LONG-TERM FACTORIAL EXPERIMENT WITH NPK ON POTATOES*

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(met opsomming in Afrikaans)

Abstract

Results of a long-term fertilizer experiment with potatoes were analysed. The parametres studied were total yield, graduation of sizes, damaged tubers, marketable crop, Leaf Area Index (LAI), plant height, and NPK leaf content. Soil analyses for P and K were available. The total analysis over years was performed after the data for each year had been standardised in order to reduce variations between years.

The results show that all three elements, N, P and K, were required to obtain maximum yield and highest marketable yield, Leaf Area Index (LAI) plant height and leaf contents were affected by the fertilization treatments.

A build-up of P and K was observed. The results indicate that larger quantities of fertilizers could result in a faster build-up and greater response. This study of the data shows the value of long-term experiments subjected to an overall analysis.

Introduction

Among the numerous experiments carried out at the Agricultural Research Station of AECI at Bapsfontein, one had been carried out on potato fertilization. This experiment was carried out over a five years period and a number of measurements was taken during this period. Some of these were taken over the whole period while others only over some years. The authors tried to collect as much data as was available from the annual reports of the research division (Hyam 1957/8 - 1962/3) from the doctorate work of one of them (Hyam 1980) and from files kept by F Dijkhuis.

The importance of long term fertilizer experiments has been discussed on many occasions (Kemmler and Maliconet 7) and (Kemmler 1979). Recently a paper which analysed fertilizer experiments in some field crops was presented in South Africa (Bazelet, Dijkhuis & Eisenberg, 1981).
Potatoes are a very important crop which is grown in many parts of the world on different soils and under varying climatic conditions. Fertilizer experiments with potatoes have been carried out in many countries and there are numerous reports dealing with the subject (Grewal & Singh 1980) (Krentos & Orphanos 1979) and (M'Dole 1978). When carrying out an experiment on an agricultural crop we are concerned with factors affecting total yield. However, even more important to the farmer is the quality of the crop and the part for which the consumer is prepared to pay — the marketable one. In potatoes, size plays an important part. In this paper the effect of fertilization with nitrogen, phosphorus and potassium on yield, size and marketable potatoes was studied as well as their influence on other growth factors. Some soil analysis for phosphorus and potassium was also carried out.

Procedure

The experiment was carried out at the Bapsfontein Agricultural Research Station of AECI Limited, over five years on the same site (1958/9 - 1962/3). The soil was a red Hutton with sandy loam structure containing 20 - 25% clay and a pH of 5,2 (water) at 0 - 33 cm. The design was a 3 x 3 x 3 factorial experiment with 2 replications. The rates of fertilizer applications were:

Nitrogen (as urea): 0, 112, 224 kg N per ha.

Phosphorus (single superphosphate): 0,44, 88 kg P per ha.

Potassium (as potassium chloride): 0, 83, 166 kg K per ha.

Fertilizers were applied at planting or side dressed after planting. The cultivar used was Up-to-date. Planting dates were during September with harvest during April the following year. Yields were weighed every year. Measurements for size and sorting for damaged potatoes were done during the first three years. Measurements of N, P, K content in leaves, plant height and leaf area index were taken in one year only, as follows:

Soil analysis Before starting, sampling was done at random from the whole site. In the fifth year of the experiment, when the plants were in bloom, 12 soil samples cores per plot, were taken from each of the 27 plots. Available P was analysed by the Bray 2 method and exchangeable K with 0,75 N ammonium acetate.

Leaf sampling was done at blossoming. The fourth leaf below the inflorescence was sampled. One hundred leaves from randomly selected plants were taken from each plant.

Plant heights were measured when it was estimated that the plants were at 50% blossom by holding the topmost leaf vertically and then measuring from the soil to the top.

Leaf Area Index (LAI) was done by measuring the total leaf area of 30 plants (3 plants x 10 rows) per plot at the same physiological age. The index was obtained by dividing the total leaf area by the area of land.

Analysis of long term factors studied: yield, size of potatoes and damaged tubers. In order to reduce the effect ot seasonal variations, the data were standardized in the following way:

$$\frac{\text{(treatment mean in year n)} - \text{(mean of trial in year n)}}{\text{standard deviation of trial in year n}}$$

Thus the data were weighed according to the accuracy of the trial. Accordingly the contribution of a year with a high error

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variance to the overall analysis, would be reduced relative to that of a year with greater accuracy. For the same reason standardized data are also used in graphical illustrations.

Results

Yield — Total

Yields in kg per hectare average for five years are given in Table 1.

TABLE 1: Average potatoe yields (five years)

	N0			N1			N2			
	P0	P1	P2	P0	P1	P2	P0	P1	P2	Average
K0	10512	12390	12919	10527	12877	13783	9989	12653	12117	11974
K1	15581	16571	17102	15245	19389	19988	11876	16985	16697	16604
K2	15896	18081	15600	14738	17807	18489	13060	16393	20415	16720
Average	N0 = 14961 P0 = 13047			N1 = 15871 P1 = 15905			N2 = 14465 P2 = 16346			

N* P*** K*** N x P* N x K* Years x P*

A significant positive main effect of phosphorus and potassium on the total yields was obtained. The main effect of nitrogen was negative, which indicates that while P and K increased yields even on their own, nitrogen had a negative effect on yield. However, there was a significant interaction between nitrogen and phosphorus and between nitrogen and potassium. The fact that there had been a significant interaction between phosphorus and years shows that the effect of P was not the same (or in the same mignitude) over the five years. The graphs (Figures 1 - 5) show an optimum for nitrogen in the N1 level beyond which it caused a severe decline in yield. In the case of P the maximum was not reached with the P2 level while for K, the K1 level was the optimum and no furhter increases can be expected with the present levels of the other nutrients. The interaction regression effects indicate that nitrogen decreased the yield without P and K but reached an optimum when N1 was combined either with P2 and K1. The regression effects for the interaction of P with years (Figure 6) shows that without P fertilizer the yield declined from year to year while with P fertilizer the yields were increasing from year to year and thus the gap between the fertilized and unfertilized plots increased. A very similar picture, of declining yields from year to year without K and increasing yields with K fertilization is presented in Figure 7.

The effect on size was studied over the first three years of the experiment.

*Linear = L, Quadratic = Q (with Figures)

Figures 8 - 10 illustrate the main effects of NPK which indicates that nitrogen increased the quantity of potatoes by less than 28 g. This may be due to delayed maturity caused by the nitrogen. The main effect of P shows an optimum point at P1 while there is a clear linear decline with increasing K. The interaction graphs show that not only the main effects should be considered. It is clear (Figures 11 - 13) that, while in the absence of P and K, N1 and N2 increased the yield of small potatoes, K1 alone resulted in a decrease with an optimum at N1. As the levels of P go up the mass of small tubers decreases and the lowest value is achieved at the medium level of N with the highest rates of P and K (P2, K2).

For the largest size of potatoes (over 196 g) the situation is the the reverse of that of the smallest size. Regression effects for main effects (Figures 14 - 16) show that increasing P and K levels increased the quantity of the large plotatoes and the linearity indicates, especially with K, that higher rates could further increase the mass of this group, whilst with P it sems that the optimum is not much higher than P2. For nitrogen the optimum is reached with the medium level of N while the increased level gives a negative result.

The significant interaction between years and potassium and the significant linear regression line (Figure 17) show very clearly that, while the plots without K showed a steep decline, those with K increased, with K2 the highest.

Interactions (Figures 18 - 19) between N and K show that nitrogen without K results in a decrease in the quantity of the large potatoes while increasing rates of K change the picture and the best combination is the medium level of N (N1) and the highest level of K (K2). Interaction regression effects between P and K show that the highest response is achieved with the highest level of K (K2) and the medium level of P (P1). However, the quadratic K's are linear over the P's and the sign of the regression has changed. This may indicate that increasing the rates of K could well result in a response to higher rates of P.

With regard to the middle group i.e. larger than 28 g and smaller than 196 g the effects of the fertilizers were smaller. There was an increase through an interaction between N and P (Figure 20) and the higher P again corrects the negative effect of N on its own with an optimum at N2 and P1. The same situation is obtained for the P x K interaction (Figure 21). The einteractions of all three elements with years (Figures 22 - 24) were significant which indicates that responses were not uniform over the years. Plots without nitrogen showed a linear decrease while those with nitrogen (N1, N2) showed an increase from year to year. Responses to P and K were inconsistant and while one treatment was higher at one year or more it was lower in the other. No explanation can be given either for the consistent change in response to N nor for the inconsistent response to P and K.

Damaged potatoes total mass was also affected by the fertilizer treatment. From the main effects (Figures 25 - 27) it is seen that N showed an optimum at the medium level while P and K (linear) leveled out at the highest level of application. From the NPK interactions (Figures 28 - 30) it can be observed that the lowest mass of damaged tubers was achieved at the levels of N2, P2, K2 and taking into account the linearity of main effects the damage could be further reduced with higher rates of P and K than were used in this experiment.

Marketable potatoes are the potato yields excluding the damaged and those which were in the smallest size (below 28 g). Their means are given in Table 2.

Main effects (Figures 31 - 33) show that nitrogen produced the maximum at the medium level (N1) while phosphorus and potassium (linear) at the highest rates applied with a possibility of producing higher yields with higher rates of P and K. However, the interactions (Figures 34 - 35) show that at the N2 level, the K2 P2 treatment were the best. The linearity of the regression effects indicates that the best treatment is N2 P2 K2 and increased rates of P and K as well as N could give even better results.

Discussion

All three nutrients, nitrogen, phosphorus and potassium in one way or another affected all the parameters which were measured and analysed. Fertilization with P and K shifts the size of the tubers to larger grade, as also found by Louè (1979). The same is true for their effects on decreasing the extent of damaged potatoes. This effect may be due to hardening the skin and increasing the resistance to mechanical damage, as well possibly as to that caused by pests and diseases. Nitrogen proved to be negative when used alone, but, when used with phosphorus and potassium, its effect became positive and also enhanced the positive effects of the two other nutrients. This positive interaction of the three elements proved to be of economical value by increasing the marketable potatoes — those which were bigger than 28 g and undamaged. Leaf area was increased as a result of increased P levels and by interaction of all three elements the highest leaf area was reached. The importance of adequate leaf area has been stressed by Milthorpe (1956) who asserted that crop yields depend extensively on the rate of development and maintenance of leaf area. Leaf content has been a criterion for yield and can be a useful guide as to the quantity of soil minerals taken by the plant. Such data could aid in the formulation of fertilizer recommendations for optimum yield. Concentration in dry matter of nutrients usually found in potato leaves are 1,5 — 3,5% for N, O, 15 — 0,30% for P and 1,5 — 5% for K. Chapman (1967) suggests critical levels of nutrients in potato leaves as follows: N = 5,2%, P = 0,15%, K = 4,5%. In the experiment, N content went up from 3,2% in NO to 4,5% and 4,2% in N1 and N2 treatments respectively. From the data of the analysed experiment it can be deduced that a satisfactory level of N has to be at 4,5%. P content which was low in the plots without P (0,18%) went up to 0,24% and 0,25% with P1 and P2 respectively. Even the highest level of 0,25% seems to be insufficient as it is still below the 0,3% mentioned by Hewitt and far below 0,53 given by others (Soltanpour, 1969), although much higher than that given by Chapman. Levels of K were 1,2% at KO and increased to 3,2% and 4,7% in K1 and K2 respectively. Lachover & Arnon (1962) found that while deficient plants contained 1% K, those fertilized contained 4,5% and this was accompanied by yield and quality increases. This critical level of 4,5% also corresponds with Chapman's.

Soil analysis is the most common tool for predicting fertilizer requirement for P and K, in field crops. In this experiment the levels of P and K in the unfertilized plots did not decline in contradiction to the decreasing yield, questioning the validity of the scale of P and K availability methods.

This indicates that the rate of release from reserves was declining over years while build-up in soil fertility due to

TABLE 2: Mean of Marketable Potatoes over three years in kg/ha

	N0			N1			N2			
	P0	P1	P2	P0	P1	P2	P0	P1	P2	
K0	8744	12025	12228	8103	11354	12153	7930	9599	10435	10286
K1	7557	12078	13182	10518	15616	14741	8928	12688	11463	11863
K2	9181	12232	10461	9734	15102	14715	8299	12424	15592	11971
	N0 = 10854 P0 = 8777			N1 = 12448 P1 = 12569			N2 = 10817 P2 = 12774			

N** P** K*** N x P** N x P x K*

Leaf Area Index (LAI) Only P had a linear significant effect on the LAI (Figures 37 - 39). However, the responses of LAI (Figures 40 - 42), whilst not necessarily significant, indicate that the highest value was obtained by the N2 P2 K1 kombination, with N2 P2 K2 a close second.

Plant height (in cm) Main effects (Figures 43 - 45) were obtained for phosphorus and potassium but not significant for nitrogen while for phosphorus the optimum was not reached and a higher rate of P could increase plant height. The optimum for potassium was reached at the medium level (K1). There was no significant interaction between the three elements or between any two of them.

Leaf content (in percent of dry matter):

Nitrogen content in the leaves was affected by N and by K levels of the fertilizers (Figures 46 - 47). While in the main effects an optimum was reached at the medium level of nitrogen (N1), interactions with K decreased N levels with increased K.

Phosphorus content in the leaves showed a linear increase (Figures 48 - 49). As with N content, higher K fertilization decreased P content overall.

Potassium content (Figures 50 - 52) was linearly increased by increasing potassium rates and could be further increased with higher rates. K content was higher when higher rates of nitrogen fertilizer and lower with increasing rates of P fertilizer.

Soil levels for P and K represent average results obtained (Figures 53 - 54). There were linear increases in available phosphorus and potassium due to fertilization. After five years fertilization, and in spite of the quantities taken by the crops, there had been a fair build-up in soil fertility. The levels of the plots without P or K fertilizers accordingly did not show a decline at time of sampling before starting the experiment and at the fifth season.

fertilization, provided a better supply of those nutrients to the soil.

From the results obtained in this experiment in can be deduced that P at Bray 2 has to be above 40 mg/kg and most probably 60 mg/kg. As far as K levels in the soil are concerned, 83 mg/kg (K1) exchangeable K seems to be below the optimum and a level higher than 115 (K2) mg/kg for this type of soil is probably more correct.

Conclusion

1. All three elements studied in the experiment — nitrogen, phosphorus and potassium were required to obtain maximum yield and highest marketable crop.

2.

2. Fertilization affected height of plants, leaf area and leaf content of the applied elements.

3. Fertilization with P and K fertilizers resulted in their build-up in the soil in addition to quantities taken up by the crop. Increased quantities could result in a faster build-up and greater response. It is probable that after reaching optimum levels in the soil, quantities could thereafter be reduced to maintenance level.

4. These data emphasise the value of long term experiments which have been subjected to an overall analysis, taking into account yearly changes and variations and interaction between nutrients.

Opsomming

LANGTERMYN FAKTORIALE NPK-PROEF OP AARTAPPELS

'n Langtermyn bemestingsproef met aartappels is ontleed en bestudeer. Die karaktertrekke wat ingesluit is, is totale opbrengs, grade van die knolle, bemarkbare massa sowel as blaaroppervlakte-indeks, plant hoogte en blaaranalises van N, P en K. Grondanalises vir P en K was beskikbaar. Die ontleding oor jare is uitgevoer nadat die data vir elke jaar gestandaardiseer is met die doel om jaarvariasie te beperk.

Die resultate dui aan dat al drie elemente benodig word om maksimum opbrengs en bemarkbare massa te verhoog. Blaaroppervlakte-indeks, planthoogte en blaarinhoud het almal die effek van die behandelings getoon.

Ophou van P en K in die grond, bo en behalwe dié wat deur die plante opgeneem is, is waargeneem. Verhoogde toedienings sou die opbou bespoedig het en 'n groter effek teweeg gebring het.

Die waarde van langtermyn proewe wat oor seisoene ontleed word, word deur hierdie data benadruk.

Acknowledgement

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POTATO YIELDS (5 YEAR AVERAGE): MAIN EFFECTS

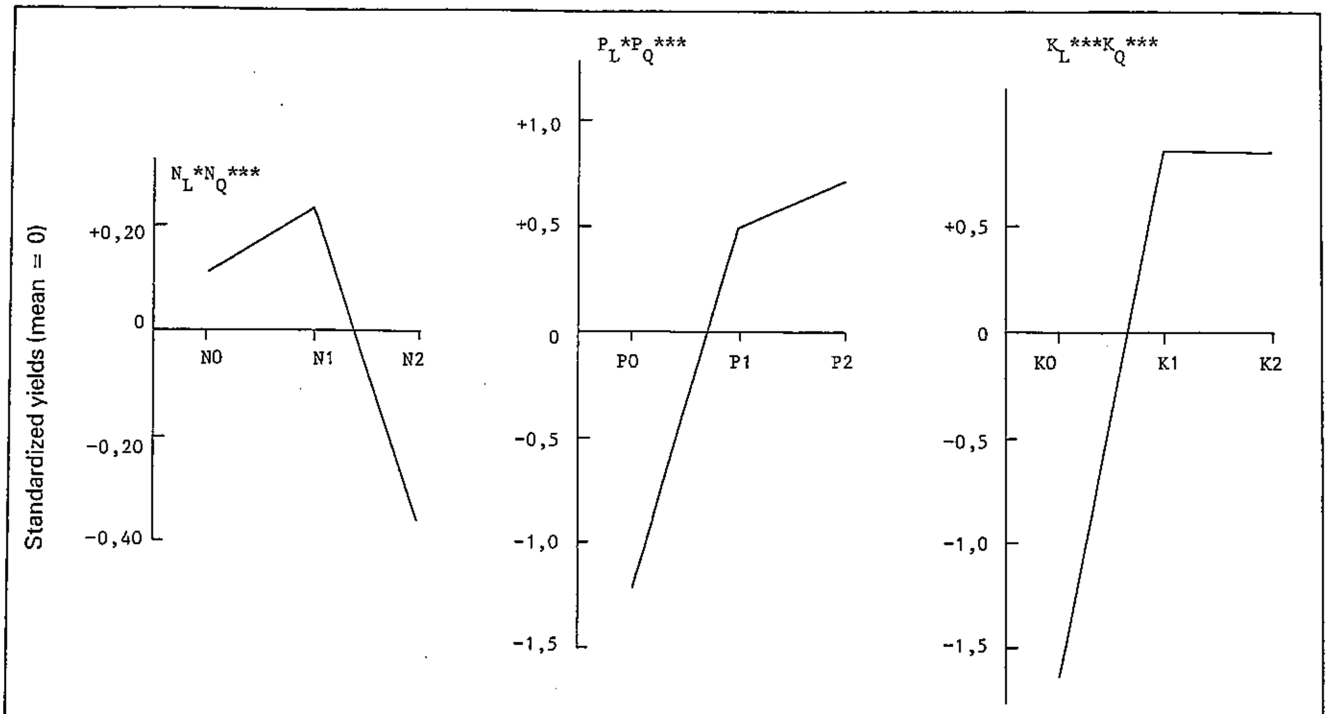

FIG 1: Nitrogen — Main effect

FIG 2: Phsophorus — Main effect

FIG 3: Potassium — Main effect

POTATO YIELDS: INTERACTIONS

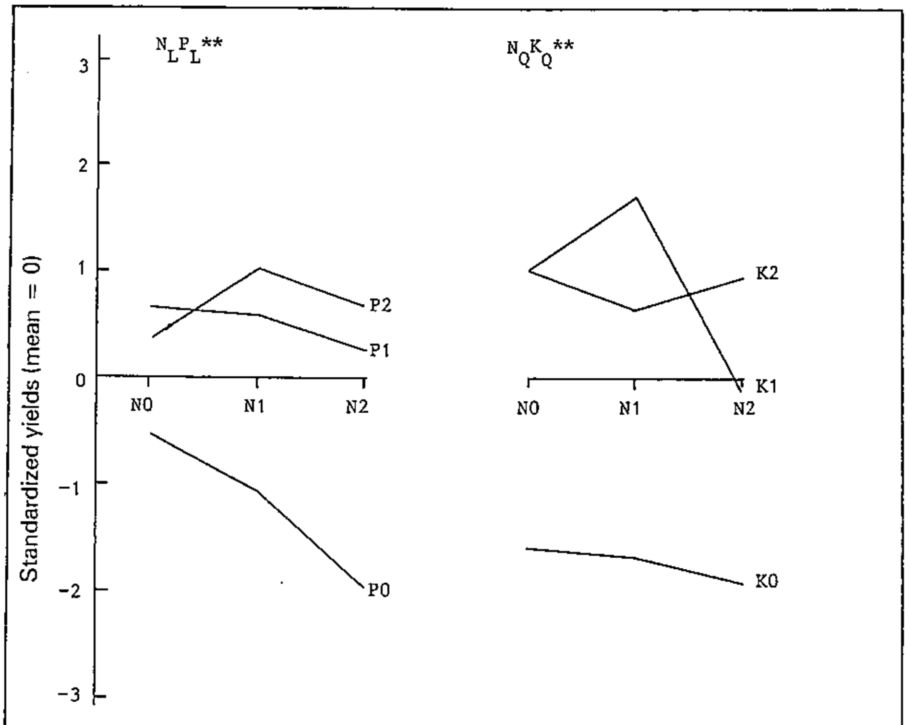

FIG 4: Nitrogen x Phosphorus interactions

FIG 5: Nitrogen x Potassium interactions

POTATO YIELDS: INTERACTIONS

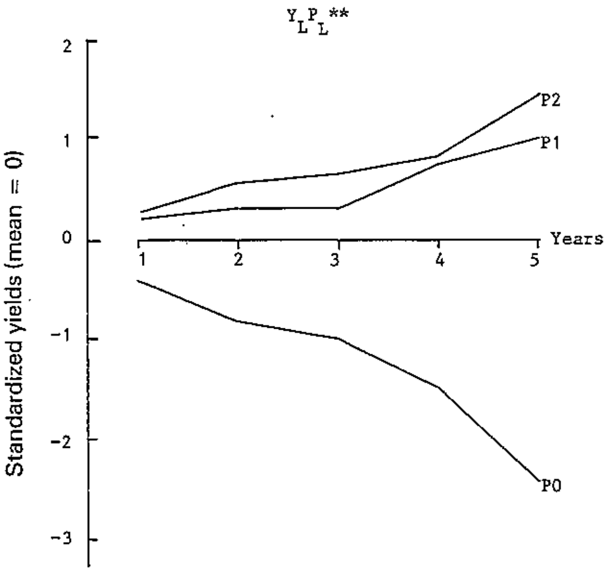

FIG 6: Phosphorus x Years interaction

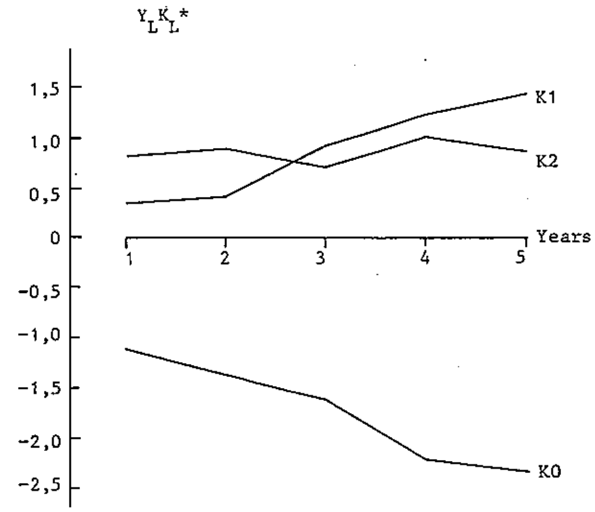

FIG 7: Potassium x Years interaction

POTATO YIELDS (SMALL POTATOES, LESS THAN 28 GRAMMES): MAIN EFFECTS

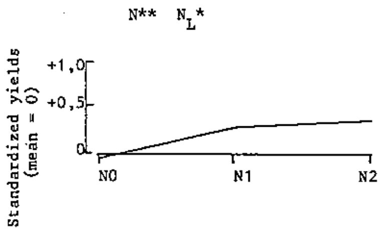

FIG 8: Nitrogen

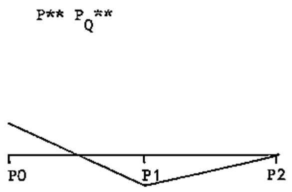

FIG 9: Phosphorus

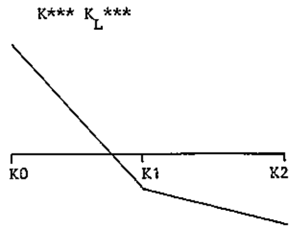

FIG 10: Potassium

POTATO YIELDS: INTERACTIONS (SMALL POTATOES)

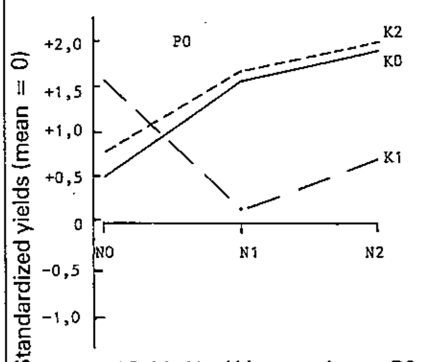

FIG 11: N x K interaction at P0 level

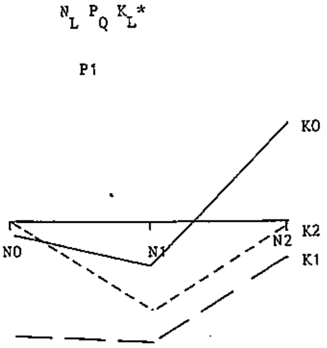

FIG 12: N x K interaction at P1 level

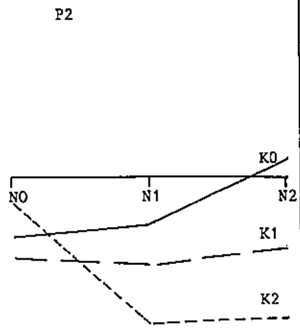

FIG 13: N x K interaction at P2 level

POTATO YIELDS (POTATOES GREATER THAN 196 GRAMMES): MAIN EFFECTS

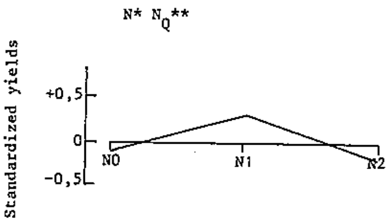

FIG 14: Nitrogen main effect

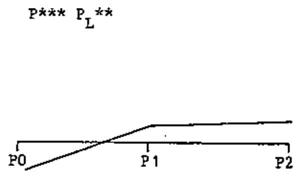

FIG 15: Phosphorus main effect

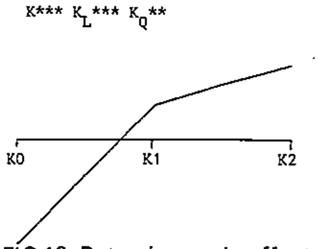

FIG 16: Potassium main effect

INTERACTIONS

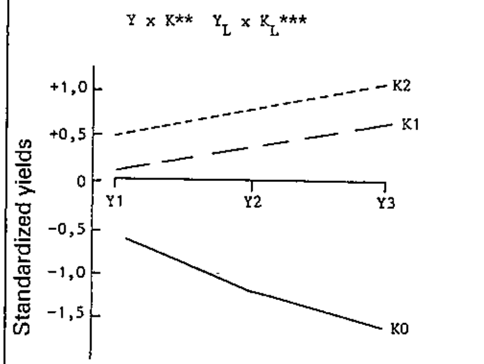

FIG 17: Potassium x years interaction

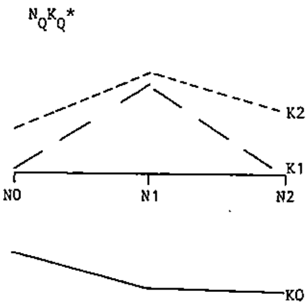

FIG 18 Nitrogen x potassium interaction

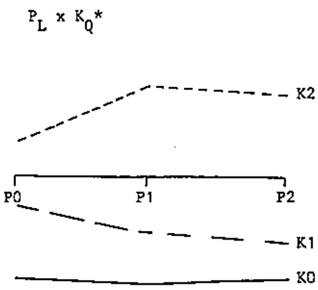

FIG 19 Potassium x phosphorus interaction

POTATO YIELDS (MEDIUM SIZES): INTERACTION

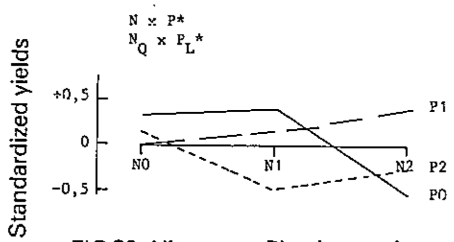

FIG 20: Nitrogen x Phoshporus interaction

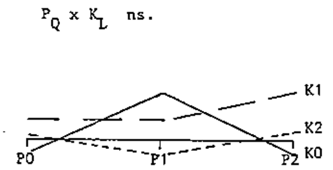

FIG 21: Phosphorus x Potassium interaction

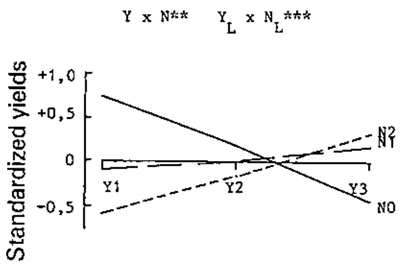

FIG 22: Nitrogen x years interaction

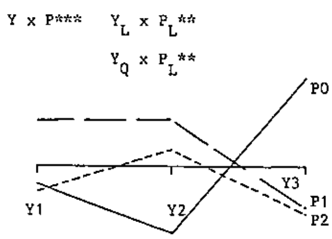

FIG 23: Phosphorus x years interaction

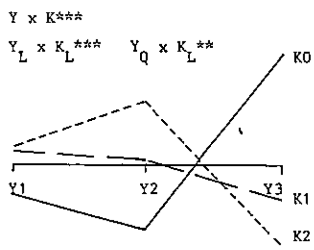

FIG 24: Potassium x years interaction

POTATOES DAMAGED: MAIN EFFECTS

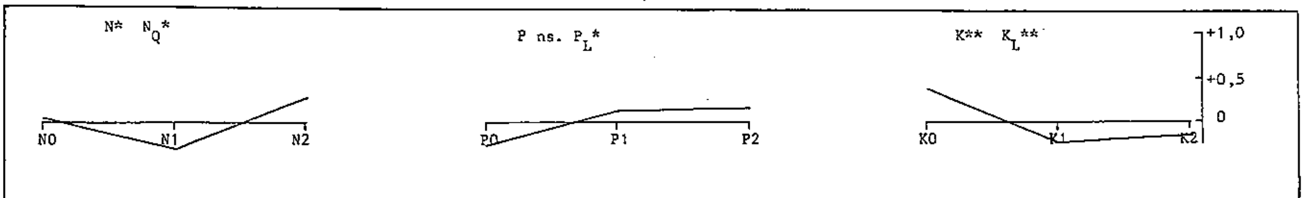

FIG 25: Nitrogen FIG 26: Phosphorus FIG 27: Potassium

POTATOES DAMAGED: INTERACTIONS

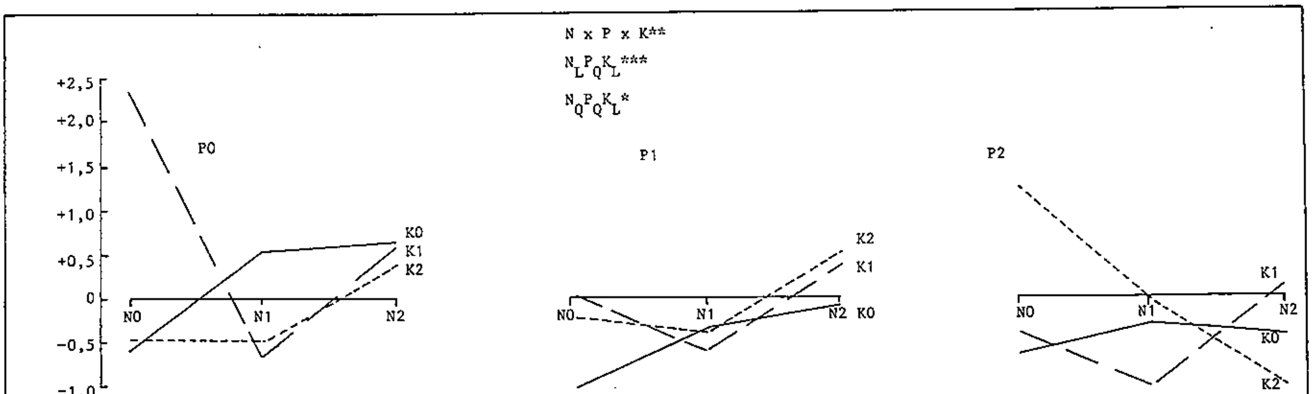

FIG 28: P x K FIG 29: N x P FIG 30: N x K

MARKETABLE POTATOES: MAIN EFFECTS

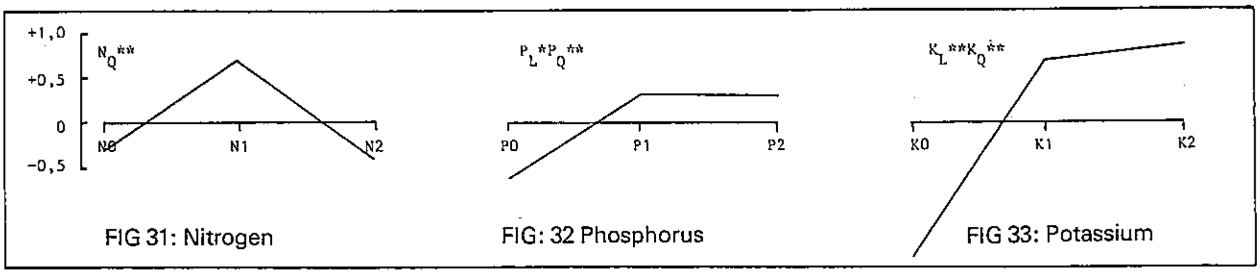

FIG 31: Nitrogen FIG: 32 Phosphorus FIG 33: Potassium

MARKETABLE POTATOES: INTERACTIONS

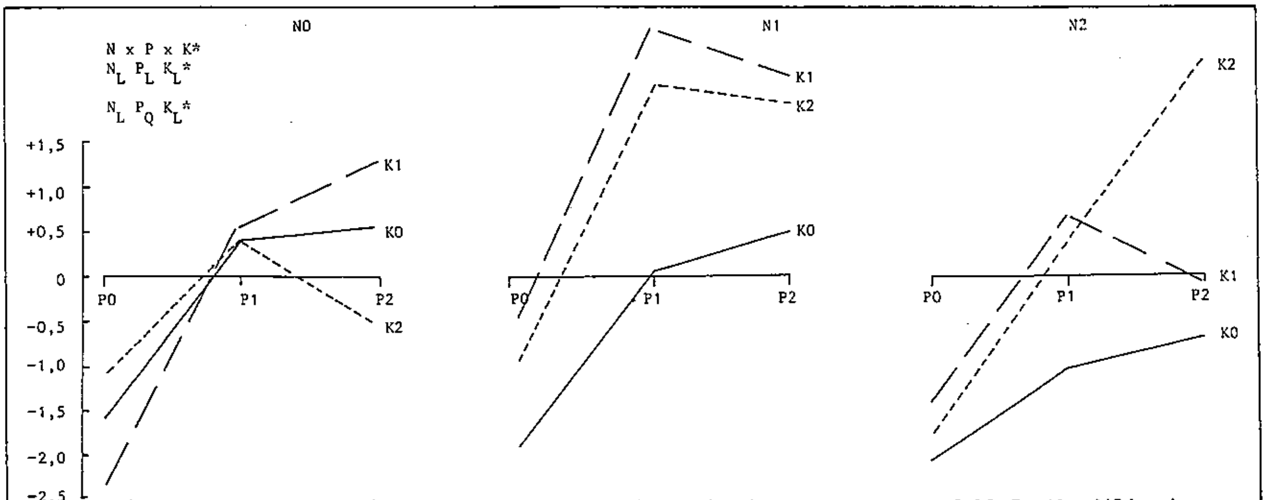

FIG 34: P x K as N0 level FIG 35: P x K at N1 level FIG 36: P x K at N2 level

POTATO LEAF AREA INDEX: MAIN EFFECTS

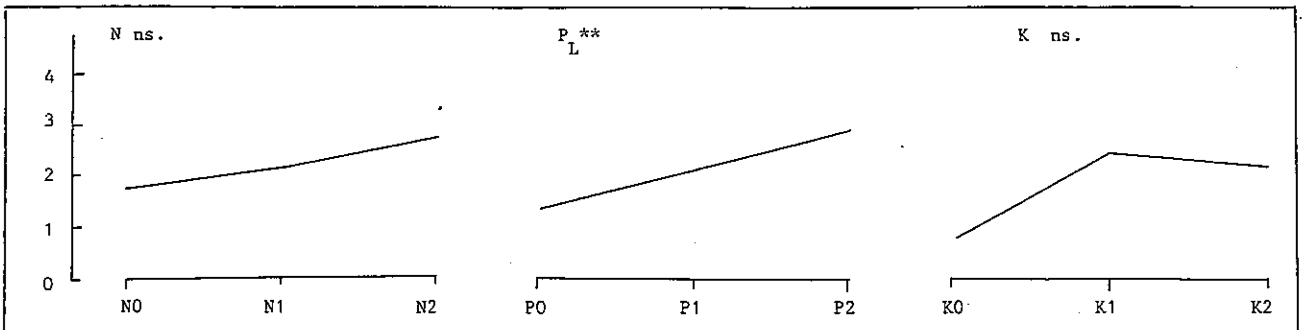

FIG 37: Nitrogen

FIG 38: Phosphorus

FIG 39: Potassium

POTATO LEAF AREA INDEX: INTERACTIONS

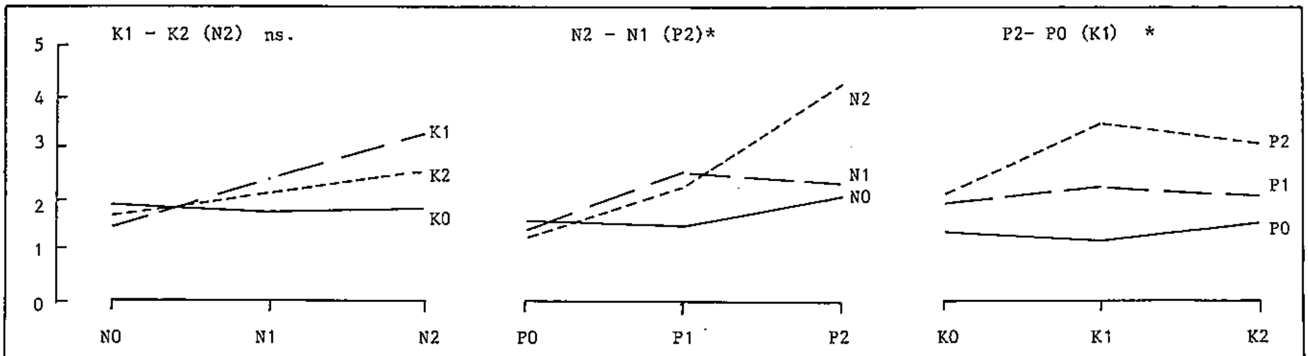

FIG 40: N x K

FIG 41: N x P

FIG 42: P x K

POTATO PLANT HEIGHT: MAIN EFFECTS

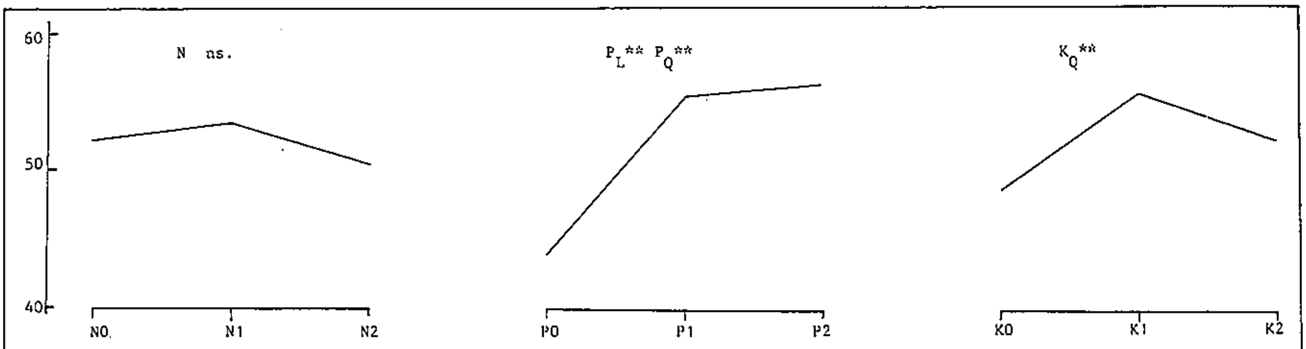

FIG 43: Nitrogen

FIG 44: Phosphorus

FIG 45: Potassium

POTATO LEAF ANALYSIS (% ON DRY MATTER)

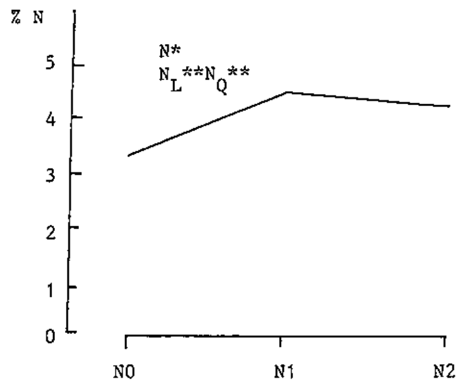

FIG 46: N content — Main effect

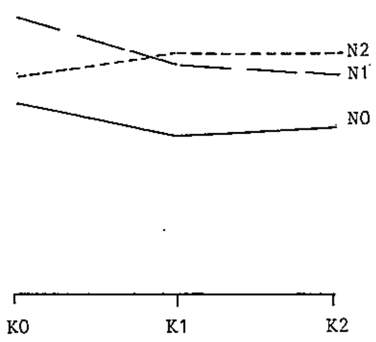

FIG 47: N content — N x K interactions

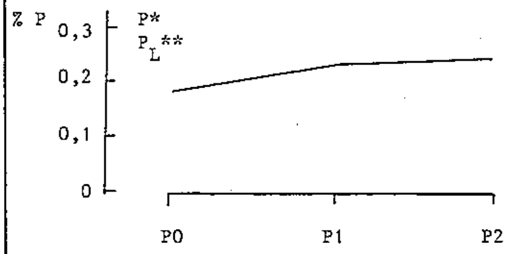

FIG 48: P content — Main effect

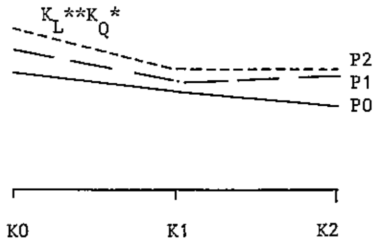

FIG 49: P content — P x K Interactions

POTATO LEAF ANALYSIS (% IN DRY MATTER)

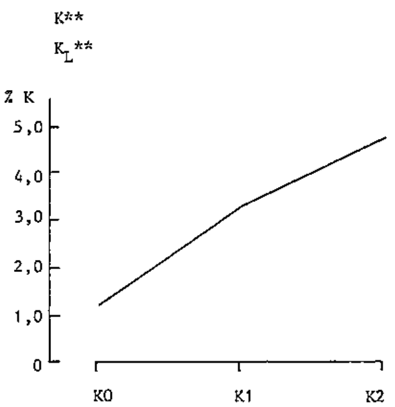

FIG 50: K content — Main effect

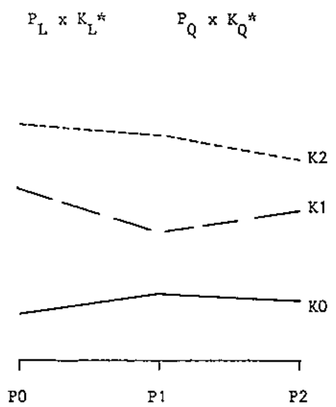

FIG 51: K content — K x P interaction

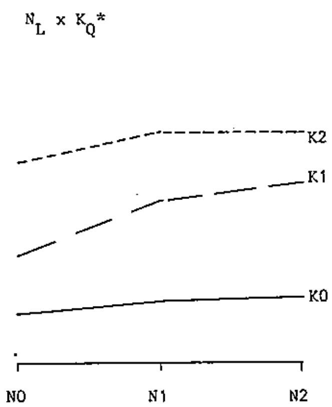

FIG 52: K content — K x N interaction

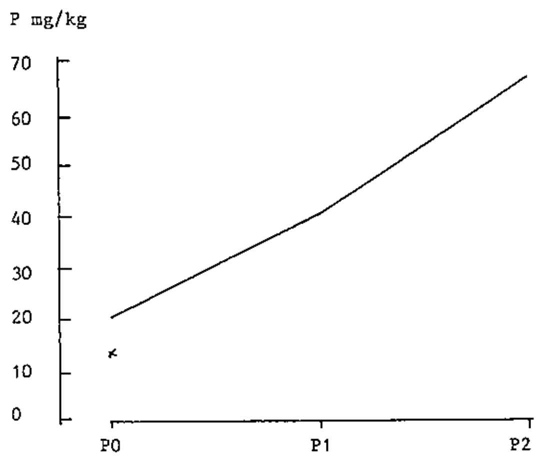

FIG 53: Soil P (Bray 2) in mg/kg before fertilizing (x) and at the last year.

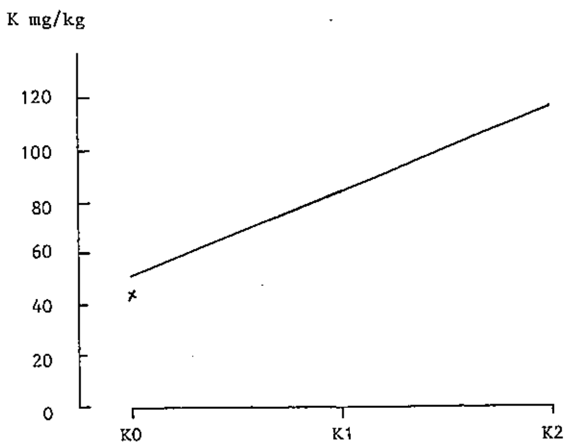

FIG 54: Soil K (Exch) in mg/kg before fertilizing (x) and in the last year.