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PHOSPHORUS AVAILABILITY AND SPRING BARLEY YIELDS UNDER GRADED P-DOSES IN A POT EXPERIMENT

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Abstract

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The pot experiment with graded P doses was carried out in 2015 and 2016 in the Crop Research Institute, Prague–Ruzyně (undermentioned CRI). Three soil types were chosen for the experiment–Chernozem, Cambisol, Haplic Luvisol. The soils were treated by graded P doses (0.3–0.6–1.2 g P/5 kg of soil). The soil without any treatment served as a control. The spring barley (variety KWS Irina) was grown up to the milky ripeness stage. Plants were regularly watered with the deionised water. Two-year results of experiments showed that the increase of spring barley dry matter was noted under graded P doses particularly in the year 2015, whereas in the year 2016 the plant growth despite to increasing trends generaly was not significant. The P-uptake by plants increased in correspondence to graded P doses and correlated with the P contents in soils determined by Mehlich 3 and NH_4-acetate soil tests. The proportion of readily available P-NH_4-acetate fractions increased in Chernozem and Luvisol in comparison with total available P-Mehlich 3 fractions under graded P doses. No evident increase of P-NH_4-acetate fractions was obtained in Cambisol having the lowest CEC from all tested soils. The correlations between P content in plants of spring barley, P-uptake and phosphorus determined by Mehlich 3 and NH_4-acetate methods, with exception of relationship between P-barley and Mehlich 3, showed significant positive relationships. The highly positive relationship between P-Mehlich 3 and NH_4-acetate methods indicating the suitability of both tests to predict phosphorus supply in soils.

Keywords: fertilization, barley, phosphorus, supply, soil tests

INTRODUCTION

Phosphorus (P) belongs among basic macronutriens which affect the level and quality of crop yields and it can limit considerably the agricultural production in most regions of the world (Holford, 1997). Therefore, the sufficient phosphorus supply is necessary for appropriate growth of agricultural crops. Despite to the fact that positive effects on the growth and maturation of plants were reported many times (i.e. Davies *et al.*, 2011; Usherwood and Segars, 2001), the enormous decrease of phosphorus fertilization related to the political transformation was noted in the Czech Republic after 1989. In 80', the medium phosphorus doses applied in the field were between 29–33 kg P/ha, after that they dropped to about 6 kg P/ha in 2014 (Čermák *et al.*, 2014). Consequently, the substantional deficiency and decrease of phosphorus content in soils was already noted in the Czech Republic and in can have adverse effects on crop yields. In fact, Rowe and Johnson (1995) or Hoppo *et al.* (1999) showed that phosphorus defficiency can reduce yields of barley. Therefore, it can be assumed that reestablishing of soil fertilization with phosphorus should increase the crop yields as documented by McKenzie *et al.* (1998) who described that phosphate fertilizer significantly increased barley silage yield at 25 out of 32 site-year locations.

Different soil tests have been used for the determination of phosphorus content in soils. They differ in used extractants and also in extraction procedures and analytical techniques which are all important for the appropriate determination of phosphorus status in soils (Matula, 2010). In addition, phosphorus in soils is divided to different fractions with the different availability for plants (Kulhánek *et al.,* 2009). The soil test indicating the phosphorus supply should be evaluated for the crop needs and should reflect the real phosphorus supply in soils. The actual criteria for phosphorus supply given by Decree No 275/1998 Coll. (subsequently amended) of the Czech Republic are based on Mehlich 3 soil test (Mehlich, 1984). The soil tests are used for the prevention of the potential disorders in the nutrient status of soils before the cultvation of the given crop (Matula, 2009). In addition the Central Institute for Supervising and Testing in Agriculture uses the Mehlich 3 soil test for soil testing through the Czech Republic and indicating of overal nutrient status of soils in the Czech Republic (Čermák *et al.*, 2014).

The aim of the research was: (1) to evaluate effects of graded phosphorus doses on growth (yield) of spring barley, P content in barley plants, P-uptake and on available phosphorus contents in three soils of different types with medium and low phosphorus supply; (2) to study the relationships between phosphorus in plants and soils and to evaluate the suitability of soil tests to predict P supply in soils.

MATERIAL AND METHODS

Pot experiment: The design of the pot experiment was described by Mühlbachová *et al.* (2017). Briefly, the experiment with graded phosphorus doses in soils of three types (Chernozem, Cambisol and Luvisol) was conducted in the outside vegetation hall in the Crop Research Institute (Prague–Ruzyne, Czech Republic) in 2015 and 2016. There were the se average month temperatures during the vegetation period (month 2015/month 2016 in °C): April: 9.0/8.8; May: 13.7/14.8; June: 16.9/18.3. The spring barley (variety KWS Irina) was used in the experiment. Three (graded) phosphorus doses were used for fertilization (0.3 g–0.6 g–1.2 g/pot) and the control without any treatment was used for comparison. 1 g of N (CAN) was added to each pot including control to ensure the right plant growth. The pots were regularly watered with the deionized water up to 60–65 % of max. WHC. 10 barley plants were grown in each pot up to milky ripeness. Thereafter, the plants were harvested, dryied at 65 °C and subsequently grounded to 200 µm. Soils were dryied at room temperature and sieved (< 2mm). The basic characteristics of experimental soils are given in the Tab. I. Fecenko and Ložek (2000) describe an optimum exchangeable soil reaction for barley between 6–7.

Laboratory procedures: The soil pH was determined by use of standard methodology of the Central Institute for Supervision and Soil Testing (Zbíral *et al.*, 2016) with the use of 0.01M $CaCl_2$ in the ratio 1:2.5.

Two extraction procedures were used for determination of available phosphorus content in soils. The first one was the Mehlich 3 soil test (Mehlich, 1984) as a standard method used for agrochemical soil testing was used in the experiment. The second one was the NH_4-acetate test developed by Matula (2007) enabling also the determination

I: *Basic soil characteristics (Mühlbachová et al., 2017)*

				Mehlich 3				
Year	**Soil type**	**CEC**	**pH_{CaCl2}**	**Mg**	**Ca**	**K**	**P**	**Criteria for P supply**
		(mmol NH_4^+/kg)			mg/kg			Decree of CR No. 275/1998
2015								
	Chernozem	203	5.33	256	2,967	231	53	Sufficient
	Cambisol	143	5.74	80	1,806	118	39	Low
	Luvisol	204	6.08	194	3,899	195	78	Sufficient
2016								
	Chernozem	234	6.21	256	3,905	179	57	Sufficient
	Cambisol	130	5.12	83	1,293	110	62	Sufficient
	Luvisol	205	6.67	189	3,492	197	53	Sufficient

of cation exchange capacity of soils (CEC). Plant samples were prepared for determination of phosphorus by digestion in concentrated nitric acid with hydrogen peroxid and using the Milestone 1200 (Connecticut, USA) microwave.

The phosphorus in plant and soil samples was determined by ICP-OES Thermo Jarrel Ash (Nebraska, USA). The phosphorus uptake was calculated from the obtained yields and the P-contents in the spring barley.

Statistical analysis: The Statistica 12.0 software was used for analysing of the significant differences among the treatments using the one-way ANOVA and Tukey's test. The different letters given in figures represent statistical differences. The correlation coefficients (r) based on Spearman's equation were calculated and the ir significance at levels $p \leq 0.05$, 0.01 and 0.001 were determined.

RESULTS AND DISCUSSION

Dry matter yield of spring barley

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. The net dry matter yield of the spring barley from our experiments is given in Fig. 1. The significant increase of dry matter yield of barley was observed in the year 2015 for Cambisol and Luvisol and in the year 2016 for Cambisol. Lošák *et al.* (2016) found out, that on haplic luvisol phosphorus fertilisation was not seen at all, demonstrating that the weight of the spring barley biomass in all the treatments was balanced (48.12–49.63 g per pot). The increase of barley weight in Chernozem (Fig. 1) was possible to see in the year 2015 (partial results with this soil type were published–Mühlbachová *et al.*, 2016) , however no significant difference was observed. No significant increase of barley yield in Chernozem soil was found also in 2016. On the contrary Lošák *et al.* (2016) describe that dry matter yields of the spring barley aboveground biomass grown on chernozem were the lowest in the control treatment not fertilised with P (38.97 g per pot) and increased significantly with the P rate applied (46.02–47.28 g per pot), although the re were no significant differences among the fertilised treatments. The Chernozem soils belong among the most fertile soils, here it has higher nutrient contents (with exception of P) and higher CEC giving the overal idea about the nutrient availability for plants. In addition also, content of othe r nutrients was higher in Chernozem soil in comparison with Cambisol or Luvisol. Therefore a buffering effect of other nutrients and field characteristics (particularly CEC) could play an important role in plant growth. From this point of view, it is not surprising that the barley growth in relatively less fertile Cambisol soil, posessing the lowest CEC, responded the best of all soils to phosphorus treatments. In 2015, the highest increase of yielded barley biomass was noted at the lowest P dose (5.4% for Chernozem, 47.9% for Cambisol and 23.6% for Luvisol) and increased only slightly with graded P doses (up to 11.6%, 52.7% and 24.1% for Chernozem, Cambisol and Luvisol). In 2016, no increase of barley dry matter yield was observed in Chernozem in 2016, and only slight and non significant increase was noted in Luvisol (max 5%). The maximum increase of barley dry matter yield in 2016 in Cambisol soil was about 11%. Prystupa *et al.* (2004) describe in container experiments with phosphorus (doses 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.

P content in aboveground biomass and P-uptake

Phosphorus treatments increased the P concentrations in barley plants (Fig. 2a). The highest contents in barley tissues were in both years 2015 and 2016 found in plants grown on Chernozem soil having evidently more capacity to release phosphorus to plants. However, the relative increase of P concentrations in barley tissues following the increasing P-rates grown on Chernozem soil were in both years (2015 and 2016) lower (max 75% in 2015 and 35% in 2016) in comparison with phosphorus found in plants grown on Cambisol (104% in 2015 and 50% in 2016) and particularly Luvisol (123% in 2015 and 131% in 2016) in relevant P-treatments. Mohammad *et al.* (2003) describe, that the addition of P (in saline soils as triple superphosphate) increased the P concentration in the barley plants of the non mycorrhizal plants to as high as that of the mycorrhizal plants.

The P-uptake by spring barley (Fig. 2b) increased in all soils in correspondence with the P dose. The differences were found between two years of the experiment. The P-uptake in Chernozem soils was higher in the year 2015 in comparison with the year 2016 where the maximum P-uptake was about 25% in comparison with the year 2015 when the maximum P-uptake achieved 96%. Similarly, the P-uptake from Cambisol soil in 2016 was affected by lower increase of barley growth and maximum P-uptake achieved 44% in comparison with 211% achieved in 2015 under the highest P-treatment. On difference of P-uptake found in Chernozem and Cambisol soils, the P-uptake in Luvisol was only slightly lower in the year 2016 and increased up to 140% in comparison with 177% in 2015.

The phosphorus content in soils

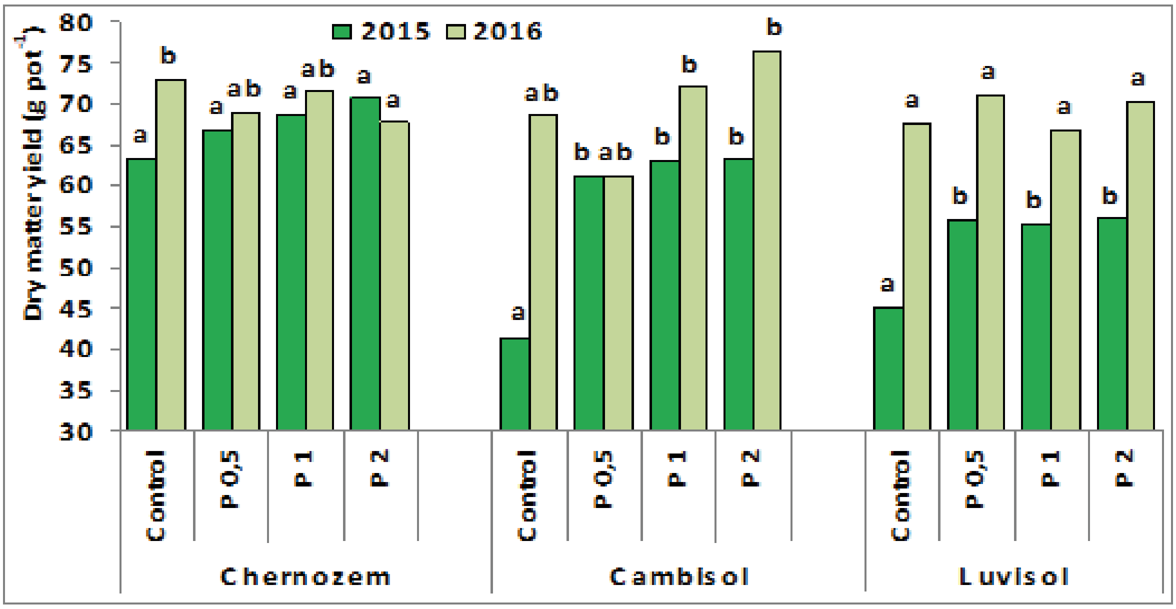
Inorganic phosphorus enters in the soil solution by mineralization or fertilizer additions (Sanchez, 2007). It was reported several times that the systematic phosphorus fertilization increases the plant extractable soil phosphorus content (Lásztity and Csathó, 1995; Blake *et al.*, 2000). On the contrary, 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). Different responses on phosphorus treatments were obtained for our two soil tests. The phosphorus content in soils determined by Mehlich 3 test increased with the graded P doses in all soils and in both years 2015 and 2016 (Fig. 3). The P content determined by Mehlich 3 test increased in studied soils in both years 2015 and 2016 of about 100%, only in 2015 the 147% increase of P-content was observed in Luvisol. The differences of P content in 2015 and 2016 determined by Mehlich 3 method were observed. The Chernozem and Luvisol achieved in all treatments higher P contents in 2016, whereas, lower P-contents were obtained in Cambisol in 2016 in comparison with the year 2015. Lošák *et al.* (2016) found out similar results, because the content of postharvest (spring barley) soil phosphorus increased significantly with the applied rates (96–141–210 mg/kg in chernozem and 128–179–277 mg/kg in haplic luvisol). McKenzie *et al.* (1998) describe, that phosphorus fertilizer is essential for optimum production, especially when soil test levels are low.

Soil exchangeable P increased in correspondence to the dose of added P. However, the results of exchangeable P determined by NH_4-acetate shoved such a different trend from Mehlich 3 test, particularly in highest P2 treatments. The highest increase of P contents was, similarly to Mehlich 3 found in the P2 treatment, but the percentage was higher reaching the maximum increase of 172%, 126% and 218% for Chernozem, Cambisol and Luvisol in 2015 and 127%, 126% and 218% in 2016 in the same soils. Soil exchangeable P at the highest P dose reached similar values for the relevant soils in both studied years 2015 and 2016 suggesting that there could exist the limits in saturation of soil solution in studied soils. Only in Chernozem soil, the highest P-NH_4 acetate was lower in 2016.

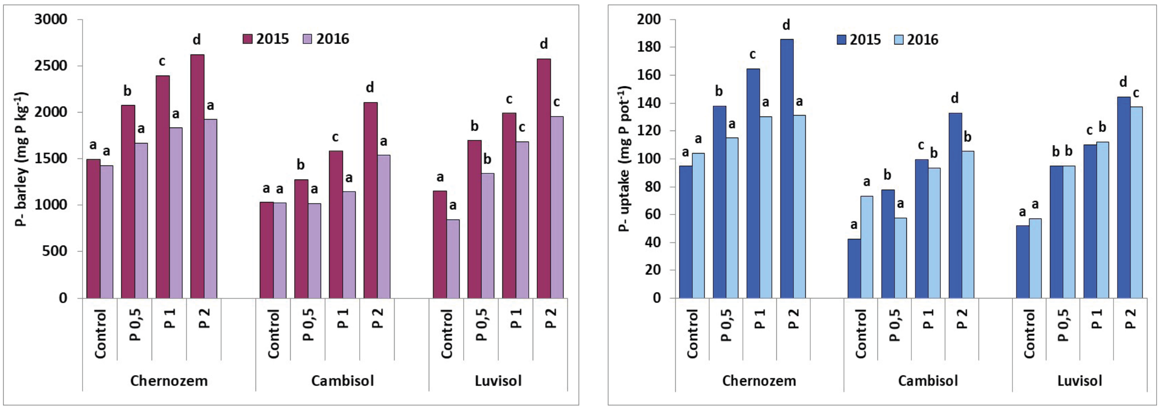
Generally, the P concentrations obtained by NH_4-acetate achieved from 9% of Mehlich 3 P content in Luvisol to 24% in Cambisol in control treatments without phosphorus additions. This percentage increased in correspondence with the increasing P added into soils up to 17–21% in Chernozem and Luvisol indicating that more labile phosphorus fractions were present in Chernozem and Luvisol when high P rates were applied. The different trend was found for Cambisol, where this percentage oscilated between 22–24% in 2015 and 15–8% and did not show any clear increasing trend. The different phosphorus fractions having also different availability for plants is possible to find in soils (Kulhánek *et al.,* 2009). The case of the studied soils showed that possibly more fertile soils (Chernozem and Luvisol) were able to conservate more phosphorus added in fertilizer in the soil possibly due to higher cation exchange capacity, whereas phosphorus in less fertile Cambisol remained more labile and was more easily taken by plants as showed also the data of P-uptake in this soil. The availability of phosphorus depends on many factors of the capacity of sorption complex to bind phosphorus, soil pH and other factors. In fact, also after 23 years of soil fertilization with phosphorus Takahashi and Anwar (2007) found only a modest increase of soil available P despite to an increase of total mineral phosphorus. In addition Káš *et al.* (2016) showed that exchangeable P fractions decreased more rapidly under nitrogen fertilization than total bioavailable P determined by Mehlich 3 method. The medium CEC of studied soils is given in the Tab. 1 and was the lowest in Cambisol which can be the reason why the exchangeable phosphorus fractions did not increase in this soil with increasing P rates. Possibly the Cambisol reached such an equilibrium in its sorption complex where no more exchangeable phosphorus fractions could be sorbed on exchangeable places.

Correlations between P content in barley plants, P- uptake and P in soils.

The correlations between phosphorus content in barley, P-uptake and Mehlich 3 or P-NH_4 acetate is shown in Fig.s 4–6. A positive correlation was found between content of P in barley biomass and P-uptake ($R^2 = 0.828$, $r = 0.910$, $P \leq 0.001$), (Fig. 4a). No significant correlation was obtained between P-barley content and P-Mehlich 3 (Fig. 5a) indicating that the phosphorus uptake in plants did not respond directly to the phosphorus content in Mehlich 3 test. However, good correlation ($R^2 = 0.365$, $r = 0.597$, $P \leq 0.001$) was obtained between P-uptake and Mehlich 3 (Fig. 5b) indicating that the phosphorus uptake by plants is more indicative for Mehlich 3 test. The exchangeable phosphorus was extracted by NH_4-acetate and the significant positive correlations were obtained for both–P-barley (Fig. 6a) and also for P-uptake (Fig. 6b) and P-NH_4 acetate content in soils ($R^2 = 0.3815$, $r = 0.618$, $P \leq 0.001$; $R^2 = 0.3594$, $r = 0.599$, $P \leq 0.001$). The NH_4-acetate extractant indicates the readily available and the refore more vulnerable soil fractions in terms of the ir relatively easy uptake from soil as it was shown by Káš *et al.* (2016). Therefore also in this case it is probable that these P- NH_4 acetate fractions can respond more rapidly to P-supply and the refore it was more easy to achieve correlation also between P-barley and P-NH_4 acetate. However, the correlation found between Mehlich 3 and NH_4-acetate tests (Fig 7, $R^2 = 0.6065$, $r = 0.779$, $P \leq 0.001$) showed that the re-exist clear relationship between these soils tests and that they can be used for soil testing.

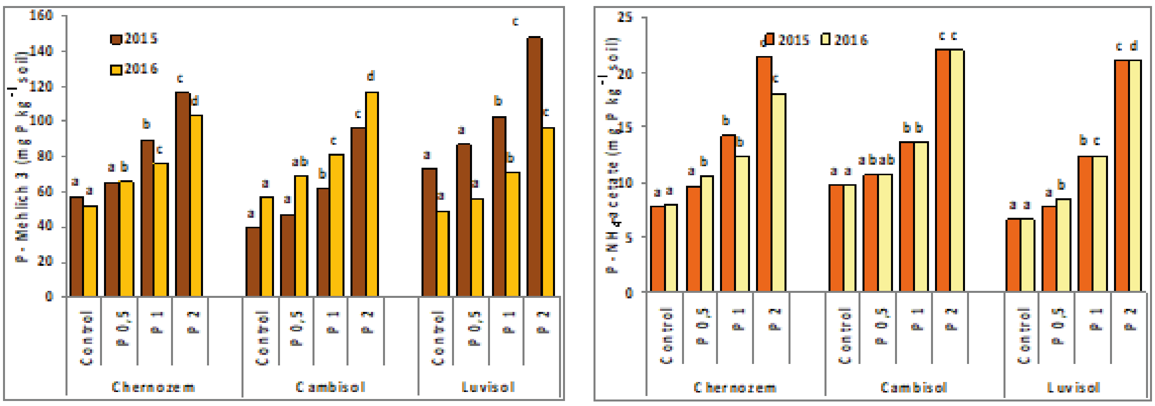


1: *The yield of spring barley above ground biomass (g DM pot*$^{-1}$*)*



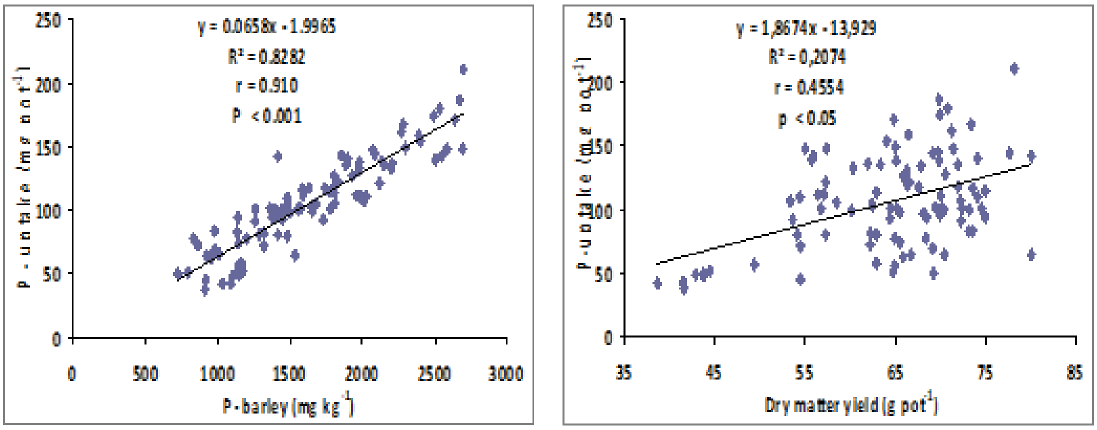
a) b)

2: *The phosphorus content in aboveground spring barley biomass (a) and P-uptake by plants (b)*



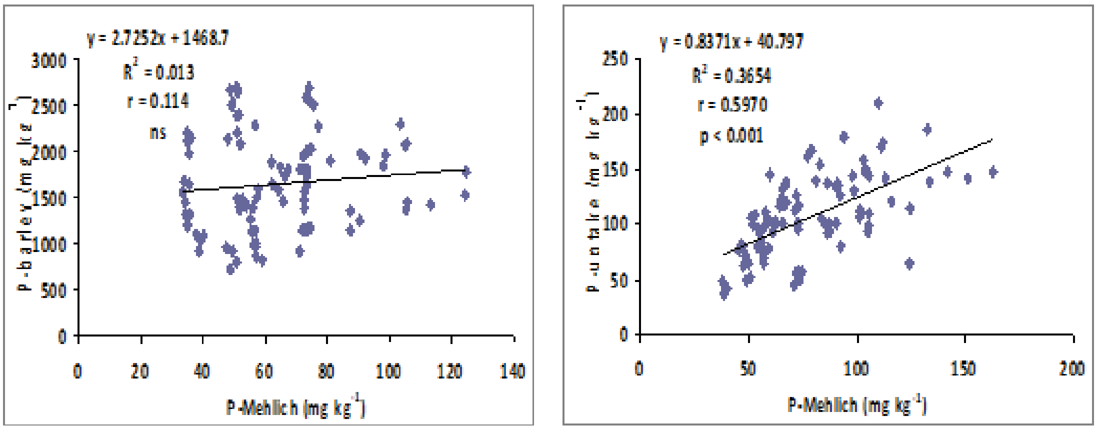
a) b)

3: *P content in soils determined by Mehlich 3 (a) and NH4-acetate tests (b)*



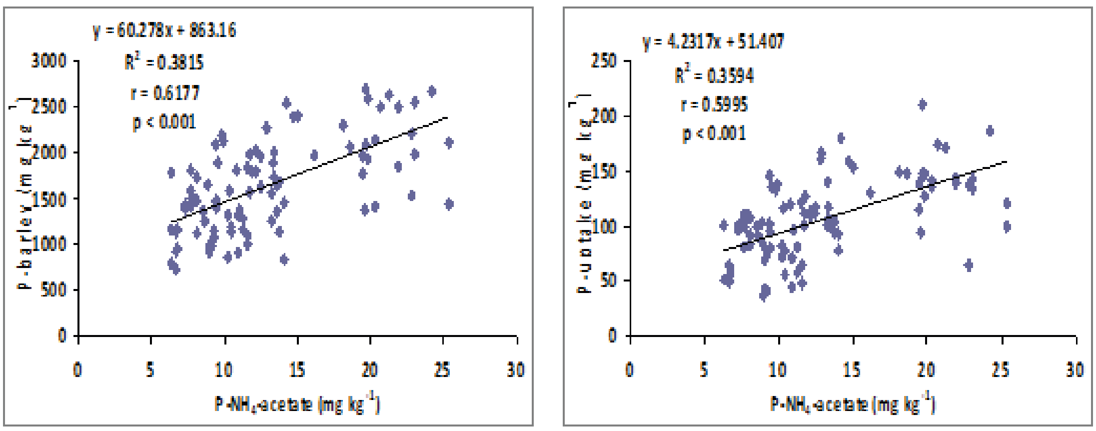
a) b)

4: *Correlation between phosphorus content in spring barley and P-uptake (a) and P-uptake and dry matter yield (b)*



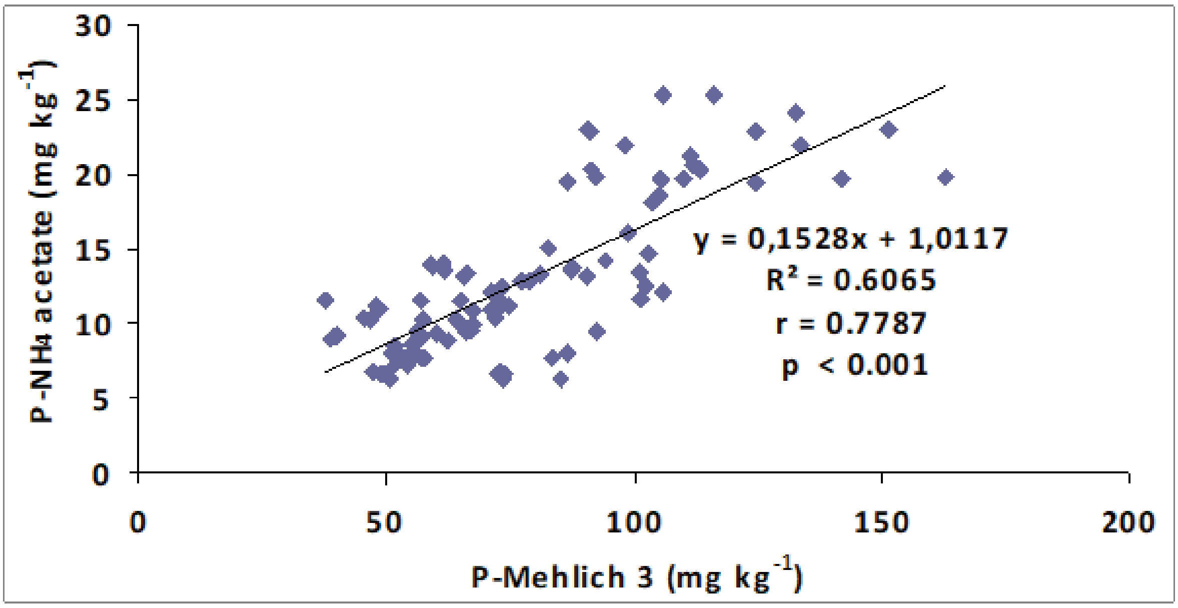
a) b)

5: *Correlation between P-Mehlich 3 in soils and P in spring barley (a) and P-uptake (b)*



a) b)

6: *Correlation between P-NH4 acetate in soils and P in spring barley (a) and P-uptake (b)*



7: *Correlation between P-Mehlich 3 and P-NH4 acetate soil tests*

CONCLUSION

The spring barley yields corresponded to graded P doses particularly during the year 2015 and the highest yield increase was noted at the lowest P dose and stagnation in yields was noted at higher P doses, lower increase of barley dry matter yield was noted in 2016. The phosphorus content in tissues of spring barley and P-uptake by plants increased in proportion of increasing P rates. However, plants in each studied soil had its own dynamics of phosphorus uptake. No significant correlation was found for phosphorus in barley plants and Mehlich 3 test indicating that not all P extracted by Mehlich 3 was directly taken by plants. Significant correlation was found between P-barley and P-NH_4 acetate representing easily available phosphorus fractions. The P-uptake by barley corresponded well to Mehlich 3 and NH_4-acetate soil tests. Positive correlations were found betweem both soil tests and indicated that both tests are suitable for soil testing. NH_4-acetate test showed that the re probably exist limits of saturation of soil solution by phosphorus.

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