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Efficiency and kinetics of phosphorus uptake from soil by various barley genotypes

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Key words Barley Kinetic parameters Phosphorus Varietal effects

Summary Barley cultivars grown under field conditions of moderate deficiency of phosphorus (P) had great differences in P uptake and grain yields.

As the rate determining step in P uptake under these conditions is located in the root net influx of P ($\bar{I}_nL^*$) per g of dry matter of the plant can be expressed by

$$\bar{I}_nL^* = \bar{I}_{max}L^* \frac{c - c_{min}}{c - c_{min} + K_m}$$

where $\bar{I}_n$, L^*, $\bar{I}_{max}$, c, c_{min} and K_m denote mean net influx per unit length of the root, root length per unit weight of the plant, maximal mean net influx per unit length of the root, P concentration at the root surface, minimum concentration in solution of which net influx appears to be zero and Michaelis–Menten factor of P uptake, respectively. Studies of P uptake kinetics in water culture showed that the values of L^*, $\bar{I}_{max}$, K_m and c_{min} of P uptake varied considerably between barley cultivars. Furthermore, agreement was found between P uptake in the field and P uptake predicted from $\bar{I}_{max}$-, K_m-, c_{min}- and L^*-values observed in water culture experiments.

The data thus indicate that it should be possible to improve the efficiency by which plants utilize soil as a source of P by selecting and/or developing genotypes of barley with a smaller c_{min} and/or K_m and a greater $\bar{I}_{max}$ and/or L^* during the main period of growth.

The results suggest therefore that it should be feasible to adapt plants to a considerably lower soil P level.

Introduction

For many years the effort by man has been to fit the soil to the plant by application of fertilizers. We have only recently tried to fit the plant to the soil. Progress in the latter requires knowledge of plant parameters controlling the efficiency by which plants utilize soil as a source of nutrients.

The aim of the present work is:

1) to show how various genotypes of barley differ in their uptake of phosphorus from soil low in phosphorus,
2) to draw attention to four plant factors (kinetic parameters) important for the efficiency of nutrient uptake from soils under conditions in which the rate determining step in uptake of the nutrient is located in the root,
3) to give data for the range of the variation of these kinetic parameters between some genotypes of barley,

4) to establish the agreement between phosphorus uptake in the field and phosphorus uptake predicted from kinetic parameters observed in water culture experiments.

Results

The results in Table 1 show that barley varieties differ much in grain yields under conditions of moderate phosphorus deficiency, whereas grain yields were almost equal in experiments on Danish farms without phosphorus deficiency.

Fig. 1 illustrates how phosphorus uptake varied between two barley varieties representing extremes of 30 barley varieties grown at moderate deficiency of phosphorus in a field experiment.

The efficiency by which plants utilize soil and fertilizers as a source of nutrients is affected by several plant factors, *e.g.* radius, length, density and geometry of the roots in the soil; kinetic parameters of nutrient uptake, root exudates and the adaptability of the roots to symbiotic and non-symbiotic soil microorganisms.

The four plant factors (kinetic parameters) important for phosphorus influx per unit weight of the plant and the efficiency of phosphorus uptake from soils are given in Table 2. The latitude of variations between 6 barley varieties in the values of these kinetic parameters can be seen from the data in Table 3.

The net influx of phosphorus per g of dry matter of the plant can be expressed by

$$\bar{I}_n L^* = \bar{I}_{max} L^* \frac{c - c_{min}}{K_m + c - c_{min}} \quad (1)$$

where $\bar{I}_n L^*$ denotes mean net influx of phosphorus per g of dry matter of the plant and c the concentration of phosphorus at the root surface. Details of the

Table 1. Grain yields of 6 barley varieties, grown at moderate phosphorus deficiency or in experimental trials on Danish farms ($\times$ 100 kg grain ha^{-1})

Barley variety	Low P level* in the soil	Average of Danish field trials**
Salka	49	48
Lofa	44	47
Rupal	41	48
Nürenberg	36	–
Mona	36	45
Zita	30	47

*Selected results from a field experiment with 30 barley varieties, Nielsen[2].

**Average yield in 1975 to 1979 of trials, conducted by the Danish Agricultural Advisory Centre.

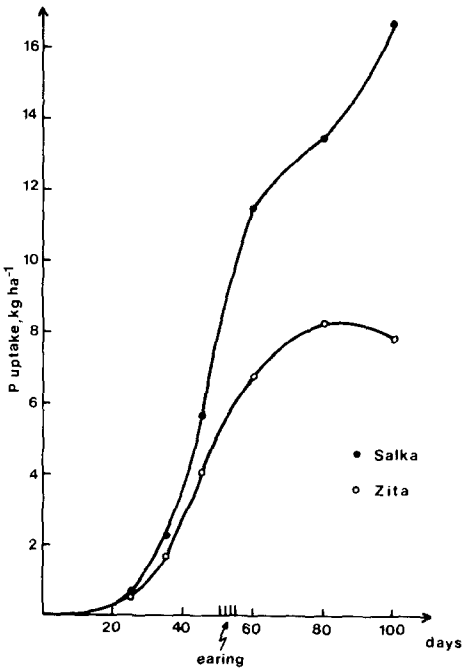

Fig. 1. Phosphorus (P) uptake by the barley varieties Salka and Zita during growth at moderate P deficiency under field conditions.

experimental procedure used to estimate L*, $\bar{I}_{max}$, K_m and c_{min} has been given by Nielsen[1] and Schjørring and Nielsen[4]. Fig. 2 shows the predicted mean rate of P uptake per g *D*M, at varying P concentrations, c, calculated from Eq. 1 by use of values of L*, $\bar{I}_{max}$, K_m and c_{min} in Table 3. From Fig. 2 it can be seen that Salka has the highest $\bar{I}$nL*-value (efficiency) of P-uptake per g DM of plant at c lower than 3 μM P, whereas Mona has the lowest efficiency.

Table 2. Plant factors (kinetic parameters) important for the efficiency of nutrient uptake from soils

Name	Symbol	Dimension
Root length per unit weight of the plant	L*	mg^{-1}
Maximal mean net influx per unit length of the root	$\bar{I}_{max}$	pmole $cm^{-1}s^{-1}$
Michaelis–Menten factor of nutrient uptake	K_m	μM
Minimum concentration in solution at which net influx appears to be zero	c_{min}	μM

Table 3. Meters of root per g of dry matter (DM) of the plant (L*), mean maximal net influx ($\bar{I}_{max}$), Michaelis–Menten factor (K_m) and minimum concentration (c_{min}) for phosphorus (P) uptake by 35 days old barley plants, grown in water culture[4]

Barley variety	L* m root g DM	$\bar{I}_{max}$ pmole P $cm^{-1}s^{-1}$	K_m μM P	c_{min} μM P
Salka	65	0.08	2.9	0.02
Lofa	77	0.08	4.1	0.04
Rupal	46	0.10	3.6	0.04
Nürenberg	68	0.11	3.6	0.06
Mona	42	0.14	5.5	0.05
Zita	57	0.12	4.7	0.03
CV in %*	8.4	16	14	17

* Coefficient of Variance = 100 $s_{\bar{x}}/\bar{x}$

In order to study the agreement between P uptake in the field and P uptake expected according to the observed values of $\bar{I}_{max}$, K_m, c_{min} and L* in water culture experiments, transport kinetic models can be used as shown by Nielsen and Barber[3], Nielsen[1] and Schjørring and Nielsen[4]. By use of such a model and the kinetic parameters in Table 3 and estimated root lengths, Schjørring and

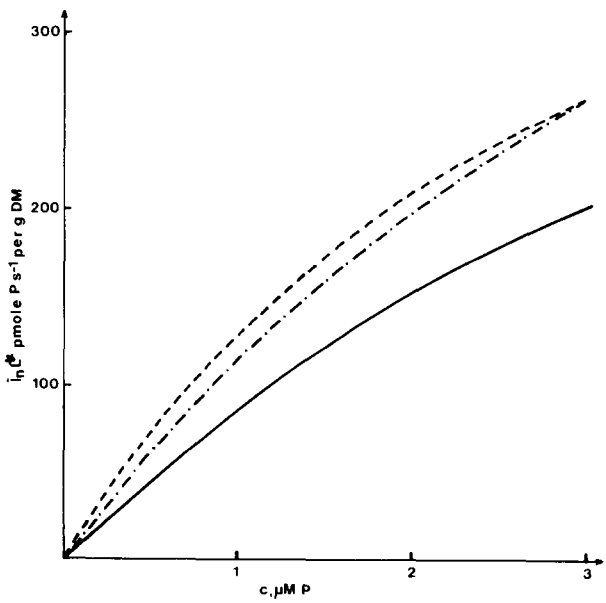

Fig. 2. Mean net influxes per g dry matter (DM) of plant, InL*, at varying phosphorus (P) concentration, c, by the barley varieties Salka (– –), Zita (– · – ·) and Mona (——).

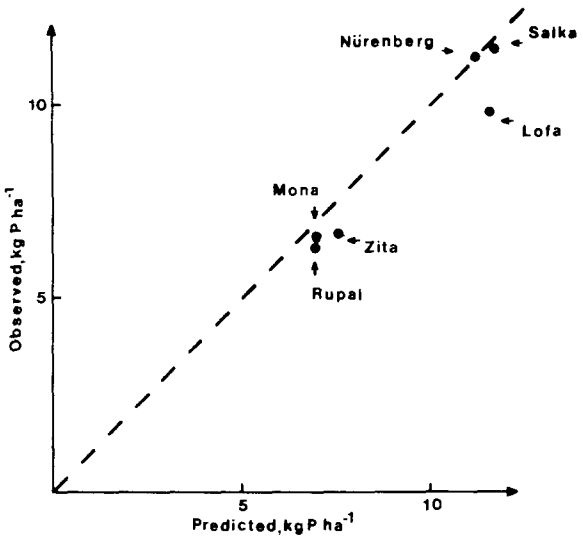

Fig. 3. The relation between observed phosphorus uptake in the field 60 days after emergence and phosphorus uptake predicted from estimated values of the kinetic parameters of 6 barley varieties in water culture experiments.

Nielsen[4] calculated the expected P uptake by some barley varieties. An example of the relation between observed and predicted P uptake is shown in Fig. 3. The agreement between observed P uptake in the field and the P uptake predicted by the model, Fig. 3, seems to justify the use of kinetic studies in water culture with the aim to characterize differences in P uptake efficiencies between plant varieties.

Conclusion

Root length, L, mean maximal net influx of nutrients into roots, $\bar{I}_{max}$, Michaelis–Menten factor for mean net influx, K_m, and the minimum concentration, c_{min}, at which mean net influx appears to be zero, are plant factors (parameters) that greatly affect the efficiency by which barley utilizes soil as a source of nutrients under conditions in which the rate determining step of uptake is located in the root.

Reliable procedures exist for estimating these plant parameters. The range of variation in the parameters between some barley genotypes are considerable. Improvement in the efficiency of phosphorus uptake may be possible by selecting from our barley varieties or by plant breeding to develop genotypes which have a smaller c_{min} and/or K_m, a higher $\bar{I}_{max}$ and/or L during the main growth period.

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