THE EFFECTS AND INTERACTIONS OF SOIL MOISTURE, PLANT POPULATIONS AND SOIL FERTILITY ON YIELD AND QUALITY OF SUGAR BEETS

by

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ABSTRACT

The effects of and interrelationships between soil moistures, plant populations, and commercial fertilizers on the yield and quality of sugar beets were studied. Multi-factor experiments were conducted for three successive years; 1954, 1955, and 1956.

Irrigation resulted in a significant increase in yield of beets only in 1955, but had no significant effects on sugar percent or yield of sugar.

A plant population of approximately 26,000 plants per acre gave a higher yield of beets and sugar than plant populations of 19,000 and 39,000 plants per acre.

Fertilizer combinations containing nitrogen gave highly significant increases in yield of beets and sugar in each of the three years. Sugar percent was significantly depressed by nitrogen treatments in only one of the three years. Phosphorus and potassium did not produce a significant effect on the yield or quality of the sugar beets.

There was a significant interaction (spacing x fertilizer) in only one year.

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INTRODUCTION

The first recorded references to the sugar beet (*Beta vulgaris*) are to be found in the writings of the ancient Romans. It would appear that both the red and white varieties were known in the first century A. D., and were in use as human and cattle food.

In 1747, Margraff, a well renowned German chemist succeeded in separating sugar crystals from the white beet. He predicted a great future for his discovery, but it remained for Franz Carl Achard, a student of Margraff, to establish the commercial importance of the discovery. Achard invented a process for extracting sugar from beets and then gained the notice and material assistance of Frederic the Great. The first sugar beet factory was built at Cunern, in Lower Silesia, in 1802. At this time the percentage of sugar averaged between three and four percent and the factory could process only a few hundred pounds of beets a day.

The work in Lower Silesia attracted the notice of Napoleon I, who visualized the enormous possibilities and value of such a discovery to his country. He established technical beet sugar schools and compelled farmers to grow sugar beets. By 1813, 334 factories were erected in France with an output of nearly 7,100,000 pounds of sugar. Real progress in the improvement of the sugar beet was not made until the Vilmorins commenced a research program designed to improve the type and the sugar content.

The first factory in England was erected in 1860. In 1881 the sugar beet industry became established in the United States, and shortly after in Canada as well.

A sugar beet processing plant was erected in Fort Garry, Manitoba, in 1940. In the first year of operation it processed 95,131 tons of beets which were harvested from 15,682 acres. Since then the acreages of beets grown, while fluctuating from year to year, have gradually increased, until in 1956, 228,917 tons were harvested from 22,818 acres.

The ability of a sugar beet crop to produce a maximum yield is influenced by the same environmental factors that influence the productivity of any other crop plant. These are the extent of the feeding area, the availability of nutrients, the amount of moisture, air, soil reaction, the presence of sunlight, and a suitable temperature. The importance of and the extent to which these factors affect the development of plants vary greatly between species and to a lesser degree within species.

The establishment of the sugar beet industry in Europe, demanded the development of a system and pattern of growing sugar beets. The factors of plant population and distribution were studied first. As a result, the spacing patterns were designed so as to give the highest possible yield per acre. This was accomplished by very close spacing both between the row and within the row. In the early stages of the industry most of the field work was accomplished through the use of hand labour. With an increase in mechanization spacing patterns and plant populations were modified. However, all these modifications were made in order to obtain the greatest profitable return per acre.

Through the years the industry became established in more and more countries. During the period that the sugar beet industry was being established in the United States, the cultural methods used were largely determined by those employed in Europe. Shortly after its establishment, however, the importance of developing proper cultural methods for the conditions in the United States growing areas became apparent. Realizing the significance of improved cultural methods in the growing of sugar beets, the industry began extensive investigations. The results of these investigations have largely influenced the cultural practices employed by sugar beet growers. The factors which were investigated most intensively and extensively were the effects of soil moisture conditions, fertility levels, and the distribution and population of plants per acre on the yield and quality of sugar beets.

The expansion of the industry made apparent the need for regional experiments, since it was found that the optimum treatment for highest yields varied between growing areas.

The sugar beet industry was established in Manitoba in 1940 and since then a number of cultural experiments have been conducted by the Manitoba Sugar Company. The factors studied were the effects of various plant populations, various plant distribution patterns, and commercial fertilizer treatments on yield and quality of sugar beets. However, these investigations did not give consistent results from year to year and did not include studies under irrigation.

In view of the limited information available on the effects of plant populations and fertilizer on sugar beets grown on Manitoba soil and the inconsistency of results, a multifactor experiment was designed to investigate the effects of an the interrelationships among soil moisture, plant populations, and commercial fertilizers on the yield and quality of sugar beets. The investigation was made on Riverdale silty clay soil at the University of Manitoba.

REVIEW OF LITERATURE

Irrigations:

Irrigation as an art has been practised for more than four thousand years in the old world and perhaps for nearly two thousand years in some parts of North America (11). The first irrigation in America by white man took place slightly over 100 years ago when settlers of the Salt Lake Valley of Utah irrigated a field of potatoes (11).

At present 85 percent of the sugar beets grown in the United States are grown in irrigated areas, whereas, in Alberta the entire commercial sugar beet acreage is confined to districts where irrigation water is available (7). Manitoba farmers have not used irrigation on commercial sugar beet crops.

Sugar beets have been found able to utilize moisture over a wide range without affecting growth or sugar content (10). This range extends from field capacity, which is the moisture held in a soil when movement has practically ceased after a rain or an irrigation, to the permanent wilting percentage, which is the soil moisture content at which plants wilt and do not recover unless water is added to the soil (10).

Archibald and Haddock (2) in Idaho found that plots kept moist all season by sprinkler irrigation and those kept moist until August 14th gave the highest yield of beets. Keeping the soil relatively moist all season by furrow irrigation had an adverse effect on yield. They also found that on plots where irrigation was delayed for ten days during a critical period the yield was reduced by five tons per acre. Nuckols (35) in Nebraska presented evidence that the greatest efficiency in the use of both water and land was obtained by frequent irrigations with a minimum application rate of three inches. Marcum <u>et al</u>. (31) in California reported that occasional wilting for limited periods of time did not affect yield adversely. Another group of investigators in Wyoming came to the same conclusions (32).

Larson (30) in Montana conducted a three year study on the irrigation of sugar beets, for the purpose of determining how much water to apply and when to apply it. He outlined and discussed four factors, which should be considered in developing sound irrigation practices. These were: the amount of water required to grow a crop of sugar beets; the amount of water a soil will retain; the feeding zone of sugar beet roots; and the frequency of sugar beet irrigation.

Firstly, he reported that a yield of 22 tons per acre was obtained from a total water use of 22.5 inches. Of this total 65% was utilized from the first foot soil, 17% from the second foot, 13% from the third foot, 4% from the fourth foot, and 1% from the fifth foot. The maximum daily water use occurred during late July and all of August. The water use figure of 22.5 inches included the loss due to evaporation from the soil as well as transpiration through the leaves. This figure was based on data from one year and can be taken only as an indication of the amount of water used. Different results could be expected under other sets of climatic conditions.

Secondly, he reported that generally soils store from 0.5 to 3.0 inches of water, available to the crops, per foot of soil. Sandy (coarse textured) soils, stored the least amount of available moisture and heavy (fine textured) soils the most. Soil texture will govern the amount of irrigation required, which at no time should exceed the moisture holding capacity of the soil.

A third factor affecting the amount and frequency of irrigation was the feeding zone of sugar beet roots. On July 1 the roots were largely in the surface foot of the soil. At that time, a 2 inch irrigation was sufficient since 2 inches of water was the available storage capacity of a foot of that soil. Late in July when the roots had extended 3 feet in depth, 6 inches of water brought the top 3 feet of soil from the permanent wilting percentage to the field capacity. Actually somewhat lesser amounts of water were needed since not all the available moisture was used prior to irrigation.

Fourthly, the frequency of irrigation was determined by the moisture tension of the soil. At field capacity the water was held by a force of five pounds per square inch. As the soil became drier the force of attraction between the soil and water increased until plants could not remove moisture from the soil. When the plants could no longer draw moisture from the soil, the soil was at the permanent wilting percentage and the water was attracted to the soil by a force of 225 pounds per square inch. The amount of energy required to draw moisture from the soil was equal to the force of attraction between the soil and water. As the energy required by the plant to obtain water became too great, growth was reduced. The most economical use of water was obtained when the plants were allowed to remove 75% of the available water from the root zone prior to irrigation. When 75% of the available water was removed the moisture tension was approximately 50 pounds per square inch.

In conducting irrigation experiments it was imperative that a relatively accurate and practical method of measuring soil moisture was available. Various investigators have used Bouyoucos gypsum blocks for determining the amount of moisture present in the soil (6, 16). Edlefsen et al. (16) of the University of California made the following report:

"From our work we conclude that the blocks have approximately the same resistance in different soils when all available moisture is used, and also have approximately the same resistance at moisture equivalent in different soils. We believe that the resistance of the blocks is a measure of the energy per unit mass required to extract the water from the soil. ... This energy per unit mass required to remove the water from the soil is approximately the same for all soils tested at the permanent wilting percentage and for moist soils at the field capacity ..."

Spacings:

Doxtator (14) in Colorado found that the yield of beets from 20 inch rows exceeded the yield from both 24 and 28 inch rows. His results also indicated that there was a trend towards higher sucrose percentage as the population per acre increased. Schreiber (U.D.)[*] in Manitoba tested various row spacings (18, 22, 26, and 30 inches) and within to row spacings (9, 12, 15, and 18 inches) and obtained maximum yields with 18-inch row spacing and 12-inch spacing in the row. Increasing space allotments either by increasing row width or spacing in the rows depressed sugar percentage. This decrease became progressively greater as the population per acre decreased or as the space allotments per beet

[*] U.D. - Unpublished Data.

increased. In comparing populations ranging from 13,050 to 31,360 beets per acre, Schreiber (U.D.) obtained the optimum yield quantitatively and qualitatively from the highest beet populations. Other workers (7, 15) have also found that close spacing increased both the yield of beets and the sugar percentage. Skuderna (41) recommended a row spacing not exceeding 22 inches to obtain quality beets in the Red River Valley of Minnesota.

In an experiment at Fort Collins, Colorado, in 1945 the highest yield of sugar beets was obtained from a full stand of 100 hills per 100 feet of row (15). There was no difference in yield from a full stand of single plant hills and a full stand with 75 percent of the hills containing single plants and 25 percent containing two or more plants per hill; the 25 percent additional population had no effect on yield. However, there was no conclusive evidence from this experiment that the quality of the crop, with reduced stand of hills, was improved by the additional population in two-plant and multiple-plant hills. Deming (9) states that multiple hills do not compensate for skips.

The type of soil on which the beets are grown is one of many factors which determine the optimum plant populations per acre. Extensive investigations have shown that the optimum populations vary from one growing area to another, but since this experiment is primarly of local interest, reference will be made only to the findings of Schreiber (U.D.) in Manitoba. His experiments in 1954 indicate that the optimum stand for highest yield and quality in the fertile clay loam soils at Altona was 29,000 beets per acre, while the optimum stand in the lighter and sandier soil types near Plum Coulee was 21,800 beets per acre.

Plant populations per acre are determined by the distance between the rows and the distance between the plants within the row. Thus, a desired population can be obtained by changing these spacings independantly or by changing them simultaneously. Although, the final population per acre is important, the method whereby this population is achieved also has a significant bearing on the yield and quality of sugar beets. An experiment conducted in Idaho stresses this very fact (34). Two spacings were tested both having the same number of plants per acre. In one treatment the rows were 22 inches and in the other 44 inches apart. Significantly higher sugar percentage, purity, and yield of beets were obtained from the 22 inch row spacing than from the 44 inch row spacing.

Tingley (43) experimenting in California obtained no significant difference in yield or sugar content from plots with constant row width of 30 inches and spacings of 6, 8, and 10 inches within the rows.

Fertilizers:

The effect of nitrogen applications on the yield of sugar beets has been studied very extensively. In most sugar beet growing areas where tests have been conducted nitrogen has effected an increase in yield of beets. The optimum rates however, vary greatly from area to area, as will be clearly seen in this review.

Larson (29) working in south central Montana obtained yield increases from nitrogen applications of 60 pounds per acre. On the basis of experiments in western Montana, Swift (42) recommended 67 pounds of nitrogen per acre. Haddock (20) studying the nitrogen requirements of sugar beets in Utah found the optimum rate to be 40 pounds per acre. He also found rates of 20 pounds per acre to be unprofitable and 80 pounds per acre to be excessive. In another experiment conducted at the Utah State Agricultural College (19) he found that when other nutrient elements were adequate, an application of 80 pounds of nitrogen per acre increased yields from one to six tons per acre. An additional 80 pounds of nitrogen per acre increased yield only slightly over the first application. Schreiber (U.D.) in 1954 obtained results showing that increased yields and sugar recovery per acre were obtained when 120 pounds of ammonium phosphate (11-48-0) was broadcast and ploughed under in fall. A test conducted by Schreiber (U.D.) in 1943 on land that had been summer fallowed for two succesive years gave a highly significant increase in yield with nitrogen applications of 60 pounds per acre.

In a test conducted at Steinbach in 1947, an ammonium sulfate treatment of 50 pounds per acre gave no increase in the yield of beets (U.D.). In another test conducted at the Manitoba Sugar Company in 1955, rates of 40, 80, and 120 pounds of ammonium sulfate per acre gave no increases in yield (U.D.). Results obtained in 1954 showed that rates exceeding 120 pounds of ammonium phosphate per acre (240 and 360 pounds per acre) had a depressing effect on yield (U.D.).

Many workers in the field (20, 24, 27, 29, 39, 46, 48) found that high rates of nitrogen had a depressing effect on sugar percentage. In one test in the Red River Valley of Minnesota, even small increments of nitrogen tended to lower the sucrose percentage and yield (13). A test conducted at Steinbach in 1947 showed that when ammonium sulfate was used in excess of 50 pounds per acre the sugar percentage was decreased (U.D.). Some workers (1, 24, 27) also observed that when nitrogen was applied early in the season, the depressing effect on sugar percentage was lessened. Extensive studies in Europe on the influence of nitrogenous fertilizers applied to sugar beets have resulted in the general conclusions that excessive quantities of nitrogen depress the sugar content of the beets, delay "ripening" at harvest time, cause excessive top growth, and increase the "harmful nitrogen" content of the beets (46). In 1942 Ulrich (46) working in California studied the relationship of nitrogen to the formation of sugar in sugar beets and found that nitrogen depresses the sugar percentage of the beet. He emphasized that it should not be inferred that all sugar beets high in nitrogen will be low in sugar, or that beets deficient in nitrogen will be high in sugar. In one environment beets high in nitrogen may also be high in sugar, and likewise in another environment beets low in nitrogen could be low in sugar.

When using high phosphate fertilizers, Larson (28) in Montana and Downie (12, 13) in the Red River Valley of Minnesota obtained highly significant increases in yield of beets and sugar per acre. In tests conducted by Schreiber (U.D.) at the Manitoba Sugar Company in 1943 and at Steinbach in 1947 significant yield increases were obtained with phosphorus applications. In the latter experiment the 150 pounds per acre treatments of treble superphosphate did not increase the yield significantly over the 50 pounds per acre treatment.

In an experiment conducted at the Manitoba Sugar Company in 1955, using three rates (40, 80, and 120 pounds) of treble superphosphate per acre, no significant effects on yield were obtained (U.D.). Hills and Veaco (23) conducted experiments at the University of California to study the effects of phosphate fertilizer on the yield of sugar beets. In twelve different experiments using phosphorus applications they got no yield response. Haddock (19) in Utah found that the yield of sugar beets was not increased as a result of phosphorus applications during the three years of experimentation. Phosphorus application caused no significant differences in quality of sugar beets as long as a deficiency did not occur.

Limited reports are available on studies involving the nutrient element potassium. However, these reported studies indicate a lack of response from the use of potassium fertilizers (19, U.D.).

Experimental results that have been reported on the relationship between nitrogen and phosphorus are conflicting. Morris (33) studied conditions favouringphosphate deficiency in sugar beets in Montana, and observed that acute phosphorus deficiencies develope usually in July or August, because by then the available nitrogen is sufficient. Tolman (44) reported on the response to nitrogen and phosphate fertilizers in the Intermountain Area. On farms where there was a response to both nitrogen and phosphate fertilizers, the yield increase on plots receiving both fertilizers was greater than the combined increase of the two added separately. Carlson and Herring (3) are in agreement with the above reports for they state that the presence of phosphate will minimize the detrimental effects of excess nitrogen. Haddock (19) in Utah, and

Larson (29) in Montana, found that phosphorus did not have any ameliorating influence on beet quality even when large quantities of available nitrogen were present in the soil.

The effects of commercial fertilizers on sugar beets is modified by other factors such as soil moisture, plant populations and soil conditions. Several investigators in Utah, found that the yield of beets in response to nitrogen fertilization increased with increasing supply of water, and that the depression of sucrose as influenced by nitrogen fertilization was lessened with increasing water supply (2, 47). In comparing methods of irrigation they found that less nitrogen was available under furrow irrigation than under sprinkler irrigation. Haddock and Kelley (21) found that when beets were grown under high moisture stress, there was little response to added fertilizers.

Haddock (20) found that when nitrogen was applied at a rate in excess of 80 pounds per acre it would increase yields if populations as high as 33,000 plants per acre were used, but would reduce yields if populations of 26,000 or 22,000 plants per acre were used.

Several workers (5, 19, 21, 38) have indicated that the preceding cropping practises and the addition of barnyard manure modify the effects of commercial fertilizer. Olson *et al*. (36) in Colorado, found that the method and time of fertilizer application and the soil moisture conditions affected the uptake by the plant.

MATERIALS AND METHODS

The experiments reported herein for the years 1954, 1955, and 1956 were designed to study the effects of and interrelations between soil moisture, plant population, and soil fertility as they affect the quality and yield of sugar beets. The experiments consisted of various moisture, spacing, and fertilizer treatments arranged in randomized split-plot designs. In each of the three years the main plots consisted of moisture treatments which are hereafter designated by the symbol "W". The varying moisture levels desired were attained by irrigation. Each main plot was subdivided into subplots used for comparing various inter- and intra-row spacings. Spacings are hereafter designated by the symbol "S". The subplots were further subdivided for comparison of various fertilizer combinations of three elements, nitrogen, phosphorus, and potassium. Each of these plots was 50 feet long and four rows wide.

The first replicate for 1954 is presented to indicate the general layout of the plots and their dimensions (See Fig. I).

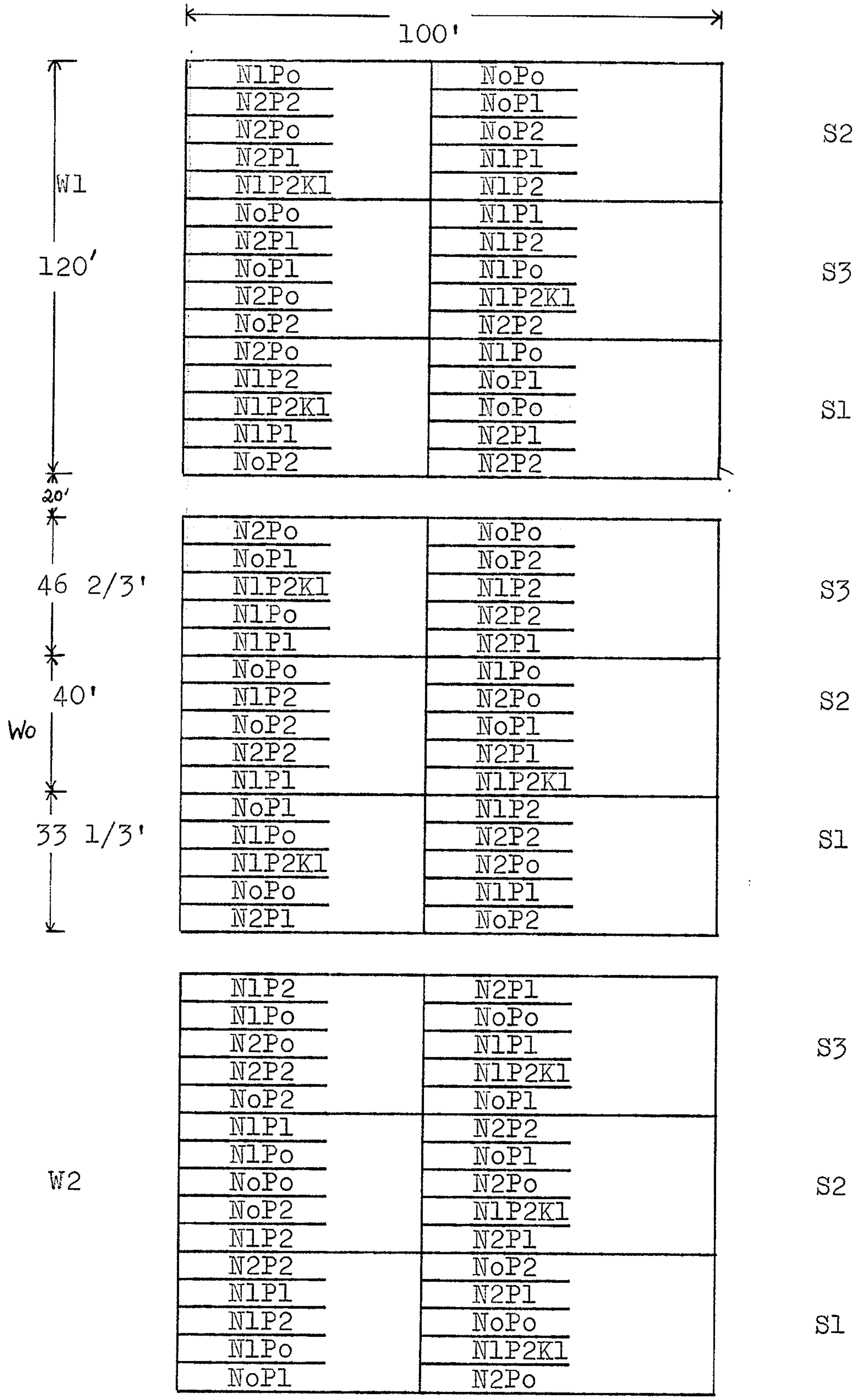

Fig. I. First replicate of experiment layout of 1954.

Details concerning irrigation treatments of the main plots are presented in Table I.

TABLE I

MOISTURE LEVELS USED IN THE SUGAR BEET EXPERIMENT FOR 1954, 1955 AND 1956

Symbol	Irrigation treatment		
	1954	1955	1956
Wo	No irrigation	No irrigation	No irrigation
W1	Continuously moist below 750 cm. water tension at 8" depth till harvest (2 irrigations) total 2"	Continuously moist below 750 cm. water tension at 8" depth till Sept. 10th. (3 irrigations) total 10"	Continuously moist below 750 cm. water tension at 8" depth till Sept. 10th. (1 irrigation) total 1/2"
W2	Same as W1 till Aug. 18th, no irrigation thereafter. (2 irrigations) total 2".		

It is evident from Table I that both irrigation treatments in 1954 received the same amount of water. Additional irrigation after August 20th was not warranted because ample precipitation was obtained. As a result of this and the fact that the irrigation treatments did not outyield the non-irrigated treatments, the experiment was modified in 1955 and 1956 to compare only one irrigation treatment with a non-irrigation treatment.

For irrigation a sprinkler system was placed over designated main plots in such a manner that the laterals bisected the smallest plots, thus assuring uniform irrigation treatment of all plots. The irrigation water was pumped from the Red River and was applied through the use of a portable aluminum sprinkler system. The rate of water application was controlled so as not to exceed the rate of absorption by the soil. Thus unnecessary puddling was avoided.

The amount of irrigation water applied to these different plots and the dates of application are recorded in Table II.

TABLE II

THE DATES OF IRRIGATION AND THE AMOUNTS OF WATER APPLIED (IN INCHES).

Date	1954	1955	1956
August 6	1	-	-
" 12	1	4.5	-
" 17	-	2.5	-
" 27	-	-	0.5
September 6	-	3.0	-
Total	2.0	10.0	0.5

The amount of irrigation water applied and the dates of irrigation varied from year to year because of the fluctuations of seasonal rainfall.

The record of precipitation received, during the summer for the three years, is presented in Table III.

TABLE III

PRECIPITATION RECORDS FOR 1954, 1955, AND 1956.

Month	Precipitation			
	1954	1955	1956	Normal
April	2.04	0.99	0.25	1.29
May	1.95	1.93	1.98	2.17
June	5.64	4.67	2.23	3.17
July	1.73	1.93	3.33	2.91
Aug.	3.32	0.51	5.39	2.52
Sept.	4.58	1.27	0.78	2.19
Oct.	1.23	1.44	2.01	1.43
Total	20.49	12.74	15.97	15.68

The relative moisture content of the soil was determined by the electrical resistance of Bouyoucos gypsum blocks, which were placed in the soil at 12, 24, and 36 inch depths. These were located at one representative place in each of the main moisture plots. The resistance readings are reported in Appendix J.

An attempt was made to maintain the soil of the irrigated plots at the optimum moisture level. On the conductivity bridge (Model RC 12c-1) the readings for optimum moisture would be in the range from 500 to 10,000 ohms. This is a relative reading which has been used satisfactorily by a number of investigators (6, 16).

The dimensions and arrangements of the subplots for spacings were presented in Fig. I.

The minimum distance between the rows that is practical when using modern machinery is about 20 inches. It was therefore decided to test various row-spacings, using the 20 inch rows as the minimum. In 1954 three row spacings 20- (S1), 24- (S2) and 28-inches (S3) were used, while the spacing within the row was kept constant at 12 inches; 12 inches being the recommended spacing for commercial sugar beet crops. These spacings gave potential plant populations of 26,135, 21,780 and 19,530 plants per acre respectively.

After reviewing the 1954 results, the spacing pattern was modified in 1955 and 1956, using only two spacing variables. Between the row spacing was kept constant at 20 inches while within the row spacing was modified to include 6-inch as well as 12-inch spacing, giving respective plant populations of 52,270 (S1) and 26,135 (S2) plants per acre.

The various fertilizer combinations and the rates used in each of the three years are summarized in Table IV. The fertilizers used were ammonium nitrate (33 1/2-0-0), treble super phosphate (0-45-0) and muriate of potash (0-0-60).

TABLE IV

NUTRIENT RATES AND COMBINATIONS

Year	1954	1955	1956
Symbol		Rates*	
No = nitrogen	0	0	00
N1 = "	15	30	30
N2 = "	30	60	60
N3 = "	---	---	90
Po = phosphoric acid	0	0	00
P1 = " "	25	25	25
P2 = " "	50	50	50
K1 = potash	30	30	
		Combinations	
	NoPo	NoPo	NoPo
	NoP1	NoP1	NoP1
	NoP2	NoP2	NoP2
	N1Po	N1Po	N1Po
	N1P1	N1P1	N1P1
	N1P2	N1P2	N1P2
	N1P2K1	N1P2K1	N2Po
	N2Po	N2Po	N2P1
	N2P1	N2P1	N2P2
	N2P2	N2P2	N3P1

*In pounds of Plant nutrients per acre.

Band applications of fertilizer were made, using a Planet Junior planter which was accurately calibrated to apply the desired amounts of fertilizer. The fertilizers were placed in bands at the same depth (one inch) and about one inch to the side of the seed shortly after planting was completed.

Because of the size of the experiment and the special equipment required, the beets were planted by the Agricultural Research Staff of the Manitoba Sugar Company. A four row mechanical planter was used. Each year the plots were planted to the seed then in commercial use. Thinning of the beets was performed by skilled beet labour. Weeding in the row was done with a long handle hoe, while between the row weeding was accomplished with a choremaster hoe or a roto-tiller. Prior to harvest the plots were uniformly trimmed so as to eliminate any possible border effect. The plots were harvested by hand to ensure the recovery of all the beets. Only the center two rows of the plots were used to obtain yield data, thus eliminating any influence of fertilizer from the adjacent plots.

The actual dates of all operations are summarized in Table V.

TABLE V

THE DATES OF PLANTING, FERTILIZER APPLICATION, THINNING, AND HARVESTING

Year	Planted	Fertilized	Thinned	Harvested
1954	May 26	June 2-3	July 3-6	Oct. 19
1955	" 18	May 19-20	June 27-30	" 21
1956	" 19	" 21-24	" 25-28	" 24

The experiment was conducted at the University of Manitoba, in a bend of the Red River. Following is a description of this soil, as given in a Manitoba Soil Survey Report (17).

"The Riverdale soils are very juvenile, highly fertile soils found on the terraces and flood plains along the Red, Assiniboine, Seine, Roseau, and Rat rivers, The soils are recent alluvial deposits with feeble or no development of soil horizons, greyish brown throughout, and ranging in texture from fine sandy loam to silty clay. These grey brown deposits are naturally under fairly dense deciduous forest consisting of elm, basswood, ash, cottonwood, Manitoba maple, etc. Organic matter derived from the tree growth may be present at the surface but, as the thin leaf mat is often covered by alluvial sediments during subsequent inundation, the cross section of the soil profile shows numerous thin bands of organic residue interlayered with the variable textured grey brown alluvium. The Riverdale soils are slightly alkaline in reaction, and highly productive."

The data was statistically analyzed according to methods outlined by C. H. Goulden (18).

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results obtained are reported and discussed independently for each of the three factors investigated in the order of irrigation, spacing and fertilizer.

Irrigations:

The response of sugar beets to the irrigation and non-irrigation treatments are summarized in Table VI.

TABLE VI

THE AVERAGE YIELD OF BEETS PER ACRE, PERCENT SUGAR AND YIELD OF SUGAR IN POUNDS PER ACRE FOR THE IRRIGATED AND NON-IRRIGATED PLOTS IN 1954, 1955 AND 1956.*

Year	Treatment	Beets	Sugar Percent	Sugar
1954	Wo	14.98	16.86	5052
	W1	15.19	17.02	5168
	L.S.D.(.05)	N.S.	N.S.	N.S.
1955	Wo	12.12	18.90	4574
	W1	14.60	18.30	5319
	L.S.D.(.05)	1.66	N.S.	N.S.
1956	Wo	17.03	17.87	6073
	W1	16.58	18.14	6007
	L.S.D.(.05)	N.S.	N.S.	N.S.

*The analysis of variance tables are found in Appendices A to I.

Irrigation had no significant effects on the yield of beets or sugar percentage in 1954. Evidently, the well-distributed rains realized in 1954 eliminated the effects of irrigation. Only two irrigations, of one inch each, were made in early August (Table II), after which date the need for irrigation was rendered unnecessary by the ample rainfall recieved. Consequently, the treatments designated as W1 and W2 were actually the same. Therefore, the W1 and W2 yield data were combined and recorded as W1.

The lack of significant difference in yield between the irrigated and non-irrigated plots in 1954, indicates that the soil moisture at no time dropped to the critical level long enough to affect yield. This is substantiated by the resistance readings recorded in Appendix J which show that at no time did the soil moisture drop to the critical level at the first, second, or third foot depth in 1954.

In 1956 the soil moisture level dropped rapidly towards the end of August, but a 2-inch rain was received before an irrigation treatment could be completed. Hence, there were no significant differences in yield between Wo and W1.

In 1955 seven inches of water was applied during August and three inches in early September as found recorded in Table II. This irrigation treatment resulted in a significant increase in the yield of beets, with the increase in the yield of sugar approaching significance. It is clearly seen from the meteorological data in Table III that very little rain was received during August. This is reflected in the resistance readings (Appendix J) which show that the moisture content, at the one and two foot depths, reached a critical level during August and September in the non-irrigated plots. Two factors may be responsible for the low moisture content of the soil, firstly, there was less (2.94 inches) than normal precipitation during the growing season, and secondly the supply of reserve moisture was low because the plots were on land having grown barley the preceding year.

This investigation was made on only one soil type and the possibility exists that different results would be obtained from irrigation experiments conducted on different soil types. However, before irrigation can be recommended for commercial sugar beets in Manitoba the economic feasibility must be studied.

Spacings:

The effect of spacings on the yield and quality of sugar beets are reported in Table VII.

TABLE VII

THE PLANTS PER ACRE, YIELD OF BEETS IN TONS PER ACRE, PERCENT SUGAR AND YIELD OF SUGAR IN POUNDS PER ACRE FOR THE YEARS 1954, 1955 AND 1956*.

Year	Plants per acre Planned	Plants per acre Actual	Beets	Sugar Percent	Sugar
1954	19,530	19,520	14.60	16.89	4951
	21,780	21,640	14.94	17.08	5092
	26, 135	26,140	15.78	16.93	5346
L.S.D.(.05)			N.S.	N.S.	312.6
1955	26,135	24,305	13.65	18.50	5044
	52,270	34,500	13.07	18.70	4849
L.S.D.(.05)			N.S.	N.S.	N.S.
1956	26,135	26,135	17.25	17.88	6155
	52,270	39,202	16.36	18.13	5925
L.S.D.(.05)			N.S.	N.S.	N.S.

*The analysis of variance tables are found in Appendices A to I.

In 1954 the three spacings did not result in significantly different yields of beets or sugar percentages. However, the yield of sugar from the 20 inch row spacing (26,140 plants per acre) was significantly higher than the yield from the 28 inch row spacing (19,530 plants per acre). Although, the yield increase, in sugar, of the 20-inch over the 24-inch row spacing (21,780 plants per acre) did not prove significant, there was a definite trend toward increased yields as the population increased.

In 1955 and 1956 no significant differences in yield of beets, sugar percent, or yield of sugar were obtained.

The yield data indicate that plots with plant populations as low as 19,520 plants per acre yield significantly less sugar than plots with plant populations of 26,140 plants per acre. The 1955 and 1956 data show that increases in the yield of sugar were not obtained when populations as high as 34,000 plants per acre were used. The evidence from the present investigation seems to indicate that, with uniform distribution of hills, plant populations moderately in excess of about 26,000 plants per acre will produce approximately a full crop of sugar beets. On the other hand, when the stand of beets was reduced below the full stand, there were associated reductions in yield.

The ideal stand of sugar beets would, of course, be a stand of vigorous single plants spaced uniformily at exactly the distance that would result in maximum yields. Plants growing in close proximity compete with each other for light, water, and plant nutrients. Experiments have indicated that when sugar beet plants were spaced at as great a distance as 40 inches by 40 inches this competition was eliminated (7). There was also a marked reduction in yield and sucrose percentage from these 40 x 40 inch stands in comparison with stands spaced 10 x 20 inches.

There is general agreement among workers in the field that excessively low populations have a depressing effect on sugar percent (7, 8, 14, 15, U.D.). However, the various population sizes used in this investigation did not significantly affect sugar percentage. Nevertheless, there was a trend towards higher sugar percentage when the higher populations were used. This was most pronounced in 1955 and 1956. However, despite the upward trend in sugar percent there was a downward trend in sugar yield when high populations were used. The effect of spacing on sugar beets is closely related to the effect of soil fertility and therefore will be discussed in greater detail under "Fertilizer."

Fertilizers:

The average yield of beets, percent sugar, and yield of sugar per acre for the different fertilizer treatments for the three years under consideration are presented in Tables VIII to XIII. The analysis of variance tables are presented in Appendices A to I.

TABLE VIII

THE AVERAGE YIELD OF BEETS IN TONS PER ACRE FOR THE VARIOUS NUTRIENT LEVELS IN 1954, 1955, AND 1956.

Year	Nutrient Level	No	N1	N2	N3	L.S.D. (tons per acre) (.05)	(.01)
1954	Po	14.43	15.23	15.30			
	P1	14.41	15.77	15.67			
	P2	14.38	14.95	15.59			
	P2K1		15.48				
						0.85	1.10
1955	Po	10.60	13.00	15.14			
	P1	11.11	14.65	14.87			
	P2	11.42	13.81	15.18			
	P2K1		13.83				
						1.31	1.73
1956	Po	15.03	17.36	17.68			
	P1	15.71	17.11	17.90	17.26		
	P2	15.25	17.09	17.69			
						0.91	1.19

It is obvious from Table VIII that the rate of potassium used did not have a significant effect on yield of beets, since in both 1954 and 1955 the yields from the N1P2K1 treatments did not yield significantly more than the N1P2 treatments. In 1956 a treatment with an added increment of nitrogen N3P1, which replaced the N1P2K1 treatment, did not yield significantly different from the N1P1 and N2P1 treatments. As a result the nine remaining treatment combinations were analyzed (i.e. excluding N1P2K1 in 1954 and 1955 and N3P1 in 1956). The interaction between nitrogen and phosphorus was used to test the significance of differences due to nitrogen and phosphorus treatments. This analysis was performed on the means of the nine treatments which were presented in Table VIII. The means for each of the levels of the treatments and the L.S.D.'s are presented in Table IX. This method of presenting the data was chosen in order to more clearly indicate the differences in response from the various levels of nitrogen and phosphorus used. This same procedure will be followed in analyzing and presenting the data on sugar percent and yield of sugar.

TABLE IX

THE AVERAGE YIELD OF BEETS IN TONS PER ACRE FOR THE NITROGEN AND PHOSPHORUS TREATMENTS IN 1954, 1955, AND 1956.

Nutrient Level	Year 1954	1955	1956
No (PoP1P2)	14.41	11.04	15.33
N1 (PoP1P2)	15.32	13.82	17.18
N2 (PoP1P2)	15.52	15.06	17.76
Po (NoN1N2)	14.95	12.91	16.69
P1 (NoN1N2)	15.28	13.54	16.97
P2 (NoN1N2)	14.97	13.47	16.67
L.S.D. (tons per acre)			
(.05)	0.56	1.17	0.53
(.01)	0.92	1.93	0.88

The N2 level of nitrogen (30 lbs. per acre) in 1954 was the same as the N1 levels in 1955 and 1956. In all three years highly significant increases in yield of sugar beets were obtained from this rate. In 1955 and 1956 further significant increases in yield over the 30 pound rate were obtained from the N2 rate of 60 pounds of nitrogen per acre. In 1954 the yield from the N1 rate of 15 pounds of nitrogen per acre was not significantly different from the N2 rate.

The effect of the fertilizer treatments on sugar percentage is summarized in Table X.

TABLE X

THE AVERAGE PERCENT SUGAR FOR THE VARIOUS NUTRIENT LEVELS IN 1954, 1955, AND 1956.

Year	Nutrient Level	No	N1	N2	N3	L.S.D.(%) .05	.01
1954	Po	17.03	17.06	16.93			
	P1	16.93	17.02	16.88			
	P2	17.04	16.94	17.02			
	P2K1		16.82				
						N.S.	N.S.
1955	Po	18.68	18.68	18.73			
	P1	18.63	18.56	18.48			
	P2	18.55	18.56	18.48			
	P2K1		18.58				
						N.S.	N.S.
1956	Po	18.13	18.03	17.86			
	P1	18.27	18.22	17.96	17.66		
	P2	18.18	18.02	17.73			
						0.30	0.39

The data presented in Table X clearly indicate that in 1954 and 1955 the N1P2 treatments to which potassium (K1) was added did not differ significantly in sugar percentage from the N1P2 treatments. The N3P1 treatment (90 lbs. of nitrogen per acre), which replaced the N1P2K1 treatment in 1956, produced a significantly lower sugar percentage than the NoP1, N1P1, and N2P1 treatments. The difference in sugar percent between the N3P1 and N2P1 treatments was barely significant at the five percent level, while the differences between the N3P1 treatment and the NoP1 and N1P1 treatments were significant at the one percent level. Thus there was a steady decrease in sugar percent as the rates of nitrogen increased.

The means of the nine remaining treatment combinations were analyzed as mentioned previously. The mean yields of these levels of treatment are presented in Table XI.

TABLE XI

THE AVERAGE SUGAR PERCENT FOR THE NITROGEN AND PHOSPHORUS LEVELS IN 1954, 1955, AND 1956.

Nutrient Level	1954	Year 1955	1956
No (PoP1P2)	17.00	18.62	18.19
N1 (PoP1P2)	17.01	18.60	18.09
N2 (PoP1P2)	16.94	18.56	17.85
Po (NoN1N2)	17.01	18.70	18.01
P1 (NoN1N2)	16.94	18.56	18.03
P2 (NoN1N2)	17.00	18.53	17.98
L.S.D. (% Sugar)			
(.05)	0.15	0.12	0.21
(.01)	0.25	0.20	0.35

The higher rates of phosphorus (P2) depressed the sugar percent significantly below the Po treatment in 1955, but had no significant effect on sugar percent in the other two years. The only significant change in sugar percent in the three years from nitrogen treatments, as recorded in Table XI, was a significant reduction from the N2 rates in 1956.

The average yield of sugar per acre for the fertilizer treatments in the three different years are recorded in Table XII.

TABLE XII

THE AVERAGE YIELD OF SUGAR IN POUNDS PER ACRE FOR THE VARIOUS NUTRIENT LEVELS IN 1954, 1955, AND 1956.

Year	Nutrient Level	No	N1	N2	N3	L.S.D. (lbs. per acre) .05	.01
1954	Po	4908	5193	5169			
	P1	4883	5363	5278			
	P2	4899	5084	5307			
	P2K1		5210				
						285	454
1955	Po	3938	4838	5658			
	P1	4101	5418	5471			
	P2	4200	5103	5599			
	P2K1		5141				
						475	621
1956	Po	5434	6268	6308			
	P1	5726	6225	6424	6090		
	P2	5532	6140	6254			
						326	425

The data presented in Table XII indicate that potassium did not have a significant effect on the yield of sugar.

In neither 1954 nor 1955 did the N1P2K1 treatment result in yields significantly different from the N1P2 treatment. The N3P1 treatment in 1956 resulted in a significantly lower yield of sugar than the N2P1 treatment. The nine remaining treatment combinations were analyzed as discribed for the yield of beets. The means of the yield data of these levels of treatments are presented in Table XIII.

TABLE XIII

THE AVERAGE YIELD OF SUGAR IN POUNDS PER ACRE FOR THE NITROGEN AND PHOSPHORUS TREATMENTS IN 1954, 1955, AND 1956.

Nutrient Level	1954	Year 1955	1956
No (PoP1P2)	4897	4080	5564
N1 (PoP1P2)	5213	5120	6211
N2 (PoP1P2)	5251	5576	6328
Po (NoN1N2)	5090	4811	6001
P1 (NoN1N2)	5175	4997	6125
P2 (NoN1N2)	5097	4967	5975
L.S.D. (lbs. per acre)			
(.05)	217	464	225
(.01)	359	768	372

In each of the years, 1954, 1955, and 1956 significant increases in the yield of sugar were obtained from the nitrogen treatments. In 1954 the increase in yield was significant at the 5% level, while in 1955 and 1956 the increases were significant at the 1% level. In no year did the N2 treatments increase yields significantly over the N1 treatment. Phosphorus did not have a significant effect on the yield of sugar.

The increases in yield of beets and sugar obtained in this investigation, through use of nitrogenous fertilizer were usually significant at the one percent level. The yield increases which were obtained in each of the three years of testing clearly indicated that sugar beets respond to nitrogen applications even when grown on agricultural land of high fertility. These results support the findings of many workers as discussed in the literature review that nitrogen was the one element which appeared to be most universal in giving increases in yield.

The lack of a yield response from phosphorus indicated that the soil on which the experiments were conducted had an adequate supply of available phosphorus. The significant depression of sugar percent at the higher rates of phosphorus observed in 1955 are most likely due to chance occurrence. The depression was observed in only one year and was significant at only the five percent level. However, in that year the experiment was conducted on stubble land and a phosphorus deficiency would appear more probable than an excess, especially since there was no response in both 1954 and 1956 when the experiment was conducted on fallow. The results obtained by Schreiber (U.D.) from experiments conducted in some of the sugar beet growing areas of Manitoba revealed inconsistent responses to phosphorus from area to area. More extensive investigations, including phosphorus placement studies, have begun and should reveal more of the factors influencing the availability and utilization of this element by sugar beets.

The data show that in 1955 the treatments with 60 pounds of nitrogen per acre were not significantly different in sugar percent from the non-nitrogen treatments. On the other hand the 60 pounds of nitrogen per acre treatments resulted in a significant decrease in sugar percent in 1956. This differential response from one year to the other could be partially due to the crop history of the land on which the plots were located. In 1955 the experimental plots were located on land having grown barley the preceding year. Thus the supply of available nitrogen was probably very low, with the result that the additional nitrogen applied was utilized by the plants well before harvest. Therefore additional nitrogen did not have a substantial depressing effect on sugar percent. In 1956 the plots were laid out on fallow land. This soil probably had a higher level of available nitrogen and therefore additional applications may not have been completely used by the plant at harvest time. Thus the excess supply of available nitrogen at harvest is assumed to have caused the decrease in sugar percent.

The results obtained by Ulrich (45), in California, indicate that sugar beet plants have no internal mechanism for "ripening" or "sugaring up" when the plants are grown in a controlled temperature environment highly favourable to beet growth. He also found that during the early period of growth of the sugar beet plant the sucrose concentration of the beet root increased slowly and then gradually reached a maximum value of 8 to 10 percent. This occurred about the time of maximum top development. Thereafter, the sucrose concentration of the storage root remained relatively constant over a wide range of light intensities and day lengths. The reason for the relative stability of the sucrose concentration of the beet root appeared to be that when there was more sugar formed by the beet plant than needed for maintaining top and root growth, the extra sugar was not used to increase the sucrose concentration of the storage root nor to form more and larger leaves but mainly to increase the size of the storage root.

There appears to be an inverse relationship between the nitrogen status of the plant and the sucrose concentration of the beet root. This has been observed many times and has led to the suggestion that beets should be harvested when they have become deficient in nitrogen (45).

Ulrich (45) in 1954 had the following to say on this subject:

"The precaution in the use of nitrogen could be disregarded if a variety could be found that is high in sucrose even though the plant is high in nitrogen. Such a variety if it is to be acceptable commercially, should produce large tops and fibrous roots early in its life cycle, and thereafter, the sugar produced should be distributed within the plant in such a manner that the storage root is always high in sucrose regardless of its nitrogen status. Under these conditions the losses in sugar production that often occur from nitrogen deficiencies or from nitrogen excesses would be avoided, and instead, the sugar produced would be proportional to the time the beets are left in the field."

Interactions:

Of all the interactions studied only one was statistically significant and that in only one year. This interaction was between spacing and fertilizer treatments in 1956 and is presented in Table XIV.

TABLE XIV

THE YIELD OF BEETS PER ACRE FOR THE VARIOUS FERTILIZER TREATMENTS AT THE TWO SPACINGS IN 1956.

Spacings	Treatment combinations									
	NoPo	NoP1	NoP2	N1Po	N1P1	N1P2	N2Po	N2P1	N2P2	N3P1
S1	15.37	15.98	14.70	16.75	16.43	15.88	16.97	17.62	17.09	16.81
S2	14.69	15.43	15.80	17.98	17.75	18.30	18.39	18.18	18.30	17.72

The data in Table XIV indicate that the addition of nitrogen gave greater yield responses with the lower populations (S2) than with the higher plant populations (S1). These findings are contrary to those obtained by previous investigators, as reported in the review of literature. Since this interaction was obtained in only one of the three years under study, additional evidence would be desirable before reaching any definite conclusions.

SUMMARY AND CONCLUSIONS

A three year multifactor experiment with sugar beets was conducted at the University of Manitoba to investigate the effects of and interrelationships among soil moisture, plant spacing, and fertilizers as they affect the yield and quality of this crop.

In three years of experimentation irrigation resulted in a significant response only in 1955 by affecting an increase in yield of beets. In no year did irrigation have a significant effect on sugar percent or yield of sugar per acre.

In 1954 the plant population of 26,140 plants per acre, achieved through the use of 20 inch rows, yielded significantly more sugar than did a population of 19,520 plants per acre, achieved through the use of 28 inch rows. This was the only significant difference obtained from the spacings studied, but there was a trend towards lower yields of sugar beets at the 39,000 plants per acre treatment. As a result of these studies it appears that the optimum population of beets per acre is approximately 26,000 and should be achieved at a 20- or 22-inch row spacing.

Highly significant increases in the yield of beets were obtained for all rates of nitrogen used in each of the three years. Phosphorus and potassium, on the other hand, failed to give a significant yield response. In 1954 the rates of nitrogen used did not give significantly different yields, whereas, in 1955 and 1956 the nitrogen treatments of 60 pounds per acre increased yields significantly over the 30 pound treatments.

The nitrogen rates used in 1954 and 1955 did not have a significant effect on the sugar percent. In 1956 nitrogen applications of 60 pounds per acre and over gave a significant depression of sugar percent. During the three years of this investigation potassium and phosphorus did not have a significant effect on sugar percent.

The results of the fertilizer treatments clearly indicate the importance of adding nitrogen to a crop of sugar beets. The rates used should give significant increases in yield of beets without unduly depressing sugar percent. Even though phosphorus failed to give yield increases in this experiment it could be recommended on the basis of other investigations made in the sugar beet growing area of Manitoba.

Only one significant interaction was obtained (spacings x fertilizers) and this in only one year. Further tests would be desirable before attaching practical importance to it.

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APPENDICES

APPENDIX A

ANALYSIS OF VARIANCE TABLE FOR YIELDS OF BEETS IN TONS IN 1954

Source of Variance	D.F.	S.S.	M.S.	F.	F.05	F.01
Replications (R)	3	812.9314	270.9771	5.77	9.28	29.46
Irrigations (I)	1	3.1463	3.1463	--		
Error (a)	3	140.9595	46.9865			
Main-Plot Total	7	957.0372				
Spacings (S)	2	81.7303	40.8651	3.70	3.88	6.93
I. x S.	2	12.2684	6.1342	--		
Error (b)	12	132.6550	11.0546			
Sub-Plot Total	23	1183.6909				
Fertilizers (F)	9	96.5187	10.7243	3.07	1.94	2.53
I. x F.	9	27.2861	3.0318	--		
S. x F.	18	48.3740	2.6874	--		
I. x S. x F.	18	54.1138	3.0063	--		
Error (c)	162	565.5425	3.4910			
Sampling error	120	677.9561				
Total	359	2653.4821				

APPENDIX B

ANALYSIS OF VARIANCE TABLE FOR SUGAR PERCENT IN 1954

Source	D.F.	S.S.	M.S.	F.	F.05	F.01
Replicates (R)	3	47.15	15.72	34.17	9.28	29.46
Irrigations (I)	1	2.00	2.00	4.35	10.13	34.12
Error (a)	3	1.38	.46			
Main-Plot Total	7	50.53				
Spacings (S)	2	2.48	1.24	1.01	3.88	6.93
I. x S.	2	1.31	.66			
Error (b)	12	14.77	1.23			
Sub-Plot Total	23	69.09				
Fertilizers (F)	9	1.99	.22	1.00	1.93	2.52
I. x F.	9	1.96	.22	1.00	1.93	2.52
S. x F.	18	2.75	.15	-		
I. x S. x F.	18	2.38	.13	-		
Error (c)	162	35.79	.22			
Sampling error	120	54.44				
Total	359	168.38				

APPENDIX C

ANALYSIS OF VARIANCE TABLE FOR POUNDS OF SUGAR IN 1954

Source of Variance	D.F.	S.S.	M.S.	F.	F.05	F.01
Replicates (R)	3	100,751,127	33,583,709	5.78	9.28	29.46
Irrigations (I)	1	997,107	997,107	--		
Error (a)	3	17,433,867	5,811,289			
Main-Plot Total	7	119,182,101				
Spacings (S)	2	9,585,042	4,792,521	3.88	3.88	6.93
I. x S.	2	777,871	388,936	--		
Error (b)	12	14,806,163	1,233,847			
Sub-Plot Total	23	144,351,177				
Fertilizers (F)	9	10,266,400	1,140,711	3.07	1.94	2.53
I. x F.	9	3,776,340	419,593	1.13	1.94	2.53
S. x F.	18	4,903,033	272,391	--		
I. x S. x F.	18	6,029,713	334,984	--		
Error (c)	162	60,224,100	371,754			
Sampling error	120	75,594,261				
Total	359	305,145,024				

APPENDIX D

ANALYSIS OF VARIANCE TABLE FOR TONS OF BEETS IN 1955

Source of Variance	D.F.	S.S.	M.S.	F.	F.05	F.01
Replicates (R)	3	117.8410	39.2803	1.95	9.28	29.46
Irrigations (I)	1	246.9841	246.9841	12.26	10.13	34.12
Error (a)	3	60.4446	20.1482			
Main-Plot Total	7	425.2697				
Spacings (S)	1	13.4734	13.4734	2.60	5.99	13.74
I. x S.	1	4.0864	4.0864	--		
Error (b)	6	31.0878	5.1813			
Sub-Plot Total	15	473.9173				
Fertilizers (F)	9	437.5255	48.6139	13.82	1.97	2.59
I. x F.	9	18.1103	2.0122	--		
S. x F.	9	22.6022	2.5113	--		
I. x S. x F.	9	28.3452	3.1495	--		
Error (c)	108	379.9816	3.5183			
Total	159	1360.4821				

APPENDIX E

ANALYSIS OF VARIANCE TABLE FOR SUGAR PERCENT IN 1955

Source of Variance	D.F.	S.S.	M.S.	F.	F.05	F.01
Replicates (R)	3	96.5315	32.1771	8.75	9.28	29.46
Irrigations (I)	1	14.6410	14.6410	3.98	10.13	34.12
Error (a)	3	11.0375	3.6791			
Main-Plot Total	7	122.2100				
Spacings (S)	1	.6250	.6250	1.05	5.99	13.74
I. x S.	1	.1960	.1960	--		
Error (b)	6	3.5840	.5973			
Sub-Plot Total	15	126.6150				
Fertilizers (F)	9	1.0577	.1175	1.71	1.97	2.59
I. x F.	9	.8778	.0975	1.43	1.97	2.59
S. x F.	9	.3363	.0373	--		
I. x S. x F.	9	1.1002	.1222	1.79	1.97	2.59
Error (c)	108	7.3920	.0684			
Total	159	137.3790				

APPENDIX F

ANALYSIS OF VARIANCE TABLE FOR POUNDS OF SUGAR IN 1955

Source of Variance	D.F.	S.S.	M.S.	F.	F.05	F.01
Replicates (R)	3	1,706,971	568,990			
Irrigations (I)	1	22,187,592	22,187,592	6.63	10.13	34.12
Error (a)	3	10,032,440	3,344,146			
Main-Plot Total	7	33,927,003				
Spacings (S)	1	1,521,390	1,521,390	3.08	5.99	13.74
I. x S.	1	446,266	446,266			
Error (b)	6	2,960,337	493,389			
Sub-Plot Total	15	38,854,996				
Fertilizers (F)	9	60,688,374	6,743,152	14.49	1.97	2.59
I. x F.	9	2,585,182	287,242	--		
S. x F.	9	4,003,382	444,820	--		
I. x S. x F.	9	3,875,110	430,568	--		
Error (c)	108	50,272,925	465,490			
Total	159	160,279,969				

APPENDIX G

ANALYSIS OF VARIANCE TABLE FOR TONS OF BEETS IN 1956

Source of Variance	D.F.	S.S.	M.S.	F	F.05	F.01
Replicates (R)	3	30.1022	10.0340	--		
Irrigations (I)	2	8.0505	8.0505	--		
Error (a)	6	38.8271	12.9424			
Main-Plot Total	11	76.9798				
Spacings (S)	2	31.6394	31.6394	4.64	5.99	13.74
I. x S.	4	14.5505	14.5505	2.13	5.99	13.74
Error (b)	18	40.9242	6.8207			
Sub-Plot Total	35	164.0939				
Fertilizers (F)	9	163.6584	18.1843	10.62	1.97	2.59
I. x F.	18	11.1960	1.2440	--		
S. x F.	18	30.8368	3.4263	2.00	1.97	2.59
I. x S. x F.	36	7.5969	.8441	--		
Error (c)	243	184.8580	1.7116			
Total	359	562,2400				

APPENDIX H

ANALYSIS OF VARIANCE TABLE FOR SUGAR PERCENT IN 1956

Source of Variance	D.F.	S.S.	M.S.	F.	F.05	F.01
Replicates (R)	3	18.8421	6.2807	6.51	4.35	8.45
Irrigations (I)	1	2.8355	2.8355	2.94	5.59	12.25
Error (a)	3	2.8958	.9653			
Main-Plot Total	7	24.5734				
Spacings (S)	1	2.4750	2.4750	3.96	5.99	13.74
I. x S.	1	1.1391	1.1391	1.82	5.99	13.74
Error (b)	6	3.7464	.6244			
Sub-Plot Total	15	31.9339				
Fertilizers (F)	9	6.0450	.6717	3.67	1.97	2.59
I. x F.	9	1.9601	.2178	1.19	1.97	2.59
S. x F.	9	1.9281	.2142	1.17	1.97	2.59
I. x S. x F.	9	1.7016	.1891	1.03	1.97	2.59
Error (c)	108	19.7582	.1829			
Total	159	63.3269				

APPENDIX I

ANALYSIS OF VARIANCE TABLE FOR POUNDS OF SUGAR IN 1956

Source of Variance	D.F.	S.S.	M.S.	F.	F.05	F.01
Replicates (R)	3	480,715	160,238			
Irrigations (I)	1	177,422	177,422			
Error (a)	3	2,726,797	908,932			
Main-Plot Total	7	3,384,934				
Spacings (S)	1	2,105,662	2,105,662	3.25	5.99	13.74
I. x S.	1	986,804	986,804	1.52	5.99	13.74
Error (b)	6	3,884,556	647,426			
Sub-Plot Total	15	10,361,956				
Fertilizers (F)	9	17,376,733	1,930,748	8,86	1.97	2.59
I. x F.	9	1,338,340	148,704	--		
S. x F.	9	3,315,924	368,436	1.69	1.97	2.59
I. x S. x F.	9	1,188,776	132,086	--		
Error (c)	108	23,543,559	217,996			
Total	159	57,125,288				

APPENDIX J

AVERAGE ELECTRICAL RESISTANCE (IN OHMS) OF THE MOISTURE BLOCKS IN THE VARIOUS MOISTURE TREATMENTS AND AT THE THREE DEPTHS AS RECORDED FOR THE DIFFERENT DATES IN 1954, 1955 AND 1956

	Depth of	1954							
Moisture	Bouyoucos	July				August		September	
Variable	Units (Ft.)	8th	20th	23rd	28th	3rd	9th	4th	11th
Wo	1	1120	500	470	520	1570	2420	2270	2930
	2	510	490	460	450	890	870	5110	10270
	3	710	600	560	550	530	540	1090	1370
W1	1	570	520	520	770	1765	640	570	570
	2	580	480	480	410	410	425	435	440
	3	590	490	490	460	460	430	475	445
W2	1	1445	505	540	1240	5180	670	600	590
	2	670	520	490	895	640	535	540	520
	3	735	580	560	550	525	530	485	520

		1955					
		July		August		September	
		11th	21st	10th	16th	6th	12th
Wo	1	650	1170	37,500	57,750	115,200	465,000
	2	570	570	2,700	8,850	60,750	90,000
	3	570	520	530	600	4,565	11,190
W1	1	790	2700	70,750	880	1,450	820
	2	910	600	27,820	30,300	19,965	655
	3	570	520	2,190	4,360	4,750	600

		1956		
		July		August
		24th	28th	28th
Wo	1	1,180	2,760	96,500
	2	1,550	2,520	36,900
	3	650	830	7,110
W1	1	8,600	10,740	142,000
	2	1,130	1,300	55,750
	3	745	710	5,240