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HORIZONTAL TRANSFER OF NUTRIENTS IN LONG-TERM FIELD EXPERIMENT

by

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Summary:

The horizontal movement of soil phosphorus and potassium was investigated by soil sampling in two long-term field experiments at Aas Norway. After 30 years with 3-4 years ley and 3-4 arable crops in 6-8 years rotations the transfer of P and K was estimated to roughly 5-6 % after correcting for the border areas. After 10-15 % carry over was measured within the border areas.

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HORIZONTAL TRANSFER OF NUTRIENTS IN LONG-TERM FIELD EXPERIMENT

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INTRODUCTION

Transport of soil and nutrient elements across the border of experimental plots represents a problem, especially in long-term experimentation. According to the results of danish investigations such transport could invalidate the results of long-term field research (Sibbesen 1986, Sibbesen et al 1995). Preventing such transport by barriers, either concretes, steel plates or by grass or fallow strips was therefore recommended (Christensen BT & U. Trentemøller 1995). In experiments with many treatments and plots the construction of such experiments are very expensive, and may result in faulty cultivation practices as well. Frame experiments with ordinary plots or microplots have been used in long term-investigations (Lønsjø 1973, Persson 1995) and also for comparison of field, frame and pot techniques (Uhlen & Rød 1983).

In the field experiments dealt with in this publication, all cultivations were done in the longitudinal direction of the individual plots and with reversible ploughing from year to year. Nevertheless, transport of soil particles can not be avoided also in side direction. The harrowing is probably the main cause of soil transport in the longitudinal direction. Njøs & Steenberg (1962) found larger transport of ^{32}P applied in superphosphate after use of spring and tine cultivators than after the plough, disc harrow or rotary cultivator.

MATERIALS AND METHODS

A. Long-term phosphorus and potassium experiment.

The experiment was started in 1966 and the soil sampling were undertaken in spring 1996 before the yearly application of fertilizer. Four rates of P, (0,16, 32 and 48 kg per hectare) and four rates of K (0,50, 100 and 150 kg per hectare) were combined in a factorial design (4^2). The soil investigation in 1996 was restricted to four transects (four lines) in both direction across the borders between O-plots and high rate P, respectively K, applications. Within each line 15 individual samples were taken and analysed. The individual samples consisted of four sticks in 0-20 cm of the plough layer.

B. Long term nitrogen, phosphorus and potassium experiment.

This experiment was started already in 1939 and in first 30 years farm manure was given every sixth year to most of the plots. Large changes in the treatments and also in plot sizes were introduced in 1969 and in 1981. After 1980 the rates were increased to 40 kg P and 150 kg K per hectare and year.

For grain crops P and K rates were reduced to 30, respectively 100 kg. The sampling for investigation of the carry over effects was done in spring 1997 following one year without any fertilizer applied. Samples were taken from three replicates in both directions across the border lines between 0 plots and plots with P or K.

The soil in both experiments, A and B, was clay loam high in organic matter. The carbon content was 3-4% of soil dry matter, the clay content about 25%, while the silt and sand fractions were roughly 50, respectivly 20-25%.

The crop sequence in the two last rotational periods has been 4 years timothy ley with some red clover in the first two years, followed by spring grain, potatoes, swedes and spring grain. The sampling was undertaken after 4 years of arable crops in experiment A and in the second year after ploughing of 4 years old ley in experiment B.

The soil analyses of phosphorus were carried out according to Bondorffs method (1950). 4 g soil was extracted in 80 ml 0.1 M H_2SO_4 for 3 hours. This method is assumed to extract most of the inorganic soil phosphorus (Sibbesen 1986). In a few samples also determination of total-P was undertaken. After combustion at 550 °C the ash was treated twice with 6 M H_2SO_4 and heated to 70 °C for 10 min.

Potassium was extracted by boiling 1 M HNO_3 (Reitemeier et al 1948). This method will extract much more K than the exchangeable fraction, especially from clay soil, but only a small proportion of the total-K in soil. More information of experimental set up and some results obtained in the earlier periods of these experiments are reported by Uhlen (1976), Uhlen & Rød (1983).

RESULTS OF SOIL INVESTIGATION.

A. Phosphorus-potassium experiment.

The results given in Fig. 1 and Fig. 2, respectively, for the transects across and along plots, are averages for 4 replicates. Of the fertilized plots, 3.6 m x 7.5 m, only 2.4 m x 5.5 m has been harvested for yield determination. The excluded border width was 1.2 m, respectively 2 m, in the two directions.

The figures show marked changes in the P and K content in the transects within the excluded border area moving from unfertilized to heavy fertilized plots or vice versa. Some carry over effects are apparent also in the harvest plots. However, these effects are relatively small, compared to the results found elsewhere (Sibbesen et al 1995). Based on analyses of variances (5 x 4 observations) the differences within the harvest plots were not significant for any of the four comparisons shown. (LSD 5%)

The P and K amounts measured do not represent the total content in soil. A complete balance of K, based on soil analysis is not obtainable due to the huge amount of total K in clay soil. The amount of P measured by the Bondorff method was less than expected. Therefore, total-P, including also P in organic compounds, was determined in 6 + 6 samples taken from the central areas of the no P, respectively high P plots. The mean results were 110 mg P per 100 g for P_0 and 145 mg P for P_{48}. The difference, 35 $\pm$ 6 mg P, as well as the total content, were nearly 4 times higher than obtained by the Bordorff method. It is not likely that these large differences can be explained as P in organic compounds alone, but may result also from the more concentrated sulfuric acid used in the extraction of total-P. The increase in total-P left in the plough layer (25 cm) after adding 1.45 tons P per hectare in sum for 30 years was estimated to about 1 ton. Unfortunately the P removed in harvested crops were not determined in all years, and not in the last 10 years of this experiment. For 8 years during the period 1979-86, representing all the 8 crops in the rotation, the increased P in crops after P_{48} compared with P_0 was 8 kg per hectare and year. For the 30 years period increased P in crops may be estimated to 240 kg. In field and lysimeter trials with these soil the leaching of P to drain depth has been very small (Uhlen 1994). The phosphorus was applied on the surface of grassland in 4 of 8 years. This result in accumulation of P in the top 0-2 cm of the soil. After ploughing down the P-rich material, some additional transport to the layer below the plough depth can not be ruled out.

Of the added K during 30 years, 4,5 tons per hectare, the increase in acid soluble K was about 600 kg. Plant analyses in the eight years period, 1979-86, revealed increased uptake of as much 125-130 kg K per hectare and year. In long-time greenhouse pot experiment with eleven soils, (Semb et al. 1959) decreases in K-HNO_3 (41 mg K/100 g) were equal to the amounts of K removed in crops (39 mg K/100 g). In the field some losses of K by leaching from the top layer may take place, even if leaching to drain depth has been negligible in this soil (Uhlen 1994). The difference in K-HNO_3 value seems to be a fairly estimate of the difference in total soil potassium in this experiment.

B. Long-term NPK experiment.

The results are shown in Fig 3 and Fig 4 as averages for 3 transects across and 3 transects along selected plots. The, excluded border areas in the last 15 years were 1.2 m and 1.3 m, respectively, for the two directions.

Most of the differences in P and K content of the soil originate from the last 15 years with rather heavy applicaton rates. The after effects of P and K given in the earlier periods, 1939-68 and 1969-80 appeared to be small. In the first 30 years period 25-35% of the P and 75% of the K added in fertilizer and manure were removed in crops. Added P will have a more lasting effect upon the soil P content, and, consequently, the carry over effect of long time cultivations will be more marked for P than for K as may be indicated in fig 3 and 4.

The results from experiment B are fairly similar to those of of experiment A shown in Fig 1 and 2. Analyses of variance based upon 3 replicates and 6 distances from the borders, showed no significant differences within the harvest plots except for P_{40} in the longitudinal direction. We notice also the much higher variability in the soil analyses for the P_{40}, and especially the K_{150} plots, than for the unfertilized plots. In experiment B the samples were taken first year year after the ploughing of four year old ley. In another long-term experiment on ley in the same area it was demonstrated that the content of P and K below 10 cm depht was practically unaffected by heavy annual rates of P and K during 10 years, wheràs a large accumulation took place in the 0-2 cm top layer (Ødelien 1967). It will most likely take many years of ploughing and harrowing to level out such differences. This explain the much higher variability in the fertilized than the unfertilized plots. (Fig. 3 and 4).

Total-P was examined in 6 + 6 samples. The difference between total-P in central area of the P_{40} and P_0 plots was 127-109 = 18 ± 3 mg P per 100 g soil. The P added during the last 15 years was 550 kg P and, like the result for experiment A, the increase in the top layer 2.5-3 tons of soil seems to take care of most of the added P in the last 15 years. The increase in P uptake after adding 40 kg P/hectare were for four years, in 1983-1986, only 2-7 kg P per hectare and year. The yield increases for P were less in experiment B than in A.

The strong K-deficiency (Plate 1) resulted in yield reduction to less than fifty per cent for most crops. The increases in K uptake after adding 150 kg K were in two ley years more than added, whereas large surplusses of K were apparent with arable crops.

The K-HNO_3 figures were about 20 mg pr 100 g higher in the K_{150} plots compared to the K_0 plots. Of the total K added (2.2 tons per hectare) about 25% was recovered in the soil, while the reminding was most likely removed by the crops.
Calculations of P and K balances are difficult due to an incomplete plant analytical program, and also due to the different fertilizer application in earlier periods. In 4 out of 6 cases the P_{40} and K_{150} plots (in 1981-95) received more P and K than the P_0 and K_0 plots also in the period 1939 to 1980. These earlier applications had no apparent effect upon K-HNO_3 and P according the Bondorff method, whereas some residual effects upon total-P were shown. These results are not further documented.

DISCUSSION

The long-term transfer of soil, measured by soil analyses, was found to be more or less the same for P and K in a 30 years old experiment (A). In another experiment (B) a tendency of larger effect of long term application of P than of K was indicated. The percentage recovery of K in crop yield was much higher than that of P, giving relatively larger soil residuals for horizontal transfer of P than of K.

The transfer across the plots, due to ploughing, was less than along the plots, which has been the main direction of cultivation in these experiments. This is demonstrated in Table 1. The regression coefficent depict a straight line increase in soil analytical values of P and K within the excluded border areas between unfertilized and fertilized plots. These increases are about twice as high per meter in the across direction as along the plots.

An attempt was made to estimate the transfer of P and K from the harvest area into the border area by simple planimetry as demonstrated by the hatched area in Fig 1. As seen from Table 1 the estimated carry over of P and K outside the excluded border areas come to roughly five to six per cent in totals for both direction. The effect upon soil K in experiment B was less. In these calculation we presuppose that the P and K in the central areas of the plots are not affected. As discussed earlier, the differences in total-P together with increased plant uptake seem to take care of added P, and likewise, the increase in acid soluble K together with a large proportion in plant uptake account for the K addition.

The sharp transition zone between plots with and without K as shown in Plate 1 might partly be due to the fact that the spring grain followed 4 years ley with no soil cultivation and also that the K transferred to the K_0 plots might have been effectively utilized by the ley crops. The transfer of P and K from the fertilized to the not fertilized half of the excluded border area was from the straight line regression calculated to 10-15% of the total difference between fertilized and unfertilized plots. These transport of nutrients did not, however, affect the actual yield measurements.

The less transfer of soil and nutrients measured in these experiments, compared with those reported from many other long-term experiments (Sibbesen 1986, Sibbesen et al. 1995, McGrath & Lane, 1989), could partly be explained by careful cultivation procedures. It should also be taken into account that the high propertion of perennial leys has resulted in soil cultivation in only half the number of years in these experiments.

The lateral transfer of P and K in these experiments was not found to be very critical for most parameter measurements. The border areas excluded in harvest should be twice as wide in the direction of cultivation than in the across plot direction. Sites for soil sampling should be restricted to the more central parts of the plots in long-term field experiments.

Summary

The lateral movement of soil phosphorus and potassium was investigated in two long-term experiments on a clay loam at ÅS, Norway. Soil samples from each 25-50 cm were taken in transects across the border between control plots, plots with no P or K, and heavily fertilized plots. The procedure was in experiment A replicated in four places along the plots and four across the plots. In experiment B the same sampling were performed in three replicates along and three across plots. Sulfuric acid was used for extracting inorganic P and boiling nitric acid for K-determination. For a few samples also total-P was analysed.

After 30 years with 3-4 year ley and 3-4 arable crops in 6-8 years rotations the transfer of P and K was estimated to roughly five to six per cent after correcting for the border areas. Another ten to fifteen percent carry over was measured within the border areas.

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Table 1. Changes in soil P and K across the border between fertilized and not fertilized plots.

			Per meter b[1]	Total diff.[2]	Estimated carry over[3] %
Experiment A	P mg/100 g	Across	7.2	11.6	2.5
		Along	2.4	9.4	3.2
	K mg/100 g	Across	9.1	18.6	3.0
		Along	4.6	17.3	2.8
Experiment B	P mg/100 g	Across	7.6	12.4	2.7
		Along	3.6	10.0	2.9
	K mg/100 g	Across	16.9	22.0	0.4
		Along	12.8	21.0	1.1

1. Regression coefficients. Including only observations within the border areas.

2. Differences in the analytical figures between central areas of fertilized and not fertilized plots.

3. Relative loss from harvest plots, exclusive border areas.

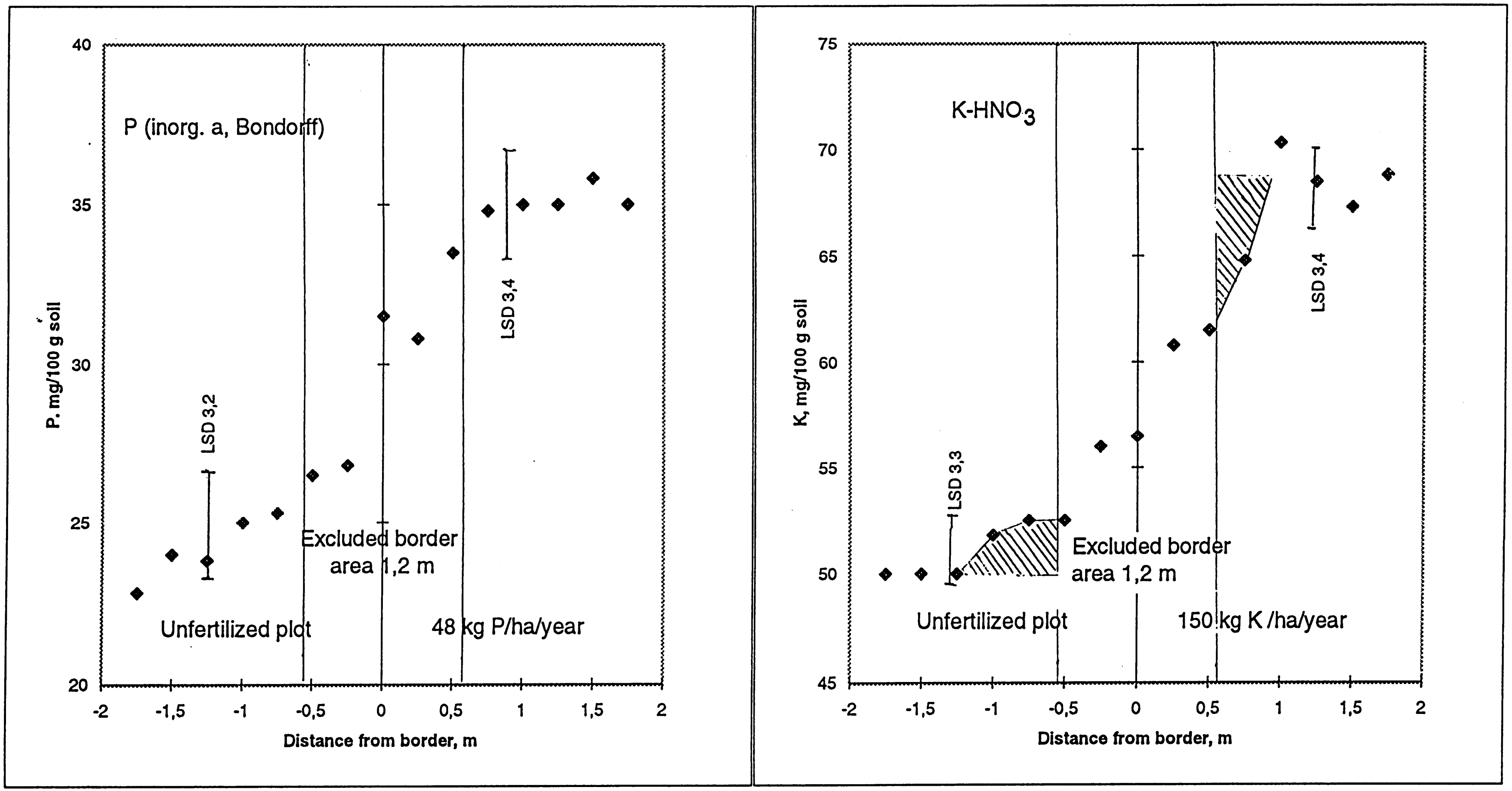
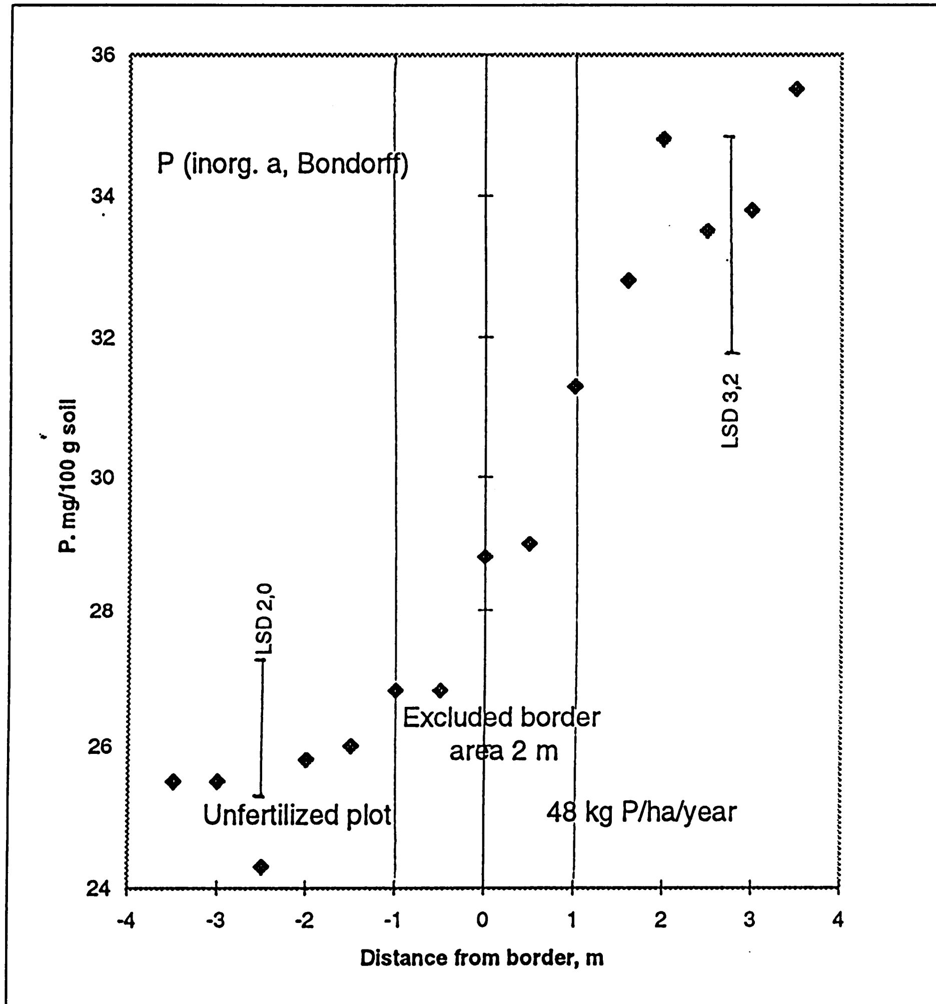


Fig. 1. Phosphorus and potassium content of soil in transects across plots.Experiment A. Means figures, 4 replications (plots).
Hatched = Affected areas of harvest plots.



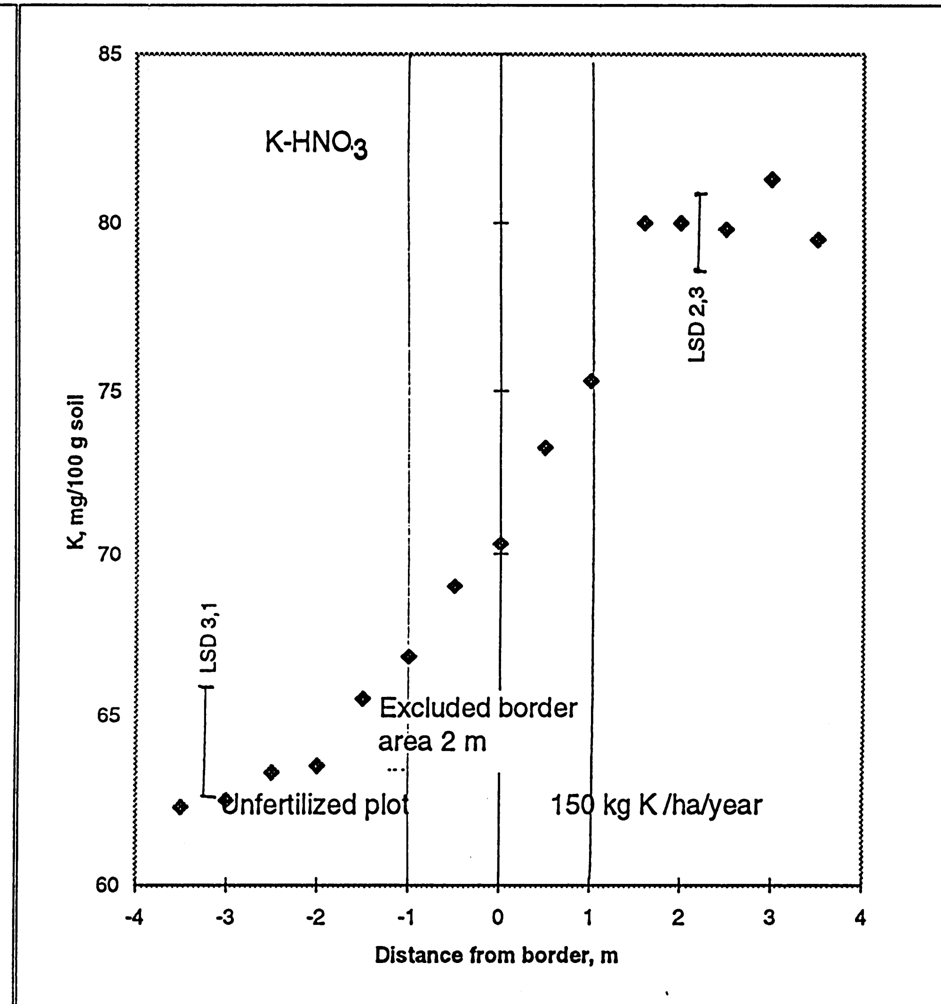
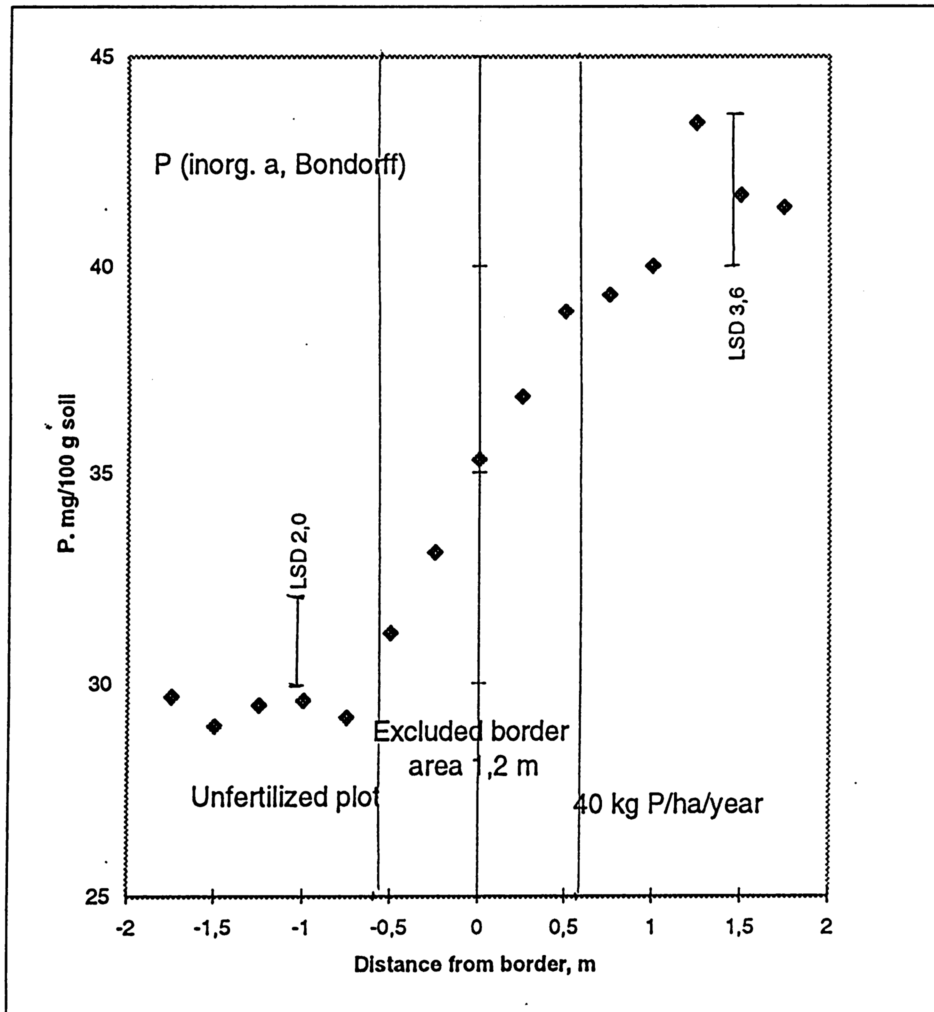


Fig. 2. Phosphorus and potassium content of soil in transects along plots. Experiment A. Means figures, 4 replications (plots).



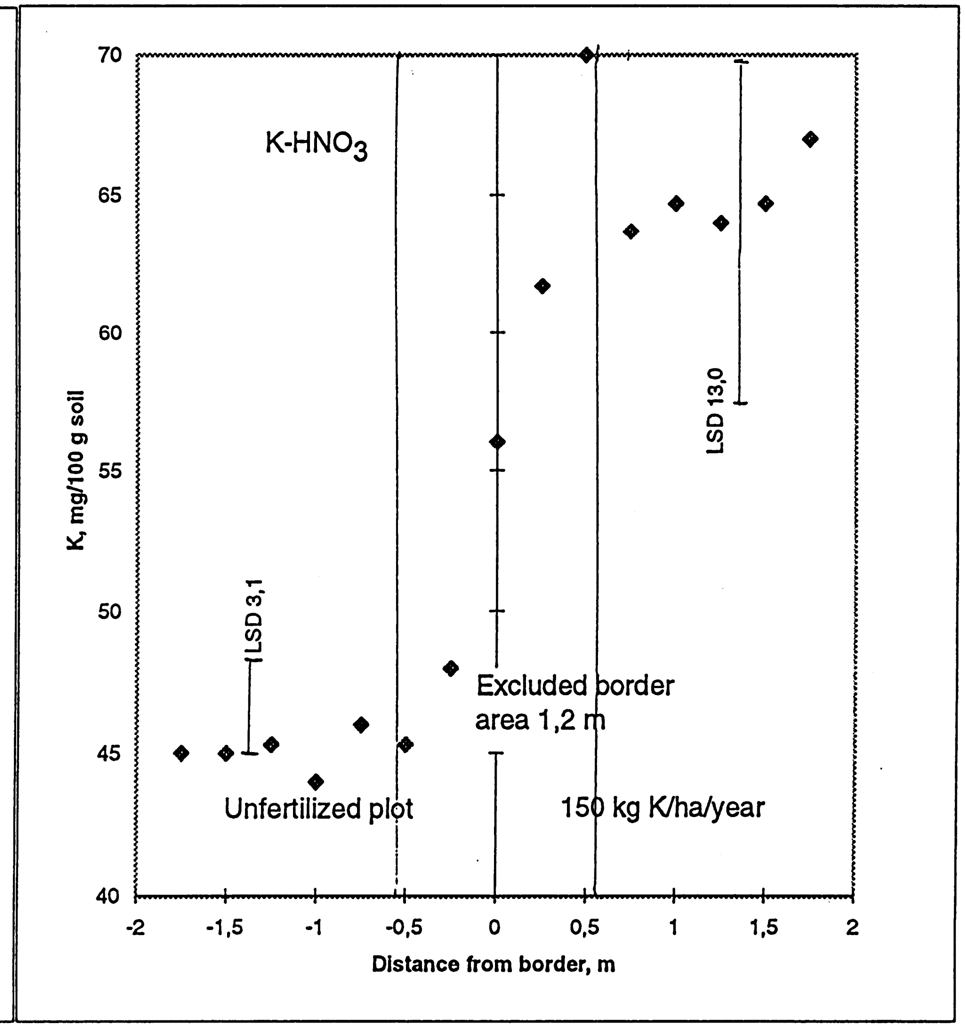


Fig. 3. Phosphorus and potassium content of soil in transects across plots. Experiment B. Mean figures, 3 replications (plots).

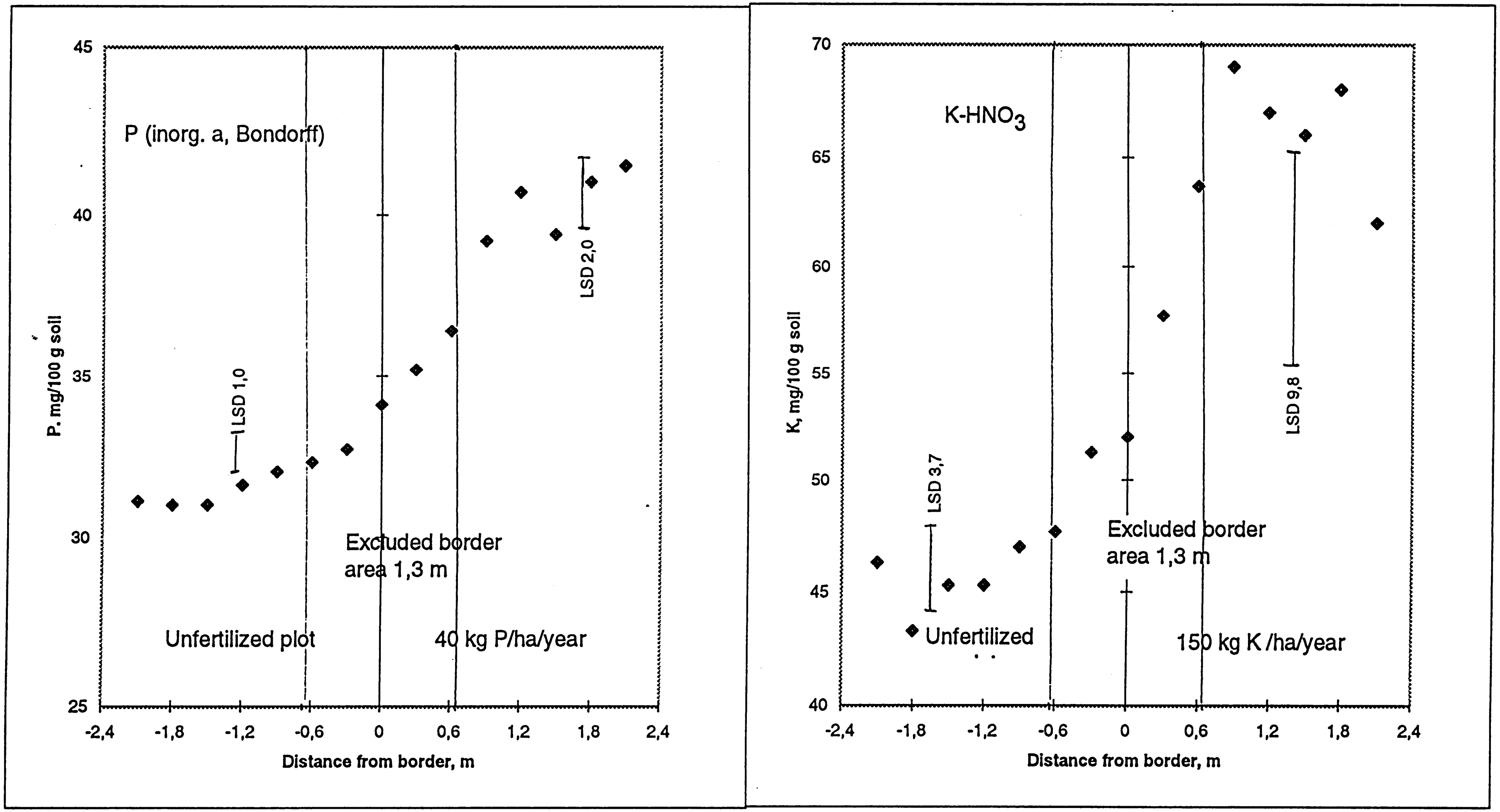


Fig. 4. Phosphorus and potassium content of soil in transects along plots. Experiment B. Mean figures, 3 replications (plots).

Plate 1. The yellow plots of spring barley have been without potassium in 16 years or more.