THE EFFECT OF PHOSPHORUS APPLICATIONS ON CHANGES IN THE SOIL CONTENT OF P AND YIELDS OF BARLEY BIOMASS

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Abstract

Balanced nutrition and fertilisation is essential for soil fertility and a prerequisite for achieving adequate yields and quality of production. As part of the national research project a pot experiment was established (Mitscherlich pots) with spring barley, variety KWS Irina. The experiment was conducted in the vegetation hall of the Crop Research Institute in Prague. The soil (chernozem) had a satisfactory supply of phosphorus – 57 mg/kg (Mehlich 3) and alkali soil reaction. The rates of phosphorus in the form of triple superphosphate (45% P_2O_5*) were increased from 0.3 – 0.6 – 1.2 g per pot (5 kg of soil). Nitrogen was applied in the form of CAN (27% N) at a rate of 1 g N per pot in all the treatments incl. the control. The content of post-harvest soil phosphorus increased with the applied rate (65 – 90 – 116 mg/kg). Dry matter yields of the aboveground biomass were the lowest in the control treatment not fertilised with P (63.3 g per pot) and increased significantly with the P rate applied (66.7 – 68.6 – 70.7 g per pot).*

Key words: *phosphorus, fertilization, barley, soil, biomass*

1. INTRODUCTION

Phosphorus (P) is an essential nutrient for plants that can considerably affect the yield level and yield stability of many crops. Its interaction with nitrogen significantly contributes to optimum crop yield and nitrogen use efficiency (Usherwood & Segars 2001). Phosphorus is an essential nutrient for the provision of sufficient crop production, sufficient foods, for the increasing human population on the Earth (Denison & Kiers 2005, Reid & Scholas 2005). The significant decrease in use of mineral phosphate fertilizers began in the Czech Republic after political-social changes in the year 1989. If in 80´s of the 20th century about 29-33 kg P/ha/year was applied annually, between years 1991-2013 a decrease of P supply to 6 kg P/ha/year was noted! Together with the decrease of mineral fertilizers, also phosphorus input into soils from organic fertilizers decreased as consequence of decrease of livestock to about a half of quantity of livestock units before the year 1989 (Čermák et al. 2014). In consequence, the decrease of available phosphorus between years 1990-2005 from 107 to 92 mg/kg was noted (Vaněk et al. 2007). The acreage of arable soil (%) in terms of P-supply categories are as follows: low - 4.27%, satisfactory - 28.56%, good - 21.35%, high - 16.55%, very high - 6.47%. More than 75% of arable land in the Czech Republic (low category - satisfactory - good) therefore requires fertilization with phosphorus. A similar situation is also in orchards, vineyards and hop fields (Smatanová & Sušil 2015). The uptake of phosphorus converted per 1 ton of barley grain yield from the field is 3.3 kg P/ha (Klír et al. 2008).

The total soil P content (inorganic and organic forms) is usually dividend into different pools (e.g. stable, labile, available (Jones et al. 1984). In upper layer of arable soils, the percentage of organically bound phosphorus can range from 20% to 80% of total P concentration. Approximately 40% of organic soil P are in the inositol P fractions whereas 7% are bound in lipids and nucleic acids (Dalal 1977). It is known that organic P is involved to a great extent in the dynamics and cycling of soil P (Helal & Sauerbeck 1984, Helal & Dressler 1989).

From the aspect of the long-term strategy of soil fertility conservation for necessary production of foods and feeds for the increasing human population on the Earth phosphorus taken up by the crop yield from the soil must be recompensed (Tilman et al. 2002, Denison & Kiers 2005). It is to note that only the efficient reserve of labile forms of phosphorus should be maintained in agricultural productive soils. This should be ensured by a systematic testing of the nutrient status of soils including agronomic calibration for the present needs of agriculture (Fixen 2005). Soil testing as a remarkable and unique activity that synthesises a large amount of research information and scientific knowledge for practical needs of the identification and prevention of the majority of disproportions in plant nutrition in a given field. Soil testing provides farmers with the highest quantity of practically applicable information (Raij 1994, 1998). Regarless of their present drawbacks chemical methods of agricultural soil testing are the most frequently used tools of diagnostics of the nutrient status of soil and the need of fertilisation derived from it. The main advantage of soil tests is a possibility of preventing potential disorders of the nutrient status of the crop before its own cultivation in a given field (Matula 2009). To evaluate the phosphorus supply in soils, different soil test have been used for a long time; however they differ markedly in extractants and extraction methods. Nevertheless, the result of the test is generally reported as phosphorus available to plants. When the supply of ´available´phosphorus in soil is given, it is always necessary to specify the used soil test including the end-point analytical technique of phosphorus determination to avoid the misleading interpretation of results (Matula 2010). The need for economic use of phosphorus in agriculture is accentuated by the finite supply of economically P resources (phosphates) for the production of concentrated fertilizers. Sufficient reserves of P resources are estimated to last for about 70 years and maximally for 300 years (Roberts & Stewart 2002, Isherwod 2003). Phosphorus can also be a harmfull polluting agent of surface waters (Schröder et al. 2011). The long-term intensive applications of phosphoric fertilizers to soils and phosphorus recycling in farmyard manure caused the situation when soil, originally a strong sink of phosphorus, became a source of its escape to the environs (Sharpley et al. 1992, 1996, 2001, 2004, Haygarth et al. 1998). Adequate dose of P-fertilizer (including knowledge about soil P-content) has very important environmental aspect too.

2. MATERIAL AND METHODS

The vegetation pot experiment was established on 1stApril 2015 in the outdoor vegetation hall of Crop Research Institute in Praque. Mitscherlich vegetation pots were filled with 5 kg of medium heavy soil characterised as chernozem; Tab. 1 gives the agrochemical properties.

Table 1. Agrochemical characteristics of the soil prior to trial establishment (Mehlich III) – Regulation of Czech Republic No. 275/ 1998

pH/ $CaCl_2$	mg/kg			
	P	K	Ca	Mg
7.6	57	244	3,011	241
alkali	satisfactory	good	good	good

The experiment involved 4 treatments given in Tab. 2.

Table 2. Treatments of the experiment

Treatment No.	Description	Dose of P (g/pot)	Dose of N (g/pot)
1	P0	0	1
2	P1	0.3	1
3	P2	0.6	1
4	P3	1.2	1

Phosphorus was applied in the form of triple superphosphate (45% P_2O_5) and nitrogen in the form of CAN (27% N) at a rate of 1 g N per pot in all the treatments incl. the control. The pots were watered with demineralized water to a level of 60% of the maximal capillary capacity and were kept free of weeds. The aboveground biomass of spring barley (variety KWS Irina) was harvested at stage of milk-wax maturity (10 plants/pot) on 22 June 2015. Soil analysis before experiment and after harvest were carried out using Mehlich 3 method (0.015 M NH_4F + 0.2 M CH_3COOH + 0.25 M NH_4NO_3 + 0.013 M HNO_3) (Mehlich 1984). Plant samples were grounded and digested in microwave Milestone 1200 MLS system in concentrated HNO_3 and H_2O_2. Concentrations of P, K, Ca and Mg in soil extracts were determined using ICP-OES iCAP 7400 Duo, Thermo Fisher Scientific (Newington, USA)

The results were processed statistically using one-way ANOVA followed by testing according to Scheffe (P = 95%).

3. RESULTS AND DISCUSSION

Phosphorus deficiency is a main limiting factor for cereal production in many regions of the world (Sharpley et al. 1994, Holford, 1997). P deficiencies also diminished yield of barley (Rowe & Johnson 1995, Hoppo et al. 1999). Overwhelming evidence indicates that for annual crops, phosphorus fertilizers should largery be applied preplant. Phosphorus moves to plant roots primarily by diffusion, and young seedlings of most annual crops are very sensitive to phosphorus deficits (Burns 1987).

3.1. The content of post-harvest soil phosphorus

Inorganic phosphorus enters in the soil solution by mineralization or fertilizer additions (Sanchez 2007). It was reported several times that the systematic phosphorus fertilization increases the plant extractable soil phosphorus content (Lásztity & Csathó 1995, Blake et al. 2000, Izsáki 2009, Ma et al. 2009). The accumulation rate was found to be dependent on the soil type, cropping system, climatic conditions, as well as on the phosphorus dose. Phosphorus content in soil after harvest of our experiment is shown in Table 3. Phosphorus content in a soil significantly increased with increasing dose of P-fertilizer up 65 (P1) – 90 (P2) – 116 (P3) mg/kg in comparison with 57 mg/kg in non-fertilized control (P0). Phosphorus fertilizer is essential for optimum production, especially when soil test levels are low (McKenzie et al. 1998). In European field experiments (three sites with different soils in the humid oceanic and humid continental climatic regions), where the annual P fertilizer dose ranged between 23 and 35 kg/ha, the soil phosphorus content did not increase significantly (Blake et al. 2000). On a chernozem soil (Hungary: temperate climate) a 100 kg/ha increase of the P balance raised the Al-P content of the ploughed layer by 3.1-4.4 mg/kg/year, when the different P fertilizer levels were compared (Izsáki 2009). At different sites in China having different soil types, with 65.5 kg/ha/year P fertilization dose accumulation rates of P_{Olsen} content varying between 0.95 and 1.24 mg/kg/year were observed (Ma et al. 2009).

Table 3. The content of post-harvest soil phosphorus

Treatment No.	Description	Dose of P (g/pot)	Soil P content (mg/kg)	Supply category
1	P0	0	57 a	satisfactory
2	P1	0.3	65 b	satisfactory
3	P2	0.6	90 c	good
4	P3	1.2	116 d	high

Different letters (a, b, c, d) indicate significant differences between treatments

3.2. Dry matter yields of the aboveground biomass

The yields of aboveground biomass (g DM/pot) is shown in Table 4. The lowest yield was found in P-non fertilized treatment (63.3 g DM/pot), then the significant increase of yield was obtained with the increase of applied phosphorus (66.7-68.6-70.7 g DM/pot). McKenzie et al. (1998) described that phosphate fertilizer significantly increased barley silage yield at 25 of 32 site-year locations. Varieties responded differently to applied P. Some varieties responded to P fertilization regardless of soil test level. Applied P commonly increased yield by about 25%, but occasionally response was much higher.

Table 4. Dry matter yields of the aboveground biomass (g DM/pot)

Treatment No.	Description	Dose of P (g/pot)	Yields (g DM/pot)
1	P0	0	63.3 a
2	P1	0.3	66.7 b
3	P2	0.6	68.6 c
4	P3	1.2	70.7 d

Different letters (a, b, c, d) indicate significant differences between treatments

Nyborg et al. (1999) conducted field experiments at 60 sites to determine the yield response of barley to phosphorus fertilizer. On the unfertilized plots, barley yield increased with increasing concentration of extractable P in the soil. Nitrogen (Gregory et al. 1984, Léon 1992, Le Gouis et al. 1999) and phosphorus (Gregory et al. 1984, Rodriguez & Goudriaan 1995) deficiencies diminish biomass accumulation, but they seem to follow a different timing. P deficiencies usually diminish barley biomass accumulation early in the growth period and, then, differences between stressed and non-stressed crops tend to be maintained in absolute terms and reduced in relative terms (Gregory et al. 1984). On the other hand, N deficiency also diminished biomass accumulation early in the growth period, but differences between stressed and non-stressed crops tend to increase in absolute terms during crop growth (Gregory et al. 1984, Léon 1992, Le Gouis et al. 1999). Prystupa et al. (2004) describe in container experiments with phosphorus (dose corresponding to 19 kg P/ha – P1 and 57 kg P/ha – P2) increase of aboveground dry matter content of barley at heading: 602 (N0P0) - 878 (N0P1) - 978 (N0P2) g DM/m^2. If the nitrogen was applied additionally, yield of barley aboveground biomass was increased only in connection with a lower P-dose: 896 (N0P0) - 1622 (N0P1) - 1390 (N0P2) g DM/m^2.

CONCLUSIONS

Obtained results showed, that the application of water-soluble phosphorus forms in soils can significantly increase P content in soils with lower phosphorus supply including moving to higher categories of supply (good – high). Adequate amount of available phosphorus in soils increases nutrients utilization efficiency, which is reflected in higher yield of biomass.

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