0.01 M $CaCl_2$ EXTRACTED PHOSPHORUS IN THE SOILS OF HUNGARIAN LONG-TERM FERTILIZATION TRIAL NETWORK AND ITS CORRELATION WITH WINTER WHEAT YIELDS

Lazányi János*, Loch Jakab*

* University of Debrecen, Centre for Agricultural and Applied Economic Sciences, Hungary

Abstract

One of the most important nutrients for plant production is phosphorus (P), but in the European Union, agricultural runoff is considered to be a primary source of phosphorus pollution as many point sources are largely under control and high concentrations of P may occur in runoff from agricultural fields. In many regions of European Union, through years of fertilizer and manure management, phosphorus has built up in the surface soil to levels far exceeding the requirements for plant production. Rainstorms and subsequent runoff events transport dissolved phosphorus to waterways. Phosphorus is indispensable for crop production and economically viable yields. In Hungary, a sharp decline in livestock numbers and in the use of mineral P fertilisers occurred in the early 1990's and P balances become close to zero or even negative.

The aim of this study was to compare ammonium lactate - acetic acid extraction method (AL-P) (Egner et al., 1960), which is widely used by extension service in Hungary and the 0.01M $CaCl_2$ extraction (Houba et al., 1986), which is used to evaluate phosphorus loads in surface waters to optimize the phosphorus fertilizer recommendations. Through 28 years of fertilizer management practices P fertilization significantly increased the amount of P in the soils of the Hungarian Fertilization Trial Network. The relationship between the crop yield and P content of soil were studied at the experimental sites and a close correlation was found between the 0.01 M $CaCl_2$ and ammonium lactate acetic acid extractable P contents of soils. The 0.01 M $CaCl_2$ extraction methods can be used to optimize the phosphorus fertilizer recommendations and study P diffuse contamination of agricultural land.

Key words: phosphorus (P), ammonium lactate- acetic acid (AL) extraction, calcium chloride ($CaCl_2$) extraction, wheat yield, Hungarian Fertilization Trial Network.

INTRODUCTION

Phosphorus is often limiting nutrient of biological productivity in surface water and as a result, P inputs to surface water can lead to accelerated eutrophication. According to the final report to the European Commission of Soil Service of Belgium, the contribution of agriculture to the phosphorus loads in surface waters is estimated between 20 % and more than 50 % and includes both point sources (waste water from farms and seepage from manure stores) and diffuse contamination (agricultural land). Due to reductions in the discharge from household and industry sources, the relative contribution from agriculture has risen in recent years, and has reached more than 50 % in areas with intensive agriculture.

In environmental studies, phosphorus is usually measured with procedures that simulate P transfer into solution such as calcium chloride extraction Houba et al. (1991), Houba and Novozamsky (1998). Behaviour of phosphate in soil extracts was also studied by Houba and Temminghoff (1999) using weak unbuffered $CaCl_2$ extracting solutions, while Jászberényi and Loch (1995) studied phosphate adsorption and desorption in 0.01 M calcium chloride electrolyte. The 0.01 M $CaCl_2$ extracted soil P concentration has been used as an indicator of potential P loss. McDowell and Sharpley (2001) proved correlation between field losses and soil phosphorus levels. Tarafdar and Jungk (1987) found increased phosphatase activity in the vicinity of roots coinciding with a decrease of organic phosphorus and an increase of inorganic phosphorus concentration in barley field.

Concentration of organic and inorganic phosphorus in calcium chloride extracts was 7.8 and 1.8 mol/dm^3. When soil microbial biomass was destroyed by autoclaving, organic phosphorus concentration increased to 64.8 mol/dm^3 whereas the inorganic phosphorus was hardly changed. Inoculation of the autoclaved soil with non-sterile soil and incubation for 5 days decreased the organic phosphorus concentration to 27.9 mol/dm^3 but did not change inorganic. In Hungary, farmyard manure application increased 0.01 M ($CaCl_2$) extracted inorganic phosphorus content, but do not resulted evident changes in 0.01 M ($CaCl_2$) extracted organic phosphorus (Lazányi and Loch, 2008). Organic component in each series of 15 crop rotations were higher at 40-60 cm sampling depth.

Mismanagement of fertilizer or manure can lead to P build-up in surface soils and elevate P loss in runoff. Diffuse losses of phosphorus from agricultural territory are a major component of surface water pollution in countries with developed animal husbandry. Water quality survey in Ireland indicate that agriculture can be a significant source of P loss to water, perhaps of the order of 50 % of the total (EPA, 1991- 1994). In Ireland, over 90 % of agricultural land is devoted to grassland. Fertiliser and animal manures are added to the soil surface each year, and most of it tends to accumulate in the soil surface, which can easily become saturated with P. Water can run over or infiltrate through this P enriched surface soil and carry significant amounts of P with it. The quantities lost from fertilised agricultural land is generally very small (1 kg P /ha/year) from an economic viewpoint but increases algae and higher plants production in rivers and lakes where phosphorus is usually the limiting nutrient. When soils were low in phosphorus in their natural state the loss to water is generally was in the order of 0.1 to 0.2 kg P /ha/year or less including water erosion and deflation.

Maximum cumulative total P losses from Broadbalk were 5 kg P ha/year and 2 kg P ha/year at Woburn (Olsen P range about 15 to 150 kg P ha/year) at Rothamsted Experimental Station. At Broom's Barn and Long Ashton, losses were much smaller (less than 0.25 kg P ha/ha/year), reflecting the lower Olsen P concentrations in these soils (5-15 mg P kg soil) (Brookes, 2005). Eutrophication has adverse effects on water quality in terms of organisms that live in water, on the amenity value of water and on the suitability of the water for drinking or industrial use, unless it receives prior treatment.

MATERIAL AND METHODS

The Long-Term Fertilization Trial Network experimental sites established in 1968 offers an excellent possibility to study phosphorus accumulation and loss in Hungary and determine the relationship among soil P test results, phosphorus fertilizer application rate and plant response. In this paper the relationship between the crop yield and ammonium lactate - acetic acid (AL-P) and 0.01M $CaCl_2$ extracted P were studied. Samples were collected from top 0-30 cm soil layer of 9 experimental sites (Bicsérd (BI), Hajdúböszörmény (HA), Iregszemcse (IR), Karcag (KA), Keszthely (KE), Kompolt (KO), Mosonmagyaróvár (MO), Nagyhörcsök (NA), Putnok (PU) representing various ecological and soil conditions of Hungary. Selected NPK treatments include 000, 101, 111, 121, 201, 220, 221, 222, 331, 341, 421, 441, where N and P doze increase with 50-50 kg/ha increments and K doze with 100 kg/ha increments.

The experiment makes it possible to study the phosphorus balance of different treatments. Soil samples were collected in 27th and 28th years of treatment in the Hungarian Fertilization Trial Network in 4 replications. Cropping pattern is winter wheat (Triticum aestivum L.) maize (Zea mays L.) double cropping system in a four-year rotation and yield data were evaluated for a period of 5 years. Phosphorus concentrations were determined using 0.1 M ammonium lactate + 0.2 M acetic acid extraction method (AL-P) (1:20 w/v, at pH = 3.7 ± 0.05; 2 h shaking; EGNER et al., 1960) and 0.01M $CaCl_2$ extraction methods (Houba et al., 1986). The availability of phosphorus and the relationship among soil P test results, phosphorus fertilizer application rate and plant response was studied. Statistical analysis of the experimental data was done by ANOVA and REGRESSION using of SPSS for Windows statistics.

RESULTS AND DISCUSSION

In Hungary, fertiliser recommendation systems are based on ammonium lactate - acetic acid extraction method (AL-P), but the activity of soil laboratories has fallen since 1990. Method for P advice is based mostly empirical field research, carried out under the local agro-ecological conditions. The correlation between the extraction methods varies mainly in function of soil type. According to Bomans et al. (2005) harmonisation of the analysis and advisory methods at European level is not considered to be essential, but a confrontation of methods is desirable in order to make a better assessment of P-fertilisation. Phosphorus uptake and P contents in soils were measured in the topsoil and plant samples taken on nine long-term field experiments with different soil and climatic conditions.

Phosphorus concentrations were determined using traditional ammonium lactate - acetic acid (AL-P) and 0.01M $CaCl_2$ extraction method. The amount of AL-P is between the values of 30-210 mg P_2O_5/kg depending on the treatments and experimental sites (Figure 1). Traditionally, AL-extractable phosphorus has been used by soil testing laboratories to describe the amount of phosphorus in soil available for crop uptake and to determine the probability of crop response to added phosphorus, and thereby fertilizer phosphorus requirements.

The 0.01 M $CaCl_2$ extraction method is used to describe phosphorus in soil or sediment that is available for uptake by algae or macrophytes in surface waters (Beauchemin, Simard, 2000). We used 0.01M $CaCl_2$ extraction method to describe the availability phosphorus to winter wheat. The amount of P ($CaCl_2$) is between ranges between 1-6 mg/kg of soils depending on the treatments and experimental sites (Figure 2). The P ($CaCl_2$) content of soil is low compared to AL-P content. Highest level of P ($CaCl_2$) is 12 mg/kg of soils determined in Hajdúböszörmény (HA) experiment. Both soil test extraction procedures attempt to extract a fraction of P that is accessible to plants, but considering that different plant species growing in the same soil and similar plants growing in different soils, designing a universal soil test to measure plant available P is very difficult or virtually impossible. When the amount of phosphorus applied to the soil exceeds the amount removed by a crop, there is a positive phosphorus balance and phosphorus will accumulate in the soil, except when it is lost.

Once the extracting methods have been selected, it is essential to relate soil test level to crop yield so that a critical level of P can be identified. Correlation analysis was performed and close relationship was obtained for winter wheat yield and ammonium lactate - acetic acid extracted phosphorus (Figure 3). Significant relationships were also found for 0.01M $CaCl_2$ extraction methods (Figure 4). Determination coefficient (R^2) for P ($CaCl_2$) and winter wheat yield was also high. These fractions also correlate well with plant uptake. Figures 1 and 2 show P fertilizer rate response of two different soil test levels repeated over a wide range of soil at the nine experimental sites of Hungarian Long-Term Fertilization Trial

Network. Regression analysis between AL-P and P ($CaCl_2$) also expressed a good linear regression (Figure 5).

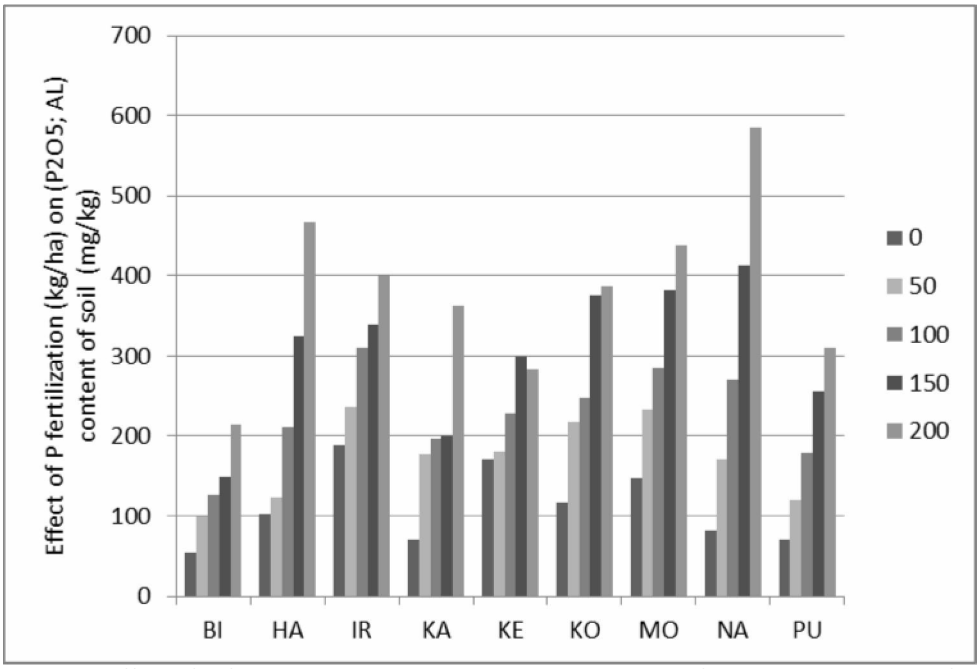


Fig. 1. Effect of P fertilization (kg/ha) on (P_2O_5; AL) content of soil in the treatment of Hungarian Fertilization Trial Network (mg/kg)

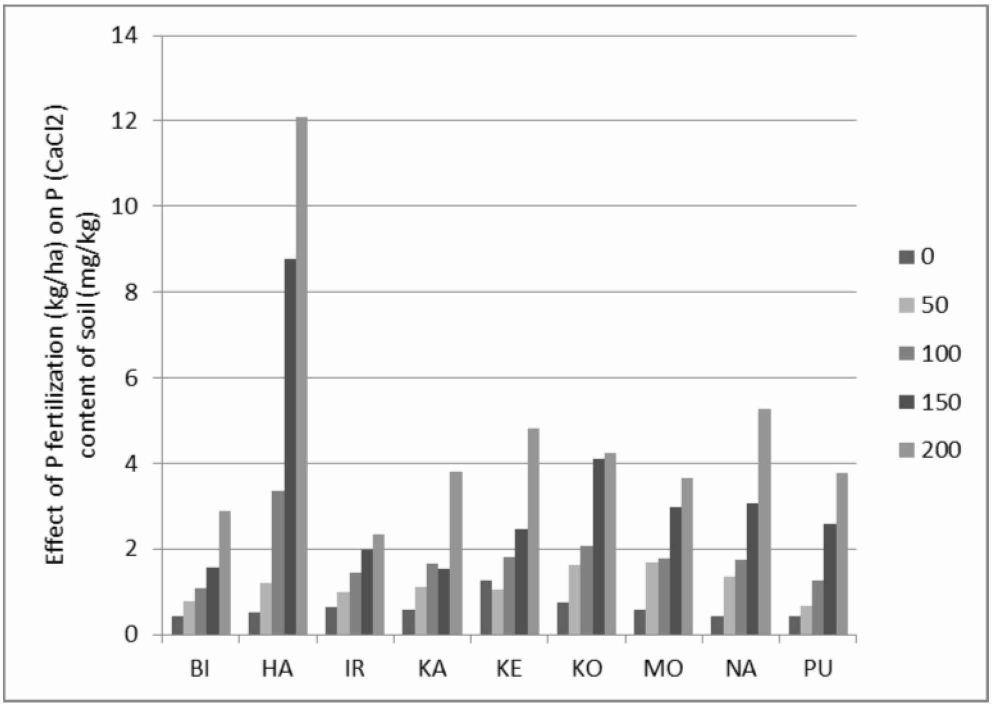


Fig. 2. Effect of P fertilization (kg/ha) on P ($CaCl_2$) content of soil in the treatment of Hungarian Fertilization Trial Network (mg/kg)

Phosphorus is an essential nutrient, which is commonly applied to agricultural fields to increase crop yields. The aim of this work was to compare P ($CaCl_2$) and AL-P content of soil to help site-specific P management as mismanagement of P fertilizer or manure can lead to P build-up in surface soils and elevate P loss in runoff possibly resulting in accelerated eutrophication. The interpretation of the soil P test and the fertilizer P recommendation may be established on Table 3 and 4. Phosphorus is available in soil reserves, fertilisers and/or organic manures. Excessive levels of phosphorus in soil are financially wasteful and likely to cause pollution of surface waters, leading to eutrophication. This causes algal blooms and can destroy aquatic life. In order to plan your use of phosphate fertilisers you need to know: (i) soil indices for phosphorus from soil sampling to lab analysis (ii) target soil indices for phosphorus for the crop (iii) phosphorus application policies and (iv) whether you need to build up or run down the soil phosphorus index.

According to Osztoics et al. (2007) many unfertilised soil in Hungary are low in phosphorus, and this can have adverse effects on plant as phosphorus (with nitrogen) controls primary productivity in most natural cultivated crops. The increased used P fertilisers in the 20th Century resulted in a dramatic increase in crop production. The presence of excess phosphorus in soil increases the risk of leaching process, which could results soil degradation and accelerates the eutrophication in aquatic ecosystems (Bomans et al., 2005). The increased mobility of soil colloids in the presence of high amount of phosphorus is reported to be connected with higher dispersion and instability of soil particles, but it requires further research in Hungary.

Phosphorus is an essential element for plant growth and is also added to animal feed. In the soil, phosphorus is associated with soil particles, exists in different mineral forms mostly as Fe-Al oxides or Ca-carbonates and incorporated in organic matter and dissolved in the soil solution. Phosphorus can move into surface waters, where phosphorus is often found to be the growth-limiting nutrient, and cause water quality problems (Bomans et al., 2005). If excessive amounts of phosphorus enter the water, aquatic plants can grow in large quantities and results eutrophication, if soluble forms of phosphorus in soils are not substituted for less soluble forms by reacting with inorganic or organic compounds of the soil and P becomes immobilized.

Phosphorus is indispensable for crop production and economically viable yields. Phosphorus is supplied to agricultural land by organic manure, slurry and by broadcasting mineral fertilisers. Since phosphorus is not very mobile in the soil solution, most soils contain too little quantities that are readily available for plants and fertilising strategies in many countries aim at building up and maintaining a high soil reserve (Bomans et al., 2005). Trends in developed countries show a growing substitution of mineral fertilisers by manure due to the development of intensive livestock farming. In developing countries, soils are extremely phosphorus deficient and consumption of mineral P fertiliser is still increasing. Phosphorus is indispensable for crop production and economically viable yields in Hungary, where a sharp decline in livestock numbers and in the use of mineral P fertilisers occurred in the early 1990's and low intensity farming account for millions of hectares. P balance of the country is close to zero or even negative.

Eutrophication is one of the greatest challenges facing water quality management in many EU countries, which is generally related to input of nutrients to surface water. Consequently, the control of nutrients, especially P, in surface runoff and leaching (subsurface drainage) is considered as the best way to minimize risk of eutrophication (Bomans et al., 2005). Increased concentration of dissolved P in surface runoff is highly correlated with increased soil test P and soils that contain high levels of P due to excessive fertilization can become a source of eutrophication. The ability to measure phosphorus (P) concentrations in soils is important from both an agricultural and an environmental perspective. One of the purposes of soil testing is to identify soils that would likely have increases in crop yield with additions of P fertilizer. The crop and soil type are widely considered in the fertilizer recommendations as critical soil test level varies depending on crop type and management practices and phosphorus is considered to be the key element of eutrophication.

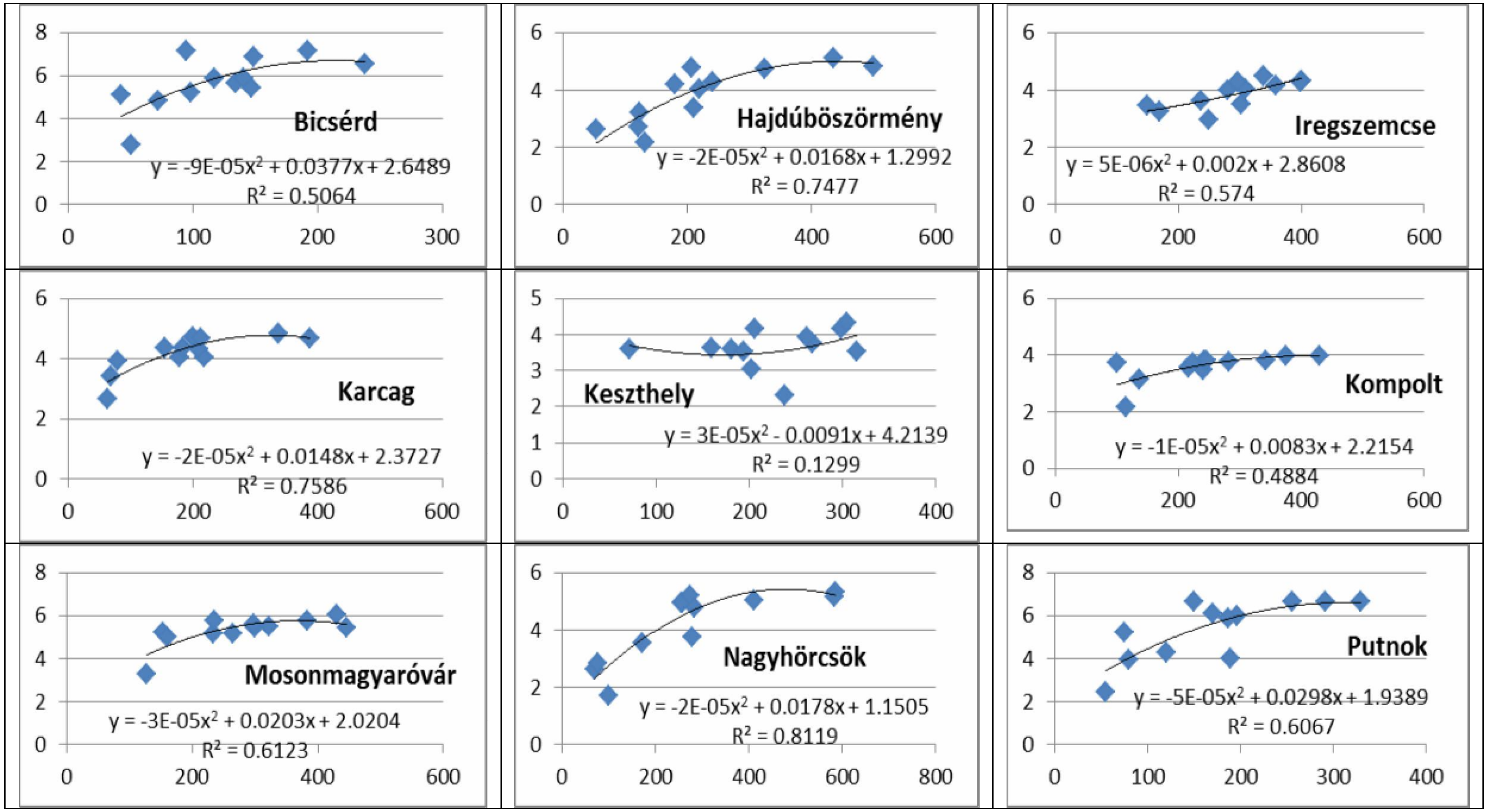
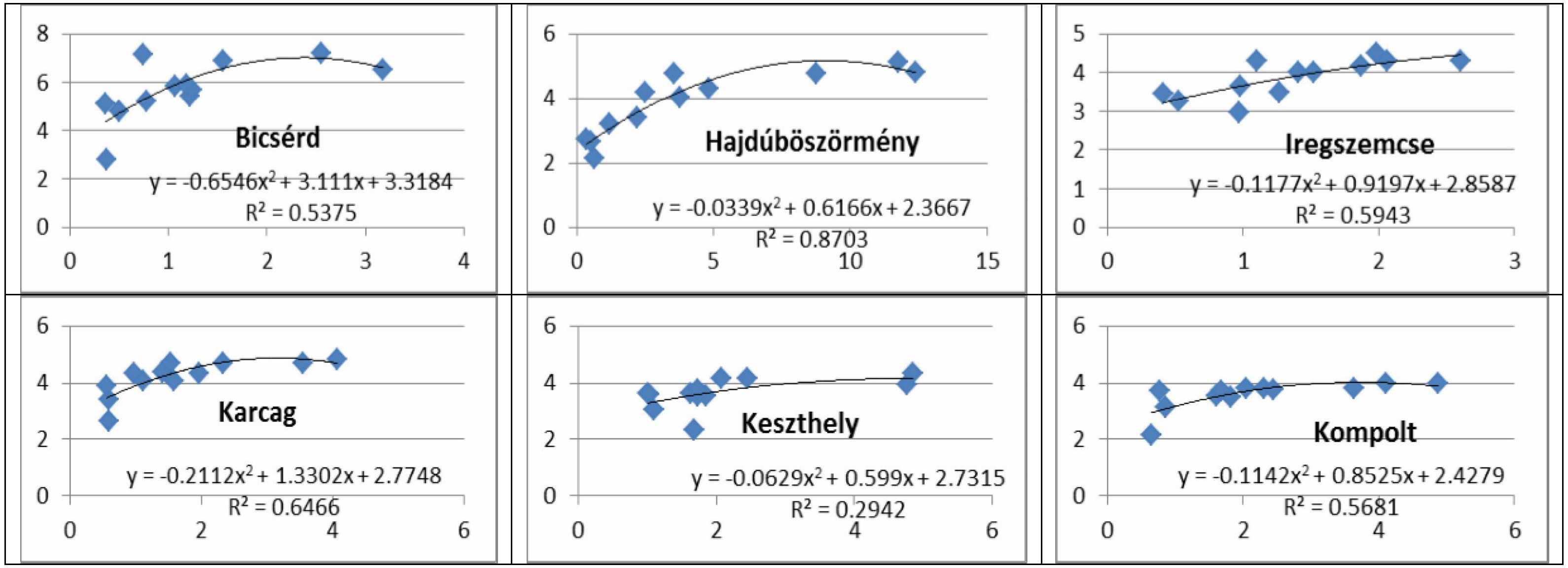


Fig. 3. Relationship between winter wheat yields (t/ha) and P (AL) content of soil (P_2O_5; mg/kg)


Bicsérd
y = -0.6546x² + 3.111x + 3.3184
R² = 0.5375
Hajdúböszörmény
y = -0.0339x² + 0.6166x + 2.3667
R² = 0.8703
Iregszemcse
y = -0.1177x² + 0.9197x + 2.8587
R² = 0.5943
Karcag
y = -0.2112x² + 1.3302x + 2.7748
R² = 0.6466
Keszthely
y = -0.0629x² + 0.599x + 2.7315
R² = 0.2942
Kompolt
y = -0.1142x² + 0.8525x + 2.4279
R² = 0.5681

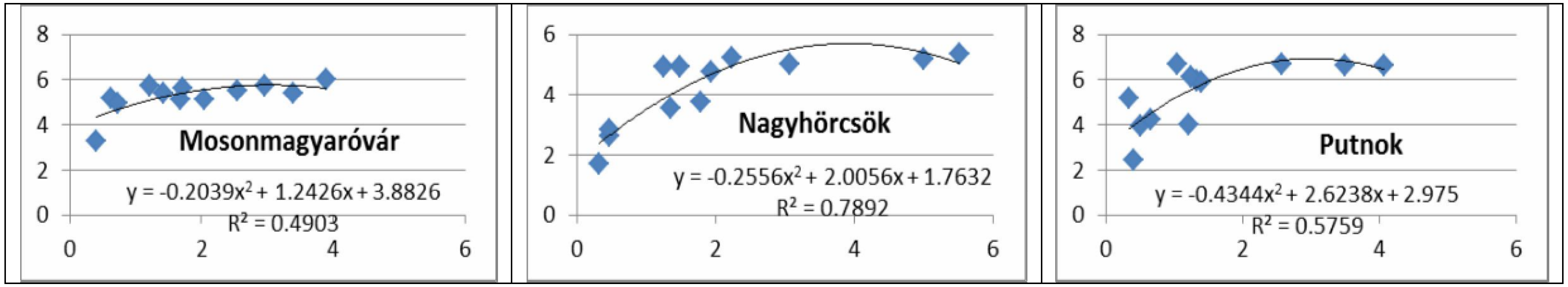


Fig. 4. Relationship between winter wheat yields (t/ha) and P ($CaCl_2$) content of soil (mg/kg)

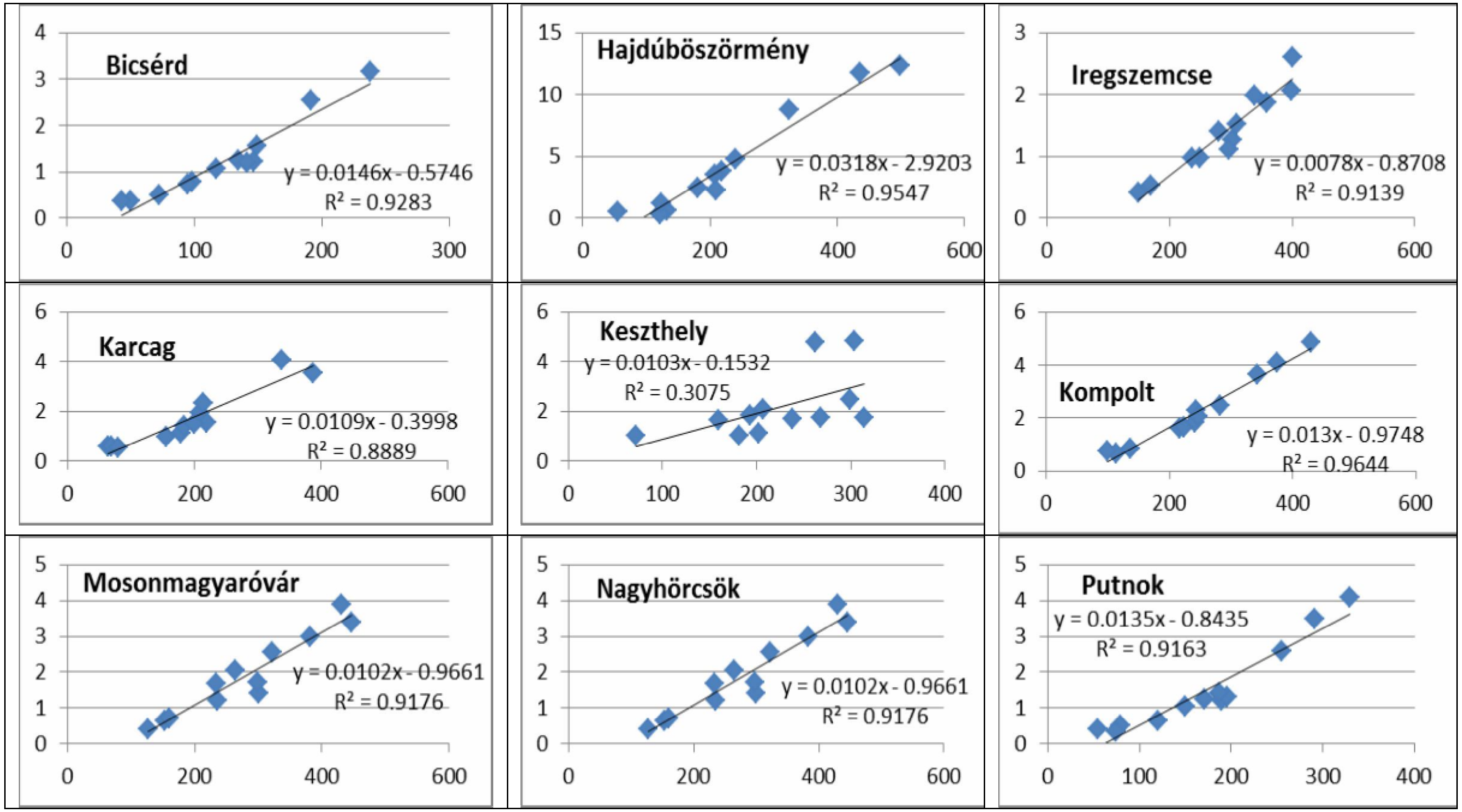


Fig. 5. Relationship between P (AL) (P_2O_5; mg/kg) and P ($CaCl_2$) content of soil (mg/kg)

CONCLUSIONS

Fertilizer recommendations in Hungary are based on soil test and crop response data that have been obtained within region with similar soils, cropping systems, and climatic conditions. The goal of testing AL-P and P ($CaCl_2$) content of soil is to provide farmers with a fertilizer recommendation. Current fertilization practices can be improved if P measured in 0.01 M ($CaCl_2$) extract is taken into consideration. The optimal P ($CaCl_2$) content of soil solution ranges between 2-3 mg P/kg of soils at the experimental sites of the Hungarian Fertilization Trial Network. These fractions should correlate well with P uptake of winter wheat. Over fertilization and elevated 4-6 mg P ($CaCl_2$)/kg of soils generally does not cause agronomic problems, but it might contributes to the high P concentration of surface waters. Continued application of high dosage (150-200 kg/ha) of P fertilizer increases the potential for loss of phosphorus to the environment. It is also demonstrated that the application of P fertilizers or manures will provide an increase in winter wheat yield. Growers can minimize P loss to the environment by growing winter crops to minimize winter runoff and deflation. These practices are particularly important if those fields were slopes generating runoff and deflation can increase the problem of nutrient loss.

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