greater competition for light. Beets were 30 cm taller than beans and intercepted more light than beans in narrow spacing (11"). Reduction of corn yield by sugar beets was probably due to nitrogen deficiencies which occurred in corn in both spacings being more pronounced in narrow rows. This deficiency of nitrogen contributed to the reduced yield of corn in both alternate single and alternate paired rows.

Reduction in the yield of barley by beets was not significant in alternate single rows at 11" spacing, but it was in alternate paired rows. At 22" spacing, reduction in barley yield was significant for both alternate single and alternate paired rows. This result could also be explained in deficiency of phosphorus for barley (Table 14).

III. Shading Experiment

A. The Effect of Shading on the Yield and Sugar Content of Beets

Calculated F values for shading treatments are presented in Table 20. Shading markedly reduced the average yield of sugar beets and percent sugar in both 1969 and 1970 (Table 21). A 92% reduction in light intensity reduced the yield and percent sugar more than the lowest level of shading (51%) or full daylight but the differences between the highest and second highest (92 and 76%) levels of shading was not significant (Table 21). The same pattern was found for percent sugar both years but not for yield data since the highest shading of 1970 gave

Table 19. Yield of beans, corn and barley when planted with sugar beets in alternate single or alternate paired rows with different spacings at Huntley, Montana, in 1969.

Crops	Yield - Means (T/A) Row Spacings 11"	22"
Beans alone	.860a*	.560a
W/sugar beets (alternate single)	.090b	.140b
W/ " " (" paired)	.060b	.100b
Corn alone	32.85a	19.57a
W/sugar beets (alternate single)	8.98b	8.45b
W/ " " (" paired)	5.75b	5.25b
Barley alone	1.79a	1.58a
W/sugar beets (alternate single)	1.64ab	.87b
W/ " " (" paired)	1.16b	.84b

* Means in the same column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

Table 20. A summary of the analyses of variance of the sugar beet shading experiment conducted at Huntley, Montana, in 1969-1970.

	DF	Yield		% N Leaves		% N Roots		% P Leaves		% P Roots		% K Leaves		% K Roots		% Sugar	
		1969	1970	1969	1970	1969	1970	1969	1970	1969	1970	1969	1970	1969	1970	1969	1970
Reps	3																
Treatment	3	**	**	*	**	no data	**	**	**	**	*	**	**	NS	**	**	*
Error	9																
Total	15																

* Significant at .05 level

** Significant at .01 level

Table 21. The effect of three degrees of shading upon the yield and sugar content of sugar beets grown at Huntley, Montana, 1969-1970. (Tons fresh weight/Acre).

Treatments	Root Yield 1969	Root Yield 1970	Top Yield 1969	Top Yield 1970	% Sugar 1969	% Sugar 1970
0% Shade	27.68a*	12.10a	17.23a	17.97a	16.10a	12.52a
51% Shade	15.96b	6.46b	17.80a	16.19a	14.90ab	12.07ab
76% Shade	11.87c	3.75c	15.52a	12.25b	14.50bc	11.30bc
92% Shade	9.46c	2.27d	11.30b	7.94c	13.18c	11.05c

* Means in the same column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

significantly lower yields than the other treatments while in 1969 the yield with the highest and second highest shade levels did not differ. On the other hand, increased shading markedly reduced the yields of beet tops in 1970 but in 1969 only the highest level of shading affected above ground beet yields significantly (Table 21).

When the light intensity was reduced, the overall growth rate decreased but root growth was decreased more than leaf growth resulting in a higher leaf to root ratio (Table 22). These results could be attributed to the reduction of light intensity. Sugar beet is a heliophyte (sun plant, it requires light for normal development)(48). Shading affected soil and air temperatures within the beet canopies (Table 23). Air temperature under the shade cloths above the beet canopies on August 24, 1970 were 37.5, 31.5, 28, and 28 C when shaded 92, 76, 51 and 0% respectively. The corresponding soil temperatures at a 4" depth were 23, 19, 19, and 20 C. Increased temperatures, both air and soil, should adversely affect the growth of beets since beets are considered a cool climate crop (49). Sugar accumulation was also inversely related to temperature (Ulrich et al. 44). Shortening the length of growing period (164 days in 1969 vs 144 days in 1970), reduced the yield of roots and tops of beets in 1970. This reduction was not obtained in the 1969 experiment. Beets continue uptake of CO_2 and fix it in the shade at slower rate in 1969. A higher yield of beets in 1969 than 1970 could be evidence of this.

Table 22. The effect of shading upon the top/root ratio of sugar beets grown at Huntley, Montana, 1969-1970.

Treatments	Top/Root Ratio 1969	Top/Root Ratio 1970
(4) Full sunlight (100)	0.62	1.48
(1) 51% Shade	1.11	2.51
(2) 76% Shade	1.30	3.26
(3) 92% Shade	1.20	3.50

Table 23. Air and soil temperatures recorded in shading experiment at Huntley, Montana in 1970.

Time and treatment	Temperatures in the canopies of sugar beets			Soil temperatures at (4")		
	8/24	9/3	9/16	8/24	9/3	9/16
9:00 AM						
0% shade	16.5	22.5	21.0	20.5	19.0	17.0
51% shade	21.5	22.5	21.0	23.0	17.0	16.0
76% shade	25.0	21.0	22.0	25.0	18.0	18.0
92% shade	27.0	28.0	25.0	29.5	19.0	19.0
11:00 AM						
0% shade	20.0	22.5	21.5	20.5	18.0	18.0
51% shade	24.0	31.0	21.0	22.0	16.0	17.0
76% shade	29.0	25.5	23.0	25.0	16.5	19.0
92% shade	29.0	32.5	25.5	28.0	19.0	20.0
1:00 PM						
0% shade	28.0	23.5	22.0	20.0	17.5	15.0
51% shade	28.0	23.5	21.0	19.0	15.5	15.0
76% shade	31.5	24.0	21.0	19.0	16.5	15.0
92% shade	37.5	24.0	21.5	23.0	18.5	15.0
3:00 PM						
0% shade	22.0	24.0	21.0	20.5	18.0	17.0
51% shade	24.0	22.0	21.0	24.0	16.5	15.0
76% shade	24.0	23.0	22.0	25.5	17.0	15.0
92% shade	30.0	25.0	22.5	30.0	19.0	15.0
5:00 PM						
0% shade	22.0	28.0	19.0	21.0	20.0	16.0
51% shade	24.0	27.0	17.0	24.5	19.0	14.0
76% shade	24.5	28.0	17.0	25.0	21.0	14.5
93% shade	31.0	29.0	17.5	30.0	21.0	15.5

The lower top : root ratio in 1969 than in 1970 resulted from more root growth in 1969 with the longer growing period.

B. The Effect of Shading on Nitrogen, Phosphorus and Potassium Content of Sugar Beets

The analysis of variance values for nutrient components are presented in Table 20.

Reduced light intensity significantly affected the percentage of N, P, and K in leaves and roots of sugar beets both years (Table 24). Figure 4 shows the relationships between percent N, P, and K and the shading treatments. The N, P and K contents of leaves and roots are higher with lower light intensities. These effects of shading were more pronounced in the leaves.

Averages of percent N in the leaves were higher in 1970 than 1969 (Table 24) and % phosphorus was the same both years. Nutrient composition (N and K) increased with reduced light intensity in both leaves and roots. Percent K increased with shading in 1970. In 1969 % K in roots was increased by shading but the opposite was true for leaves.

The inverse relationships between nitrogen and sugar content of the roots can be seen in Figure 5 and Table 25.

These results could be attributed to the accumulation of sugar in the roots when the quantity of carbohydrates produced by the leaves exceeds that required for respiration and growth. Shading reduced the light intensity falling on some leaves below light saturation and some

Table 24. The effect of shading upon the nitrogen, phosphorus and potassium content of sugar beet leaves and roots at Huntley, Montana in 1969-1970.

Treatments	% N (Leaves)		% N (Roots)		% P (Leaves)		% P (Roots)	
	1969	1970	1969	1970	1969	1970	1969	1970
0% Shade	1.99b*	3.17c	no	1.26b	.21d	.22c	.16a	.16b
51% "	2.23a	3.34b	data	1.39b	.31c	.29b	.15a	.19b
76% "	2.33a	3.37b		1.30b	.32b	.32ab	.13b	.19b
92% "	2.56a	3.55a		1.79a	.36a	.36a	.11c	.27a

* Means in the same column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

Table continued. . .

Table 24. (continued)

Treatments	% K (Leaves) 1969	% K (Leaves) 1970	% K (Roots) 1969	% K (Roots) 1970
0% Shade	3.15a	1.77c	.94c	1.27c
51% "	2.81b	2.52b	1.00b	1.57bc
76% "	2.61b	2.85ab	1.07b	1.78b
92% "	2.17c	3.19a	1.26a	2.66a

* Means in the same column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

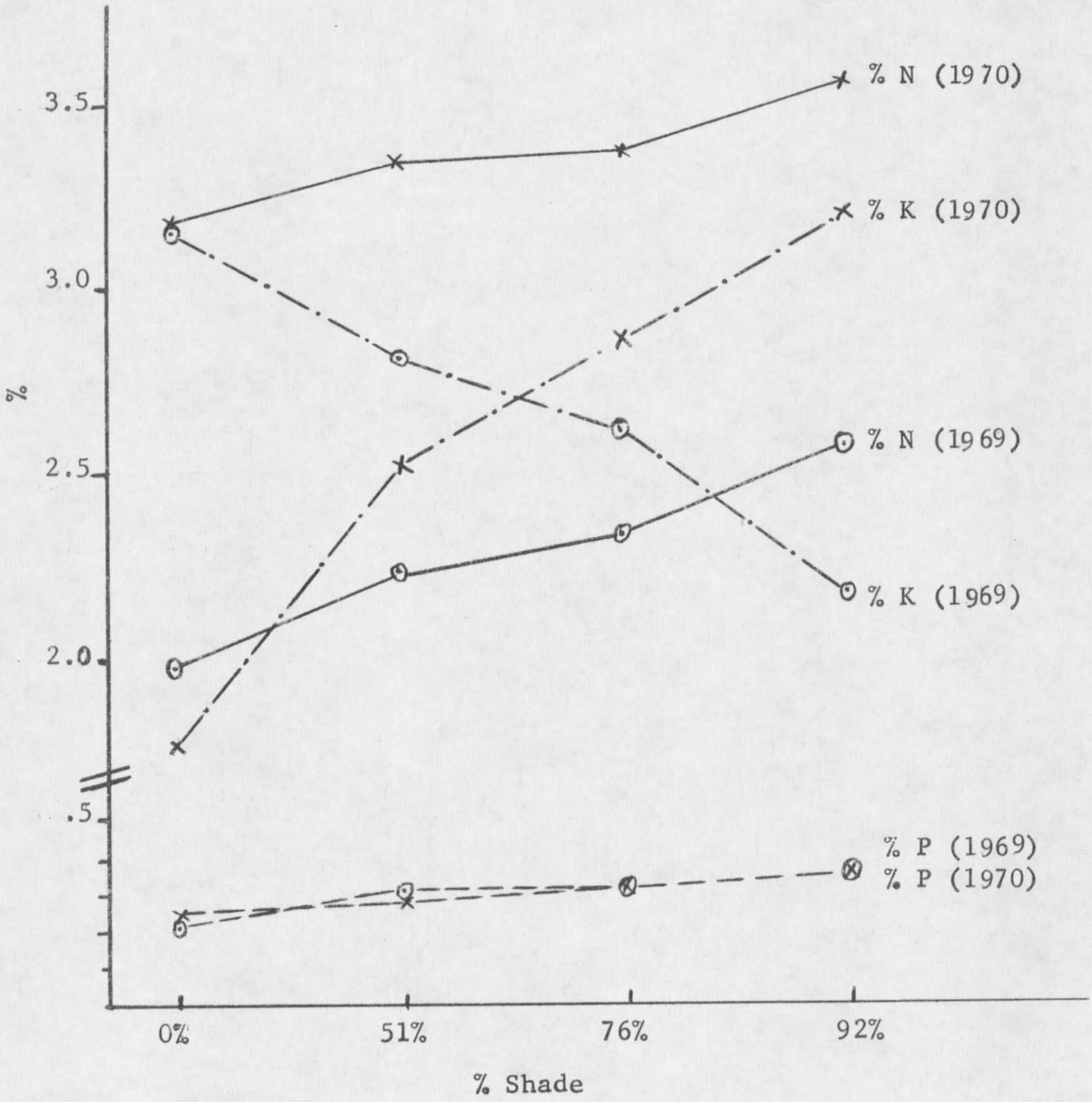

Figure 4. Effects of shading on N, P, and K content in the leaves of sugar beets

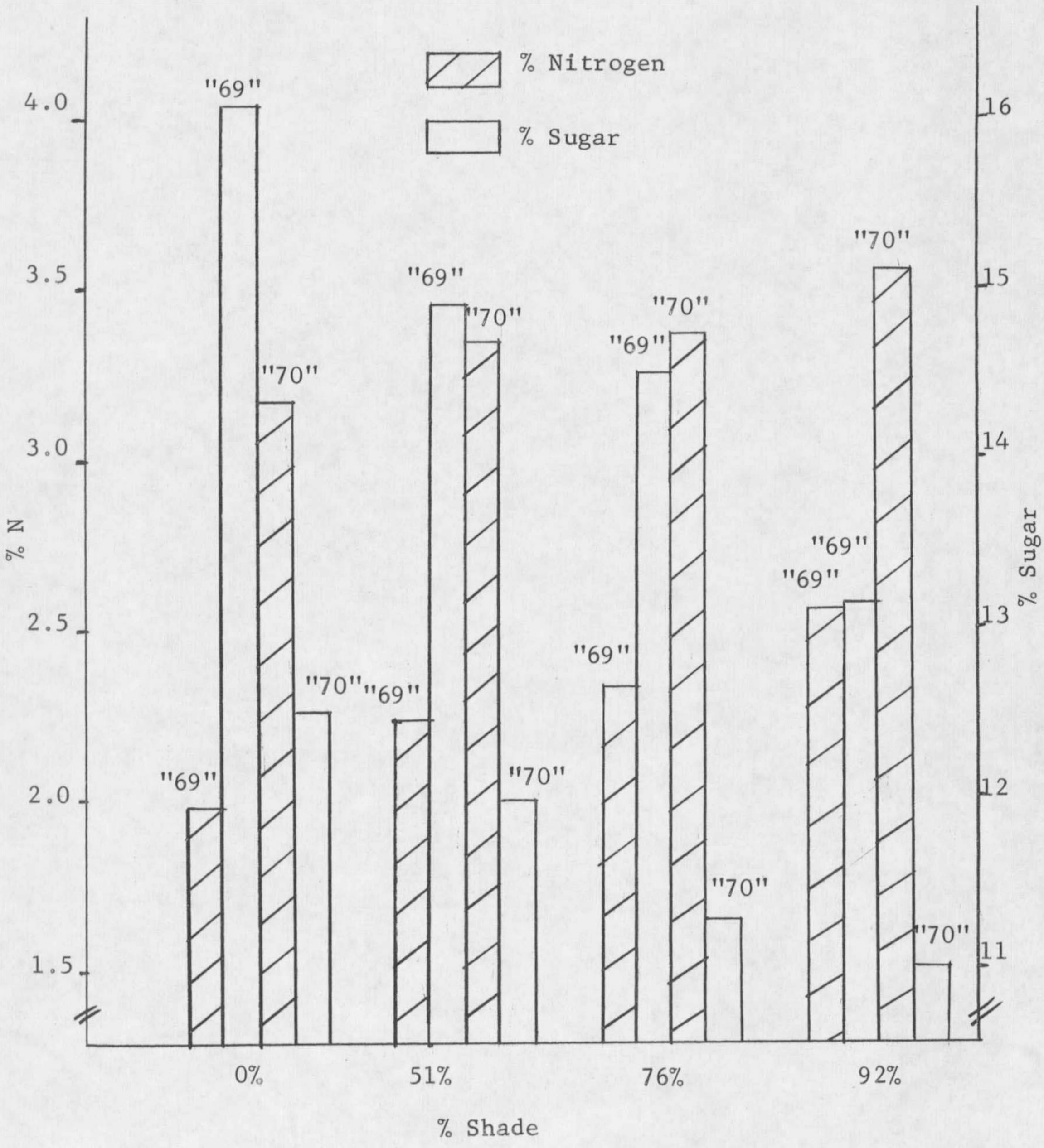

Figure 5. Nitrogen and sugar relationships in the roots with different light intensities in 1969 and 1970.

Table 25. The relationships between nitrogen and sugar contents (percentages) of the sugar beet roots as affected by different levels of shading at Huntley, Montana, in 1969-1970.

Treatments	% N (Leaves)		% Sugar	
	1969	1970	1969	1970
0% Shade	1.99b*	3.17c	16.10a	12.52a
51% "	2.23a	3.34b	14.90ab	12.07ab
76% "	2.33a	3.37b	14.50bc	11.30bc
92% "	2.56a	3.55a	13.18c	11.05c

* Means in the same column followed by the same letter are not significantly different at the .05 level according to Duncan's New Multiple Range Test.

leaves were below the compensation point (same as corn shaded beets in interseeded experiment). Therefore, accumulation of sugar by the roots was reduced but the carbohydrates allowed growth and development of sugar beets. On the other hand, early in the season adequate light and soil nitrogen promoted rapid establishment of the top growth (a large leaf area) before the shade cloth was applied (or before corn shaded beets). After application of shade cloths the top growth slowed down but root uptake of nutrients was not reduced proportionately resulting in high N, P, and K contents. High nitrogen could stimulate the top growth and thus cause beets to remain vegetative and thereby delay sugar accumulation by the roots. This would result in higher leaf to root ratio. Maximum sucrose accumulation is expected with low temperatures and nitrogen deficiency (Ulrich et al. 44). Under the shade cloth temperatures were higher than check plots. The higher temperature in shaded plots would also contribute to lower sugar content in the beet roots.

SUMMARY AND CONCLUSIONS

The objectives of this study were: (1) to determine the competitive effects of other crops (barley, corn, beans, or turnips) on the yield and sugar content of sugar beets, (3) to determine the effect of reduced light intensity on the yield, sugar content and composition of sugar beets, (3) to compare the gross returns per acre from growing two crops in a mixed-culture with returns from growing one crop in a monoculture, (4) to compare the yield and sugar content of intercropped sugar beets planted in alternate single versus alternate paired rows, (5) to determine the effects of a companion crop on the micro-climate (we planned to measure light intensity, soil and air temperatures) and composition of sugar beets.

Three different experiments (1) An Interseeded Experiment, (2) An Alternate VS Paired Rows Experiment and (3) A Shading Experiment were conducted at the Huntley Branch Station of Montana State University at Huntley during 1968, 1969 and 1970.

Results obtained from these studies:

Corn had the greatest and beans the least competitive effect on sugar beet yields. Barley was nearly as competitive as corn. It appears that the taller intercrops (corn 128 to 163 cm and barley 87 to 96 cm) had a competitive advantage for light interception over beets (30 to 55 cm), or beans (20 to 30 cm). Corn reduced light intensity to sugar beets in 11" spacing by 94 percent while corn in 22" spacing reduced light intensity 74 percent at solar noon on August 24, 1970. At this same time barley reduced light intensities 11 percent and 6 percent in 11" and 22" spacings respectively. Beans and turnips did not reduce light intensity in the beet canopies when planted in alternate rows. Increased air temperature in canopies of intercropped sugar beets also may have contributed to the reduction of sugar beet yields since sugar beets grow better in a cool climate.

Sugar beets were more competitive to intercropped beans than to other intercrops.

The relative competitiveness of the different intercrops to sugar beets was the same for alternate paired 22" rows as for alternate single 22" rows. Corn and barley were almost equally competitive to sugar beets in alternate or paired rows but beans and turnips were less competitive to sugar beets in alternate single rows than in paired rows. It appears that plants shorter than sugar beets do not obtain enough light to compete effectively with sugar beets when planted in alternate single rows.

Narrow (11") spacing of pure stand sugar beets gave a higher sugar percentage in 1969 and a higher yield in 1970 than wide rows.

Sugar beets grown with beans in alternate 22" rows produced the largest gross return per acre.

Shading of the sugar beet canopy decreased the overall growth and root weights, which were farther from the source of photosynthate, were decreased more than leaf weights resulting in higher leaf to root ratios.

Shading reduced growth of sugar beets but increased the percentage content of nitrogen and phosphorus in the leaves and roots. Shading had no significant effect on potassium content. Nutrient contents were higher in leaves than in roots.

Nitrogen and sugar content are inversely related. High nitrogen in the leaves and roots of sugar beets adversely affected the sugar content of sugar beets in 1970. The higher sugar contents obtained in 1969 were associated with nitrogen contents that were lower than in 1970.

The following conclusions can be drawn from this study:

(1) Narrower spacing may be practical for pure stand sugar beets since percent sugar and yield are increased due to changes in the morphology of beets if the machinery is available for cultivation and harvest.

(2) Planting sugar beets with beans may be profitable if the cost of labor is low or suitable machinery is available for harvesting.

(3) Planting sugar beets with beans might also be recommended since less nitrogen fertilizer would be needed giving more profit per acre.

(4) If the market is good for barley or corn and the growing season is longer, then planting sugar beets with corn or barley can be profitable.

(5) Since government allowances are based on acreages, planting

mixed cultures in a unit area, will provide more income as well as weed control and another agronomic aspect of crop production.

(6) Additional sugar beet studies are needed to determine the interactions of factors such as purity, different fertilizer elements and rates, and plant content of nitrogen, phosphorus and potassium.

APPENDIX

Table 26. Summary of analyses of soil from sugar beet intercropping experiment at Huntley, Montana in 1969.

Soil Depths (in.)	Soil pH	Conductivity (mmhos)cm	Organic Matter	Avail. P (Lbs./A)	Avail. K (Lbs./A	Nitrate Nitrogen PPM	Sodium Meg/ 100 g
0-6	6.9	2.2	4.13 (M)	245 (H)	1000	19.2	1.74
6-12	7.5	2.0	3.55 (M)	245 (H)	1000	26.2	1.65
12-24	8.1	1.4	1.82 (L)	100 (L)	1360	14.2	3.1
24-36	8.1	1.4	1.47 (L)	124 (M)	960	13.5	3.0
36-48	8.3	2.0	1.47 (L)	136 (M)	1000	12.2	5.0

Table 27. Summary of climatic data by months for the calendar year 1969 and averages for the period 1910-69 at the Huntley Branch Station, Huntley, Montana.

	Month - 1969												Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	or Avg.
Precipitation (inches)													
1969	1.08	.12	.38	2.27	.78	6.04	1.16	.79	.56	1.30	.28	.13	14.89
1910-69	.55	.42	.73	1.23	1.94	2.59	.96	.94	1.29	.98	.64	.61	12.88
Max. Temperature (F°)													
1969	14	31	43	69	72	73	85	91	78	54	53	42	59
1911-69	32	37	45	59	69	78	88	86	74	62	46	36	59
Min. Temperature (F°)													
1969	-9	8	17	34	39	46	53	51	43	29	24	17	29
1911-69	7	12	20	31	41	49	54	51	42	32	21	12	31
Mean Temperature (F°)													
1969	3	20	30	52	56	60	69	71	61	41	38	29	44
1911-69	19	24	33	45	55	63	71	69	58	47	34	24	45
Wind (M.P.H.)													
1969	2.3	1.9	2.7	3.3	2.4	2.7	1.6	1.3	1.5	2.6	3.0	2.2	2.3
1911-69	4.5	4.2	4.4	4.8	4.3	3.3	2.8	2.7	2.9	3.3	3.7	4.2	3.8
Evaporation (inches*)													
1969				5.93	7.69	6.67	8.00	8.59	5.23				42.11
1911-69				4.93	7.02	8.19	10.26	9.37	5.79				45.56

Frost Free Period**

1969 June 13 (31°) to Oct. 5, (29°) - 114 days

1911-69 May 18 (30°) to Sept. 22, (30°) - 127 days

* Class A pan (1911 through 1960 - B.P.I. pan - adjusted to Class A pan basis in 1968)

** 32° considered a killing frost.

Table 28. Summary of climatic data by months for the calendar year 1970 and averages for the period 1910-70 at the Huntley Branch Station, Huntley, Montana.

	Month - 1970												Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	or Avg.
<u>Precipitation (inches)</u>													
1970	.59	1.52	.68	2.54	4.43	1.85	.47	.05	1.91	1.00	.92	.44	16.40
1910-70	.55	.44	.73	1.25	1.98	2.58	.95	.93	1.30	.98	.64	.61	12.94
<u>Max. Temperature (F°)</u>													
1970	31	46	44	53	71	83	88	91	73	61	45	34	60
1911-70	32	37	45	59	69	78	88	86	74	62	46	36	59
<u>Min. Temperature (F°)</u>													
1970	7	18	20	26	42	50	54	50	39	30	20	10	31
1911-70	7	12	20	31	41	49	54	51	41	32	21	12	31
<u>Mean Temperature (F°)</u>													
1970	19	32	32	40	56	66	71	70	56	45	33	22	45
1911-70	19	25	33	45	55	63	71	69	58	47	34	24	45
<u>Wind (M.P.H.)</u>													
1970	3.2	3.9	4.4	5.1	3.2	2.7	2.3	2.0	2.7	2.9	2.7	3.2	3.2
1911-70	4.5	4.2	4.4	4.8	4.2	3.3	2.7	2.7	2.9	3.3	3.7	4.1	3.7
<u>Evaporation (inches*)</u>													
1970				4.50	5.96	8.00	8.55	8.17	4.20				39.38
1911-70				4.93	7.00	8.19	10.23	9.35	5.76				45.46

<u>Frost Free Period**</u>

1970 May 13 (30°) to Sept. 12 (32°), 122 days

1911-70 May 18 (30°) to Sept. 22 (30°), 127 days

* Class A pan (1911 through 1960 - B.P.I. pan - adjusted to Class A pan basis in 1968)

** 32° considered a killing frost.

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