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Influence of Fertilizer Treatment on the Response of Sugar Beet Yield to Moisture

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INFLUENCE OF FERTILIZER TREATMENT ON THE RESPONSE OF SUGAR BEET YIELD TO MOISTURE

by

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I wish to express my gratitude to Dr. Sterling A. Taylor, who has not only guided me during this study and helped me in obtaining data, but has also encouraged me throughout my academic program. I also extend sincere thanks to Dr. N. R. Bohidar, who contributed valuable statistical guidance to this study. I wish to thank Dr. Gordon H. Flammer and Dr. Gaylen L. Ashcroft for acting as graduate committee members and for reviewing the manuscript. I would also like to thank Dr. Jay L. Haddock for his assistance in obtaining and interpreting the original data which were used in this study.

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INTRODUCTION

Many factors that influence the growth and quality of sugar beets behave in one way under one set of conditions and in quite another under other conditions. Consequently, these factors should be considered together under a dynamic situation to find their interrelations and their influence on sugar beet yield.

This study is a statistical analysis of the interaction of fertilizer and soil moisture potential with the yield of sugar beets grown in a crop rotation under different regimes of irrigation conducted over a period of seven years.

The data are available for the years 1949 through 1956, from an intensive field experiment conducted under Western Regional Research Project W-29, entitled Soil-Water-Plant Relations under Irrigation.

There is need of a complete statistical analysis of third order interaction for the whole cultural rotation. This third order interaction has been examined for the sugar beet crop grown in the seven years of the general cultural rotation, which includes peas, first year alfalfa, second year alfalfa, potatoes, and sugar beets.

REVIEW OF LITERATURE

Factors Affecting Plant Growth

The plant is a product of its genetic constitution and its environment. The most important environmental factors that influence plant growth are temperature, radiant energy, moisture supply, soil reaction, gas content of the soil, composition of atmosphere, biotic factors, and supply of mineral nutrient elements.

The moisture and nutrient supply (nitrogen and phosphate) and particularly their interacting influence on the sugar beet yield will be reviewed here.

Plant and water

The processes of growth and transpiration use water. The water that is used by transpiration or growth should be immediately replaced in plants so that the plant water remaining will be in an active state. The moisture activity will decrease as a result of decreasing plant water content. When the rate of transpiration exceeds the rate of water uptake by plants, wilting occurs and growth is retarded. The need for water to supply the evapotranspiration demands is controlled by climatic factors. On the other hand, the rate at which water can be taken up is influenced markedly by the soil water potential.

Unfavorable physiological environment resulting from either a soil water surplus or deficiency is harmful to plants. In general, factors which affect the availability of moisture for plants can be divided into three categories (15):

1. Plant factors, which include plant condition (nutrients present, stage of growth), root habit (depth of rooting, degree of ramification, and absorptive activity), and plant resistance to drought
2. Climatic factors, which include air temperature, air humidity, fog, wind, solar radiation, and advective energy
3. Soil factors, which include moisture potential, concentration of salt in soil solution, kinds of ions present in soil solution, soil moisture transmission, soil depth, soil stratification (effect of hardpan and texture layering), soil temperature and temperature gradients.

The dynamic process of water in soil-plant-atmosphere is not yet well understood. The yield response is the result of the integrated effects of all factors that have acted upon the plant during its growth (9).

The passive movement of water from soil to plant and from plant to atmosphere is the result of moisture potential gradients along the path of supply to the point of loss into the atmosphere.[1] Transpiration and growth processes decrease the potential of water in plant tissue. As a result of this decrease in water potential, water moves from the soil in the vicinity of the roots into the plant, thus restoring the moisture potential. The difference in water potential between root and soil depends upon the rate of uptake and inversely upon the conductivity of the soil for water.[2] Energy barriers and temperature differences may modify the simple flow mechanisms discussed above.

In general, the state of water in the plant-soil system is determined by a combination of four factors.[3] They are temperature, pressure, nature of the soil or plant matrix, and composition of the system. Mathematically the relation can be written as

$$\psi = \psi_T + \psi_P + \psi_\theta + \psi_\tau \quad \text{- - - - - - - - - - - - - - - - -} \quad 1$$

in which ψ is moisture potential and subscripts T, P, θ, and τ are related to temperature, pressure, water concentration, and composition of the system (usually confined to solutes). Metabolic activity of plants may be considered as the fifth factor which affects the state of water in plant-soil systems.

[1] Taylor, S. A. Irrigation Science, Soil-Plant-Water Relationships. Textbook for Physical Edaphology at Utah State University. Unpublished.

[2] Taylor. Ibid.

[3] Taylor. Ibid.

The best thermodynamical function to describe the soil-water-plant relationship is partial Gibb potential.[1] This equation for water at one location is

$$d\mu_w = \left(\frac{\partial \mu_w}{\partial T}\right) dT + \left(\frac{\partial \mu_w}{\partial P}\right) dP + \left(\frac{\partial \mu_w}{\partial n_w}\right) dn_w + \sum_j \left(\frac{\partial \mu_w}{\partial n_j}\right) dn_j \qquad - - - - - 2$$

in which

μ_w thermodynamic potential of water in the system

$\frac{\partial \mu_w}{\partial T}$ the partial specific entropy

$\frac{\partial \mu_w}{\partial P}$ the partial specific volume of water

n_w concentration of water in the system

n_j concentration of component j in the system, and

( ) indicate that all variables except the one under consideration are held constant.

If the matric potential is used instead of water content, the above equation can be written as follows

$$d\mu_w = \left(\frac{\partial \mu_w}{\partial T}\right) dT + \left(\frac{\partial \mu_w}{\partial P}\right) dP + \left(\frac{\partial \mu_w}{\partial \tau}\right) d\tau + \sum_j \left(\frac{\partial \mu_w}{\partial n_j}\right) dn_j \qquad - - - - 3$$

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[1] Taylor. Ibid.

The water potential in soil and plants is defined as

$$\psi = \int_{\mu_w^o}^{\mu_w} d\mu = \left(\mu_w - \mu_w^o \right) = RT\ln \frac{p}{p^o} = RT \ln a_w \quad - - - 4$$

in which

ψ = moisture potential

μ_w^o = thermodynamic potential of free water

μ_w = thermodynamic potential of water in the system

R = gas constant

T = absolute temperature

p = vapor pressure of water in the system

p^o = vapor pressure of free water

$\frac{p}{p^o}$ = relative humidity or relative activity.

Although the potential gradient constitutes the force which causes the passive movement of water in the soil, from soil to plant, within the plant, and from plant to atmosphere, the movement of water will also be influenced by the resistance to flow. This resistance may appear as permeability of soil and tissues or as energy barriers. It may be influenced by heat and electrical charges and possibly other unknown factors.[1]

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[1] Taylor. Ibid.

Plant and fertilizer

Nitrogen availability. In soils, plant nutrients are frequently held as exchangeable ions, and consequently their persistence in the soil and their availability for plant growth depends on exchange reactions.

Inorganic forms of nitrogen, chiefly ammonia and nitrate, are available to plants (30). The rate at which nitrogen in soil becomes available to plants depends upon the rate of organic matter decomposition, the quantity of fertilizer added to the soil, the rate of adsorption of growing plants, and the rate of use by microorganisms. Leaching is also a factor that influences the availability of nitrogen to plants (30).

Supply of phosphate to plants. Plant growth requires a net removal of phosphorus from the soil system into the plant. This process can be divided into four stages (8):

1. Release of the phosphorate ion from the solid phase into soil solution
2. Movement of phosphorate ion toward the root vicinity
3. Movement of the ions from the root vicinity into the root
4. Movement of the phosphorate ion in the upper part of the plant.

Ion-exchange, bulk movement of water, viscous flow, and diffusion are responsible for the movement of phosphorus through soil (22).

When phosphate fertilizer is applied to soils, four factors affect its availability to a specific crop (17, 21). These factors are:

1. Particle size of fertilizer
2. Percentage of fertilizer phosphorus soluble in water
3. Fertilizer treatment and placement
4. Certain soil properties, as level of available soil phosphorus, soil texture, and soil reaction.

A majority of the common procedures for evaluating the phosphorus fertility status of soils are based on solubility rather than on anion exchange reactions. Thus, much of the phosphorus which has accumulated in fertilized soils is not considered when evaluating phosphorus fertility (5, 6, 23, 24).

<u>The interaction of fertilizer and water on the yield of sugar beets</u>

It has been shown[1] that an increase in crop growth in response to the fertilizer treatment results in increased production for each unit of water evapotranspired. Haddock and Kelly (13) found that sugar beets grown under conditions of high moisture stress obtained little if any benefit from nitrogen fertilization. When sugar beets were grown under conditions of low moisture stress, yield increases were obtained with nitrogen fertilizer.

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[1] Taylor. Ibid.

Experiments conducted on a variety of soils in the western United States indicate that nitrogen and phosphorus are taken up more readily from moist soil than from dry. It has been shown that potatoes take up more fertilizer and soil phosphorus when the moisture tension is low (water potential is high) (16). This phenomenon is a result of the influence of moisture on the physiology of the root and the nutrient availability in the soil (4).

It is possible that the increased availability of phosphorus that occurs in moist soil is related to temperature. Moist soils are generally cooler because of high evaporation, and cool soils hold a higher concentration of carbon dioxide, which may bring more soil phosphorus into solution (10). The phosphorus percentage in plant material depends on the moisture condition and also on the fertilizer placement (27). In a continuously moist soil where the crop is never short of water, additional fertilizer may increase the yield without a corresponding increase in the use of water. The result is a greater crop production per unit of water which is evapotranspired (27). Phosphorus uptake is also limited in soil which is too wet to have proper aeration.

Sugar beets do not show significant response to moisture when there is no fertilizer in the rotation or if either nitrogen or phosphorus is applied alone to a nutrient starved soil.[1]

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[1] Taylor. Ibid.

Using the same data which have been used in the present analysis, Taylor ran a graphical analysis of the response of sugar beets to water potential for different fertilizers.[1] His analysis showed that there was no response to residual nitrogen applied five years before the sugar beets were grown. Also there was no significant response to varying matric potential of soil water when nitrogen was applied five years earlier. The response of sugar beet yield to mean integrated matric potential under some combinations of fertilizer is given in Figure 1. As shown in this figure (Curve N_3P_1), nitrogen applied three times with phosphorus at least once in the rotation gave maximum yields when the mean integrated soil water potential was -40 to -50 joules/kg. Only a slight response to increasing matric potential is shown if nitrogen and phosphorus both appear twice in the rotation (Curve N_2P_2).

Higher moisture potential reduces the yield because of inadequate aeration or some other factor associated with the soil. Little response to moisture was found when nitrogen and phosphorus were both applied twice in the rotation.

Both purity and sucrose content were increased by high mean integrated matric potential. Purity response to water potential is increased by nitrogen and decreased by phosphorus.

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[1] Taylor. Ibid.

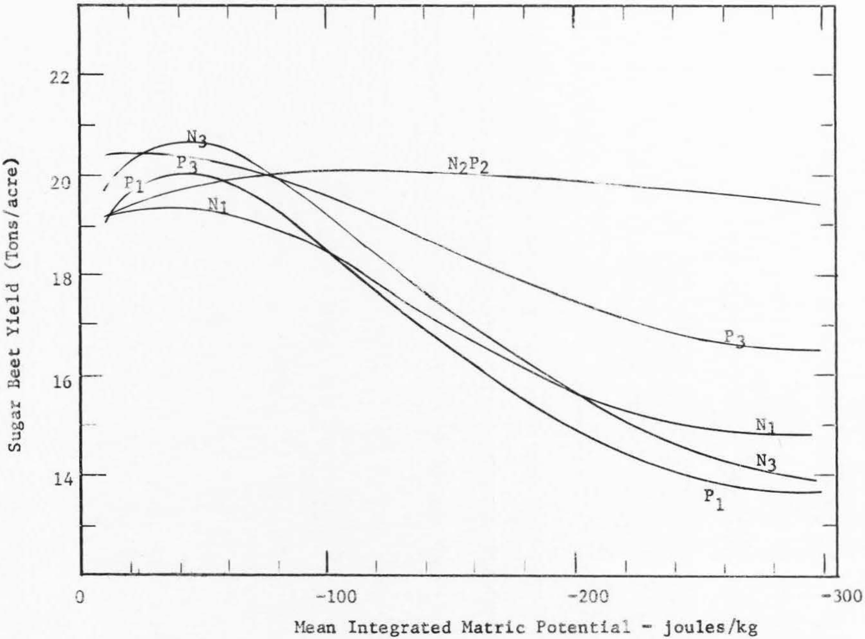

Figure 1. Response of sugar beets to soil water matric potential for different fertilizer regimes. Subscripts indicate the number of times the indicated fertilizer element was applied to the soil during the five-year rotation (redrawn from Taylor, unpublished data).

In general, the yield of sugar beets increases with an increase in nitrogen fertilizer. The sucrose concentration, however, decreases with nitrogen fertilization. There is an inverse relationship between sucrose percentage and mean root size (11, 13, 18, 19, and 20). Nitrogen has a strong residual effect on the yield of sugar beets. It has an adverse effect on the sucrose percentage.

Annually, applied and residual phosphorus fertilizer increases sugar beet yields on calcareous Millville loam. Dubetz, Russel, and Hill (7) believe that the increase of sugar beet yield after beans in rotation results from the additional nitrogen made available to the subsequent crops by the legume. Stout (25) says that high yield, high sucrose percentage, and quality are evidently not incompatible, but the factors responsible for their simultaneous occurrence have not been clearly recognized.

Conclusions From the Literature

The interaction of moisture potential and fertilizer application affects sugar beet yield and quality. The level of this interaction and its nature are not clear.

The graphical analysis which has been made on the same data shows the interaction of a few fertilizer treatments with moisture potential on sugar beet yield, but it does not include all possible treatments which have been used in the experiment. Meanwhile it is not clear that the difference which is shown in the graph is significant and that the response is due to the slopes of the curves or their elevations, or to both of them.

Study Proposal

A statistical analysis will be made of the interaction of fertilizer treatment with moisture suction on the sugar beet yields for different fertilizer treatments under different methods of irrigation, to find the nature of the response of sugar beet yield to the interaction of moisture potential and fertilizer treatment.

EXPERIMENTAL PROCEDURE

An intensive field crop rotation experiment was initiated in the spring of 1949 and continued until the close of the harvest season of 1956.[1] The experimental area was located on the Utah Agricultural Experiment Station Greenville Experimental Farm at North Logan, Utah. The soil type is Millville loam, which is strongly calcareous (approximately 50 percent calcium carbonate equivalent) with an increase in pH from 7.9 in the surface to 8.0 at six feet below the surface. The soil has an alluvial fan formation with a well-drained and uniform texture for more than 25 feet in depth. The surface topography is smooth with a 2 percent slope toward the south and west.

The crop rotation included:

1. Canning peas, followed by alfalfa seeded immediately following harvest of the peas
2. First year alfalfa
3. Second year alfalfa, which was crowned and plowed in the fall following the harvest of the third cutting
4. Potatoes

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[1] Taylor, S. A., C. H. Milligan, and J. L. Haddock. Relation of soil moisture regime and nutrient supply on plant nutrients and soil productivity. Annual Report to the Technical Committee of Western Regional Research. Project W-29. 1957.

5. Sugar beets.

Each crop with border occupied 1.92 acres, which was divided into four replications consisting of 0.48 acres. Each replication was divided into eight irrigation plots, 45 feet wide by 54 feet long. Four of these irrigation plots were irrigated by sprinkler and four of them were furrow irrigated by means of surface corrugations. The irrigations were on the basis of four moisture regimes as indicated in Table 1.

The matric potential at various locations and depths was measured at intervals using a moisture tensiometer for wet plots and calibrated resistance blocks for drier plots. A mathematical equation was found statistically fitting the data for the distribution of matric potential in depth. This equation was integrated in depth and averaged over the time that the crop was on the soil (28, 29). Both yield and moisture potential were statistically adjusted to the 7-year average by adding or subtracting the difference between the annual average and the 7-year average to each individual observation for each year.

The amount of water in the soil was estimated from a curve relating the amount of water in an initially saturated soil to the soil matric suction as measured in the laboratory using a pressure plate and pressure membrane equipment (2).

Table 1. Irrigation and soil moisture description and symbols

Irrigation symbols[a]	Soil moisture level and symbol	Description and treatment
1F + 1S	High tension Low moisture (W_1)	Irrigate when average soil moisture suction in the root zone reaches about 8 to 10 atmospheres suction as shown by plaster blocks (roughly equivalent to 20 to 25 percent of the soil moisture remaining).
2F + 2S	Medium high tension Medium low moisture (W_2)	Irrigate when average soil moisture suction in the root zone reaches about 3 to 4 atmospheres suction as shown by plaster blocks (roughly equivalent to 35 to 50 percent of available soil moisture remaining).
3F + 3S	Medium low tension Medium high moisture (W_3)	Irrigate when average soil moisture suction in the root zone reaches about 0.7 to 0.8 atmospheres suction as shown by tensiometer (roughly equivalent to 65 to 75 percent of available soil moisture remaining).
4F + 4S	Low tension High moisture (W_4)	Irrigate when average soil moisture suction in the root zone reaches about 0.2 to 0.3 atmospheres suction as shown by tensiometer (roughly equivalent to about 85 to 90 percent of the available soil moisture remaining).

[a] F = Furrow, S = Sprinkler irrigation

The irrigation plots under each method of irrigation were further subdivided into eight fertilizer plots, 9 feet wide by 25 feet long. Fertilizer was applied in the spring of each year several days before planting. Canning peas, potatoes, and sugar beets received fertilizer at the rate of 80 pounds per acre nitrogen as ammonium sulfate and 44 pounds per acre of phosphorus as treble superphosphate.

The statistical design of this experiment was a half replication of a 2^6 factorial experiment with DEFGHI as defining contrast and confounding, DFH = EGI, IFH = DEG, DI = EFGH, in blocks of eight as follows:

++	+-	-+	--
gh	ih	gi	(1)
fh	fi	fgih	fh
eh	egih	ei	eg
ef	efgi	efih	efgh
di	dg	dh	dgih
dfih	dfgh	df	dfgi
degi	dc	dcgh	deih
defghi	defh	defg	defi

There were 32 fertilizer treatments over four replications under each irrigation regime for each crop.

The six main factors were:

D Nitrogen, which was applied to peas at the rate of 80 lbs N/acre

E Phosphorus, which was applied to peas at the rate of 44 lbs P/acre

F Nitrogen, which was applied to potatoes at the rate of 80 lbs N/acre

G Phosphorus, which was applied to potatoes at the rate of 44 lbs P/acre

H Nitrogen, which was applied to sugar beets at the rate of 80 lbs N/acre

I Phosphorus, which was applied to sugar beets at the rate of 44 lbs P/acre

STATISTICAL PROCEDURE AND ANALYSIS

Adjusted yield and adjusted moisture suction have been averaged for the seven years of data on each fertilizer plot.[1] Thus, for each fertilizer combination and method of water application there are four average values, one for each of the four moisture levels shown in Table 2.

A statistical study on these data showed that the yield does not change linearly with moisture suction, but it appears that a logarithmic relation exists.

The log of yield was related to linear moisture suction. Regression lines were calculated (26) on the average adjusted data for each separate fertilizer treatment and irrigation method. Thirty-two regression lines were thus obtained for both sprinkler and furrow irrigation methods. The curves are shown in Figures 2 to 33. In these figures the data for each of the seven years and their averages for each year are shown. To find the individual effects of 32 different fertilizer combinations and at the same time to find the main effect of annual and residual fertilizer on the response of yield to moisture suction under each method of application, an analysis of variance was run on elevations of regression lines, a's, and slopes of regression lines, b's, of the 64 lines relating log yield to water

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[1] Bohidar, N. R., Assistant Professor, Applied Statistics and Applied Science. Utah State University. Personal communication.

Table 2. Seven-year average of adjusted yield and adjusted moisture suction data

	Sprinkler		Furrow			Sprinkler		Furrow	
		Moist.		Moist.			Moist.		Moist.
Treat-ment	Yield t/acre	suct. atm.	Yield t/acre	suct. atm.	Treat-ment	Yield t/acre	suct. atm.	Yield t/acre	suct. atm.
(1)	16.26	3.14	13.33	2.61	EI	16.32	3.03	15.89	2.22
	16.44	2.18	15.20	1.79		16.80	1.96	15.82	2.64
	16.85	0.36	16.70	0.38		19.47	0.37	17.02	0.39
	14.77	0.29	17.76	0.28		17.23	0.28	19.43	0.25
HI	14.08	2.89	15.06	3.03	EH	13.55	3.17	14.90	2.86
	16.66	1.85	17.81	2.02		16.24	2.17	16.17	2.07
	21.75	0.40	18.34	0.34		17.84	0.37	15.44	0.38
	18.74	0.27	20.08	0.26		17.51	0.27	17.57	0.26
GI	16.98	3.03	16.44	2.25	EG	14.64	3.14	16.39	2.61
	16.67	1.96	15.73	2.64		18.26	2.18	17.25	1.79
	19.25	0.37	16.96	0.39		17.03	0.36	18.74	0.38
	18.75	0.28	19.03	0.25		16.81	0.29	16.80	0.28
GH	14.19	3.15	14.82	2.86	EGHI	16.23	2.89	15.63	3.03
	16.86	2.17	18.77	2.07		16.68	1.85	18.09	2.02
	19.62	0.37	18.24	0.36		22.83	0.40	18.40	0.34
	18.80	0.27	19.63	0.26		18.97	0.27	22.42	0.26
FI	14.49	2.89	14.99	3.03	EF	15.57	3.15	13.07	2.86
	17.23	1.87	18.48	2.02		13.26	2.17	17.82	2.07
	19.16	0.40	18.56	0.34		19.44	0.37	15.17	0.38
	18.57	0.27	16.70	0.26		17.12	0.27	15.65	0.26
FH	12.83	3.14	12.41	2.61	EFHI	15.16	3.03	17.61	2.25
	15.84	2.18	19.40	1.79		17.42	1.96	16.17	2.64
	15.53	0.36	18.76	0.38		20.38	0.37	18.62	0.39
	15.76	0.29	15.21	0.28		17.00	0.28	19.81	0.25
FG	16.38	3.15	14.98	2.86	EFGI	17.05	2.89	15.96	3.03
	16.72	2.27	18.46	2.07		15.82	1.85	19.77	2.02
	18.63	0.37	17.49	0.38		22.72	0.40	18.11	0.34
	19.01	0.27	19.13	0.26		20.31	0.27	19.26	0.26
FGHI	17.33	3.03	16.96	2.25	EFGH	13.62	3.14	16.00	2.61
	16.31	1.96	17.92	2.64		19.88	2.18	17.36	1.79
	20.36	0.37	19.87	0.39		20.42	0.36	20.45	0.38
	19.67	0.28	21.58	0.25		21.97	0.29	21.04	0.28

Table 2. Continued

Treat-ment	Sprinkler Yield t/acre	Sprinkler Moist. suct. atm.	Furrow Yield t/acre	Furrow Moist. suct. atm.	Treat-ment	Sprinkler Yield t/acre	Sprinkler Moist. suct. atm.	Furrow Yield t/acre	Furrow Moist. suct. atm.
DI	15.65	3.15	15.55	2.86	DE	12.02	2.89	11.74	3.03
	15.63	2.17	18.73	2.07		14.78	1.85	17.17	2.02
	18.67	0.37	16.23	0.38		20.08	0.40	16.07	0.34
	19.37	0.27	16.36	0.26		17.37	0.27	15.56	0.26
DH	14.87	3.03	15.60	2.25	DEHI	14.04	3.14	16.74	2.61
	13.64	1.96	15.78	2.64		18.16	2.18	17.50	1.79
	16.16	0.37	14.11	0.39		18.86	0.36	21.00	0.38
	15.00	0.28	18.53	0.25		20.62	0.29	19.03	0.28
DG	16.89	2.89	15.06	3.03	DEGI	17.88	3.15	14.90	2.86
	15.61	1.85	17.09	2.02		17.14	2.17	19.60	2.07
	21.32	0.40	17.58	0.34		20.15	0.37	16.96	0.38
	19.36	0.27	18.23	0.26		18.81	0.27	16.96	0.26
DGHI	15.42	3.14	16.42	2.60	DEGH	14.56	3.03	18.68	2.25
	20.12	2.18	18.04	1.79		16.81	1.96	17.91	2.64
	18.95	0.36	20.13	0.38		19.46	0.37	18.22	0.39
	21.14	0.29	21.31	0.28		19.72	0.28	19.90	0.25
DF	13.25	3.03	15.22	2.25	DEFI	15.06	3.14	15.62	2.61
	12.34	1.96	14.14	2.64		18.78	2.18	15.31	1.79
	17.56	0.37	12.23	0.39		17.99	0.36	19.41	0.38
	14.10	0.28	18.16	0.25		17.54	0.29	18.13	0.28
DFHI	15.48	3.13	13.34	2.86	DEFH	11.78	2.89	13.59	3.03
	16.48	2.17	19.05	2.07		15.92	1.85	17.72	2.02
	19.37	0.37	16.95	0.38		19.40	0.40	17.23	0.34
	19.78	0.27	18.95	0.26		18.09	0.27	17.51	0.26
DFGI	15.59	3.14	16.77	2.61	DEFG	16.49	3.03	16.83	2.25
	18.65	2.18	18.08	1.79		17.72	1.96	16.01	2.64
	18.74	0.36	19.93	0.38		20.21	0.37	17.21	0.39
	18.63	0.29	18.21	0.28		18.72	0.28	18.56	0.25
DFGH	16.19	2.89	13.49	3.03	DEFGHI	15.89	3.15	15.25	2.94
	15.75	1.85	18.23	2.02		17.63	2.17	19.65	2.07
	21.66	0.40	18.55	0.34		20.37	0.37	17.96	0.38
	18.96	0.27	19.81	0.26		19.93	0.27	20.77	0.26

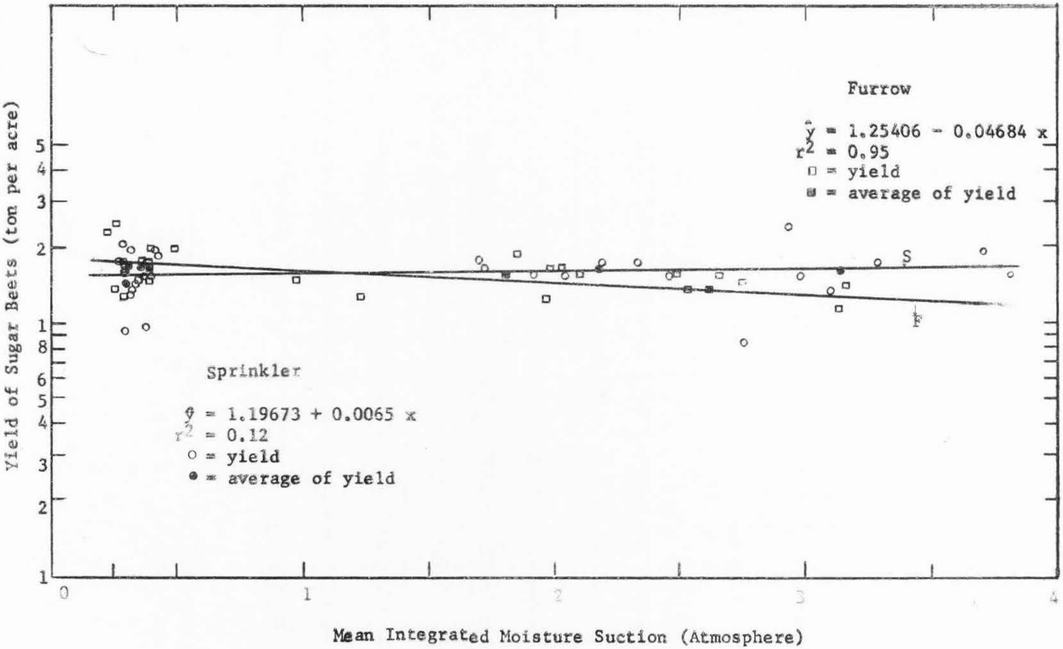

Figure 2. Response of sugar beets to soil water suction under treatment (1).

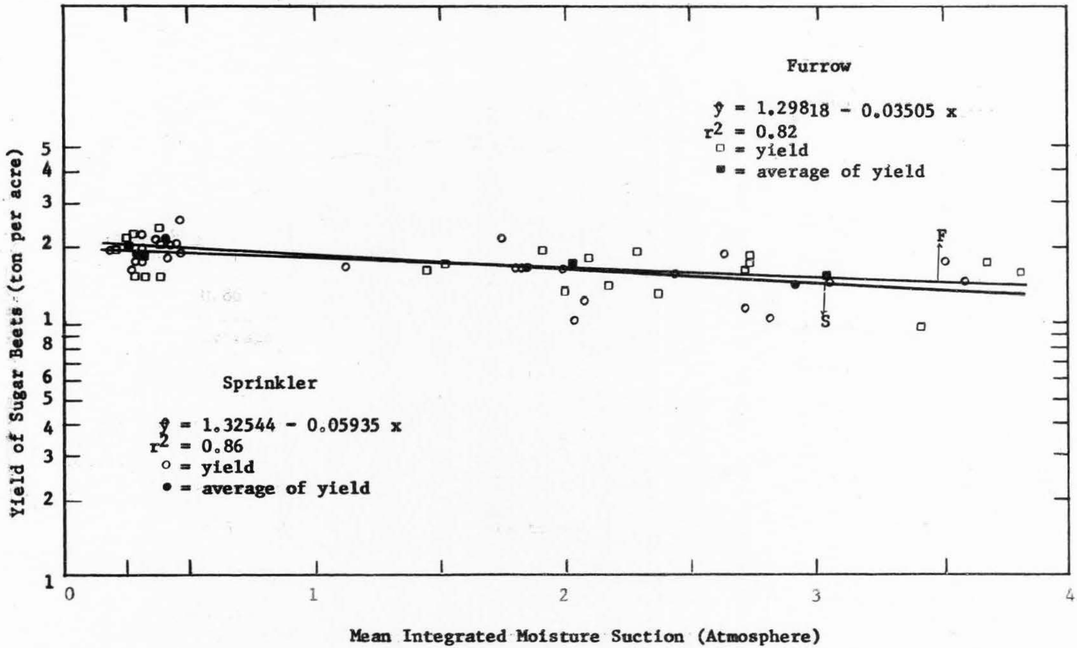

Figure 3 . Response of sugar beets to soil water suction under treatment HI = N_1P_1.

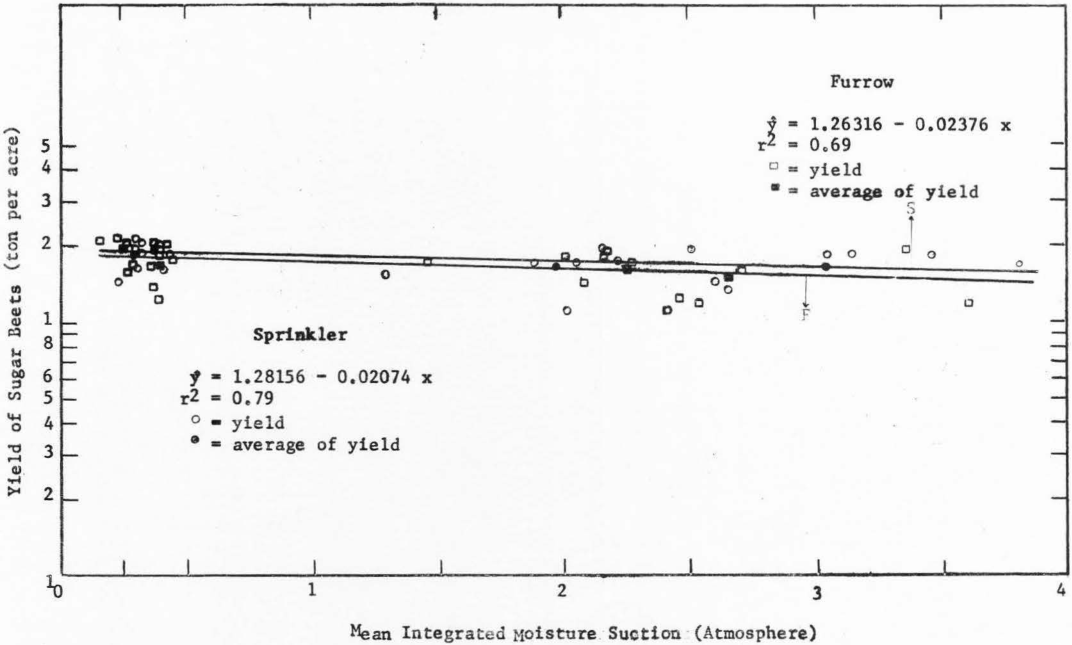

Figure 4. Response of sugar beets to soil water suction under treatment GI = P_2.

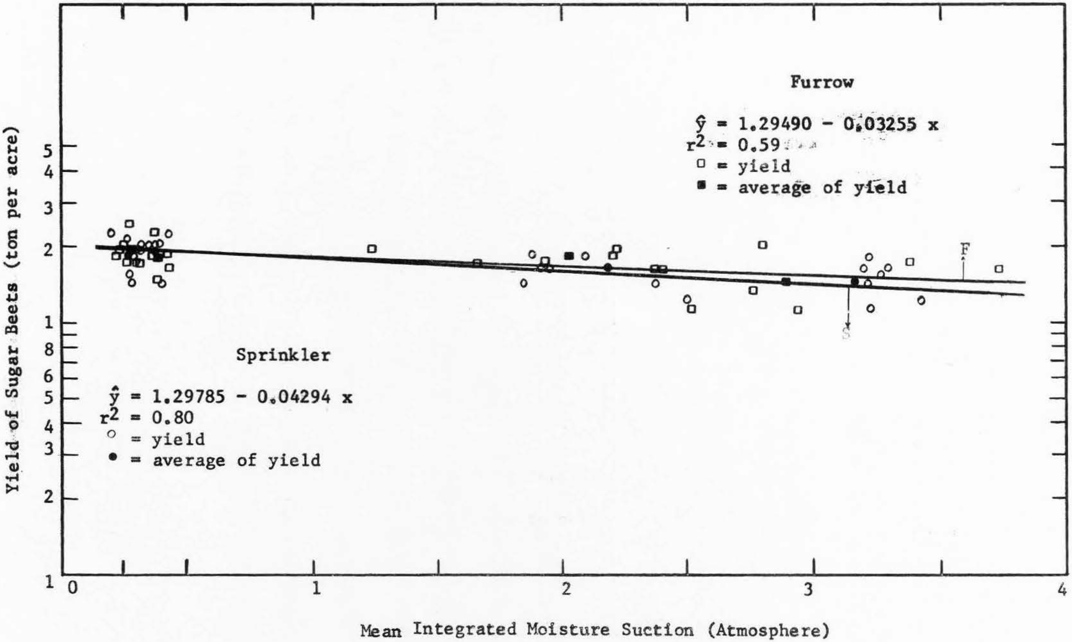

Figure 5. Response of sugar beets to soil water suction under treatment GH = N_1P_1.

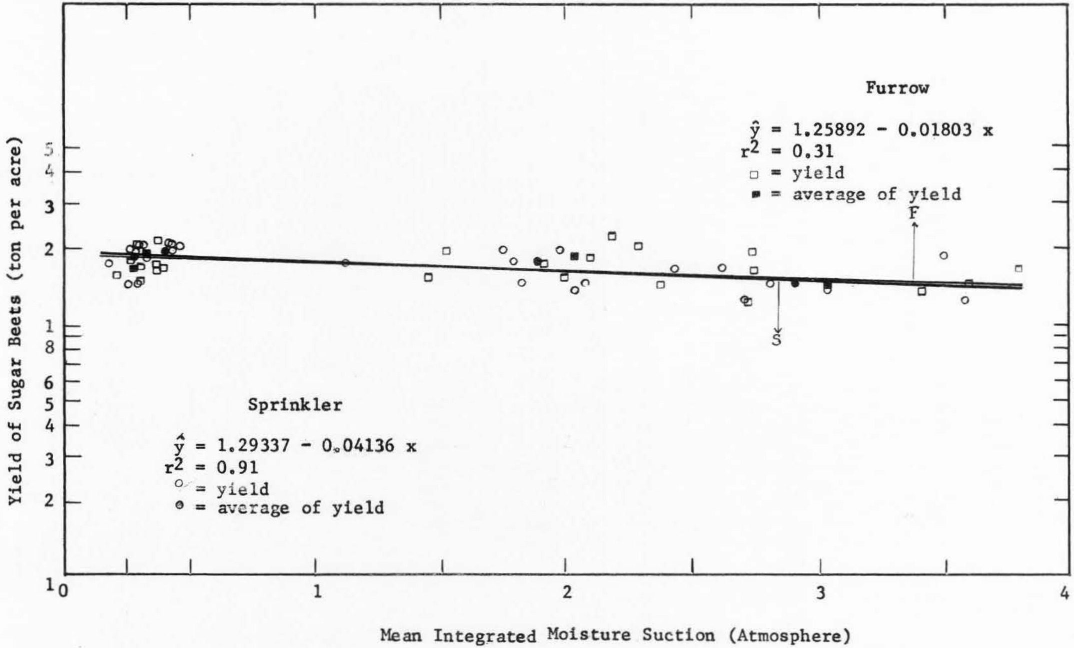

Figure 6. Response of sugar beets to soil water suction under treatment FI = N_1P_1.

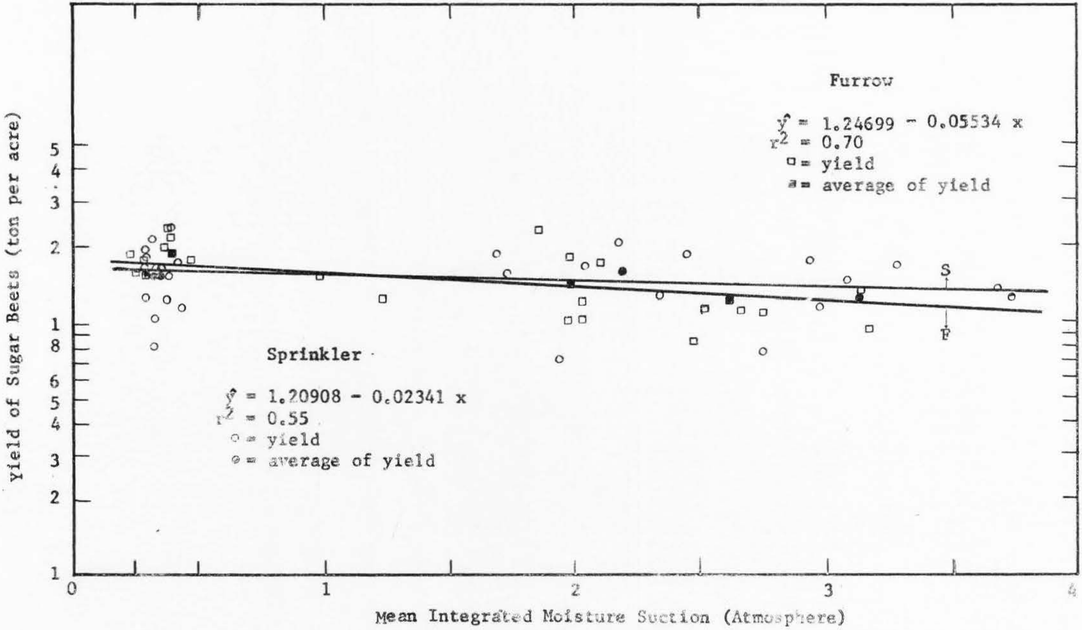

Figure 7. Response of sugar beets to soil water suction under treatment FH = N_2.

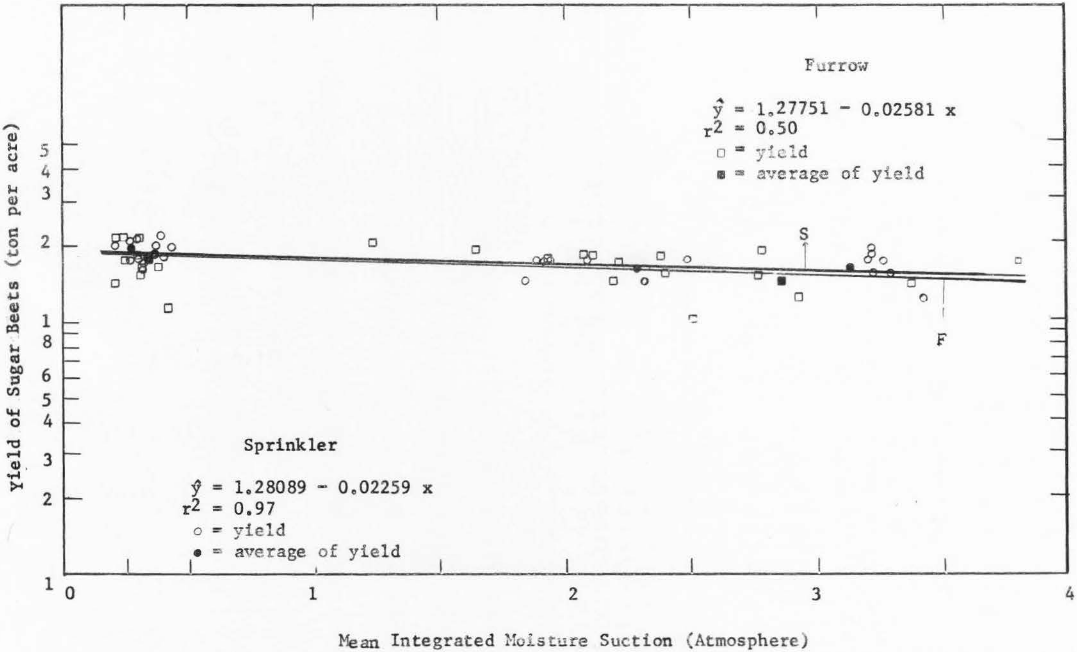

Figure 8. Response of sugar beets to soil water suction under treatment $FG = N_1P_1$.

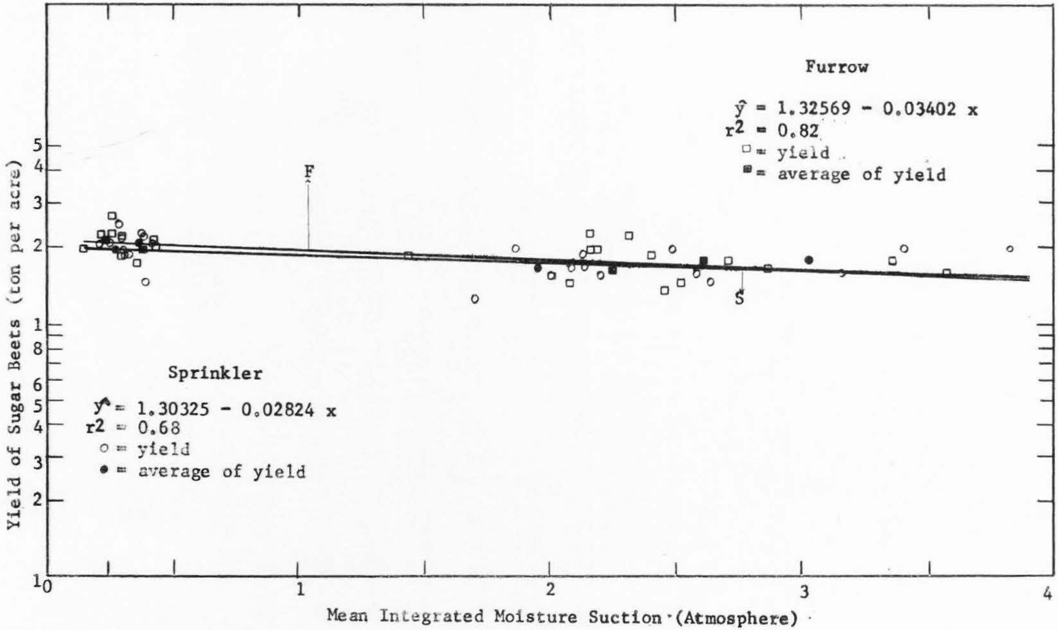

Figure 9 . Response of sugar beets to soil water suction under treatment FGHI = N_2P_2.

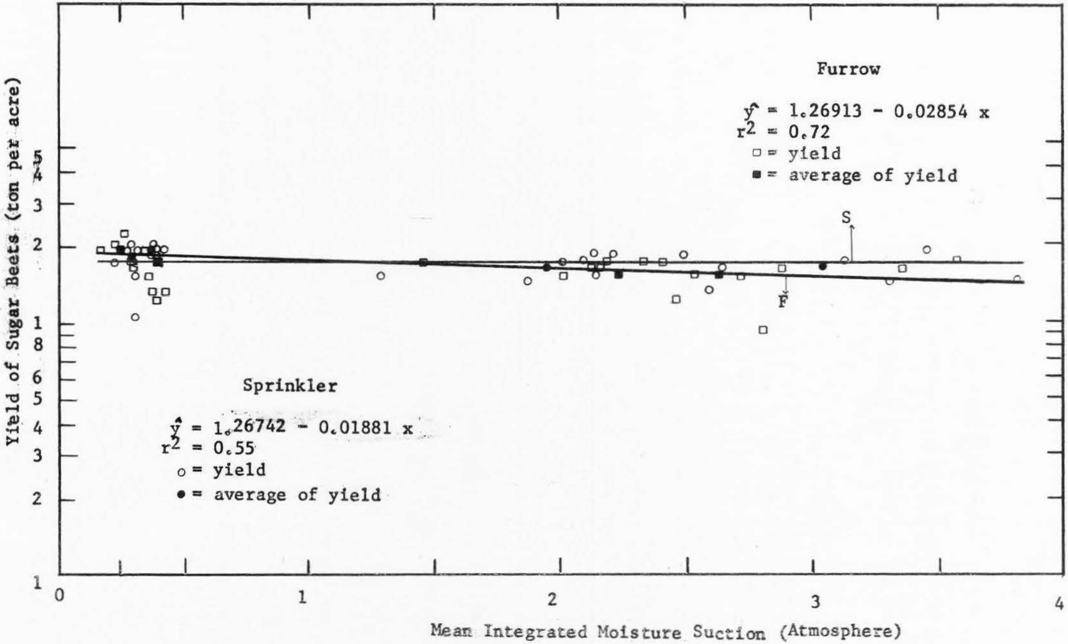

Figure 10. Response of sugar beets to soil water suction under treatment EI = P_2.

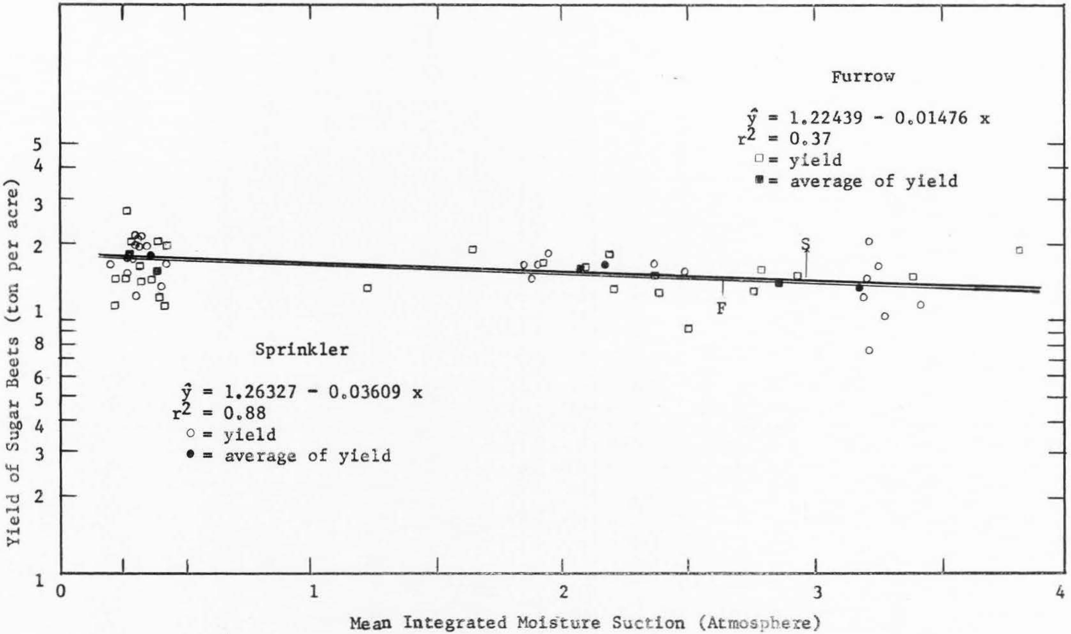

Figure 11. Response of sugar beets to soil water suction under treatment $EH = N_1P_1$.

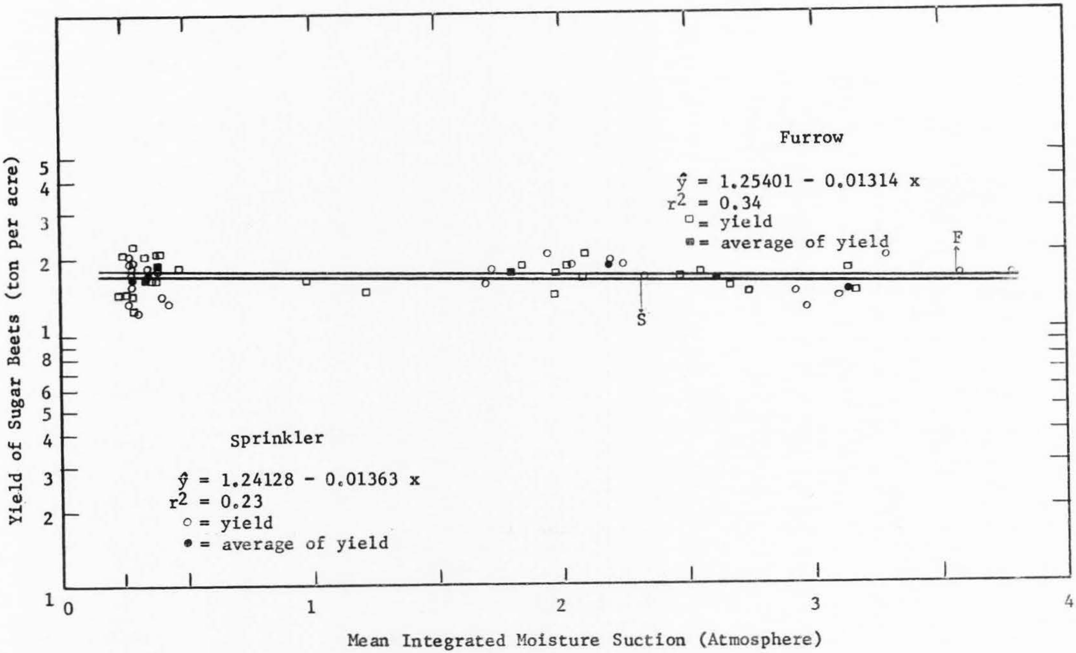

Figure 12. Response of sugar beets to soil water suction under treatment EG = P_2.

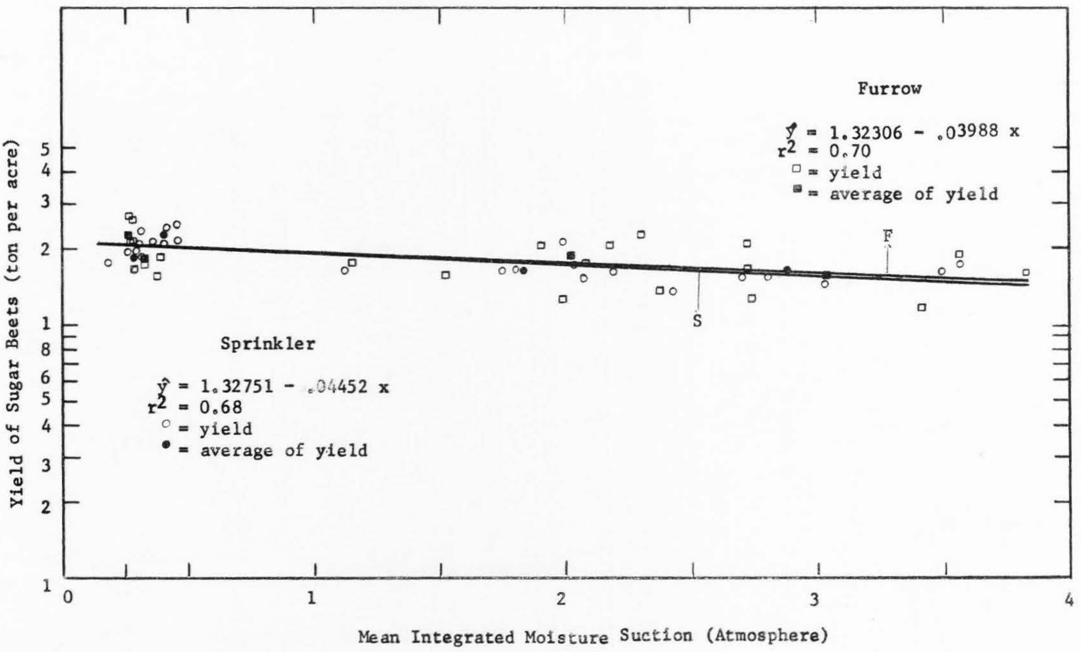

Figure 13. Response of sugar beets to soil water suction under treatment EGHI = N_1P_3.

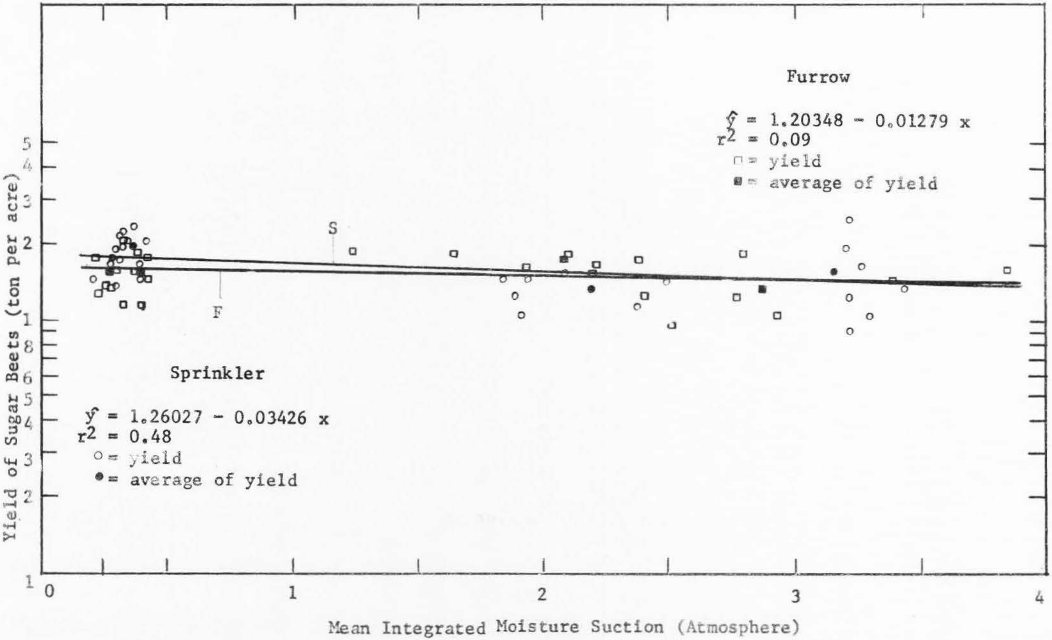

Figure 14. Response of sugar beets to soil water suction under treatment EF = N_1P_1.

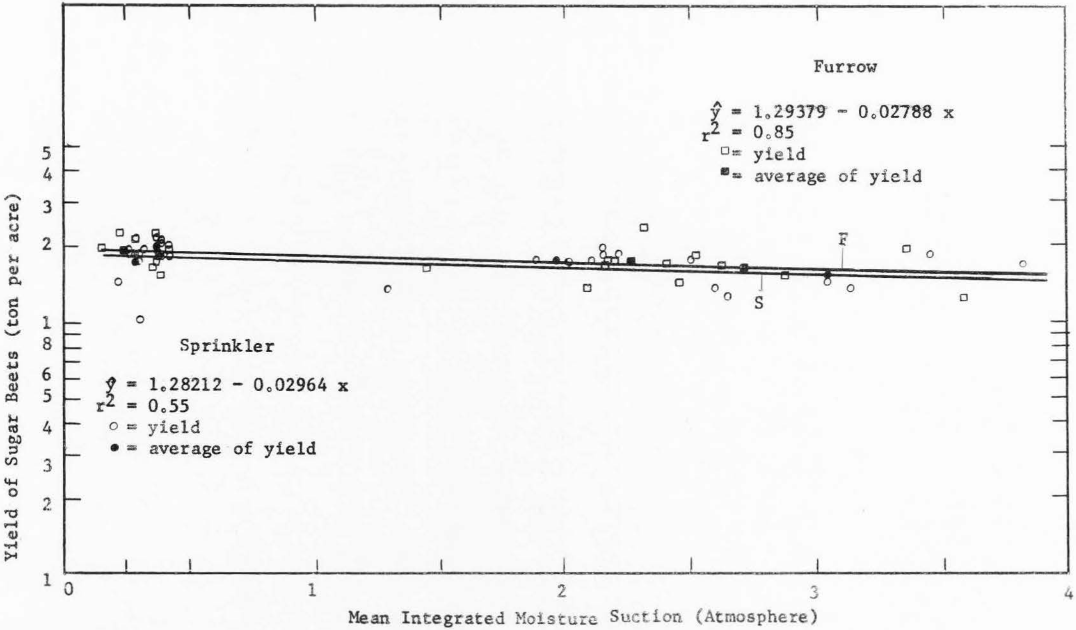

Figure 15. Response of sugar beets to soil water suction under treatment EFHI = N_2P_2

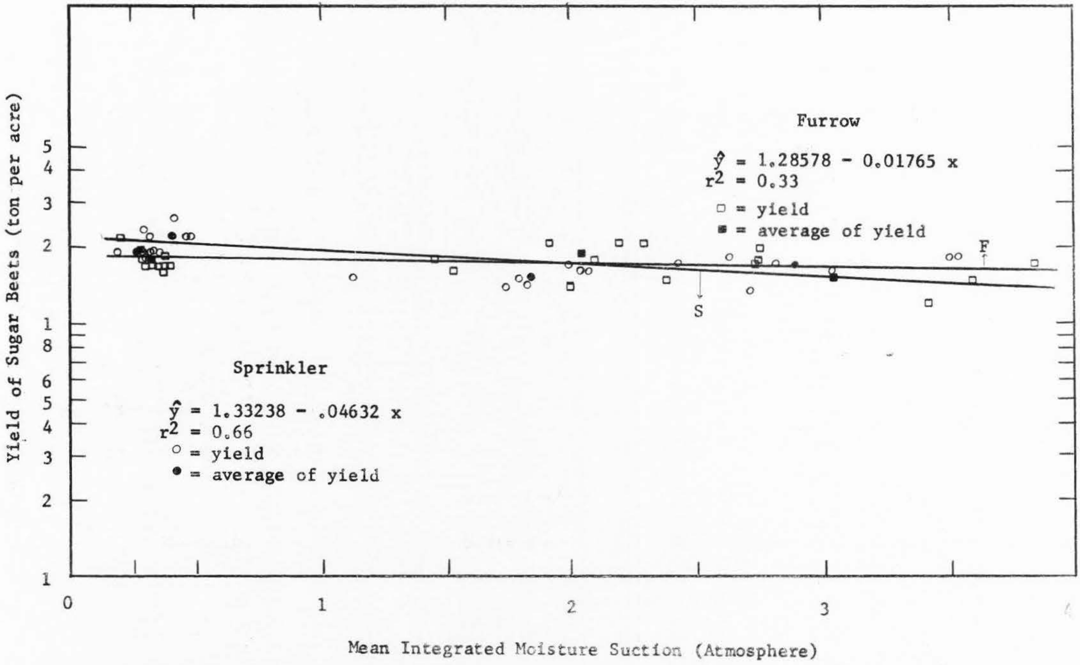

Figure 16. Response of sugar beets to soil water suction under treatment EFGI = N_1P_3.

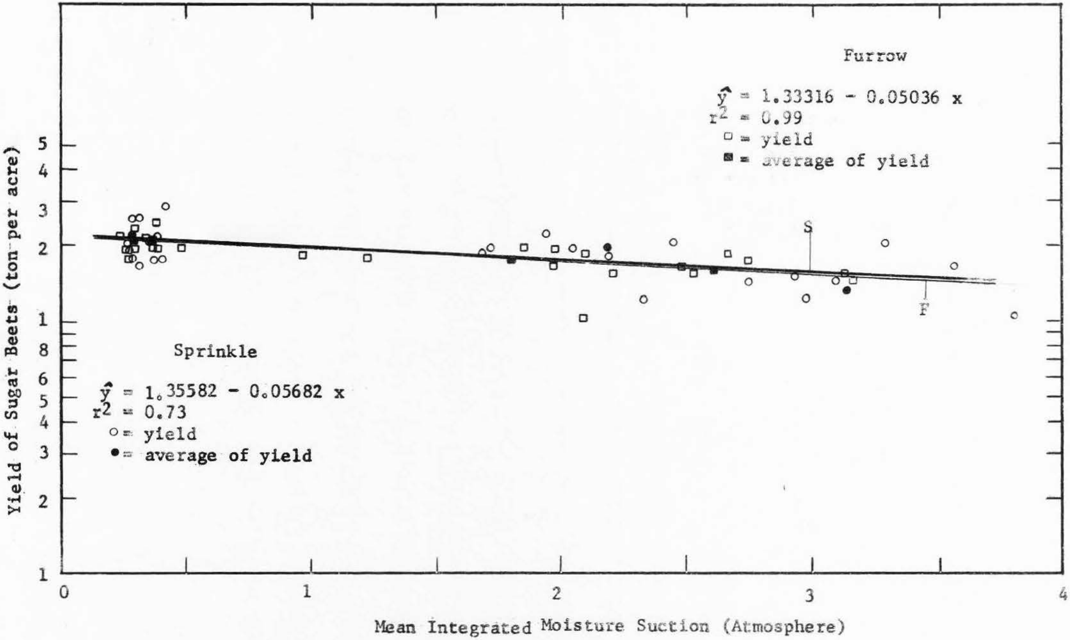

Figure 17. Response of sugar beets to soil water suction under treatment EFGH = N_2P_2.

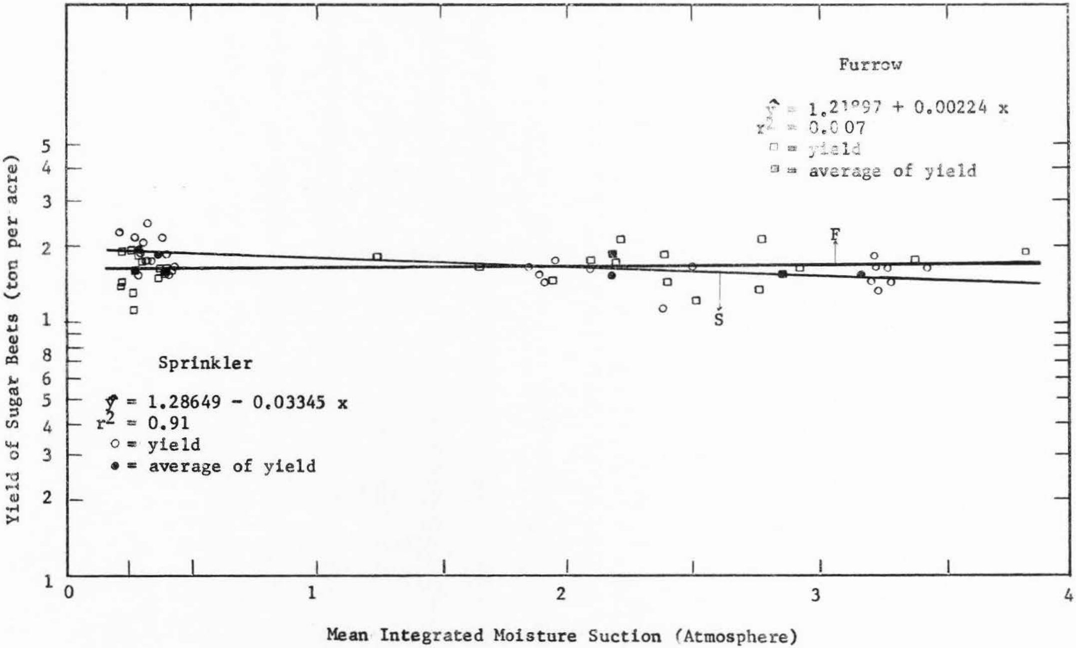

Figure 18. Response of sugar beets to soil water suction under treatment DI = N_1P_1.

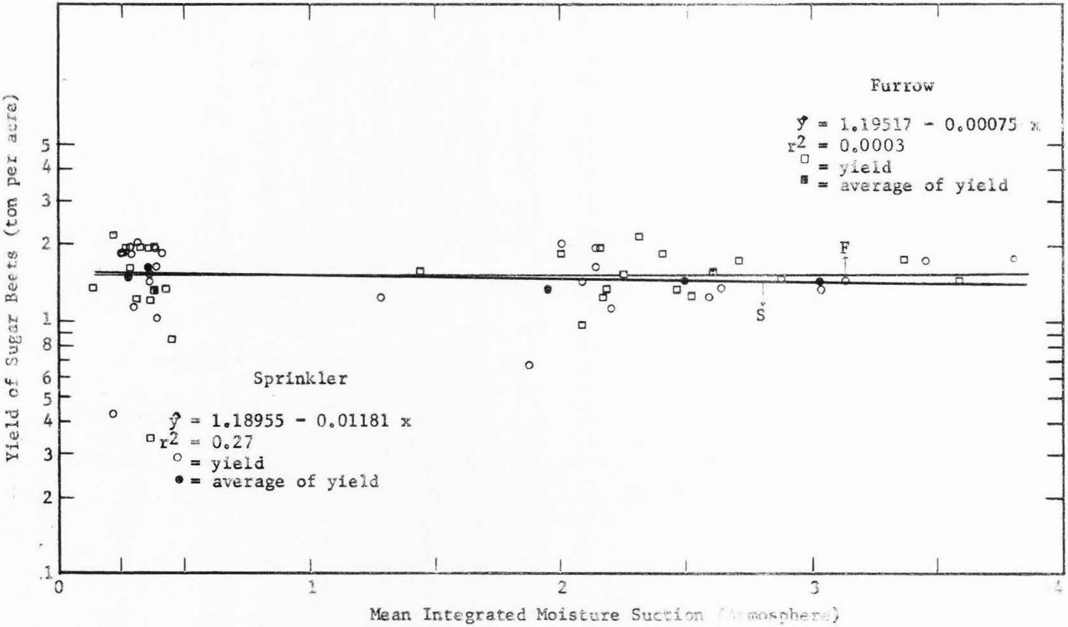

Figure 19. Response of sugar beets to soil water suction under treatment DH = N_2.

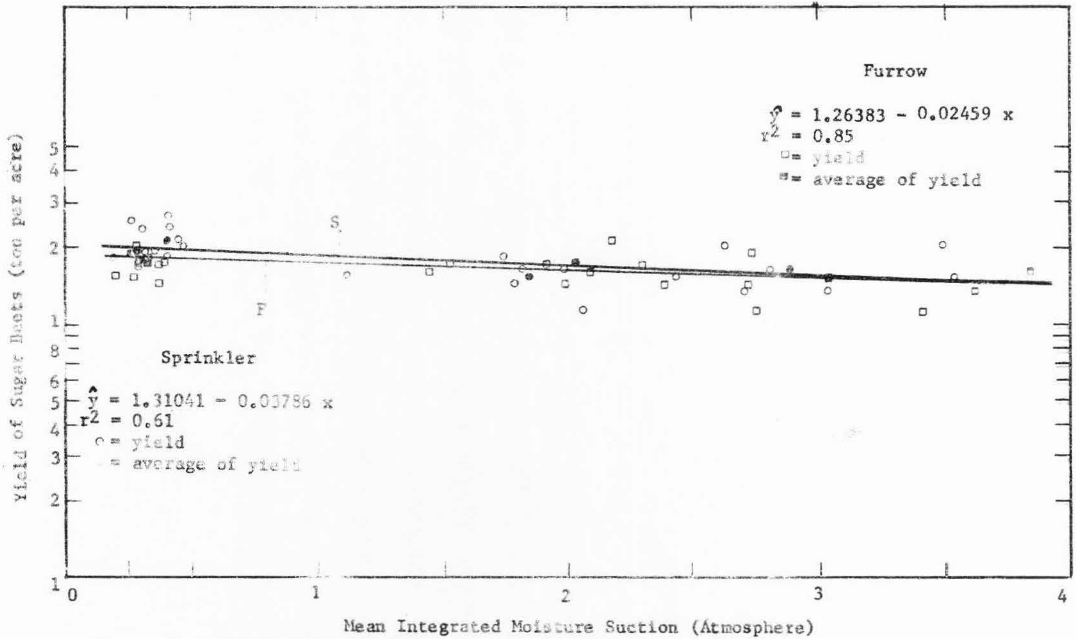

Figure 20. Response of sugar beets to soil water suction under treatment DG = N_1P_1.

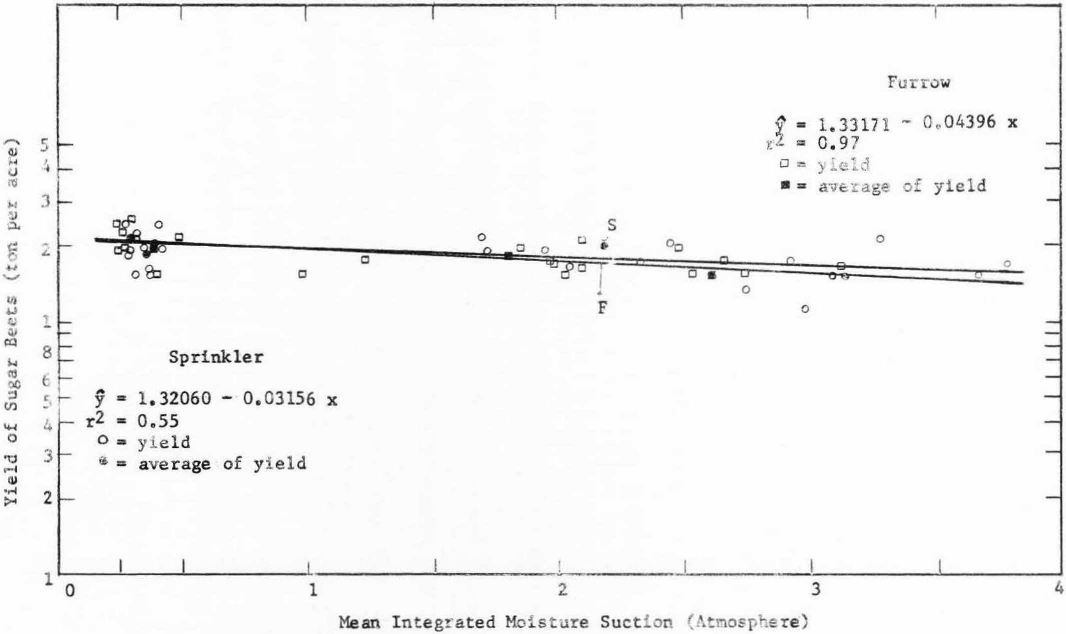

Figure 21. Response of sugar beets to soil water suction under treatment DGHI = N_2P_2.

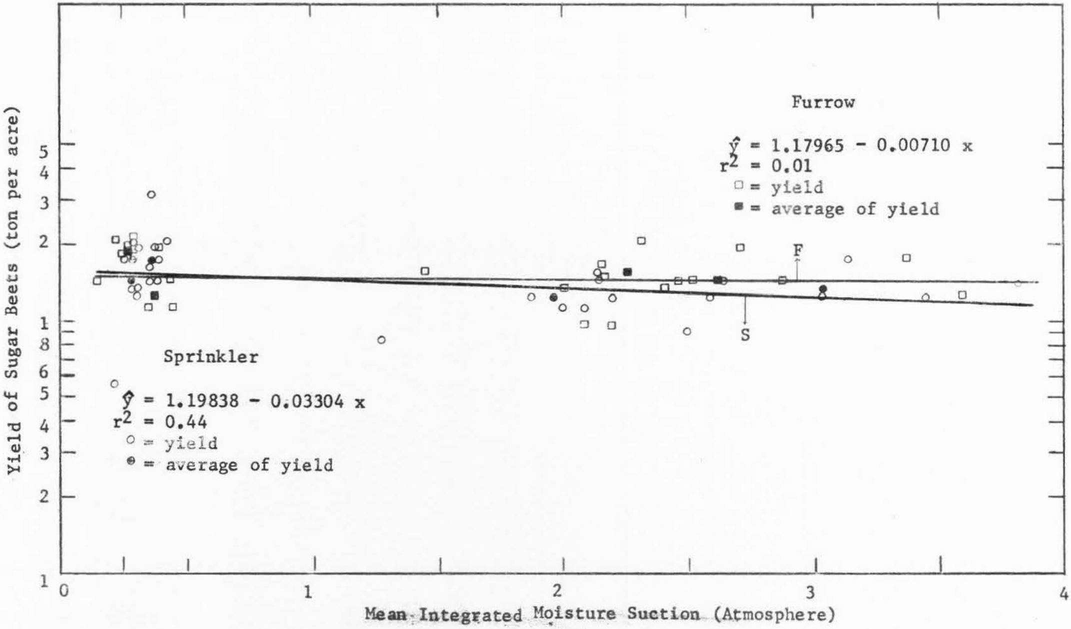

Figure 22. Response of sugar beets to soil water suction under treatment DF = N_2.

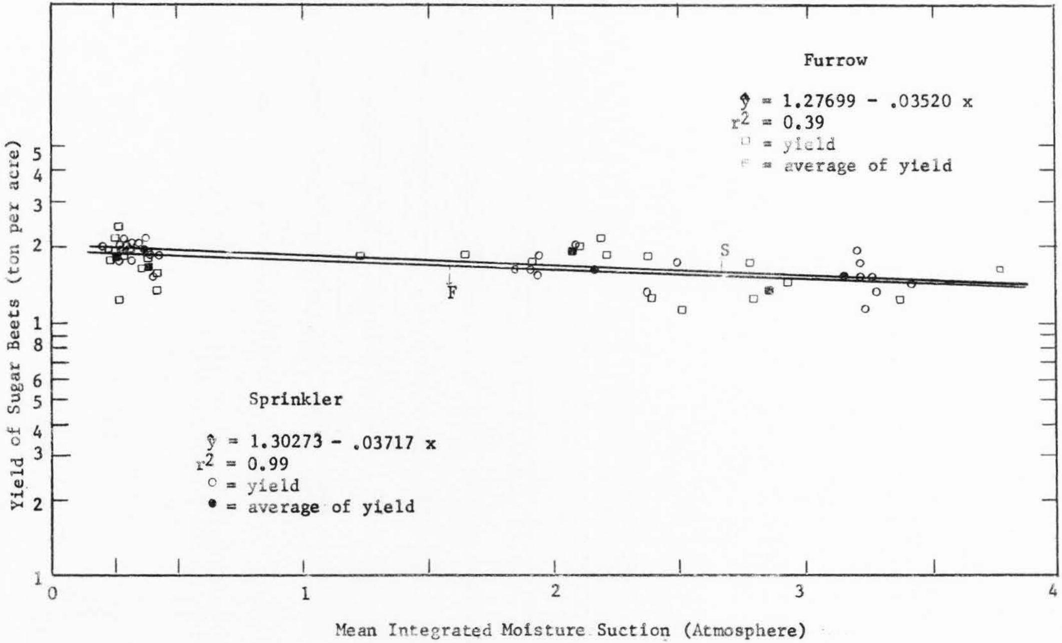

Figure 23. Response of sugar beets to soil water suction under treatment DFHI = N_3P_1.

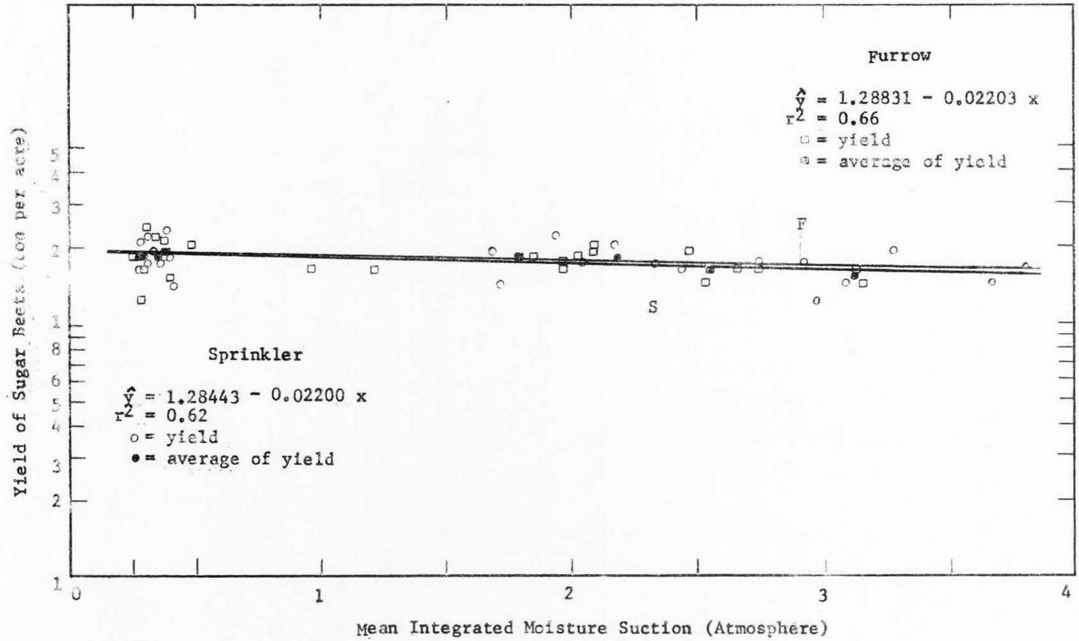

Figure 24. Response of sugar beets to soil water suction under treatment DFGI = N_2P_2.

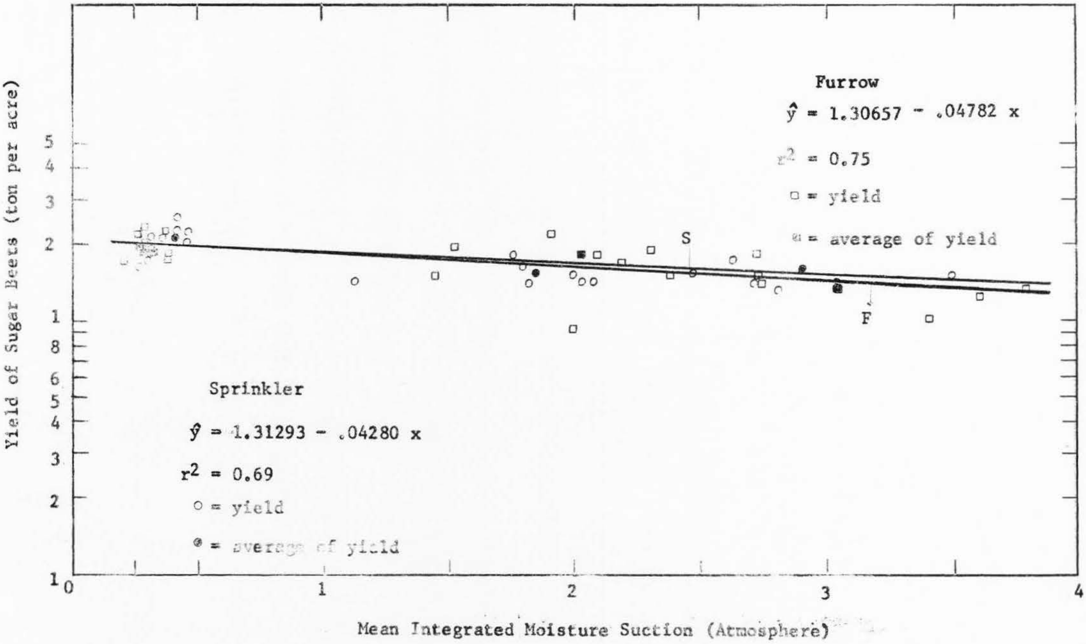

Figure 25. Response of sugar beets to soil water suction under treatment DFGH = N_3P_1.

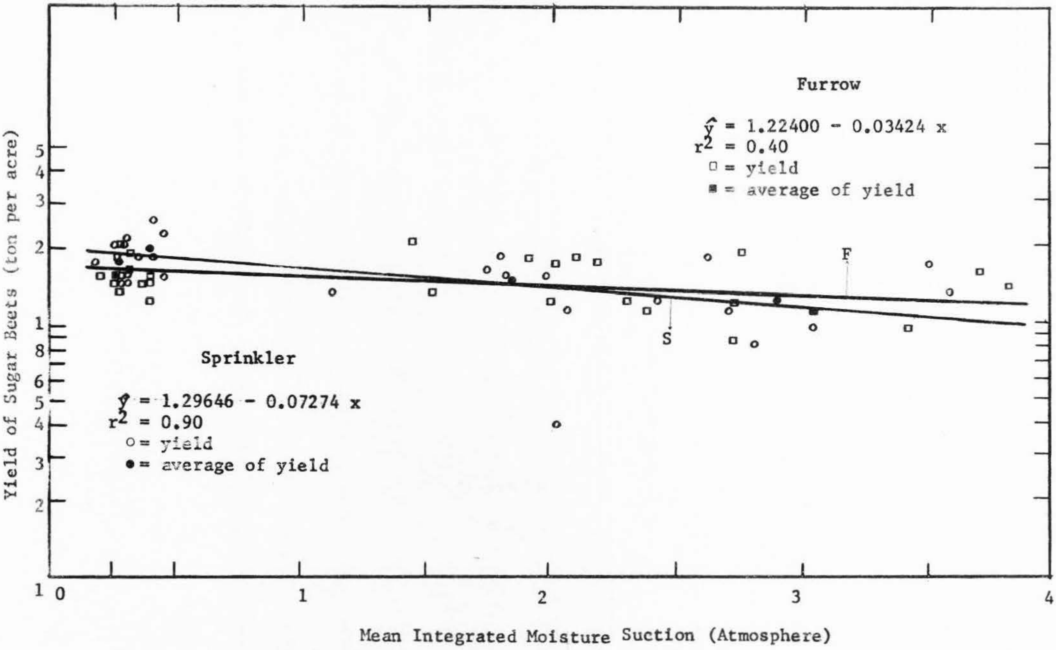

Figure 26. Response of sugar beets to soil water suction under treatment DE = N_1P_1.

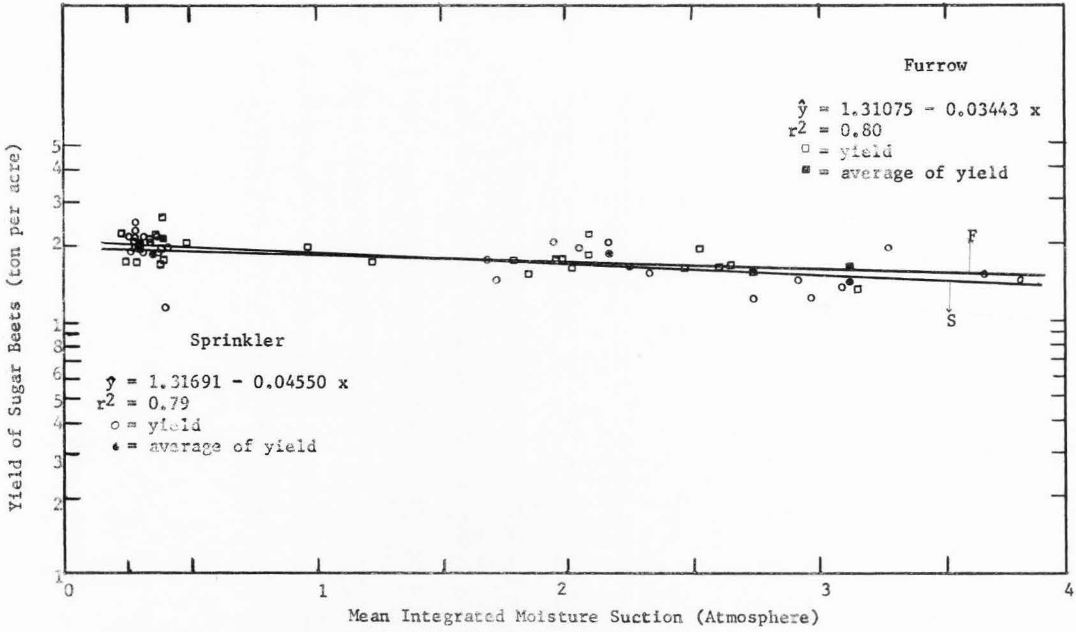

Figure 27. Response of sugar beets to soil water suction under treatment DEHI = N_2P_2.

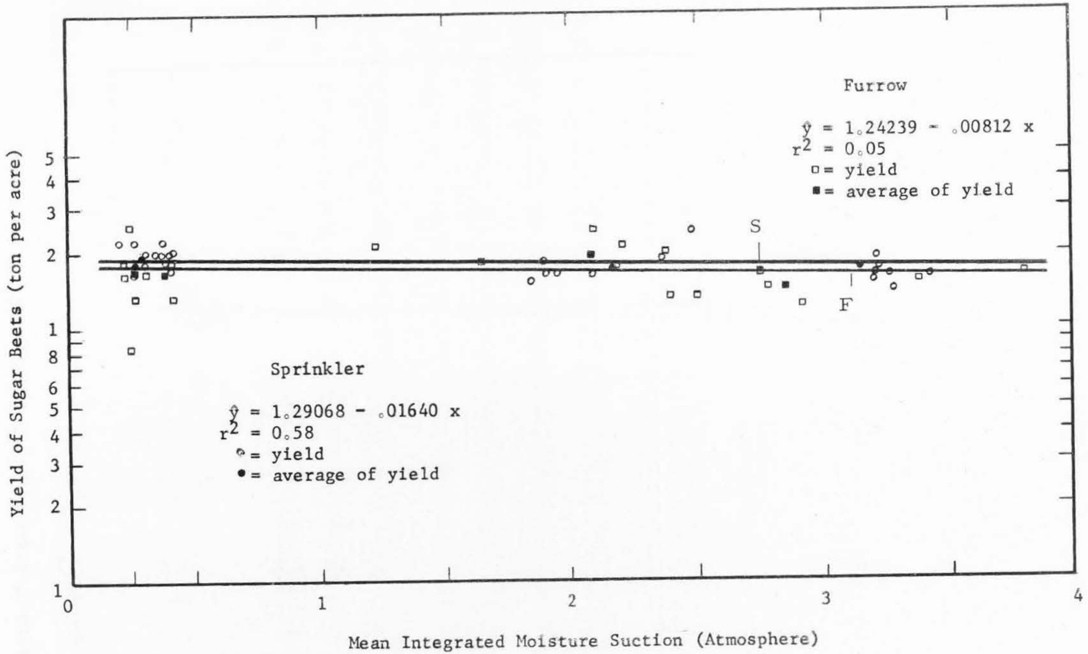

Figure 28. Response of sugar beets to soil water suction under treatment DEGI = N_1P_3.

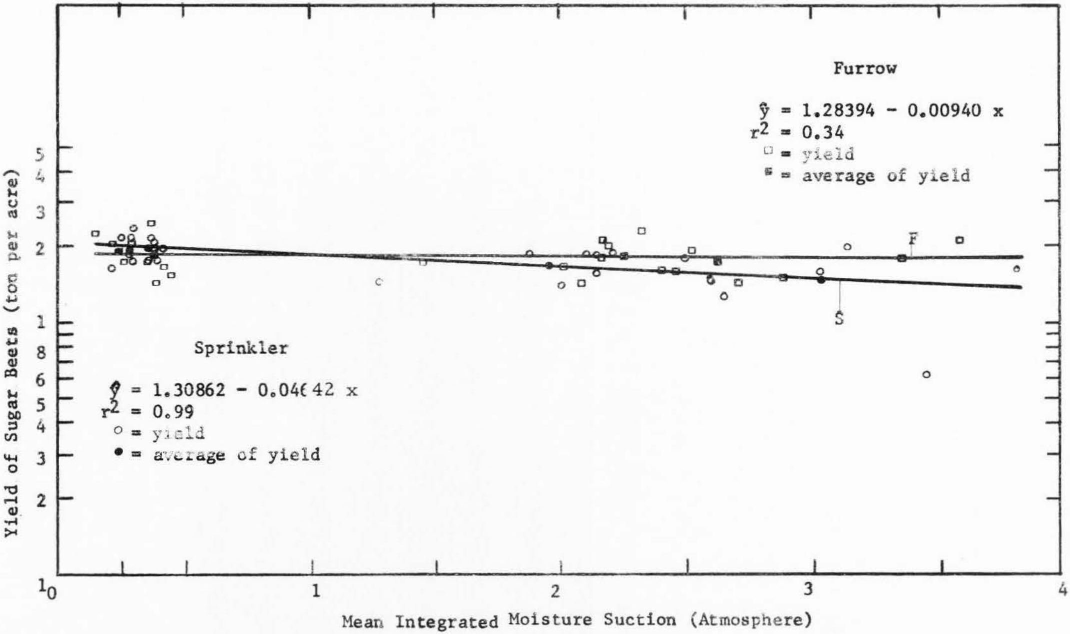

Figure 29. Response of sugar beets to soil water suction under treatment DEGH = N_2P_2.

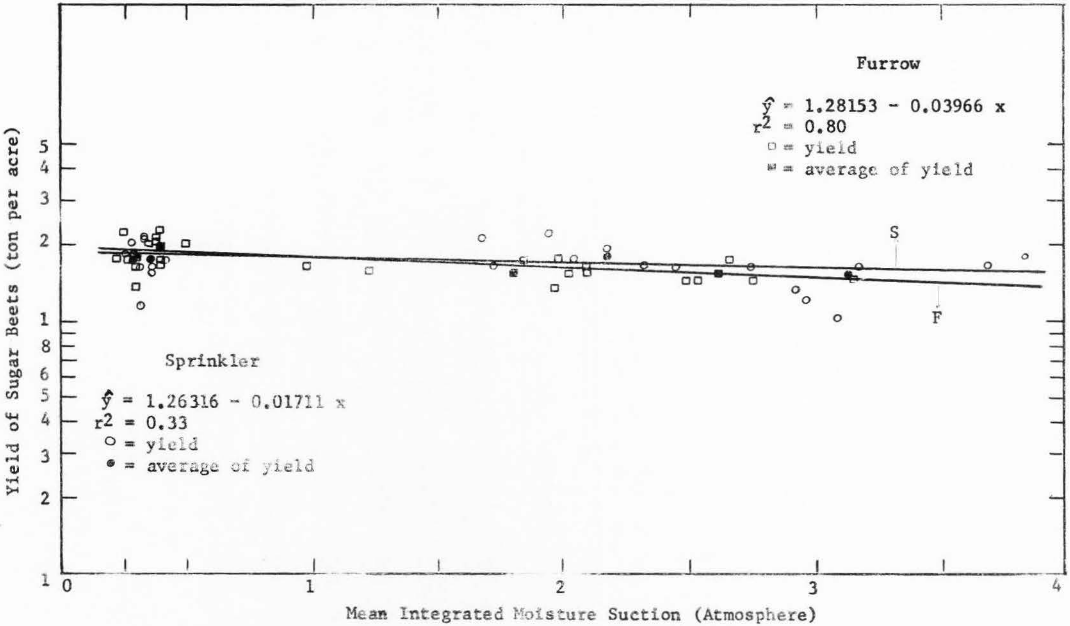

Figure 30. Response of sugar beets to soil water suction under treatment DEFI = N_2P_2.

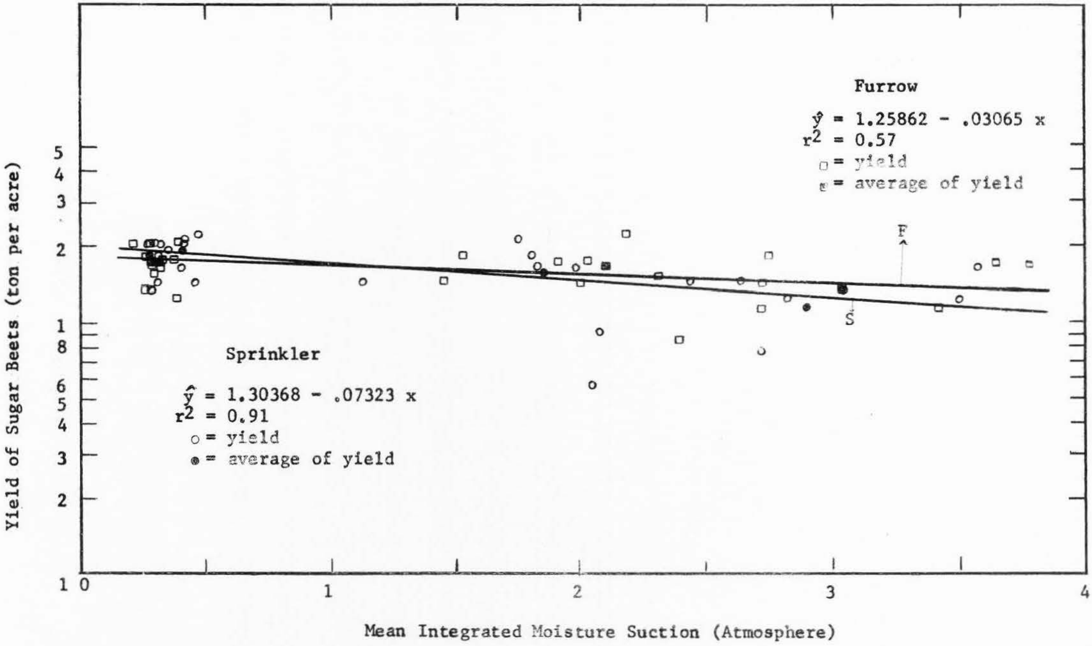

Figure 31. Response of sugar beets to soil water suction under treatment DEFH = N_3P_1.

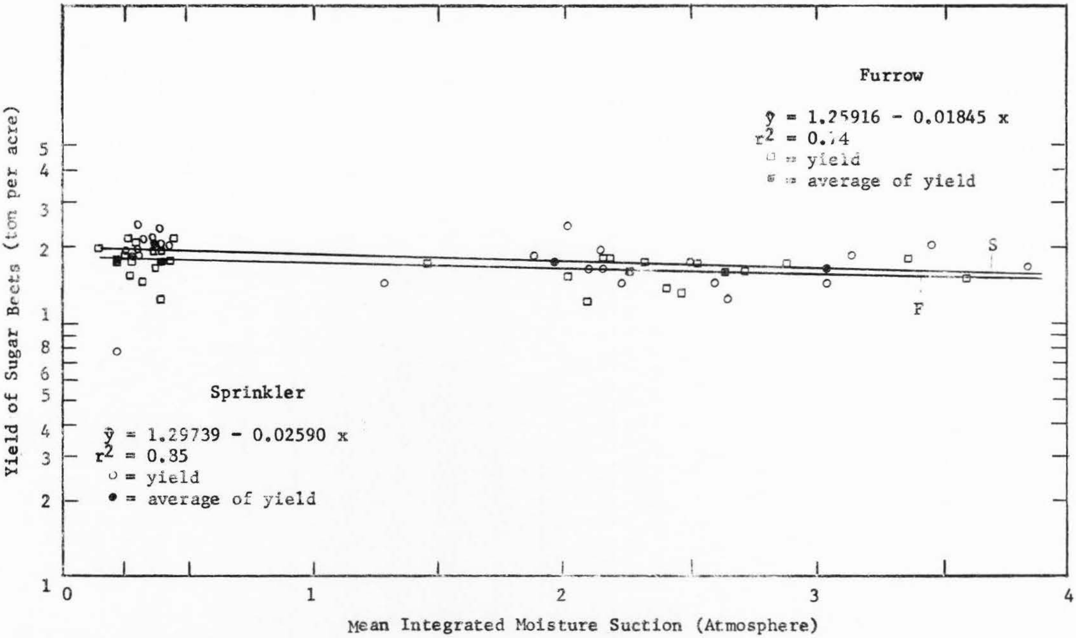

Figure 32. Response of sugar beets to soil water suction under treatment DEFC = N_2P_2.

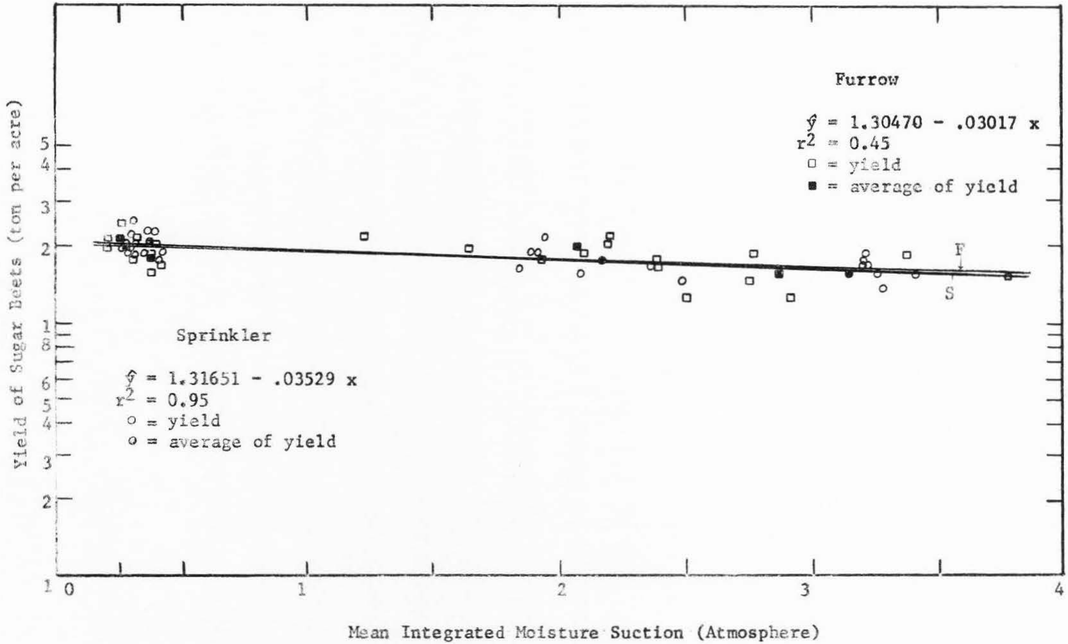

Figure 33. Response of sugar beets to soil water suction under treatment DEFGHI = N_3P_3.

suction. The values of b were nearly all negative and showed decreasing yields with increasing moisture suction (decreasing potential). The two cases in which the values of b were positive were:

Treatment 1 in the sprinkler irrigated series, which received no fertilizer during the course of the experiment, and

Treatment DI in the furrow series, which received nitrogen five years earlier and phosphorus on the current crop.

In both cases the magnitude of the positive regression was negligible. Consequently, no noticeable error was introduced by ignoring the positive slopes and considering them to be negative.[1]

A large dispersion of the values of b was found, as shown in Table 3. This dispersion was removed by a transformation in which the values of b are multiplied by -10000. The analysis of variance was run on the log of these values.[2]

In the analysis of variance the assumption was made that there was a normal population with homogeneity of variance, s^2. This latter assumption was tested by Bartlett's test, in which the estimated values of variance, s^2 are calculated for each treatment

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[1] Bohidar. Ibid.

[2] Bohidar. Ibid.

Table 3. Values of elevation and slope for 64 regression lines

Treatment		Sprinkler			Furrow		
		Elevation a	Slope b	r^2x100	Elevation a	Slope b	r^2x100
	(1)	1.19673	+0.00605	12.7	1.25406	-0.04648	95.0
N_1P_1	HI	1.32544	-0.05935	86.1	1.29818	-0.03505	82.2
P_2	GI	1.28156	-0.02074	79.1	1.26316	-0.02376	69.4
N_1P_1	GH	1.29785	-0.04294	80.8	1.29490	-0.03255	59.3
N_1P_1	FI	1.29337	-0.04136	91.1	1.25892	-0.01803	31.0
N_2	FH	1.20908	-0.02341	55.4	1.24699	-0.05534	70.7
N_1P_1	FG	1.28089	-0.02259	97.2	1.27751	-0.02581	49.8
N_2P_2	FGHI	1.30325	-0.02824	68.3	1.32569	-0.03402	82.0
P_2	EI	1.26742	-0.01881	54.9	1.26913	-0.02854	71.6
N_1P_1	EH	1.26327	-0.03609	88.3	1.22439	-0.01476	37.3
P_2	EG	1.24128	-0.01363	22.6	1.25401	-0.01314	34.4
N_1P_3	EGHI	1.32751	-0.04452	67.6	1.32306	-0.03988	69.9
N_1P_1	EF	1.26027	-0.03426	47.5	1.20348	-0.01279	8.8
N_2P_2	EFHI	1.28212	-0.02964	55.4	1.29379	-0.02788	85.2
N_1P_3	EFGI	1.33238	-0.04632	65.6	1.28578	-0.01765	33.0
N_2P_2	EFGH	1.35582	-0.05682	73.3	1.33316	-0.05036	99.5
N_1P_1	DI	1.28649	-0.03345	90.7	1.21897	+0.00224	0.67
N_2	DH	1.18955	-0.01181	27.0	1.19517	-0.00075	0.03
N_1P_1	DG	1.31041	-0.03786	61.4	1.26383	-0.02459	84.7
N_2P_2	DGHI	1.32066	-0.03156	54.8	1.33171	-0.04396	97.0
N_2	DF	1.19838	-0.03304	44.0	1.17965	-0.00710	1.5
N_3P_1	DFHI	1.30273	-0.03717	99.4	1.27699	-0.03520	38.7
N_2P_2	DFGI	1.28443	-0.02200	62.0	1.28831	-0.02203	65.8
N_3P_1	DFGH	1.31293	-0.04280	68.9	1.30657	-0.04782	75.4
N_1P_1	DE	1.29646	-0.07274	90.2	1.22400	-0.03424	40.2
N_2P_2	DEHI	1.31691	-0.04550	79.3	1.31075	-0.03443	80.3
N_1P_3	DEGI	1.29068	-0.01640	58.2	1.24239	-0.00812	4.6
N_2P_2	DEGH	1.30862	-0.04642	99.2	1.28394	-0.00940	34.0
N_2P_2	DEFI	1.26316	-0.01711	33.1	1.28153	-0.03966	80.0
N_3P_1	DEFH	1.30368	-0.07323	91.2	1.25862	-0.03065	56.6
N_2P_2	DEFG	1.29739	-0.02590	84.8	1.25916	-0.01845	73.7
N_3P_3	DEFGHI	1.31651	-0.03529	94.9	1.30470	-0.03017	45.4

from the following equation[1]:

$$S^2_{(y,\ x)_i} = \frac{\Sigma(y_s - \bar{y}_s)^2 - b_s^2\Sigma(x_s - \bar{x}_s)^2 + \Sigma(y_f - \bar{y}_f) - b_f^2\Sigma(x_f - \bar{x}_f)^2}{2n - 4} \quad - - - 5$$

where

s	is sprinkler irrigation
f	is furrow irrigation
n = 4	is the number of points which were used in calculating the regression lines
i	is used to indicate the "i"th treatment

The X^2 is obtained from:

$$X^2 = 2.3026\ (n-1)\ (T \log s^2 - \log \bar{s}^2) \quad - - - - - - - 6$$

where

n = 2	is the method of irrigation
T = 32	is the number of treatments
$\bar{s}^2$	is the average of the variances

The factor 2.3026 is a constant ($\log_e 10$) necessary because common logarithms are used.

The results of this test are shown in Table 4. The small value of calculated X_{31} = 7.37 compared with the table value of X = 43.8 with 5 percent probability shows that the variance is homogeneous.

The results of analysis of variance on b and a are shown in Tables 5 and 6. The analysis of variance in Table 5 shows that the

[1] Bohidar, N. R. Notes on experimental design.

Table 4. Bartlett test of homogeneity of variance

Treatment	Regression coefficient		Mean square s^2	Log s^2
	Sprinkler	Furrow		
(1)	0.00605	0.04684	0.00052	-3.2840
HI	0.05935	0.03505	0.00102	-2.9914
GI	0.02074	0.02376	0.00044	-3.3565
GH	0.04294	0.03255	0.00110	-2.9586
FI	0.04136	0.01803	0.00119	-2.9245
FH	0.02341	0.05534	0.00186	-2.7305
FG	0.02259	0.02581	0.00084	-3.0757
FGHI	0.02824	0.03402	0.00077	-3.1135
EI	0.01881	0.02854	0.00076	-3.1192
EH	0.03609	0.01476	0.00071	-3.1487
EG	0.01363	0.01314	0.00126	-2.8996
EGHI	0.04452	0.03988	0.00204	-2.6904
EF	0.03426	0.01279	0.00403	-2.3947
EFHI	0.02964	0.02788	0.00108	-2.9666
EFGI	0.04632	0.01765	0.00219	-2.6596
EFGH	0.05682	0.05036	0.00174	-2.7595
DI	0.03345	0.00224	0.00108	-2.9666
DH	0.01181	0.00075	0.00325	-2.4881
DG	0.03786	0.02459	0.00121	-2.9172
DGHI	0.03156	0.04396	0.00130	-2.8861
DF	0.03304	0.00710	0.00585	-2.2328
DFHI	0.03717	0.03520	0.00242	-2.6162
DFGI	0.02200	0.02203	0.00069	-3.1612
DFGH	0.04280	0.04782	0.00198	-2.7033
DE	0.07274	0.03424	0.00305	-2.5157
DEHI	0.04550	0.03443	0.00108	-2.9666
DEGI	0.01640	0.00812	0.00198	-2.7033
DEGH	0.04642	0.00940	0.00022	-3.6576
DEFI	0.01711	0.03966	0.00125	-2.9031
DEFH	0.07323	0.03065	0.00159	-2.7986
DEFG	0.02590	0.01845	0.00030	-3.5229
DEFGHI	0.03529	0.03017	0.00151	-2.8210
Sum		0.05031		-92.9333
Mean		0.00157		-2.8041
		$X^2 = 7.37$		

Table 5. Analysis of variance on the regression coefficients

Source of variance	Degree of freedom	Sum square	Mean sum square	F
Between treatment	31	4.0416388	0.1303754	1.4[a]
Error	32	2.9956875	0.0936152	
Total	63	7.0373263		

[a] Not significant at p = 0.05.

Table 6. Analysis of variance on elevation of regression lines

Source of variance	Degree of freedom	Sum square	Mean sum square	F
Between treatment	31	0.0856309	0.0027623	4.99**
Error	32	0.0177041	0.0005532	
Total	63	0.1033350		

** Significant at 1 percent level.

values of b are not significantly different between treatments. The analysis of variance in Table 6 shows that the differences among the values of a are highly significant.

To find the individual effects of fertilizer combinations, partitions of the responses were run over the 32 different fertilizer combinations under two methods of irrigation using the Yates method (3). The results are shown in Table 7. The factorial effect totals appear in Column 5 of this table. The identification of each of the 32 factorial effect totals appears in Column 6.

The basic experiment was designed in such a way that only one half, or 32, of fertilizer combination effects occur in the data. The other half of the factorial effects are the aliases of the 32 combinations, which appear in the last column of Table 6, when DEFGHI is considered the defining contrast. The error mean square per unit was computed from the third order interactions which are the estimation of errors as follows:

$$s^2 = \frac{\Sigma(\text{estimate of errors})^2}{2^n \cdot 2 \cdot 10} = 0.00133$$

where n is the number of factors that were actually in the factorial experiment, five in this study, as shown in Table 7. There were two methods of irrigation (sprinkler and furrow) and ten third order interactions between the factors.

Table 7. Partitions of elevation effect

Treatment combination	Treatment total	(1)	(2)	(3)
(1)	2.45079	4.95625	10.01326	19.95202
d(i)	2.50546	5.05701	9.93876	20.45317
e(i)	2.53655	4.93032	10.14732	20.29766
de	2.52046	5.00844	10.30585	21.04688
f(i)	2.55229	5.11896	10.12366	- 0.05474
df	2.37803	5.02836	10.17400	0.02003
ef	2.46375	5.13114	10.48825	0.01114
def(i)	2.54469	5.17471	10.55863	0.07560
g(i)	2.54472	5.00834	0.03858	0.16288
dg	2.57424	5.11532	- 0.09332	- 0.04703
eg	2.49529	5.03579	0.06730	0.20940
deg(i)	2.53307	5.13821	- 0.04727	0.05966
fg	2.55840	5.24512	- 0.09890	0.18444
dfg(i)	2.57274	5.24313	0.11004	- 0.08421
efg(i)	2.61816	5.24844	0.00161	0.24164
defg	2.55655	5.31019	- 0.07721	- 0.17596
		81.74973	81.65056	82.20138
h(i)	2.62362	0.05467	0.10076	- 0.07450
dh	2.38472	-0.01609	0.06212	0.15853
eh	2.48766	-0.17426	- 0.09060	0.05034
deh(i)	2.62766	0.08094	0.04357	0.07038
fh	2.45607	0.02952	0.10698	- 0.13190
dfh(i)	2.57972	0.03778	0.10242	- 0.11457
efh(i)	2.57591	0.01434	- 0.00199	0.20894
defh	2.56230	-0.06161	0.06165	- 0.07882
gh	2.59275	-0.23890	- 0.07076	- 0.03864
dgh(i)	2.65237	0.14000	0.25520	0.13417
egh(i)	2.65057	0.12365	- 0.00826	0.00456
degh	2.59256	-0.01361	0.07595	0.06364
fgh(i)	2.62894	0.05962	0.37890	0.32596
dfgh	2.61950	-0.05801	- 0.13726	- 0.06796
efgh	2.68898	-0.00944	- 0.11763	- 0.51616
defgh(i)	2.62121	-0.06777	- 0.05833	0.05930
	81.74973	81.65056	82.20138	82.25492

* Significant at 5 percent level

** Significant at 1 percent level

Table 7. (continued)

(4)	Effect Total (5)	(6)	Alias	
40.40519	81.74973	Ground		
41.34454	- 0.09917	D	EFGHI	
- 0.03471	0.38491	E	DEFGHI	
- 0.06446	0.16591	DE	FGHI	
0.11585	0.20475	F	DEFGHI	
0.26906	- 0.11635	DF	EGHI	
0.10023	0.16373	EF	DGHI	
0.06568	- 0.19859	DEF	GHI	error
0.08403	1.25037	G **	DEFHI**	
0.12072	- 0.01197	DG	EFHI	
- 0.24647	- 0.35965	EG	DFHI	
0.13012	- 0.68625	DEG	FHI	error
0.09553	0.25307	FG	DEHI	
0.06820	- 0.27043	DFG	EHI	error
0.25827	0.23189	EFG	DHI	error
- 0.45686	0.18181	DEFG	HI	
82.25492	82.84376			
0.50115	0.93935	H**	DEFHI**	
0.74922	- 0.02975	DH	EFGI	
0.07477	0.15321	EH	DFGI	
- 0.08674	- 0.03455	DEH	FGI	error
- 0.20991	0.03669	FH	DEGI	
- 0.14974	0.37659	DFH	EGI	error
- 0.26865	- 0.02733	EFH	DGI	error
- 0.41760	- 0.71513	DEFH*	GI*	
0.23303	0.24807	GH	DEFI	
0.02004	- 0.16151	DGH	EFI	error
0.01733	0.06017	EGH	DFI	error
- 0.28776	- 0.14895	DEGH	FI	
0.17281	-0.21299	FGH	DEI	error
0.05908	-0.30509	DFGH	EI	
- 0.39365	-0.11373	EFGH	DI	
0.57546	0.96911	DEFGHI**	I **	
82.84376	83.87792			

The standard error of a single observation was: S = 0.03655 and the standard error of a factorial effect total was:

$$\sqrt{2^n \cdot 2 \cdot s^2} = 0.29240.$$

For 10 degrees of freedom, the 5 percent and 1 percent values of t were 2.228 and 3.169, respectively. Hence, the two numbers required for statistical inference were

(2.228) (0.29240) = 0.65147 and (3.169) (0.29240) = 0.92661.

A comparison of the effect total (Column 5, Table 6) with these values shows that total effect of treatments G=DEFHI, H=DEFGI, GI=DEFH,and DEFGH=I exceeds the calculated values and has a significant effect on the response of sugar beet yield to moisture potential.

DISCUSSION AND CONCLUSION

The response of sugar beets to moisture potential is affected by fertilizer treatment. Indeed, it is the combination of plant nutrition and the state of water which determines the yield response.

Haddock (13) showed that moisture should be included as a variable or at least a controlled factor to get meaningful results from fertilization studies under irrigation. He showed (11) a difference of nearly 12 tons in the yield of sugar beets under favorable conditions of soil moisture potential and fertilizer treatment than under unfavorable conditions.

The analysis of variance in Table 5 shows that different combinations of nitrogen and phosphorus and their time of application in the rotation do not significantly influence the slope b of regression relating log yield to moisture suction, but comparing the F value of this analysis (1.4) to table value (1.8) there is evidence that the value of F approaches a significant region. Possibly the lack of data between the four levels of moisture causes a high error and prevents a sufficiently accurate continuum of moisture data. If it were possible to obtain data concerning the entire moisture suction continuum, the results might be different. Haddock (11) showed the interaction of moisture with some combinations and placements of fertilizer in some years. The same conditions produced no significant results in other years. Possibly analyzing the data as a whole during rotation to get regression between yield and water suction might contribute to adjusting the variation and might get non-significant results for the whole rotation.

It was expected that the yield response of sugar beets to moisture would be influenced differently by nitrogen fertilizer on furrow than on sprinkler irrigated plots. The reason is that fertilizer moves out of the root zone and up into the ridges between furrows more than under sprinkler irrigation. Thus, in furrow plots, fertilizer may limit growth unless there is a high fertility level, in which case more fertilizer remains in the moist part of the root zone soil and the plant responds better to moisture conditions.

The analysis of variance, Table 6, shows that the differences between the values of a, elevation of regression relating log yield to moisture suction , are highly significant between fertilizer application and placement treatments. Elevation is almost always higher under sprinkler irrigation than under furrow except for certain high (or low) treatments. The reason is greater uniformity of water availability and more fertilizer availability under the sprinkler method.

The partition of the factorial effect total for elevation of regression lines (Table 6) shows that treatments G=DEFHI (one year residual phosphorus or nitrogen three times plus annual and residual phosphorus twice, H=DEFGI (annual nitrogen or phosphorus three times plus residual nitrogen twice, and I=DEFGH (annual phosphorus or three times nitrogen plus residual phosphorus twice) have a highly significant effect at one percent probability on the elevation of regression lines relating log yield to moisture suction. In the same way, treatment GI=DEFH (annual and residual phosphorus twice or nitrogen three times plus one year residual phosphorus) showed a significant effect at 5 percent. There is no way to say that the responses are due to treatments or their aliases or the mixture of them.

The only method by which it is possible to remove this ambiguity is to run a new experiment consisting of the 32 combinations that were omitted in the experiment and put the results of the new experiment together with the data which are available to get a complete replicate and the independent estimate of these factors. This procedure is not practical in the case of this experiment, and one should get some inference from the nature of available data and results and combine it with the results of other investigators to get an estimate of factorial effect.

The elevations, a, and the slopes, b, of regression lines are arranged in Table 8 according to the repetition numbers of the treatments which were used in the rotation; nitrogen, phosphorus, or a combination of the two. As shown in Table 8, when there is no fertilizer in the rotation or when nitrogen appears twice without phosphorus, the yield under all moisture conditions and the coefficient of determination for water suction and yield, r^2, are low. In these cases the yield is somewhat higher under the furrow method than under sprinkler irrigation. If phosphorus appears twice without nitrogen, the yield is somewhat higher than for no fertilizer or for nitrogen twice, but there is no difference between methods of applying water. When phosphorus is applied in the rotation with or without nitrogen, the yields are higher than without phosphorus. The increase in yield appears to be greater when there is a combination of nitrogen and phosphorus than when there is only phosphorus in the rotation. There is also a higher correlation between yield and moisture suction when there is only phosphorus in the rotation than when nitrogen appears alone.

The response of yield to water suction behaves in a similar manner, but the interaction between this response and the method of applying water is so great that the differences are not statistically significant. In most cases when there are both annual and residual

Table 8. Value of elevations and slopes of regression lines which are arranged according to the number of nitrogen and phosphorus in the rotation

Treatment		Sprinkler			Furrow		
		a	b	r^2	a	b	r^2
(1)		1.19	.0.00	.0.12	1.25	-0.04	0.95
P_2	GI	1.28	-0..02	0.79	1.26	-0.02	0.69
	EI	1.27	-0.02	0.55	1.27	-0.03	0.72
	EG	1.24	-0.01	0.23	1.25	-0.01	0.34
N_2	FH	1.21	-0.02	0.55	1.25	-0.05	0.70
	DH	1.19	-0.01	0.27	1.19	0.00	0.02
	DF	1.20	-0.03	0.44	1.18	-0.01	0.01
N_1P_1	HI	1.32	-0.06	0.86	1.30	-0.04	0.82
	HG	1.30	-0.04	0.81	1.29	-0.03	0.59
	HE	1.26	-0.04	0.88	1.22	-0.01	0.37
	FI	1.29	-0.04	0.91	1.26	-0.02	0.31
	FG	1.25	-0.02	0.97	1.28	-0.02	0.50
	FE	1.26	-0.03	0.47	1.20	-0.01	0.08
	DI	1.29	-0.03	0..90	1.21	0.00	0.00
	DG	1.31	-0.04	0.61	1.26	-0.02	0.84
	DE	1.29	-0.07	0.90	1.22	-0.03	0.40
N_2P_2	HFIG	1.30	-0.03	0.68	1.32	-0.03	0.82
	HFIE	1.28	-0.03	0.55	1.29	-0.03	0.85
	HFGE	1.35	-0.06	0.73	1.33	-0.05	0.99
	HDIG	1.32	-0.03	0.55	1.33	-0.44	0.97
	HDIE	1.32	-0.04	0.79	1.31	-0.03	0.80
	HDGE	1.31	-0.05	0.99	1.28	-0.01	0.34
	FDIG	1.28	-0..02	0.62	1.29	-0.02	0.66
	FDIE	1.26	-0.02	0.33	1.28	-0.04	0.80
	FDGE	1.30	-0.03	0.85	1.26	-0.02	0.74
N_1P_3	HIGE	1.33	-0.04	0.68	1.32	-0.04	0.70
	FIGE	1.33	-0.05	0.66	1.28	-0.02	0.33
	DIGE	1.29	-0.02	0.58	1.24	-0.01	0.05
N_3P_1	HFDI	1.30	-0.04	0.99	1.28	-0.04	0.39
	HFDG	1.31	-0.04	0.69	1.31	-0.05	0.75
	HFDE	1.30	-0.07	0.91	1.26	-0.03	0.57
N_3P_3	HFDIGE	1.32	-0.03	0.95	1.30	-0.03	0.45

nitrogen in the rotation, the yield response to moisture under furrow irrigation is equal to or greater than that under sprinkler irrigation. However, when there is only residual nitrogen, the yield response to moisture under sprinkler irrigation is equal to or higher than that under furrow irrigation. Higher yields are generally obtained when both nitrogen and phosphorus are applied twice in the rotation, as against once, but the response to moisture seems to be about the same and is generally higher for sprinkler irrigation. Under furrow irrigation the correlation is better for phosphorus twice plus nitrogen twice, but under sprinkler irrigation phosphorus twice plus nitrogen twice gives a lower correlation than phosphorus once plus nitrogen once. In the sprinkler method, when phosphorus is applied three times and nitrogen at least once in the rotation, the yield is higher than when nitrogen is applied three times and phosphorus once. This conclusion is true except in the case of DIGE (which is 5-year residual nitrogen and 3-year phosphorus). Also, in the sprinkler method, the correlation is higher when nitrogen is applied three times and phosphorus at least once than when phosphorus is applied three times and nitrogen at least once.

Nitrogen applied three times and phosphorus at least once gave higher yield and correlation than phosphorus applied three times and nitrogen at least once in the furrow method except in the case of HIGE, which is current year nitrogen plus phosphorus three times.

Annually or more currently applied fertilizer appears to have more effect in increasing the yield than is the case with more residual fertilizer except in some cases in which residual phosphorus has more effect. This, too, may be a nitrogen effect operating through a higher production of symbiotic nitrogen during the alfalfa growth.

Maximum elevation is obtained when nitrogen is applied twice annually and one-year residual nitrogen plus twice one year and five-year residual phosphorus under both methods of irrigation, but correlation is better under the furrow method in this case. When there is a combination of nitrogen and phosphorus in the rotation, correlation is better under sprinkler irrigation except in some cases, where nitrogen is applied twice and phosphorus twice in the rotation. the correlation is better in furrow irrigation.

The nature of the data, the parameters of the regression lines, and the correlation coefficient show that a combination of phosphorus and nitrogen fertilizer gives higher yield at the same level of moisture potential than the application of nitrogen or phosphorus alone, and the application of nitrogen and phosphorus alone gives higher yield at the same level of moisture than non-fertilized plots. When fertilizer is applied in the rotation the maximum yield is obtained when the mean integrated moisture suction is in the region of 0.25 to 0.4 atmosphere.

It has been shown (1, 7, 11, 12, 13, 25) that nitrogen fertilizer, applied either annually or residually, has a positive effect in increasing the yield of sugar beets. The combination of phosphorus and nitrogen has always given greater yields than either one alone. Therefore, it can be said that the significant responses of I=DEFGH, G=DEFHI, and IG=DEFH are due to DEFGH, DEFHI, and DEFH, which have nitrogen three times (240 lbs.) plus phosphorus two and one (88 and 44 lbs.) than to I, G, and GI, which are annual and residual phosphorus.

Hansen and Haddock (14), working on the same data on the basis of each year and comparing years, found that a combination of phosphorus and nitrogen increased yield under favorable moisture conditions.

It cannot be said that the annual and residual phosphorus or nitrogen separately did not increase yield. The fact is that the annual and residual phosphorus or nitrogen separately increased the yield, but had less effect than the combination of nitrogen and phosphorus annually and residually. In the case of H=DEFGI, it is probable that the response was due to mixture of H and DEFGI which was nitrogen three times, (240 lbs.) plus phosphorus three times, (132 lbs.) or DEFGI, which was nitrogen twice, (160 lbs.) plus phosphorus three times, (132 lbs.) than to H, which is annual nitrogen.

Taylor[1] found no significant response to moisture when there was no fertilizer in the rotation. He found only slight response when there was either phosphorus or nitrogen alone in the rotation, and no significant effect on the response of yield to moisture with five-year residual nitrogen. Taylor's explanation of the case when nitrogen three times plus phosphorus three times or the case when 80 lbs. of nitrogen and 44 lbs. of phosphorus are applied to sugar beet crops, accompanied by the application of a similar amount of fertilizer to one or both of the other two crops was not exactly as it was obtained here by comparing the values of a and b and their correlation coefficient. He found that differences in results were not large enough to be statistically significant. Here, these combinations are in groups that had some of the highest responses.

The conclusion of the entire study is that the response of sugar beet yield to moisture potential depends on the fertilizer program. The combination of phosphorus and nitrogen has an effect on the response to moisture in the region of 0.25 to 0.40 atmosphere moisture suction. The effect is on the elevation of regression rather than on the slope of regression relating log yield to moisture suction. The magnitude of yield decrease per unit of water suction increase is not affected markedly by a fertilizer program, but the level of yield is certainly influenced by fertilizer. There

[1] Taylor. Op. cit.

is some evidence that the slope of the response curve might be affected, and it could be shown if data were available to cover the entire water suction continuum.

Both elevations and slopes of regression lines tend to be higher under sprinkler irrigation, because the fertilizer is more available and there is more uniformity of water availability under the sprinkler than under the furrow method.

Maximum yield is produced when nitrogen is applied three times (240 lbs.), or twice (160 lbs.) more recently, plus phosphorus (44 lbs.) at least once in the rotation. At soil water suction greater than 0.40 atmosphere, the yield decreases because of low water potential. In wetter soils, yield may also decrease because of problems that accompany wet and inadequately drained soils.

The minimum yield is produced when there is no fertilizer in the rotation or when there is either nitrogen or phosphorus alone. Phosphorus alone gives higher yields than nitrogen alone. This may be due to the existence of nitrogen in soil as a result of symbiotic nitrogen remaining from alfalfa in the rotation.

There is a higher correlation between log yield and linear moisture suction when both phosphorus and nitrogen are in the rotation than when they are absent. When nitrogen is applied three times plus phosphorus at least once, the correlation is better under sprinkler than under furrow irrigation. Nitrogen once plus phosphorus at least once and also nitrogen twice alone give a higher correlation coefficient under sprinkler irrigation, but phosphorus and nitrogen twice or phosphorus only twice gives a higher correlation coefficient under furrow irrigation.

More studies should be made and more accurate data are needed to determine the actual effect of fertilizer on the slope of regression relating yield to moisture.

SUMMARY

The integrated effect of soil moisture potential and fertilizer treatment and placement on the yield of sugar beets during a usual rotation under two methods of irrigation (sprinkler and furrow) has been found by relating yield to moisture suction under each fertilizer treatment and placement for each method of irrigation, and the results of seven years of experiment have been compared.

The effect of different fertilizer treatments and placements on the slopes of regression lines relating log yield to linear moisture suction during seven years of experiment is not significant at the 5 percent level but approaches significance at this level.

The actual effect of fertilizer on the response of sugar beets to moisture suction has been shown to be on the elevation of regression relating log yield to moisture suction.

A combination of nitrogen and phosphorus showed more effect on increasing the elevation, and, consequently, on the yield of sugar beets at the same level of moisture potential than in the case when nitrogen or phosphorus alone are included in the rotation. Increased elevation, and consequently yield, of sugar beets is also more evident than when there is no fertilizer in

the rotation for the same level of moisture. The correlation between log yield and linear moisture suction is high when both phosphorus and nitrogen are in the rotation and it is higher under sprinkler than under furrow irrigation unless there is enough more recent fertilizer in the rotation that causes a high correlation under furrow irrigation.

In general, the yield and its correlation to moisture potential increases with fertilization by a combination of more recent nitrogen and phosphorus unless there is a case of residual phosphorus, which, in combination with nitrogen, has more effect in increasing yield in the same level of moisture suction.. The moisture level for maximum yield is between 0.25 and 0.45 atmosphere. In most cases, the yield is greater under sprinkler than under furrow irrigation unless there is enough fertilizer to overcome the washout of fertilizer under furrow irrigation.

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