EFFECT OF SOIL APPLICATION OF CERTAIN MACRONUTRIENTS ON YIELD AND LEAF COMPOSITION OF THE POTATO

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ABSTRACT

A field experiment to study the effect of nitrogen, phosphorus, potassium, sulfur, and chlorine on the yield of potatoes, the specific gravity of the tubers, and chemical composition of the leaves was conducted under irrigation on a calcareous soil in the Beka'a, Lebanon. Nitrogen fertilization had a significant positive effect on potato yield and the nitrate concentration on the leaves and a significant depressing effect on the specific gravity of the tubers. Phosphorus tended to increase the yield and reduce the specific gravity especially when applied with nitrogen at high levels. Potassium, sulfur, and chlorine had little effect on yield and specific gravity.

The critical level of nitrate-N in the youngest mature leaves at time of blossoming was estimated to be 750 ppm. and that of acetic acid-soluble P early in the season was 0.2 percent with no definite value at later stages.

The levels of application of N and P for maximum economic return were estimated at 22 kg./du. for each element under the conditions of the experiment.

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INTRODUCTION

The potato crop is important not only for cooking but also as a source of starch. The average annual production of Lebanon from 1954 to 1962 was 38,500 m. tons. The amount and cost of production per dunum varies greatly depending on the locality, type of soil, irrigation practices, insect and disease control, and fertilization. Fertilization is one of the most important factors influencing the yield and to a certain extent the starch content of the tubers.

Potato yields in most growing areas have shown a response to nitrogen fertilizers. The amount of fertilizers necessary to produce the maximum yield is influenced by the soil, its ability to supply N and other nutrients, and other fertilizers added. In most of the cases N was found to reduce the starch content of the tubers especially if it is supplied in great amounts. The effect of P fertilizers varies from very little to great depending on the ability of the soil to supply P, and on the supply of other nutrients. The effect of sulfate on yield and starch content is not well known. It was reported by some workers to have increased the yield or starch content of the tubers while other workers reported the opposite effects.

Chlorine in very small amounts may be beneficial to the potato plants for certain physiological functions. However, in large amounts it becomes toxic to plants. Some soils and irrigation water in the Middle East may have a high content of chlorine. Therefore, it would be desirable to find the level of tolerance of potatoes for chlorine.

The purpose of this experiment was to study the effect of N, P, K, S and Cl and their interaction on:

1. Marketable yield and starch content of the tubers.
2. Chemical composition of the potato plant and to estimate the critical levels of the different elements.
3. The optimum rates of fertilizers required for the maximum economical yield.

REVIEW OF LITERATURE

Effect of Nitrogen

Nitrogen has given consistant yield response in all potato growing areas (43). Many workers including Boyd (1), Fineman (9), Hawkins (18), Kurten and Burghardt (27) and Nylund (34) reported potato yield response to N fertilizer applications up to 80 to 120 lb./acre. Hope et al. (20) and Terman et al., as reported by Hawkins (18), concluded that N increased the yield by increasing the growing season. Boyd (1) summarized the works of the 20 years since 1941 on potatoes in Britain. He stated that for some soils and seasons, even within the range of normal fertilizer practices, the response curve rises to a maximum and then begins to fall off and serious losses of crop can occur when the level of manuring exceeds the optimum for a given soil and season. The point at which the response curve for any nutrient reaches a maximum will be influenced by the supply of other nutrients from fertilizers and soil and other cultural practices. Kurten and Burghardt (27) found that relative increases in yield from N fertilizers were similar irrespective of the P and K status of the soil. However, the yield performance per kg. of N increased with increase in the P and K supply. Jacob et al. (24) reported that best response to N fertilizers under irrigation was with medium to high K depending on the potato variety. Grunes et al. (13) and Larson and Schultz (28) found that yields on plots receiving N and P were more than yields on plots receiving N and P alone.

In general, there is agreement among research workers that potato quality is directly associated with variation in dry matter content (46, 6, 44, 45). Hawkins (18) reported the findings of Terman et al. that excess application of N caused lower quality of tubers with regards to mealiness which was found by Unrau and Nylund (45) to be directly proportional to dry matter content and to specific gravity. Dunn and Nylund (6), Fineman (9) and Sheard and Johnston (37) reported an increase or decrease in specific gravity depending on soil conditions and localities. Kostleven and Pijl (26) reported a decrease in starch content of tubers and consequently in tuber yield due to N deficiency. Eastwood and Watts (7) found that the tendency of N to decrease specific gravity was enhanced with decreased K application. Fineman (9) found no interaction between N, P, and K on specific gravity.

Magnitski (30) reported that the critical level of N in potato leaves was 6.5% (leaves sampled were the youngest mature at the blooming stage). He also reported that the critical level dropped throughout the growing season. The maximum drop in N level was observed with plants that had been fertilized with N. The mature potatoes differed little or had no differences in N content for the different treatments of N fertilizer. Nitrate N was increased in the petioles by application of ammonium nitrate. Nylund (34) reported that maximum yield was obtained when there was 600 to 700 ppm. soluble N in the potato leaves at first flower bud stage. Harward et al. (15) reported increased N content of all the potato tissue due to application of potassium sulfate.

Effect of Phosphorus

Phosphorus is regarded as less critical for potatoes than N and K (21). Boyd (1) found that the fertilizer requirement of P for potatoes varied greatly depending on the ability of soil to supply this nutrient. He also concluded that potatoes responded more to P application if K and N were supplied than if they were omitted. Dunn and Nylund (6), Fineman (9) and Kurten and Burghardt (27) obtained an increase in yield as well as in specific gravity with each increase in the level of P_2O_5 from 30 to 60 lb./acre. Simpson and Crooks (38) obtained a significant positive effect on the yield of large tubers (more than 6 cm. diameter) due to application of P on low-P soils at the rate of 60 lb./acre of P_2O_5. However, yield of medium sized tubers (3 - 7 cm.) was not significantly increased. Dainty et al. (4) and Jacob and Dean (23) showed that the plant content of P depended on soil available P and P fertilizer application. Wilcox (48) obtained a decreased effect from 225 lb./acre of K on P in leaves. When chloride was banded with P the uptake of P was depressed compared to banding with sulfate. De and Singh (5) reported that N depressed the P concentration of the tops and roots at rates up to 75 lb./acre.

Effect of Potassium

Stempel (39) showed that K speeded photosynthesis catalytically and that the amount of carbohydrates formed was a logarithmic function of the K provided. Simpson and Crooks (38) reported that the fertilizer requirement of the potato crop for K varies from very little to very large according to the ability of the soil to supply this nutrient. Molen (32) reported an increase in yield with K application up to 280 kg./ha. of K_2O. Tagawa and Saki (40) found that deficiency of N or K or both in culture solution reduced starch production and consequently tuber yield. Simpson and Crooks (38) reported that tuber size was increased with K application. Kurten and Burghardt (27) obtained an increase in yield from K_2O application levels above 120 kg./ha. only with high application of N. Boyd (1) reported that the response to K fertilizers was increased as the level of N and P were increased to 1.0 and 1.4 cwt. (1 cwt. = 112 lb.) per acre respectively.

Fineman (9) and Sheard and Johnston (37) found that tubers from potatoes receiving the higher K application were lower in specific gravity. Gausman (12) obtained a decrease in starch content of tubers due to high application of sulfate of potassium. He also quoted the suggestion of Terman _et al._ that the greater solubility of the chloride of potassium over the sulfate of potassium resulted in the absorption of more K and that K concentration in the tuber rather than the chloride concentration was the chief factor causing difference in dry matter production.

Fullmer (10) found that soil K extracted with sodium acetate correlated highly (r = 0.90) with the K content of the leaf petioles at mid-season. Fullmer (10), Hawkins (17) and Magnitski (30) reported that the leaf content of K varied with date of sampling. Hawkins (17) and Magnitski (30) reported that K content of the leaves decreased as the season advanced. Magnitski (30), McAllister (31) and Wilcox (48) reported that an increase in K application caused an increase in K content in the leaves. Nylund (34) found that there was an inverse relation between soluble N and soluble P and K in leaf petioles of potatoes. He also found that when the N supply was high, K fertilizers gave significantly higher soluble-K contents and had no effect on the soluble-P content of petioles. Fullmer (10) reported that Lorenz et al. considered mid-season values over 9 percent to be in the efficient range.

Effect of Sulfur

Hooker and Kent (19) reviewing the findings of several workers reported that Sherbakoff, 1914, found in the first season a consistant increase in yield due to application of sulfur ranging from 300 to 900 lb. of S per acre. In the second season he obtained variable reduction in yield by applying 450 to 900 lb. of S per acre. Joset and Malterre, 1935, reported constant increase in yield of potato in calcareous alluvial soils following S application. Von Flitzen, 1913, reported differential response to S by different varieties; in some, yield was increased, in some decreased, and in others unaffected. Wilcox (48) obtained a linear increase of the yield with application of sulfate of potassium up to 150 lb./acre. The rate of increase fell off sharply afterwards. Harward et al. (15), Vazhenin (47) and Wilcox (48) obtained higher yields from sulfate of potassium than of chloride of potassium. Hooker and Kent (19) obtained no effect of S on yield up to 6000 lb./acre. Eastwood and Watts (8), Latzko (29), Nylund and Povian (35), Potterton et al. (36), Terman (41), Vazhenin (47), and Wilcox (48) reported that the use of sulfate of potassium resulted in tubers of higher specific gravity than the use of chloride of potassium. Latzko (29) reported that the beneficial effect of the sulfate was enhanced by N dressings. Terman et al. (42) obtained a higher starch content from application of sulfate of potassium than from chloride of potassium. Dunn and Nylund (6) and Harward et al. (15) found that the sulfate ion had no effect on the specific gravity of potato tubers.

Hawkins (17) reported that the S content of the non tuber part of the potato plant reduced with the advance of the season. Cressman and Davis (3) and Joset and Malterre, as reported by Hooker and Kent, (19) reported that the S treated plants had higher S content in the tops. Wilcox (48) found no effect of sulfate and chloride on the K content of potato tissue.

Effect of Chlorine

Nicholas and Catfov (33) reported that in conjunction with N and P both KCl and NaCl produced higher yields than K_2SO_4, but some degree of Cl injury occured.

Harward *et al*. (16) found that increasing Cl generally depressed the dry matter content of the top. They also found that with the ammonium form of N, increasing the chloride and simultaneously decreasing the sulfate reduced the chlorophyll content. Latzko (29) concluded that chloride interferred with the migration of carbohydrates from the leaf to the tubers and decreased the starch yield of the crop. Terman *et al*. (42) reported an inverse relationship between Cl in the plant and starch content of the tubers. He also found that fertilizing with KCl caused higher Cl and lower N, Mg and dry matter content. Magnitski (30) reported harmful Cl excess at 5 to 6 g./kg. of fresh weight of leaves. Gausman (12) found that K tended to be absorbed more when applied as KCl than applied as K_2SO_4. Gausman (11) reported that Cl had little influence on the sulfate content of the roots but was most negative on the S content of the tops and tubers.

MATERIALS AND METHODS

This experiment was designed to study the effect of N, P, K, S and Cl on potato yield, quality and leaf composition. A central composite, rotatable, incomplete factorial design (14) was used. The experiment was conducted at the American University Farm, Northern Beka'a, Lebanon. The elements were varied at 5 different rates coded as -2, -1, 0, +1, +2. The coded 0 rate was set to approximate a substantial addition to the soil supply of the nutrient. The coded -2 level was considered to be a possible deficiency level and the +2 a possible excess level of the element added. The different levels of each element were varied according to the natural logarithmic scale in order to cover a wide range of application levels (table 1). There were a total of 27 treatments with one treatment (0,0,0,0,0,) repeated six times in order to estimate the experimental error (table 8).

Table 1. Rates of application of N, P, K, S, and Cl for potatoes.

Level	Coded rate	lb./acre	Kg./du.
1	-2	10.0	1.13
2	-1	27.2	3.05
3	0	73.5	8.25
4	+1	200.0	22.60
5	+2	544.0	61.50

The data were analyzed and regression equations of the quadratic form for yield, specific gravity and leaf concentration of elements were computed on the basis of the coded rates as described by Cochran and Cox (2). The significance of the magnitude of each individual regression coefficient was evaluated by determining the probability of a true effect using the "t" test.

Field Procedure

On March 22, 1962, 32 field plots were established. Each plot consisted of 4 rows 8 m. long and 0.75 m. apart. The fertilizers were prepared for each row separately and were distributed by hand in each furrow. The seed potatoes[1] were placed 30 cm. apart on one side of the furrows after which the ridges were split thus covering the fertilizers and seed potatoes and leaving new furrows between the rows for irrigation.

Nitrogen was added in the form of NH_4NO_3 and KNO_3, P in the form of $Ca(H_2PO_4)_2$ and KH_2PO_4, K in the form of KNO_3, KH_2PO_4, K_2SO_4 and KCl, S in the form of $CaSO_4 \cdot 2H_2O$ and K_2SO_4 and Cl in the form of KCl and $CaCl_2 \cdot 6H_2O$. The fertilizer carriers were analyzed to determine the amounts of elements present. It was possible to control the amounts of all the nutrients except calcium. However, the soil content of Ca is high (table 2) and, therefore, the additional calcium would not be expected to have much effect.

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1 Certified variety, Alpha, imported from Holland.

Irrigation was made weekly using sprinklers for the first six weeks and the furrow irrigation method afterwards. Protective spraying against cutworms, aphids, and leaf hoppers was done whenever it was necessary.

Leaf sampling was done three times; on May 25, June 27 and July 20, 1962. The samples were taken from the youngest mature leaves. On May 25 the youngest mature leaf was the eldest leaf, and only the terminal leaflet was sampled. On June 27 and July 20 three leaflets were sampled (the terminal leaflet and the two next to it). Leaf samples were taken from the potato plants within the middle 6 meters of the 2 middle rows of each plot.

The potatoes were harvested on July 22 and weighed in the field. They were separated into 3 grades and the weight of each grade determined. Grade I included those potatoes that were more than 7 cm. along the largest dimension, grade II those between 4 and 7 cm. and grade III all those less than 4 cm. Grades I and II were considered the marketable yield. Samples were taken to the laboratory for specific gravity and keeping quality studies.

<u>Laboratory Procedure</u>

The leaf samples were washed once under tap water and three times in distilled water and then left to dry. The dry leaves were then oven-dried at 68°C under continuous air draft for 48 hours. The samples were ground in a micro Wiley mill using a 40 - mesh screen.

Water-soluble nitrate-N in the presence of excess Cl was determined by the method described by Johnson and Ulrich (25).

Acid-soluble P was extracted with 2% acetic acid and digested as described by Johnson and Ulrich (25). The P was determined using the chlorostannous-reduced molybdophosphoric acid blue color method in hydrochloric acid system as described by Jackson (22).

Sulfur was extracted the same way as P, and digested with 10 drops of 30% hydrogen peroxide over a steam bath until the color of the extract disappeared. Afterwards, it was carried to dryness and the residue was dissolved in 0.03N HCl. Sulfur was then determined by the turbodimetric method (22). Only the second leaf sample was used for this determination.

Chlorine was extracted with water and the coloration was removed by shaking for 10 minutes with activated carbon and filtering. The Cl was titrated against silver nitrate in the presence of potassium chromate as the indicater.

Potassium and sodium were extracted with 2% acetic acid and determined using a Beckman DU emission spectrophotometer with acetylene flame. Gas pressure, wave length setting, and other adjustments were as recommended by Jackson (22).

The third sample was analyzed for total N by the modified Kjeldahl procedure (22). Total P and S were determined on the nitric-perchloric digests of the second leaf sample in the same way as for the acetic acid extracted P and S. The Ca and Mg contents of the nitric-perchloric digests of the second leaf sample were determined on the flame photometer.

The specific gravity of the tubers was determined by dipping each potato into a series of salt brines of different specific gravities. The specific gravity of each individual potato was considered as that of the brine where it just floated. The average of seven potatoes of each treatment was taken as the specific gravity of the treatment.

RESULTS AND DISCUSSION

Soil and Water Analyses

The pH of the soil was 8.1 and the calcium carbonate content was 11.50% (table 2). The total N content was found to be 0.075% indicating a relatively low supply of N. The bicarbonate soluble P as determined by the Olsen method was found to be 18.0 ppm. indicating a probable medium level of supply.

Table 2. Chemical analysis of the surface soil for the experimental plots and for the irrigation water.

Soil analysis		Water analysis	
pH	8.1	Sodium	0.282 m.e./l.
Calcium carbonate	11.50 %	Calcium	0.705 "
Organic matter	1.50 %	Magnesium	0.833 "
Total nitrogen	0.075	Potassium	0.056 "
Phosphorus (bicarbonate soluble)	18.0 ppm.	Sulfur	0.125 "
		Chlorine	0.138 "
Ammonium acetate soluble, m.e./100 g.:		Electrical conductivity m.mho/cm.	0.155
K	2.24		
Ca	41.00		
Na	0.58		

The Ammonium acetate extractable calcium, potassium, and sodium were 41.00, 2.24 and 0.58 m.e./100 grams of soil, respectively, indicating a probable adequate supply.

The water was considered to be of good quality (table 2). It was estimated that approximately 6.5 kg. of Na, 14.1 kg. of Ca, 10 kg. of Mg, 2.2 kg. of K, 2 kg. of S and 4.9 kg. of Cl per dunum were added through the irrigation water considering an estimated one meter depth applied during the season.

Effect of Nitrogen

As found by many workers (1, 10, 18, 27, 34) potatoes responded positively to applied N. The first order effect of applied N on yield of marketable potatoes (grades I and II) was positive and significant as shown by the regression coefficient (table 3). The economic return above fertilizer cost as calculated from the quadratic regression equation was maximum at about the +1 level (22.6 kg./du.) when P was applied at about the +1.0 level (figure 1). However, there was a considerable range (20 to 40 kg./du.) where return was changed only slightly by difference in the amount of applied N. The response to N was considerably greater at the higher level of P (+1) than at the lower level (-1) because of the positive N-P interaction. The negative regression coefficeint for the N-K interaction (table 3) was the largest interaction and was of considerable magnitude although the probability of

Table 3. Regression coefficients (b) and the probability of a true effect (p) for marketable yield and specific gravity as affected by various combinations of levels of N, P, K, S, and Cl. (Only p values of .80 or above are shown in this table.)

Coefficient	Marketable yield m. tons/du. b	p	Specific gravity b	p
Mean	3.196		1.09337	
N	+0.208	0.99	-0.00126	0.95
P	+0.120	0.88	-0.00095	0.90
K	+0.011		+0.00004	
S	+0.020		-0.00060	
Cl	+0.025		-0.00005	
NN	-0.055		-0.00128	0.96
PP	+0.045		-0.00018	
KK	-0.046		-0.00003	
SS	-0.026		-0.00037	
ClCl	+0.056		-0.00024	
NP	+0.064		-0.00280	0.99
NK	-0.141	0.86	+0.00005	
NS	+0.051		+0.00070	
NCl	+0.054		+0.00200	0.98
PK	-0.069		+0.00004	
PS	+0.047		-0.00016	
PCl	-0.132	0.85	+0.00244	0.99
KS	+0.019		+0.00245	0.99
KCl	+0.148	0.88	-0.00018	
SCl	+0.127	0.84	+0.00005	

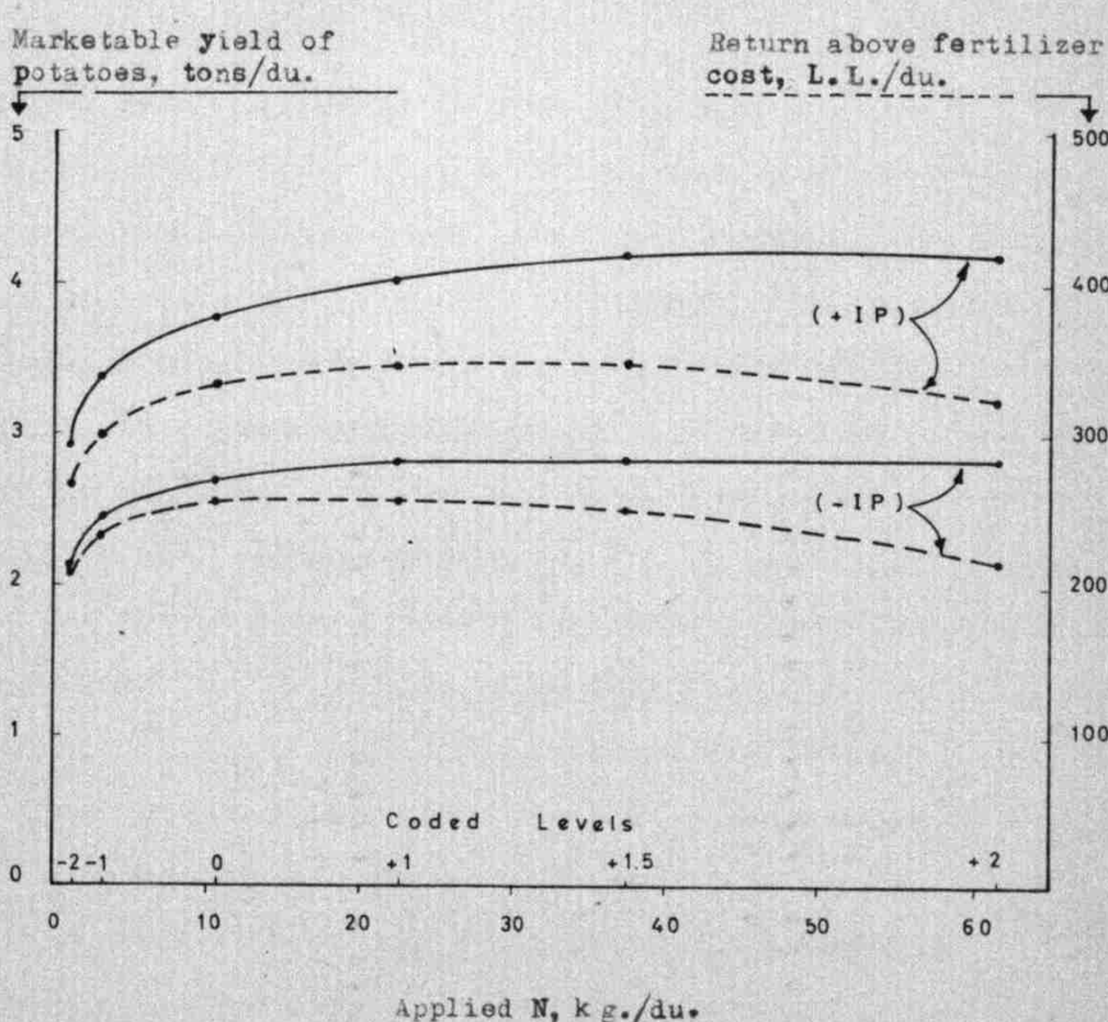
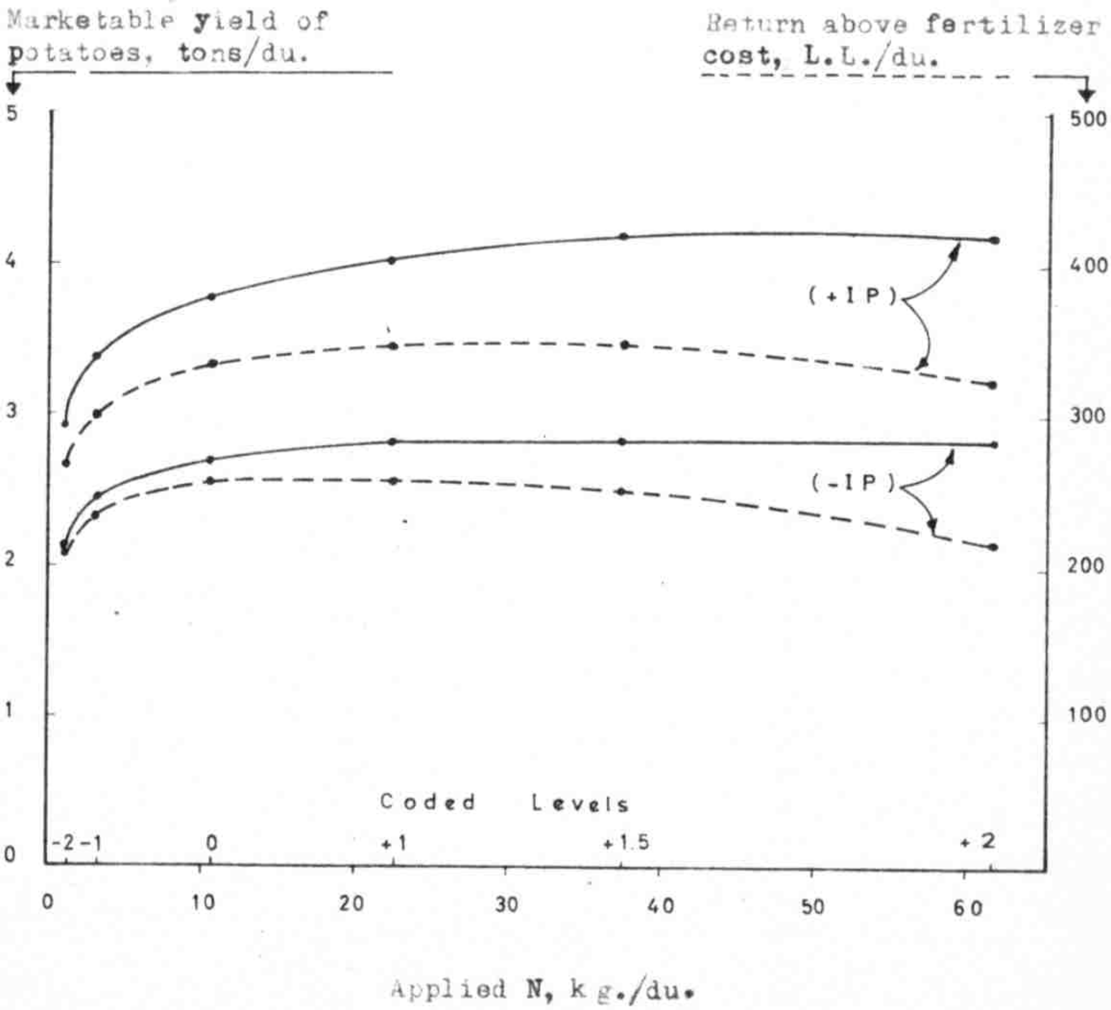


Figure 1. Effect of N on yield of potatoes and return above cost of fertilizers at -1 and +1 levels of P. Data were calculated from the regression equations. Levels of K, S and Cl were held at the -1 level. Prices used were potatoes at 100L.L./ton, N at 1L.L./kg., P at 1.45L.L./kg., KCl at 0.35L.L./ kg., and S at 0.45L.L./kg .



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a true effect was only 0.86 (figure 2) indicating that response to N was greater at the lower levels of K.

The specific gravity of potatoes reflects the accumulation and concentration of starch, and a high starch content is considered desirable from the standpoint of quality. It was found that N and P, the factors that had the greatest tendency to increase yield, tended to decrease the specific gravity (table 3). Also the N-P interaction regression coefficient was negative and highly significant indicating that when N and P were both applied at high rates the specific gravity was low. The N-Cl interaction was significantly positive for specific gravity.

The nitrate-N concentration in the leaves tended to decrease as the season progressed (table 4) indicating a probable critical level (about the +1 application level of N) of about 2000 ppm. early in the season decreasing to about 750 ppm. at time of blossom and later (figure 3). The nitrate-N level was highly significantly increased by N and tended to be decreased by P and Cl application (table 5). Application of K and S tended to increase the nitrate-N concentration of the leaves. The total N content however, tended to be increased by Cl application indicating a possible increased assimilation of N. The P-K interaction was positive and highly significant for nitrate-N concentration (table 5) indicating that when both P and K were at high application levels the nitrate-N concentration was high.

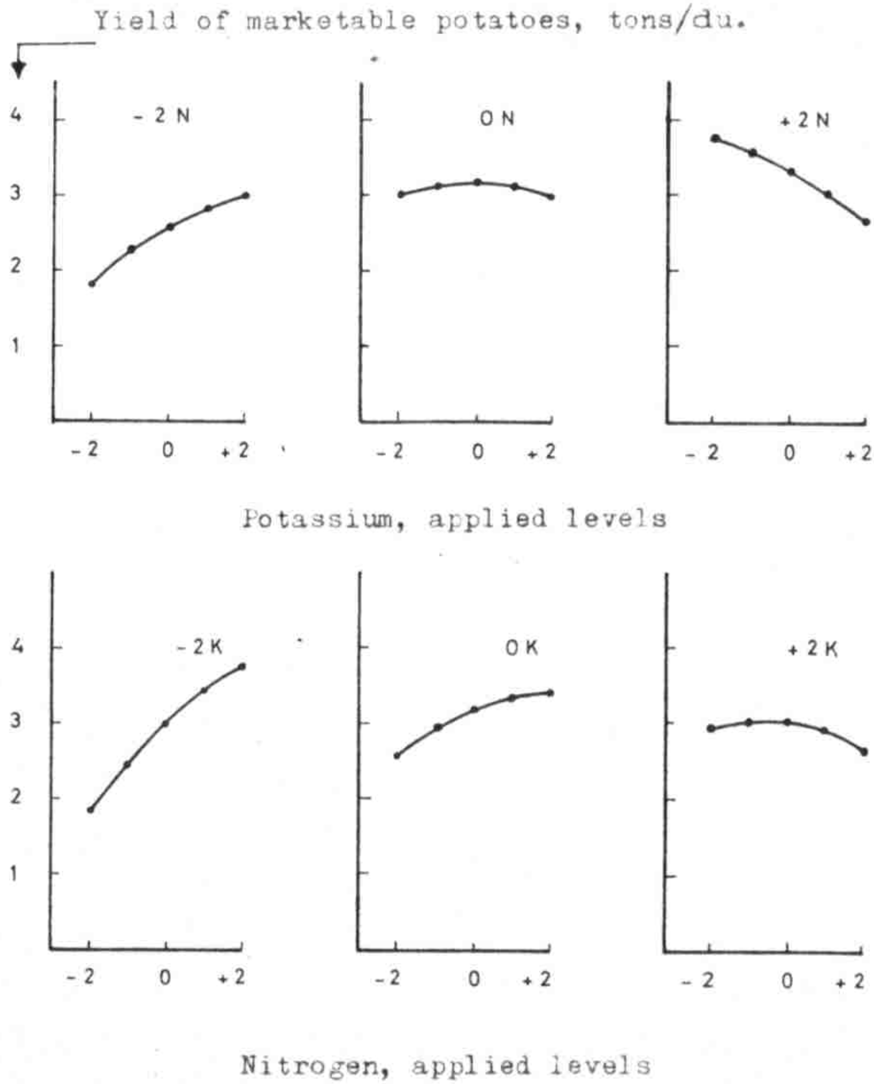

Figure 2. Yield of marketable potatoes as affected by levels of applied K at constant levels of applied N (above) and by levels of applied N at constant levels of applied K (below). The level of P, S and Cl was held at the third (0) of five levels.

Table 4. Observed leaf content of water soluble N for the 5 different N application levels for the three sampling dates and leaf content of total N for the third sampling date (dry basis).

Coded level of applied N	I (May 25) NO_3^--N ppm.	II (June 27) NO_3^--N ppm.	III (July 20) NO_3^--N ppm.	I II III (Average) NO_3^--N ppm.	III (July 20) Total N %
-2	100	480	100	227	2.88
-1	612	186	242	347	3.10
0	925	422	217	521	3.31
+1	2856	932	741	1510	3.61
+2	7105	1639	2006	3583	4.17
32 treatments average	1509	679	558	765	3.32

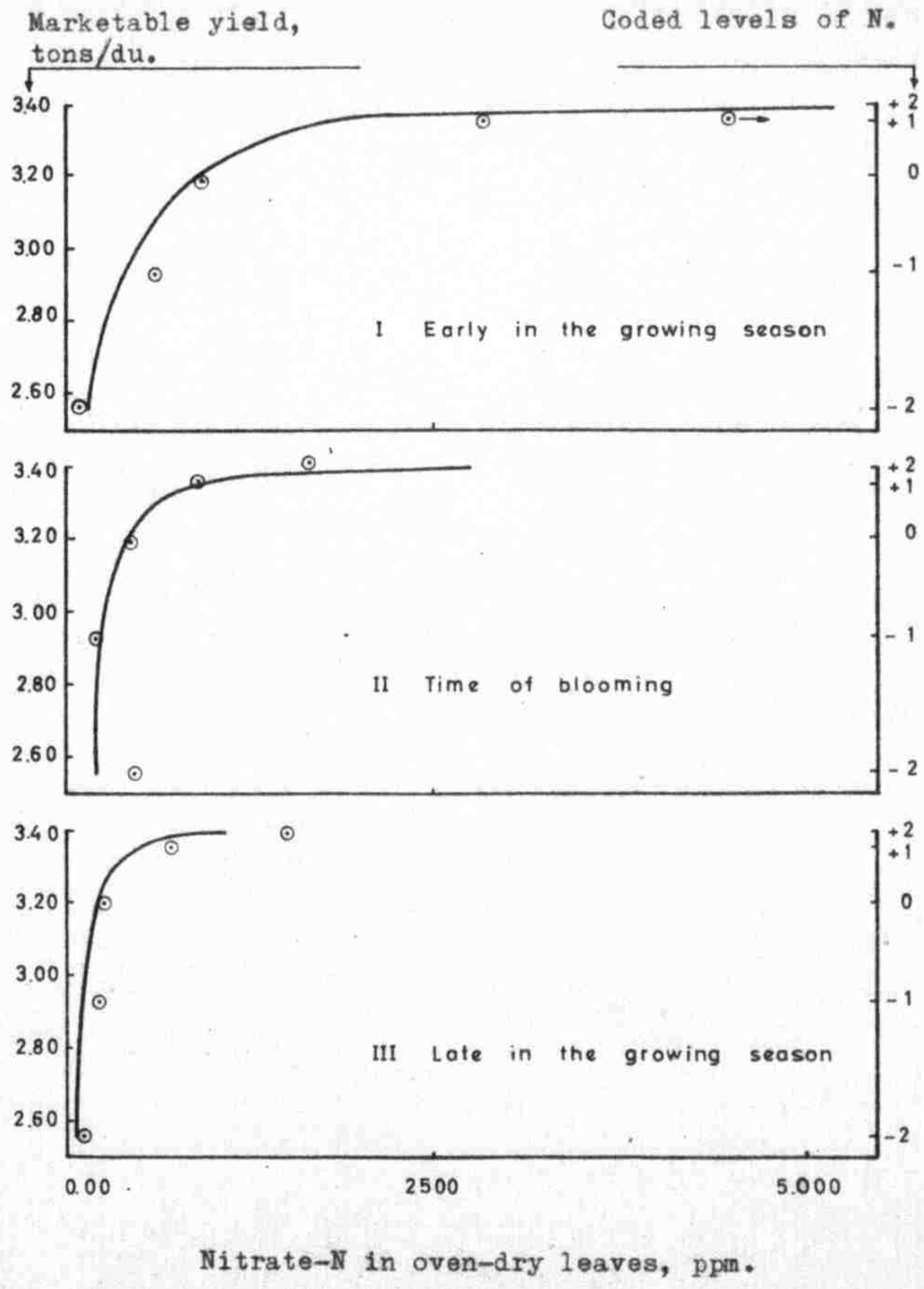

Figure 3. Relationship of marketable yield to nitrate-N in leaves at three different stages of the potato plant growth. The line is plotted from the regression equations of marketable yield and of nitrate-N content of the leaves. The points (⊙) are averages from the actual data.

Table 5. Regression coefficients (b) and the probability of a true effect (p) for the nitrate-N concentration of potato youngest mature leaves at three sampling dates (dry basis, log ppm.) and total N in the last leaf sample (in percentage of dry leaves) as affected by various combinations of levels of N, P, K, S, and Cl. (Only p values of 0.80 or above are shown in this table.)

	I (May)		II (June)		III (July)		I,II,III (averaged)		Total N III %	
Coefficient	b	p	b	p	b	p	b	p	b	p
Mean	2.953		2.609		2.353		2.588		3.214	
N	+0.377	.99	+0.283	.99	+0.276	.99	+0.229	.99	+0.280	.99
P	-0.165	.99	+0.013		-0.056		-0.042		-0.068	
K	+0.078	.99	+0.087	.92	+0.046		-0.013		-0.074	
S	+0.089	.99	-0.047		+0.076	.87	+0.039		-0.046	
Cl	-0.036		-0.015		-0.032		-0.111	.95	+0.083	
NN	+0.002		+0.069	.89	+0.032		+0.033		+0.078	
PP	+0.017		-0.029		-0.103	.96	-0.082	.95	-0.021	
KK	-0.026		-0.015		+0.146	.99	+0.033		+0.010	
SS	+0.050	.92	+0.026		+0.079	.91	+0.050	.86	+0.010	
ClCl	-0.030		-0.067	.88	+0.120	.97	+0.006		+0.066	
NP	+0.012		-0.104		-0.094	.89	-0.062	.84	+0.008	
NK	+0.067	.92	+0.050		+0.038		-0.074	.89	+0.013	
NS	+0.096	.97	+0.014		-0.088	.84	+0.007		+0.007	
NCl	-0.053	.85	+0.026		-0.044		-0.149	.95	-0.001	
PK	+0.084	.96	+0.114	.93	+0.113	.92	+0.103	.95	+0.006	
PS	-0.055	.86	-0.044		+0.030		-0.127	.95	-0.028	
PCl	+0.081	.95	-0.032		-0.058		-0.003		+0.024	
KS	-0.187	.99	+0.023		-0.063		-0.076	.93	-0.031	
KCl	+0.120	.99	-0.006		+0.012		-0.083	.92	-0.011	
SCl	+0.094	.97	+0.004		+0.028		+0.031		+0.007	

Effect of Phosphorus

The first order effect of P fertilizer application ($p = 0.88$) was a tendency to increase marketable yield (table 3). The estimated maximum return was attained at about the +1.2 level of P (30 kg./du.) and the +1 level of N when the levels of K, S, and Cl were held at the -1 level (figure 4). From the +1 to the +1.5 levels of P there was very little difference in economic return. The negative regression coefficient for the P-Cl interaction ($p = 0.85$) for marketable yield of potatoes indicated that high levels of Cl tended to reduce the response to P application (figure 5). However, at low levels, Cl application increased the yield.

Application of P tended to depress the specific gravity of the potato tubers ($p = 0.90$ for the first order regression coefficient) although other workers (6, 9, 27) obtained positive effects on specific gravity of tubers from moderate applications of P. Interaction of P with N was negative and with Cl was positive and highly significant as indicated by the regression coefficients (table 3).

The first order effect of P fertilizer application on nitrate-N content of the leaves was to depress it highly significantly early in the season and to a lesser extent later in the season (table 6). The regression coefficient for the P-K interaction was significantly positive throughout the season indicating that high application of both P and K

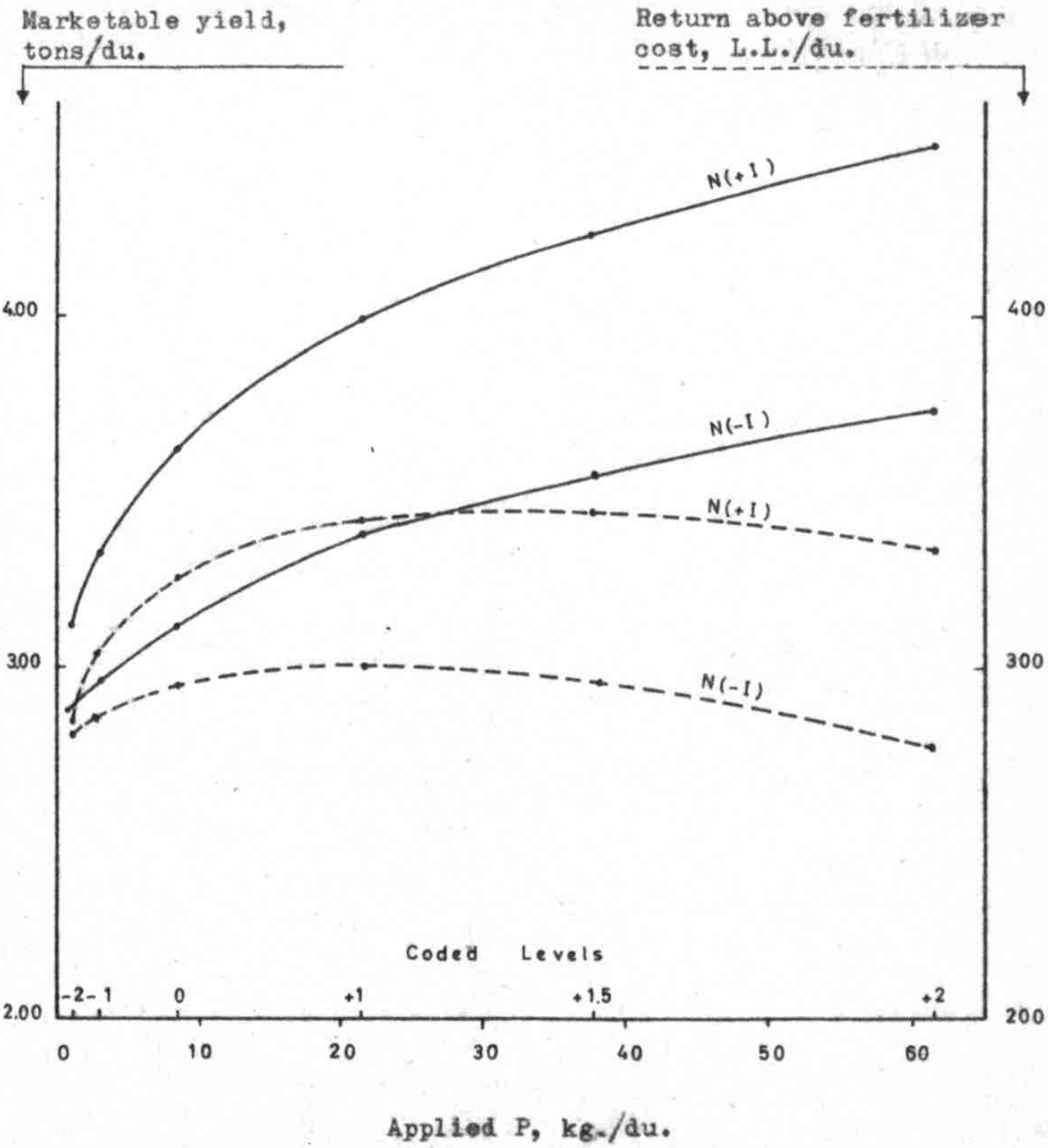

Figure 4. Effect of P on yield of potatoes and return above cost of fertilizers at the -1 and +1 levels of N. Data were calculated from the regression equations. Levels of K, S and Cl were held at the -1 level. Prices used were potatoes at 100L.L./ton, N at 1L.L./Kg., P at 1.45L.L./Kg., KCl at 0.35L.L./Kg., and S at 0.45L.L./Kg.

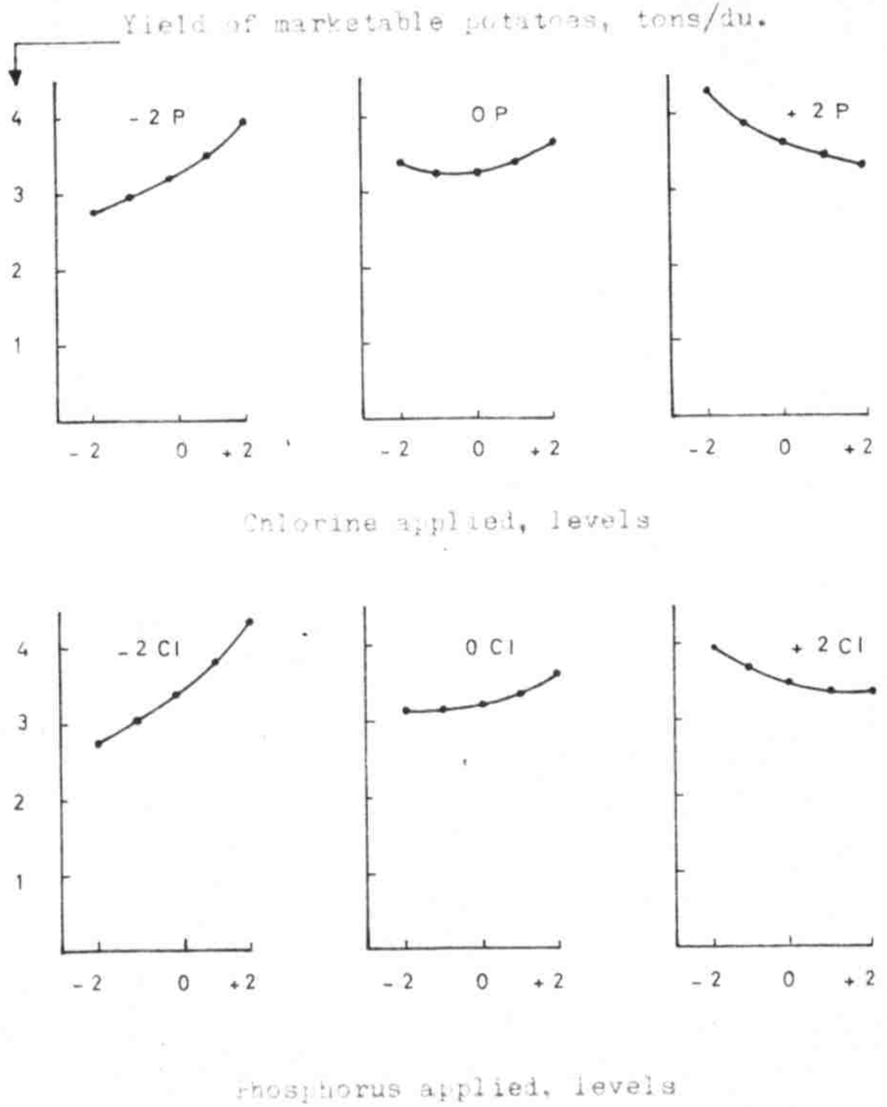

Figure 5. Yield of marketable potatoes as affected by levels of applied Cl at constant levels of applied P (above) and by levels of applied P at constant levels of applied Cl (below). The level of N, K and S was held at the third of five levels.

Table 6. Regression coefficients (b) and the probability of a true effect (p) for the acetic acid soluble P in potato leaves at three sampling dates (dry basis, in percentage) and total P in the second leaf sample as affected by various combinations of levels of N, P, K, S, and Cl. (Only p values of 0.80 or above are shown in this table.)

	I (May)		II (June)		III (July)		I,II,III averaged		Total P	
Co-efficient	b	p	b	p	b	p	b	p	b	p
Mean	0.1424		-0.1455		0.1091		0.133		0.202	
N	+0.0075	.94	-0.0022		+0.0055	.80	+0.0029	.99	-0.0064	.91
P	+0.0291	.99	+0.0039		-0.0040		+0.0103		+0.0054	.85
K	-0.0057	.87	+0.0061	.88	+0.0059	.82	-0.0000		+0.0063	.90
S	+0.0003		+0.0013		+0.0014		+0.0015		-0.0002	
Cl	+0.0016		-0.0057	.85	-0.0003		-0.0020		-0.0027	
NN	-0.0098	.95	-0.0049	.85	+0.0066	.88	-0.0033	.86	-0.0052	
PP	+0.0062		+0.0025		+0.0090	.96	+0.0051	.97	-0.0031	
KK	-0.0037		-0.0020		+0.0037		-0.0013		+0.0002	
SS	-0.0044		-0.0030		+0.0024		-0.0023		-0.0022	
ClCl	-0.0059		+0.0027		+0.0065	.88	+0.0005		-0.0020	
NP	+0.0161	.99	+0.0031		-0.0128	.96	+0.0052	.91	+0.0029	
NK	-0.0073		-0.0136		-0.0006		-0.0079	.98	+0.0039	
NS	+0.0099	.95	+0.0023		-0.0100	.92	+0.0038	.82	-0.0041	
NCl	-0.0098	.95	-0.0023		+0.0136	.97	-0.0027		-0.0054	
PK	+0.0018		-0.0034		-0.0108	.94	-0.0034		-0.0050	
PS	+0.0081	.92	+0.0013		+0.0031		+0.0008		+0.0063	
PCl	-0.0017		+0.0048		+0.0015		+0.0046	.87	+0.0040	
KS	-0.0053		-0.0033		-0.0070	.82	-0.0046	.87	+0.0050	
KCl	+0.0004		+0.0048		+0.0076	.84	+0.0034		-0.0018	
SCl	-0.0006		-0.0009		+0.0045		+0.0042	.85	+0.0041	

resulted in high nitrate-N concentration in the leaves (table 5).

The level of acetic acid soluble P in potato leaves was more closely related to yield and to applied P level early in the season than later in the season (figure 6). The tentative critical level of acetic acid soluble P in the leaves early in the season based on the maximum economic return would be about 0.2%.

Effect of Potassium, Sulfur, and Chlorine

The first order effect of K application (table 3) was positive but small for marketable yield and for specific gravity of potatoes. However, because of the reduction in N response (figure 2), K application should be kept at a low level. Application of K at a low level of N had a considerable increasing effect on marketable yield. Other workers (9, 37) reported a decreasing effect of K on specific gravity. The average K concentration of the leaves was significantly increased by K application as shown by the first order regression coefficient (table 7). However, N and S application also increased K content to a great extent and highly significantly. The positive N-K interaction regression coefficient for average K content of the leaves was significant indicating that increase of leaf K from K application was greatest at high levels of N application.

Application of S had a very slight positive effect on

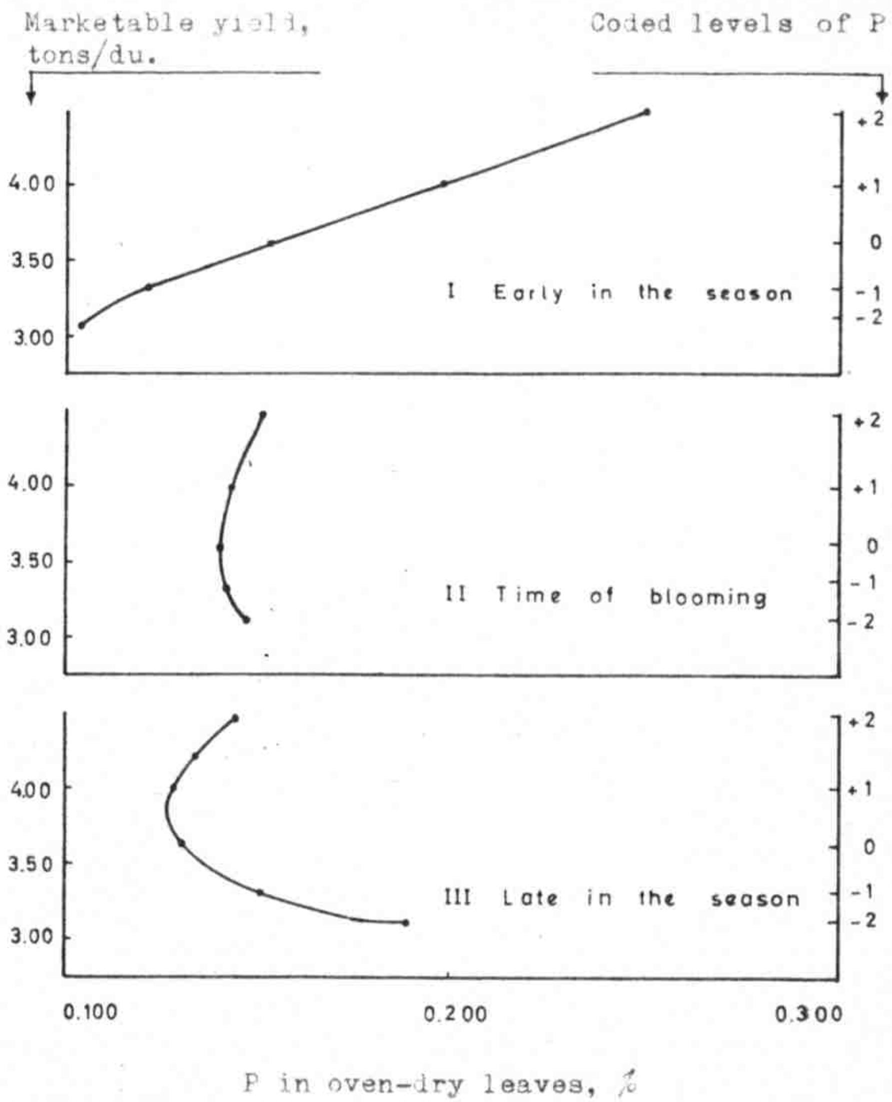

Figure 6. Relationship of marketable yield to P in leaves at three different stages of the potato plant growth. Data were calculated from the regression equations for the marketable yield and acetic acid soluble P contents of the leaves. Level of N was held at +1 and levels of K, S and Cl at -1. I, II, III are acetic acid soluble P contents early in the season, at blooming time and late in the season, respectively.

Table 7. Regression coefficients (b) and probability of a true effect (p) for the seasonal average of acetic acid soluble K, acetic acid soluble and total S of the second leaf sample, and seasonal average of water soluble Cl (dry basis, in percentage) as affected by various combinations of levels of N, P, K, S, and Cl. (Only p values of 0.80 or above are shown in this table.)

Coefficient	K		Acetic acid-soluble S		S (Total)		Cl	
	b	p	b	p	b	p	b	p
Mean	4.072		0.457		0.682		0.862	
N	+0.141	.99	-0.033	.95	-0.069	.98	-0.041	.95
P	+0.045		+0.029	.93	+0.013		-0.015	
K	+0.083	.95	-0.006		+0.005		-0.004	
S	+0.128	.99	+0.031	.94	+0.044	.93	-0.016	
Cl	+0.016		-0.034	.95	-0.026		+0.075	.99
NN	+0.078	.96	-0.047	.97	-0.033	.88	-0.017	.96
PP	-0.050		+0.004		+0.025		+0.040	.92
KK	+0.007		+0.034	.95	+0.027	.81	-0.004	
SS	+0.073	.95	-0.003		+0.046	.95	-0.033	.92
ClCl	+0.044		+0.052	.99	+0.030	.84	+0.035	.94
NP	+0.019		+0.051	.95	-0.020		-0.033	.83
NK	-0.099	.96	-0.001		-0.009		-0.040	.90
NS	+0.044		-0.005		+0.012		-0.014	
NCl	+0.031		-0.022		-0.025		-0.011	
PK	+0.038		-0.003		+0.006		+0.011	
PS	+0.008		+0.023	.82	+0.022		-0.003	
PCl	+0.045		+0.002		+0.000		-0.013	
KS	-0.008		-0.005		+0.007		-0.035	.86
KCl	-0.053		-0.017		-0.022		+0.014	
SCl	+0.060	.82	+0.001		+0.003		-0.013	

marketable yield of potatoes and a low negative effect on specific gravity of the potato tubers, as shown by the first order regression coefficients (table 3). Therefore, S application should be kept at a low level. Dunn and Nylund (6) and Harward et al. (15) reported that the sulfate ion had no effect on specific gravity. Application of either N or Cl significantly decreased the acetic acid soluble S content of leaves sampled at the middle of the growing season as shown by the first order regression coefficients (table 7). Application of S or P tended to increase the S content although not significantly. The positive N-P interaction had a significant effect on S content of leaves.

Application of Cl resulted in a very small increasing effect on marketable yield of potatoes and on specific gravity of potato tubers as shown by the first order regression coefficient (table 3). Therefore, Cl application should be kept at a low level. Several workers (16, 24, 29) reported an inverse relationship between Cl and starch and dry matter content of the tubers. The average Cl content of the leaves was highly significantly increased by application of Cl and tended to be decreased by N application (table 7). At low P application levels, Cl application increased the yield of marketable potatoes considerably (figure 5) indicating a possible partial substitution effect.

Critical levels of K, S and Cl could not be established since yield response was low. However, the following levels in the leaves at blooming time could be considered as adequate: 4% K, 0.4% S and 0.7% Cl.

SUMMARY AND CONCLUSIONS

Nitrogen, phosphorus, potassium, sulfur, and chlorine were applied to a calcareous soil to study their effect on potato yield, specific gravity and leaf composition individually and in combination. The data were analyzed statistically in order to estimate the optimum combination of the applied nutrients with consideration of current local prices for potatoes and fertilizers.

The first order effects of applied N, P, K, S and Cl on marketable yield were positive as shown by the regression coefficients, N and P being high, and K, S and Cl being low. The response to N was increased at low levels of K and the response to P was increased at low levels of Cl because of the negative N-K and P-Cl interactions. Because of the low positive response of marketable yield to K, S and Cl, it was concluded that application of these elements would not be necessary under the conditions of this experiment.

The economic return above fertilizer cost as calculated from the quadratic regression equation was maximum at about the +1 level for N and P when levels of K, S and Cl were held at the -1 level. The amount of fertilizers at these coded levels would be 22.6 kg./du. for both N and P. However, it was concluded that a range of 15 to 30 kg./du. resulted in about the same economic return.

Nitrogen and P which were the factors that had the greater tendency to increase yield had negative effects on specific gravity. The N-P negative interaction was an additional negative effect on specific gravity when both nutrients were supplied at high rates.

The nitrate nitrogen in the leaves tended to decrease with the advance of the season. Probable critical levels were calculated from the regression equations to be 2000 ppm. early in the season and 750 ppm. at time of blossoming and later. Applied N increased the nitrate-N and total N in the leaves. Applied P and Cl tended to increase the nitrate-N in the leaves.

The leaf contents of acetic acid soluble P was highest early in the season and the critical level was estimated to be 0.2% at that stage.

The seasonal average content of K in the leaves was increased highly significantly by applied K, N and S. The leaf content of K responded to applied K more at the high level of N application.

Sulfur and P application tended to increase the S content of the leaves at time of blossoming while N and Cl significantly decreased it.

The seasonal average leaf content of Cl was highly significantly increased by applied Cl and tended to decrease by applied N. No critical levels of K, S and Cl could be established but 4%, 0.4% and 0.7%, respectively, were adequate levels under the conditions of this experiment.

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APPENDICES

Table 8. Observed potato tuber yield and specific gravity as affected by various combinations of levels of N, P, K, S and Cl. Yields are recorded in m. tons/du.

Treatment levels N	P	K	S	Cl	Grade I	Marketable I+II	Total I+II+III	Specific gravity
-1	-1	-1	-1	+1	0.506	2.693	2.936	1.0933
+1	-1	-1	-1	-1	0.903	3.090	3.740	1.0950
-1	+1	-1	-1	-1	0.332	3.011	3.487	1.0950
+1	+1	-1	-1	+1	0.908	3.348	3.581	1.0950
-1	-1	+1	-1	-1	0.476	2.912	3.179	1.0925
+1	-1	+1	-1	+1	1.002	3.546	3.849	1.0933
-1	+1	+1	-1	+1	0.878	3.011	3.279	1.0950
+1	+1	+1	-1	-1	0.630	3.036	3.368	1.0768
-1	-1	-1	+1	-1	0.288	2.416	2.574	1.0907
+1	-1	-1	+1	+1	1.200	3.740	4.018	1.0950
-1	+1	-1	+1	+1	0.496	2.902	3.125	1.0933
+1	+1	-1	+1	-1	1.235	3.784	4.112	1.0768
-1	-1	+1	+1	+1	0.962	3.809	3.189	1.0908
+1	-1	+1	+1	-1	0.446	2.753	3.442	1.0960
-1	+1	+1	+1	-1	0.397	2.941	3.189	1.0925
+1	+1	+1	+1	+1	1.215	4.018	4.405	1.0950
-2	0	0	0	0	0.561	2.604	2.802	1.0900
+2	0	0	0	0	0.655	3.279	3.581	1.0850
0	-2	0	0	0	0.575	2.887	3.095	1.0908
0	+2	0	0	0	1.037	3.789	4.067	1.0930
0	0	-2	0	0	0.565	3.169	3.432	1.0917
0	0	+2	0	0	0.704	2.778	2.966	1.0933
0	0	0	-2	0	0.863	3.363	3.457	1.0933
0	0	0	+2	0	0.804	2.748	3.209	1.0890
0	0	0	0	-2	1.012	4.018	4.246	1.1008
0	0	0	0	+2	0.317	2.753	2.594	1.0825
0	0	0	0	0	0.873	3.497	3.765	1.0921
0	0	0	0	0	0.367	2.803	2.966	1.0975
0	0	0	0	0	0.769	3.462	3.725	1.0908
0	0	0	0	0	0.858	2.763	3.110	1.0930
0	0	0	0	0	0.660	3.149	3.675	1.0950
0	0	0	0	0	0.610	2.579	3.269	1.0933
no treatment					0.397	2.852	3.065	

Table 9. Regression coefficients (b) and the probability of a true effect (p) for total and grade I yields as affected by various combinations of levels of N, P, K, S and Cl. (Only p values of 0.80 or above are shown in this table.)

Coefficient	Total Yield m. ton/du. b	p	Grade I Yield m. ton/du. b	p
Mean	3.393		0.684	
N	+0.296	0.99	+0.141	0.99
P	+0.148	0.91	+0.051	
K	-0.039		+0.017	
S	+0.006		+0.020	
Cl	-0.084		+0.045	
NN	-0.031		-0.015	
PP	+0.066		+0.034	
KK	-0.029		-0.009	
SS	+0.004		+0.041	
ClCl	+0.026		-0.001	
NP	-0.049		+0.035	
NK	-0.069		-0.128	0.95
NS	+0.140	0.87	+0.044	
NCl	+0.068		-0.021	
PK	-0.029		+0.010	
PS	+0.100		+0.037	
PCl	-0.051		-0.041	
KS	+0.029		-0.034	
KCl	+0.112		+0.110	0.95
SCl	+0.097		+0.035	

Table 10. Analysis of variance for yield, m. tons/du., and specific gravity as affected by various combinations of levels of N, P, K, S and Cl.

Source	Total	Linear	Quad-ratic	Lack of fit	Error	C.V. %	E.S.[1] %
d.f	31	5	15	6	5		
Grade I							
SS	2.285	0.606	0.681	0.821	0.177	27.5	61
MS		0.121	0.045	0.137	0.036		
Marketable							
SS	6.120	1.407	1.909	1.832	0.729	9.3	64
MS		0.281	0.127	0.305	0.145		
Total							
SS	6.496	2.279	1.317	1.737	0.600	9.7	67
MS		0.459	0.088	0.383	0.120		
Specific gravity[2]							
SS	0.0818	0.0069	0.0445**	0.0276*	0.0028	0.23	65
MS		0014	0030	0.0046	0.0006		

* Statistically significant at the 5% level.

** Statistically significant at the 1% level.

1 Equation Sufficiency, percentage of total treatment sum of squares accounted for by the quadratic regression equation.

2 Statistical analysis was made on coded values for specific gravity by subtracting 1.00000 and multiplying the result by 10 to simplify calculations.

Table 11. Observed nitrate nitrogen concentration in youngest mature potato leaves for three sampling dates (dry basis) and total N for the third sampling date as affected by various combinations of levels of N, P, K, S and Cl.

Treatment levels					Nitrate-Nitrogen			Average	N, total
					I	II	III	I,II,III	III
N	P	K	S	Cl	ppm.	ppm.	ppm.	ppm.	%
-1	-1	-1	-1	+1	231	124	100	152	3.191
+1	-1	-1	-1	-1	1593	718	938	1083	3.709
-1	+1	-1	-1	-1	100	236	100	145	3.025
+1	+1	-1	-1	+1	152	452	100	235	3.564
-1	-1	+1	-1	-1	909	100	109	373	3.309
+1	-1	+1	-1	+1	3242	1008	702	1651	3.722
-1	+1	+1	-1	+1	825	351	130	435	3.111
+1	+1	+1	-1	-1	1815	1759	1119	1561	3.658
-1	-1	-1	+1	-1	1459	112	404	658	3.170
+1	-1	-1	+1	+1	3924	885	960	1923	3.736
-1	+1	-1	+1	+1	389	100	264	251	3.025
+1	+1	-1	+1	-1	1898	326	610	945	3.356
-1	-1	+1	+1	+1	829	100	234	388	3.146
+1	-1	+1	+1	-1	4734	1057	954	2248	3.654
-1	+1	+1	+1	-1	156	368	598	374	2.800
+1	+1	+1	+1	+1	5487	1252	550	2430	3.514
-2	0	0	0	0	100	480	100	227	2.878
+2	0	0	0	0	7105	1639	2006	3383	4.173
0	-2	0	0	0	1454	542	166	721	3.141
0	+2	0	0	0	633	239	100	324	3.121
0	0	-2	0	0	1111	390	1309	937	3.732
0	0	+2	0	0	378	430	1239	679	2.781
0	0	0	-2	0	1864	828	1102	1265	3.309
0	0	0	+2	0	919	436	432	596	3.200
0	0	0	0	-2	1068	266	580	638	3.064
0	0	0	0	+2	368	244	1748	753	3.896
0	0	0	0	0	957	249	245	484	3.120
0	0	0	0	0	514	334	247	365	3.317
0	0	0	0	0	992	456	262	570	3.035
0	0	0	0	0	1163	239	218	540	2.935
0	0	0	0	0	1031	470	100	534	3.075
0	0	0	0	0	891	783	123	599	3.794

Table 12. Analysis of variance for the leaf content of water soluble N at three different dates and total N at the third sampling date as affected by various combinations of levels of N, P, K, S and Cl.

Source	Total	Linear	Quadratic	Lack of fit	Error	C.V. %	E.S.[1] %
d.f	31	5	15	6	5		
May[2]							
SS	7.014	4.431**	1.156**	1.349**	0.078	4.2	81
MS		0.886	0.077	0.225	0.016		
June[2]							
SS	3.724	2.161**	0.847	0.525	0.190	7.5	87
MS		0.432	0.056	0.088	0.038		
July[2]							
SS	5.712	2.124*	2.262*	1.112	0.215	9.0	80
MS		0.425	0.151	0.185	0.043		
Season Av.[2]							
SS	3.910	1.633**	1.519**	0.645	0.113	5.9	84
MS		0.327	0.101	0.108	0.023		
Total N							
SS	3.779	2.334	0.047	0.920	0.479	9.6	72
MS		0.467	0.003	0.153	0.096		

* Statistically significant at the 5% level.

** Statistically significant at the 1% level.

1 Equation sufficiency, percent of total treatment sum of squares accounted for by the quadratic regression equation.

2 Statistical analysis was done on the log of ppm. values.

Table 13. Observed acetic acid soluble P concentration in youngest mature potato leaves at three sampling dates (dry basis, %) and total P in percentage for the second sampling date, as affected by various combinations of levels of N, P, K, S and Cl.

Treatment levels					Acetic Acid Soluble P I	II	III	P, Ave. I,II,III	P, Total II
N	P	K	S	Cl	%	%	%	%	%
-1	-1	-1	-1	+1	0.117	0.105	0.061	0.094	0.187
+1	-1	-1	-1	-1	0.108	0.138	0.156	0.134	0.180
-1	+1	-1	-1	-1	0.110	0.128	0.148	0.129	0.198
+1	+1	-1	-1	+1	0.153	0.139	0.132	0.141	0.186
-1	-1	+1	-1	-1	0.114	0.169	0.155	0.146	0.204
+1	-1	+1	-1	+1	0.072	0.113	0.212	0.101	0.173
-1	+1	+1	-1	+1	0.143	0.172	0.115	0.143	0.193
+1	+1	+1	-1	-1	0.174	0.125	0.120	0.140	0.204
-1	-1	-1	+1	-1	0.081	0.132	0.141	0.118	0.166
+1	-1	-1	+1	+1	0.104	0.117	0.148	0.123	0.119
-1	+1	-1	+1	+1	0.131	0.131	0.144	0.135	0.216
+1	+1	-1	+1	-1	0.235	0.170	0.124	0.176	0.179
-1	-1	+1	+1	+1	0.090	0.154	0.135	0.126	0.194
+1	-1	+1	+1	-1	0.092	0.126	0.139	0.119	0.184
-1	+1	+1	+1	-1	0.123	0.153	0.143	0.120	0.208
+1	+1	+1	+1	+1	0.176	0.134	0.133	0.146	0.197
-2	0	0	0	0	0.106	0.124	0.132	0.121	0.190
+2	0	0	0	0	0.094	0.139	0.137	0.123	0.185
0	-2	0	0	0	0.106	0.162	0.146	0.136	0.207
0	+2	0	0	0	0.222	0.160	0.142	0.175	0.185
0	0	-2	0	0	0.145	0.128	0.112	0.128	0.198
0	0	+2	0	0	0.104	0.158	0.134	0.132	0.210
0	0	0	-2	0	0.130	0.138	0.111	0.126	0.187
0	0	0	+2	0	0.113	0.140	0.124	0.126	0.216
0	0	0	0	-2	0.093	0.177	0.124	0.131	0.202
0	0	0	0	+2	0.138	0.147	0.144	0.143	0.199
0	0	0	0	0	0.164	0.153	0.118	0.145	0.195
0	0	0	0	0	0.138	0.151	0.143	0.144	0.214
0	0	0	0	0	0.131	0.158	0.102	0.130	0.201
0	0	0	0	0	0.157	0.117	0.104	0.126	0.178
0	0	0	0	0	0.147	0.131	0.096	0.125	0.224
0	0	0	0	0	0.124	0.152	0.094	0.123	0.197

Table 14. Averaged observed leaf content of acetic acid soluble P for the five different P application levels for the three sampling dates and leaf content of total P for the second sampling date (dry basis, in percentages).

Coded level of applied P	I (May)	II (June)	III (July)	I,II,III (Averaged)	II (Total P)
-2	0.106	0.162	0.146	0.138	0.207
-1	0.099	0.132	0.132	0.120	0.176
0	0.143	0.143	0.110	0.132	0.201
+1	0.156	0.144	0.133	0.139	0.198
+2	0.222	0.160	0.142	0.175	0.185
32 treatments averaged	0.127	0.137	0.128	0.132	0.193

Table 15. Analysis of variance for the leaf content of acetic acid soluble P at the three different dates and total P at the second sampling date as affected by various combination levels of N, P, K, S and Cl.

Source	Total	Linear	Quad-ratic	Lack of fit	Error	C.V.	E.S.[1] %
d.f	31	5	15	6	5		
May							
SS	0.4241	0.2257**	0.1557**	0.0309	0.0118	10.7	92
MS		0.0451	0.0104	0.0051	0.0024		
June							
SS	0.0106	0.0022	0.0060	0.0012	0.0013	11.2	87
MS		0.0004	0.0004	0.0002	0.0003		
July							
SS	0.0200	0.0020	0.0156*	0.0007	0.0017	16.9	96
MS		0.0004	0.0010	0.0001	0.0003		
Season Av.							
SS	0.0084	0.0029*	0.0045*	0.0005	0.0005	7.4	94
MS		0.0006	0.0003	0.0001	0.0001		
Total							
SS	0.1121	0.0280	0.0440	0.0283	0.0118	7.4	70
MS		0.0056	0.0030	0.0047	0.0024		

* Statistically analysis at the 5% level.

** Statistically analysis at the 1% level.

1 Equation sufficiency, percent of total treatment sum of square accounted for by the quadratic regression equation.

Table 16. Observed acetic acid soluble K concentration at three sampling dates, acetic acid soluble S and total S of the second sample in the youngest mature leaves of potato plant (dry basis, %) as affected by various combinations of levels of N, P, K, S and Cl.

Treatment levels					Acetic Acid Soluble K			S	S, Total
					I	II	III	II	II
N	P	K	S	Cl	%	%	%	%	%
-1	-1	-1	-1	+1	5.156	3.288	3.024	0.538	0.761
+1	-1	-1	-1	-1	4.952	3.668	3.214	0.446	0.695
-1	+1	-1	-1	-1	4.286	3.892	3.398	0.436	0.783
+1	+1	-1	-1	+1	5.542	3.796	3.109	0.458	0.534
-1	-1	+1	-1	-1	4.042	4.314	3.699	0.569	0.819
+1	-1	+1	-1	+1	5.767	3.437	3.529	0.305	0.523
-1	+1	+1	-1	+1	4.881	3.976	3.042	0.382	0.775
+1	+1	+1	-1	-1	6.259	4.024	3.480	0.550	0.680
-1	-1	-1	+1	-1	5.046	3.759	3.386	0.660	0.819
+1	-1	-1	+1	+1	5.924	4.137	3.468	0.455	0.755
-1	+1	-1	+1	+1	5.331	4.231	3.423	0.652	0.986
+1	+1	-1	+1	-1	5.158	4.135	3.575	0.732	0.827
-1	-1	+1	+1	+1	5.496	3.573	3.065	0.597	0.872
+1	-1	+1	+1	-1	6.181	4.312	3.640	0.543	0.845
-1	+1	+1	+1	-1	5.778	3.913	2.994	0.639	1.037
+1	+1	+1	+1	+1	5.188	4.237	5.925	0.572	0.768
-2	0	0	0	0	5.060	3.585	4.278	0.290	0.647
+2	0	0	0	0	5.790	3.922	3.430	0.105	0.434
0	-2	0	0	0	4.965	3.893	2.719	0.303	0.773
0	+2	0	0	0	4.931	3.721	2.784	0.500	0.774
0	0	-2	0	0	4.880	4.159	3.114	0.501	0.791
0	0	+2	0	0	5.292	3.992	2.931	0.537	0.775
0	0	0	-2	0	5.406	4.290	3.014	0.478	0.927
0	0	0	+2	0	5.910	4.028	3.318	0.266	0.787
0	0	0	0	-2	5.516	3.977	3.198	0.644	0.810
0	0	0	0	+2	5.238	4.048	3.216	0.539	0.770
0	0	0	0	0	5.455	3.521	2.535	0.489	0.655
0	0	0	0	0	4.904	4.043	3.150	0.540	0.798
0	0	0	0	0	5.422	3.862	3.091	0.412	0.779
0	0	0	0	0	5.833	3.253	3.063	0.477	0.674
0	0	0	0	0	6.106	3.289	3.312	0.533	0.683
0	0	0	0	0	5.369	3.963	3.322	0.415	0.527

Table 17. Observed water soluble Cl concentration in youngest mature potato leaves (dry basis, %) sampled at three different dates as affected by various combinations of levels of N, P, K, S and Cl.

Treatment levels					Water Soluble Chlorine			
N	P	K	S	Cl	I %	II %	III %	Ave. I,II,III Ave. %
-1	-1	-1	-1	+1	0.864	0.893	0.997	0.918
+1	-1	-1	-1	-1	0.615	0.776	0.860	0.834
-1	+1	-1	-1	-1	0.753	0.664	0.729	0.715
+1	+1	-1	-1	+1	0.578	0.663	0.953	0.731
-1	-1	+1	-1	-1	0.939	0.609	0.990	0.846
+1	-1	+1	-1	+1	0.882	0.808	1.118	0.936
-1	+1	+1	-1	+1	1.374	0.648	1.024	1.015
+1	+1	+1	-1	-1	0.548	0.681	0.679	0.636
-1	-1	-1	+1	-1	0.988	0.647	0.739	0.791
+1	-1	-1	+1	+1	1.013	0.896	1.061	0.990
-1	+1	-1	+1	+1	0.972	0.632	0.786	0.797
+1	+1	-1	+1	-1	0.666	0.657	0.901	0.741
-1	-1	+1	+1	+1	1.024	0.694	0.894	0.904
+1	-1	+1	+1	-1	0.681	0.675	0.788	0.714
-1	+1	+1	+1	-1	0.955	0.618	0.623	0.732
+1	+1	+1	+1	+1	0.607	0.522	0.803	0.644
-2	0	0	0	0	1.044	0.714	0.960	0.906
+2	0	0	0	0	0.579	0.473	0.937	0.663
0	-2	0	0	0	0.865	0.689	1.009	0.552
0	+2	0	0	0	0.856	0.717	0.921	0.831
0	0	-2	0	0	0.776	0.725	1.007	0.836
0	0	+2	0	0	1.019	0.689	0.803	0.837
0	0	0	-2	0	0.569	0.679	0.964	0.737
0	0	0	+2	0	0.939	0.956	1.018	0.704
0	0	0	0	-2	0.788	0.729	0.801	0.773
0	0	0	0	+2	1.348	0.931	1.357	1.212
0	0	0	0	0	0.935	0.884	1.074	0.964
0	0	0	0	0	0.660	0.761	0.911	0.777
0	0	0	0	0	0.924	0.913	0.829	0.889
0	0	0	0	0	0.849	0.971	1.001	0.940
0	0	0	0	0	0.783	0.708	0.847	0.779
0	0	0	0	0	0.748	0.797	0.989	0.844

Table 18. Regression coefficients (b) for acetic acid soluble K and water soluble Cl (dry basis, in percentage) at three different dates as affected by various combinations of levels of N, P, K, S and Cl

Coefficient	K I (May)	K II (June)	K III (July)	Cl I (May)	Cl II (June)	Cl III (July)
Mean	5.503	3.675	3.191	0.826	0.840	0.963
N	+0.267*	+0.062	+0.093	-0.134**	-0.013	+0.014
P	-0.009	+0.058	+0.085	-0.024	-0.040	-0.047
K	+0.126	+0.022	+0.100*	+0.044	-0.023	-0.021
S	+0.176	+0.058	+0.150**	+0.046	+0.011	-0.027
Cl	+0.043	-0.049	+0.058	+0.095**	+0.039	+0.102
NN	-0.010	+0.004	+0.207**	-0.011	-0.062*	-0.019
PP	-0.129	+0.0016	-0.069	+0.001	-0.035	-0.015
KK	-0.095	+0.084	-0.002	+0.011	-0.034	-0.030
SS	+0.048	+0.105	+0.034	-0.025	-0.006	-0.009
ClCl	-0.022	+0.069	+0.056	+0.053*	-0.003	+0.013**
NP	-0.075	-0.028	+0.161*	-0.064	-0.016	-0.002
NK	+0.091	-0.021	+0.228**	-0.054	-0.009	-0.042
NS	-0.210	+0.119	+0.224**	+0.021	-0.003	+0.040
NCl	-0.115	+0.018	+0.192**	-0.002	-0.021	+0.005
PK	+0.086	-0.043	+0.068	+0.029	+0.011	+0.023
PS	-0.140	-0.015	+0.174*	-0.029	-0.010	+0.013
PCl	-0.168	+0.119	+0.182*	+0.003	-0.052	-0.004
KS	+0.011	-0.084	+0.047	-0.082*	+0.002	-0.041
KCl	-0.214	-0.083	+0.144*	+0.022	-0.009	+0.012
SCl	-0.128	+0.090	+0.211**	-0.032	-0.002	-0.021

* Statistically significant at the 5% level.

** Statistically significant at the 1% level.

Table 19. Analysis of variance for leaf content of acetic acid soluble K at three different dates as affected by various combinations of levels of N, P, K, S and Cl.

Source	Total	Linear	Quadratic	Lack of fit	Error	C.V. %	E.S.[1] %
d.f	31	5	15	6	5		
May							
SS	7.880	2.874	3.868	0.273	0.865	7.5	96
MS		0.575	0.258	0.046	0.173		
June							
SS	2.829	0.319	1.451	0.460	0.599	9.5	79
MS		0.064	0.097	0.077	0.120		
July							
SS	9.681	1.248*	6.377**	1.892**	0.164	5.6	80
MS		0.250*	0.425**	0.315**	0.033		

* Statistically significant at the 5% level.

** Statistically significant at the 1% level.

1 Equation sufficiency, percentage of total treatment sum square accounted for by the quadratic equation

Table 20. Analysis of variance for leaf content of water soluble Cl in potato leaves (dry basis) at three different dates as affected by various combinations of levels of N, P, K, S and Cl.

Source	Total	Linear	Quadratic	Lack of fit	Error	C.V. %	E.S.[1] %
d.f	31	5	15	1	5		
May							
SS	1.285	0.757*	0.396	0.075	0.057	13.1	94
MS		0.151	0.026	0.012	0.011		
June							
SS	0.464	0.093	0.222	0.098	0.050	11.9	72
MS		0.019	0.015	0.016	0.010		
July							
SS	0.647	0.334*	0.152	0.116	0.046	10.2	81
MS		0.067	0.010	0.019	0.009		

* Statistically significant at the 5% level.

** Statistically significant at the 1% level.

1 Equation sufficiency, percentage of total treatment sum of squares accounted for by the quadratic regression equation.

Table 21. Observed acetic acid soluble Na concentration at three sampling dates and Ca and Mg concentration in the second sample of the youngest mature potato leaves (dry basis, %) as affected by various combinations of levels of N, P, K, S and Cl.

Treatment levels					Acetic Acid Soluble Na			Ca	Mg
					I	II	III	II	II
N	P	K	S	Cl	%	%	%	%	%
-1	-1	-1	-1	+1	0.105	0.055	0.056	2.662	0.372
+1	-1	-1	-1	-1	0.105	0.065	0.058	2.425	0.464
-1	+1	-1	-1	-1	0.074	0.050	0.050	2.380	0.250
+1	+1	-1	-1	+1	0.130	0.050	0.064	2.377	0.349
-1	-1	+1	-1	-1	0.096	0.057	0.053	2.088	0.399
+1	-1	+1	-1	+1	0.082	0.053	0.059	2.530	0.541
-1	+1	+1	-1	+1	0.104	0.041	0.068	2.179	0.356
+1	+1	+1	-1	-1	0.104	0.048	0.061	3.060	0.501
-1	-1	-1	+1	-1	0.095	0.047	0.041	1.846	0.301
+1	-1	-1	+1	+1	0.096	0.047	0.050	1.613	0.260
-1	+1	-1	+1	+1	0.080	0.048	0.054	2.065	0.343
+1	+1	-1	+1	-1	0.110	0.063	0.053	2.552	0.306
-1	-1	+1	+1	+1	0.058	0.048	0.058	2.733	0.366
+1	-1	+1	+1	-1	0.108	0.057	0.035	2.779	0.314
-1	+1	+1	+1	-1	0.064	0.041	0.060	1.652	0.401
+1	+1	+1	+1	+1	0.104	0.055	0.047	2.578	0.510
-2	0	0	0	0	0.081	0.058	0.062	2.683	0.386
+2	0	0	0	0	0.120	0.054	0.063	2.129	0.435
0	-2	0	0	0	0.080	0.054	0.061	2.215	0.335
0	+2	0	0	0	0.069	0.049	0.060	2.217	0.310
0	0	-2	0	0	0.086	0.054	0.079	2.331	0.604
0	0	+2	0	0	0.104	0.042	0.059	2.426	0.432
0	0	0	-2	0	0.087	0.046	0.042	2.385	0.341
0	0	0	+2	0	0.109	0.046	0.063	2.762	0.382
0	0	0	0	-2	0.079	0.033	0.057	2.260	0.485
0	0	0	0	+2	0.081	0.042	0.082	2.148	0.620
0	0	0	0	0	0.088	0.050	0.043	2.477	0.401
0	0	0	0	0	0.059	0.040	0.054	1.918	0.674
0	0	0	0	0	0.096	0.055	0.054	2.154	0.436
0	0	0	0	0	0.078	0.062	0.045	2.268	0.426
0	0	0	0	0	0.072	0.055	0.051	2.167	0.456
0	0	0	0	0	0.084	0.058	0.038	2.160	0.413

Table 22. Regression coefficients (b) and probability of a true effect (p) for concentrations of Ca and Mg at time of blooming and Na seasonal average in the leaves as affected by various combination levels of N, P, K, S and Cl. (Only p values of 0.80 or above are shown in this table.)

	Na		Ca		Mg	
Coefficient	b	p	b	p	b	p
Mean	0.601		2.201		0.476	
N	+0.043	.99	+0.050	.83	+0.023	
P	-0.006		+0.007		-0.002	
K	-0.019	.85	+0.078	.95	+0.017	
S	-0.033	.92	-0.047	.81	-0.015	
Cl	+0.011		-0.011		+0.018	
NN	+0.031	.95	+0.044	.82	-0.023	
PP	+0.003		-0.002		-0.045	.94
KK	+0.026	.95	+0.038		+0.004	
SS	+0.013		+0.086	.95	-0.035	.88
ClCl	+0.003		-0.006		+0.013	
NP	+0.016		+0.142	.99	+0.011	
NK	-0.019	.80	+0.144	.99	+0.014	
NS	+0.018		+0.008		-0.031	
NCl	-0.011		-0.212	.99	-0.001	
PK	+0.013		-0.093	.84	+0.019	
PS	+0.001		-0.026		+0.040	.82
PCl	+0.017		-0.051		+0.002	
KS	-0.007		+0.103	.95	+0.001	
KCl	-0.011		+0.058	.81	+0.097	
SCl	-0.008		+0.113	.95	+0.010	

Table 23. Analysis of variance for concentration of Ca and Mg of the second sampling date and of Na seasonal average as affected by various combinations of levels of N, P, K, S and Cl.

Source	Total	Linear	Quadratic	Lack of fit	Error	C.V. %	E.S.[1] %
d.f	31	5	15	6	5		
Ca							
SS	3.230	0.265	2.289**	0.509	0.166	7	63
MS		0.053	0.153	0.085	0.033		
Mg							
SS	3.161	0.324	0.666	1.629	0.541	22	38
MS		0.065	0.044	0.272	0.108		
Na							
SS	0.179	0.083*	0.074	0.007	0.015	9	95
MS		0.017	0.005	0.001	0.003		

* Statistically significant at 5% level.

** Statistically significant at 1% level.

1 Equation sufficiency, percent of total treatment sum of squares accounted for by the quadratic regression equation.