NJF Report

Volume 4, No 4 - 2008

NJF seminar 401

Phosphorus management in Nordic-Baltic agriculture

- reconciling productivity and environmental protection

Uppsala, Sweden - 22-23 September 2008

NJF

Nordic Association of Agricultural Scientists

www.njf.nu

Phosphorus uptake patterns and yield responses of barley fertilized with meat and bone meal

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Introduction

Early phosphorus (P) acquisition is considered to be essential for producing optimum yields while P availability at a later growth stage is thought to have less influence on crop yields (Grant *et al.*, 2001).

In this study we evaluated the effect of P acquisition during the growth period based on its subsequent effect on barley yield using two different P sources, either superphosphate (SP), a soluble P source, or meat and bone meal (MBM), representing a low-solubility P source (Ylivainio *et al.*, 2008).

Materials and methods

The field experiment was started in 2004 on an organic soil with a low (1 mg l^{-1}) soil test P value (STP, acid ammonium acetate, pH 4,65). MBM was applied twice, in years 2004 and 2006, before sowing at rates of 20 or 50 kg ha^{-1} of total P. SP was applied annually during 2004-06 at rates of 10, 30 and 75 kg SP-P ha^{-1}. Every year plots were cultivated to a depth of 6 cm (rotary cultivator) and all treatments received soluble nitrogen (N) and potassium (K) at 70 kg ha^{-1} as mineral fertilizers. The soluble N in MBM was taken into account according to Kemppainen (1989). The sizes of the experimental plots were 12,5m*3m and the treatments were on the same plots every year. The experimental setup was a row-column design and treatments were replicated four times. Results presented here are from year 2006.

Prior to nutrient amendments to the soil in 2006, soil samples were taken from a depth of 0-10 cm and STP values were analyzed (Table 1). MBM was mixed into the uppermost 6 cm of soil with a rotary cultivator while SP was applied during sowing close to seeds with combisowing. Barley (*Hordeum vulgare,* var. Kunnari) was sown on the 2nd of June. Soil temperatures were recorded in 9 experimental plots at a depth of 6 cm and air temperature measured at 1.65 m above the soil surface (Thermochron iButton). All the plots were equipped with 30 cm TDR- sensors and soil moisture content was recorded six times during the growing period.

Plant samples of the barley stands were collected at three different growth stages. At the leaf development stage, 17 days after sowing (BBCH 12-13), the whole biomass was cut 2 cm above the soil surface from both ends of the plots (1,75 m inside the plot and through the whole width of the plot, excluding the two outermost rows). Thus, plant samples consisted of three plants from each of the 16 rows (combisowing contained 20 rows), totaling about 100 plants. The two youngest fully emerged leaf blades were included in the second (BBCH 31, 27-31 days after sowing), and third (BBCH 45-49, 40 days after sowing) samplings and they were obtained in the same way as at the leaf development stage.

Barley was harvested 104 days after sowing. Yield (moisture content of 14%), thousand grain weight (tgw) and hectoliter weight (hw) were determined. The P concentrations in plant and grain samples were analyzed with ICP-AES, after HNO_3 (about 7 M) digestion and N was analyzed using the Kjeldahl method.

Results and Discussion

The average soil temperature was 16.8 ± 0.4°C during the growth period and the minimum and maximum temperatures were 9,6 ± 1.1°C and 25.0 ± 0.7°C, respectively. The average soil temperatures during barley growth in June, July, August and September were 17.4 ± 0.3°C, 17.4± 0.3°C, 16.7 ± 0.3°C and 14.5 ± 0.4°C, respectively. The average air temperatures were 16.3°C, 18.2°C, 17.9°C and 14.6°C, and the long term average air temperatures (years 1971-2000) are 14.7°C, 16.6°C, 14.8°C and 11.2°C, respectively. According to TDR measurements, soil moisture varied between 25.4 ± 1.5% (measured on 20 July) and 45.0 ± 3.1% (measured on 9 June).

Phosphorus concentrations of plant samples increased as growth proceeded in the control and MBM treatments, whereas it reached a maximum at the beginning of stem elongation in SP treatments (Figure 1). At the leaf development stage, P concentrations of plant samples were significantly higher for 10 kg SP-P ha^{-1} than for 50 kg MBM-P ha^{-1} treatments ($p = 0.0096$), but at the booting stage the situation was reversed ($p = 0.0049$) and leaf P concentrations were equal in 50 kg

MBM-P ha^{-1} and 30 kg SP-P ha^{-1} treatments. 75 kg SP-P ha^{-1} produced the highest plant sample P concentrations compared to other treatments.

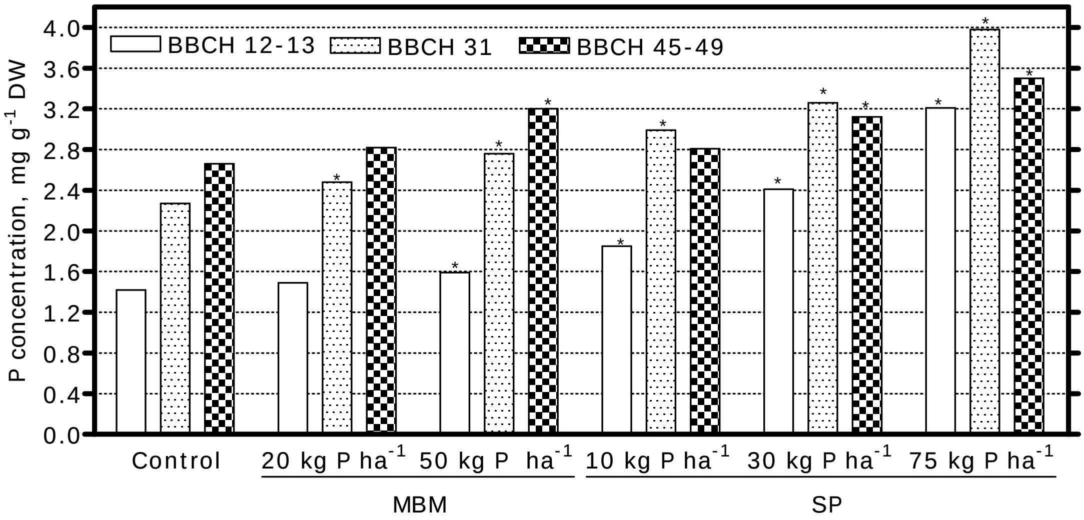

Figure 1. Phosphorus concentrations of plant samples at different growth stages. The amount of applied P indicates the total P applied in 2006. The total amounts of P applied in MBM treatments in 2004-06 were 40 and 100 kg P ha^{-1} and in SP treatments 30, 90 and 225 kg P ha^{-1}, respectively. Stars above the bars show significant differences compared to control ($p < 0.05$).

The results clearly show that barley was not able to utilize MBM-P as efficiently as SP-P at the beginning of the growth period. However, the availability of MBM-P improved later in the growing period, probably due to the dissolution of MBM-P, which is for the most part in the form of calcium phosphates. This is in line with results obtained in a pot experiment with ryegrass (Ylivainio et al. 2008). MBM was also mixed in the uppermost 6 cm of soil, whereas SP was placed close to the seeds, which probably enhanced SP-P utilization during the early growth stage. However, once the barley roots had reached more soil volume, the availability of MBM-P improved.

According to Jeng *et al*. (2004), MBM-N is almost comparable to mineral fertilizers. Of a total of 92 kg N ha^{-1} in a 50 kg MBM-P ha^{-1} treatment, only a small part (0.4 kg ha^{-1}) was taken as soluble, according to the method used (Kemppainen, 1989). Although the MBM treatments most probably received more easily available N than the SP treatments, N concentrations of plant samples in 50 kg MBM-P ha^{-1} treatments were at the highest level only at the booting stage (Figure 2). A lower level of P availability in MBM compared to SP treatments may have depressed N uptake during the earlier growth stages (Rufty *et al.*, 1993).

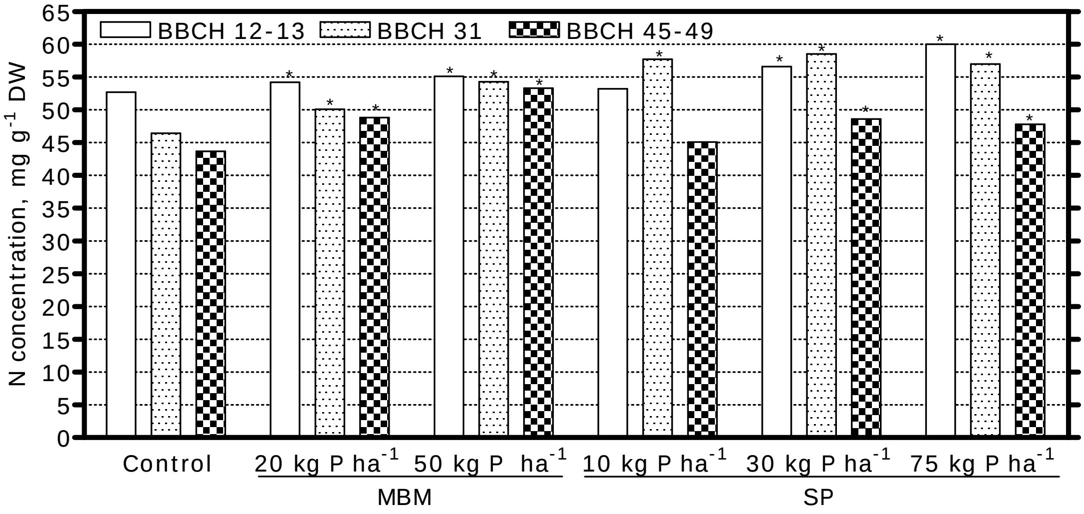

Figure 2. Nitrogen concentrations of plant samples at different growth stages. The amount of applied P indicates total P applied in 2006. The total amounts of P applied in MBM treatments in 2004-06 were 40 and 100 kg P ha^{-1} and in SP treatments 30, 90 and 225 kg P ha^{-1}, respectively. Stars above the bars show significant differences compared to control ($p < 0.05$).

All P applications increased barley yields significantly (Table 1). Although the P concentrations of plant samples during the growth period were higher for the 30 SP-P kg ha^{-1} than the 50 kg MBM-P ha^{-1} treatment up to the booting stage, yields were comparable between these treatments. Even the lower level of MBM application increased yield significantly, although the P concentrations of the plant samples were similar to those of the control except at the beginning of stem elongation. Results indicate that in our experiment early phosphorus acquisition during the growth period was not as critical for yield formation as has been suggested by Grant *et al*. (2001). In addition, the quality parameters (tgw and hw) were not statistically different between the 50 kg MBM-P ha^{-1} and the SP treatments (Table 1). Air temperature was probably not an important depressing factor for barley growth in 2006 as it was on a higher level than the statistical average in 1971-2000.

Table 1. Soil test P value (STP, 0-10 cm) in spring 2006, barley yield (14% moisture), 1000- grain weight (tgw), hectoliter weight (hw), and P and N concentrations of grains. Stars show a significant differences compared to control ($p < 0.05$).

P source and application level	STP, mg l^{-1}	Yield, kg ha^{-1}	tgw, g	hw, kg	P, mg g^{-1}	N, mg g^{-1}
Control	1.2	3633	34.7	61.9	2.8	18.3
MBM, 20 kg P ha^{-1}	1.7*	4519*	35.1	62.7	2.8	17.9
MBM, 50 kg P ha^{-1}	2.6*	5354*	36.5*	64.5*	3.0*	18.7
SP, 10 kg P ha^{-1}	1.5	4563*	35.8	64.2*	2.9	16.8*
SP, 30 kg P ha^{-1}	2.3*	5300*	37.2*	64.4*	3.1*	16.7*
SP, 75 kg P ha^{-1}	3.6*	5723*	37.7*	65.3*	3.3*	16.9*

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