Improvement of Diagnosis Accuracy of Phosphate Status for Ukrainian Soils

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Through an analysis of the effect of soil properties on the accuracy of the Olsen P soil test, a refined method and interpretive scale for available soil P supply was developed for use in alkaline soils.

Studies performed at the Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky, National Academy of Agrarian Science, Ukraine, show that some chemical methods used for the determination of plant available elements involve large errors. In particular, the error for determining available soil P or K based on former Soviet Union soil testing standards can reach 100 to 200% or more. Most methods include the use of strong acid solutions that can underestimate results for all coarse (sandy and loamy sandy) soils, as well as for strongly acid (pH_{KCl} < 4.5) soils of different textures, and can overestimate results for soils with high contents of primary P-containing apatite minerals.

Presently eight national soil test standards and five standard drafts have been developed for Ukraine's 32 million ha of arable land. The process began with the identification of Ukrainian regions and soil types for which specific chemical methods of determining plant available N, P, and K are most advisable. The potential effects of soil composition and physical properties on the results of chemical analyses were taken into consideration. New scales of soil supply for available P or exchangeable K were developed for some methods that together specify methods for determining plant available N, P, and K for all soils of the country.

The use of State standards, including the Olsen, Machigin, Chirikov, Kirsanov, and Karpinskii–Zamyatina methods (described below), has generally meant that available P status of arable soils under extensive agricultural use fall within the low-to-medium supply levels, while available K status is generally considered medium. This agrees with well-known empirical data that demonstrates high efficiency of mineral fertilizers, especially P fertilizers, on all types of arable soils of Ukraine, including its chernozems. New regulatory soil tests explained below, demonstrate an increase in accuracy of the diagnosis of soil fertility. The subsequent correction of fertilizer application rates, and more rational distribution of fertilizers among fields and crops, can increase use efficiency by an average of 30%.

Errors in soil testing theory and methodology create overestimation (or underestimation) of results for not only individual fields, but also entire regions. An illusion of rich chernozems on loessial rocks is related to the increased content of P-bearing apatites and K-bearing feldspars in these soils. However, P or K present in these minerals are not directly available to plants. At the same time, these elements are partially extracted by strong acid solutions, including 0.02 N HCl (pH 1.0, Kirsanov method) and 0.5 N CH_3COOH (pH 2.5, Chirikov method).

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; KCl = potassium chloride; K_2SO_4 = potassium sulfate; HCl = hydrochloric acid; CH_3COOH = acetic acid.

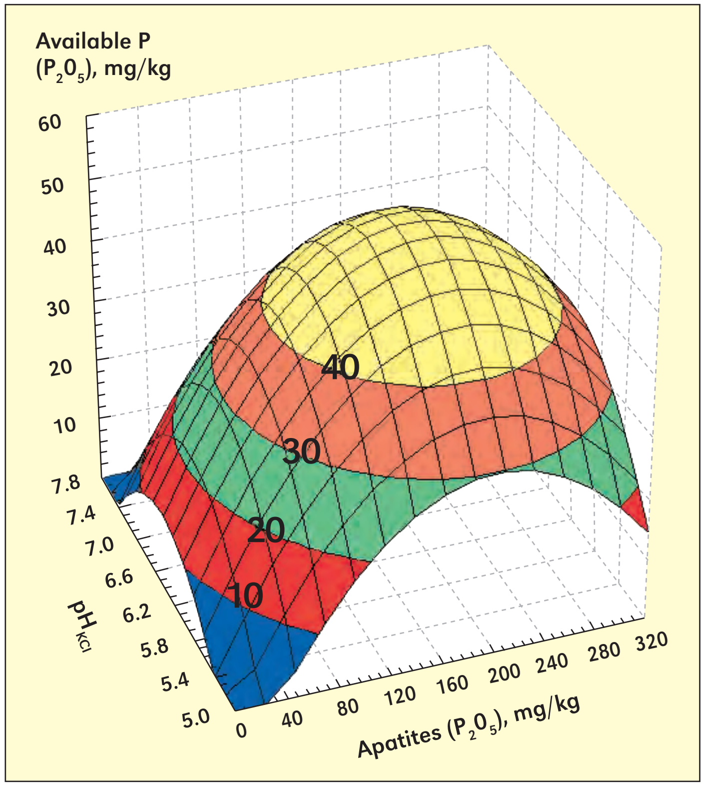

Figure 1. Determination of P in 21 soil samples representing common soil types of Ukraine and Russia by the Egner–Riehm method depending on soil pH and apatite content (Ca-P fraction).

Reported data shows that the unbiased assessment of soil fertility and available forms of macro- and micronutrient is a global challenge.

Shortcomings of the methods based on the use of acid solutions are largely typical for all methods using extractant solutions with pH below 4.5: Bray–Kurtz 2 (pH 1.0), Mehlich 1 (pH 1.2), Arrhenius (pH 2.0), Mehlich 3 (pH 2.5), Mehlich 2 (pH 2.6), Van Lierop (Kelowna, pH 2.7), Egner–Riehm (pH 3.6), Bray–Kurtz 1 (pH 3.5), Egner–Riehm–Domingo (pH 4.2), etc. For example, we found that the determination of P by the Egner–Riehm method in soils with strongly acid or alkaline reaction entails the underestimation of the results (**Figure 1**). An increase in the content of apatite in the soil, on the contrary, overestimates the results. The content of apatite is reflected in the Ca–P fraction (i.e. Chang–Jackson method).

The tendency toward a "decrease" in the content of P in soils with the very high content of apatite (prevalent in the Ukrainian steppes) is related to their alkaline reaction. The

Table 1. The content of plant available P in the main arable soils of Ukraine from the acid, alkaline, and salt methods depending on soil pH and apatite content.

Soil type*	Content of particles <0.01mm, %	pH_{KCl}	P_2O_5, mg/kg: Chang–Jackson, Ca–P fraction	P_2O_5, mg/kg: Chirikov, pH 2.5	P_2O_5, mg/kg: Olsen, pH 8.5
Albeluvisols Umbric	9	4.5	34	34.0	19.6
Albeluvisols Umbric	18	4.9	75	35.0	19.8
Cambisols Eutric	32	3.8	45	1.9	20.7
Phaeozems Albic	48	3.8	104	2.1	20.9
Chernozems Luvic	32	5.4	118	10.0	19.8
Chernozems Calcic	56	6.8	201	79.9	19.5
Chernozems Calcic	54	6.7	244	80.0	20.0
Chernozems Chernic	48	6.0	273	132.0	25.2
Chernozems Chernic	55	6.4	297	161.0	25.6
Chernozems Calcic	60	6.9	326	170.0	24.5
Mollic Gleysols	27	6.6	806	345.1	30.3

*according to the World Reference Base for Soil Resources (WRB) nomenclature

Table 2. Assessment of P supply in Chernic Chernozem soil with chemical and biological methods used in a pot study.

Soil texture	Field experimental treatment*	P_2O_5, mg/kg: Ion-exchange chromatography	P_2O_5, mg/kg: Olsen	P_2O_5, mg/kg: Karpinskii–Zamyatina (DSTU† 4729)	P_2O_5 in oat biomass, %
Clay loam	Control	20.0	19.1	0.31	0.52±0.09
	$P_{1,200}$**	58.9	52.9	1.75	0.70±0.09
Loam	Control	31.0	24.0	0.44	0.58±0.11
	$N_{400}P_{400}K_{480}$***	119.1	124.9	5.84	0.81±0.11

*Fertilizer treatment for the field from which soil was collected for use in the greenhouse pot study; subscripts indicate kg/ha on oxide basis.
**A single application of P with no cropping prior to sample collection.
***A long-term study where the indicated rates were the average application for one 5-year rotation with the experiment conducted for 11 rotations (total fertilizer applied was 11 times the rates shown).
†Denotes National Soil Test Standard

authors evaluated this through a combination of methods based on different principles: chemical methods, ion-exchange chromatography, and pot studies. A statistical analysis of data from an automated information data bank (more than 1,500 soil samples) was also performed. On the basis of these studies, a conclusion was drawn about the advisability of the wide use of so-called "mild" methods (based on the use of salt and weakly alkaline extractant solutions). A 30-year-long comparative study of different methods showed the superiority of the method based on the use of a sodium bicarbonate solution (Olsen et al., 1954). It was found that the particle-size distribution and other soil properties (e.g. presence of apatite, acid reaction) had almost no effect on the Olsen method's results. The coefficient of correlation was r < 0.33.

The content of available P in the Ukraine's unfertilized and underfertilized soils, as determined by the acid method, can vary from very low to very high values of P supply (**Table 1**). According to the Olsen method, Ukrainian soils always are within the low-to-medium P supply range. Data obtained by the Olsen method for acid and neutral soils always agree with the soil fertility estimated using other mild methods. The adequacy of the P status estimation was also confirmed by pot study (**Table 2**).

The Olsen-P method has wide applicability across Ukrainian soils: from acid Cambisols Gleyic and Albeluvisols Umbric to Chernozems Calcic and Kastanozems Haplic. In comparison, the scope of the Chirikov method is significantly smaller–only recommended for podzolized soils (Albeluvisols Umbric, Phaeozems Albic, Chernozem Luvic). Although the Olsen method is primarily designed for the analysis of alkaline soils, its use for these soils could result in the underestimation of P supply. The higher the soil alkalinity, the lower the result (**Figure 2**). As a result, the general opinion is that alkaline soils are poorly supplied with available P. The parallel use of salt solutions (Karpinskii–Zamyatina, 0.03 N K_2SO_4 with pH 5.8; Schofield) shows that no actual decrease in available P occurs in alkaline soils. Thus, the disappearance of P is an illusion related to a limitation of the method as an alkaline extract loses its extraction capacity under alkaline conditions. The maximum underestimation is about 18 mg P_2O_5/kg—a value equivalent to the effect of a single application of at least 600 kg P_2O_5/ha in a heavy soil.

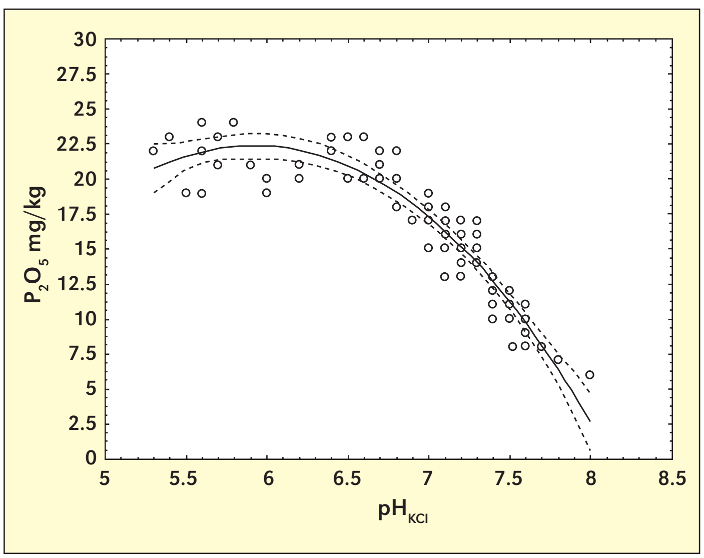

Figure 2. Results of the determination of available P by the Olsen method depending on soil pH.

Rigorous application of soil test protocols lose their value given a lack of official nutrient sufficiency ranges in terms of plant available P supply. The P status of soil cannot be impartially assessed without adequate nutrient sufficiency ranges. Available literature data are contradictory (**Table 3**). Studies performed at the Institute for Soil Science and Agrochemistry Research reveal that the P sufficiency ranges estimated by the Olsen method in accordance with the P sufficiency ranges developed earlier (Yanishevskii, 1996; Agrochemical methods of soil examination, 1975) do not usually agree with the values obtained by other alkaline and salt methods.

Table 3. Soil supply with plant available phosphorus as determined by the Olsen method.

	Soil test P_2O_5, mg/kg		
Phosphorus sufficiency ranges	Yanishevskii, 1996	Agrochemical methods of Soil Examination, 1975	Proposed ranges
Low	< 11	< 25	< 18
Medium	11-23	25-50	19-34
Increased	23-41	50-90	35-50
High	> 41	> 90	51-66
Very high	-	-	> 67

The authors propose refined P sufficiency ranges, as determined by the Olsen method, which now coincide with estimates of soil P supply from other mild chemical methods (Machigin, pH 9.0; Chang–Jackson, Al–P fraction, pH 8.5; Karpinskii–Zamyatina, pH 5.8). A category of very high supply was also added in hopes of further contributing to the more rational use of the resources available. Optimum plant available P for stable, high crop yields lies within the range corresponding to high P supply. An increase above the optimum level results in an abrupt decrease in crop response to P fertilizer. Liberal application of P fertilizers to highly alkaline soils is also unadvisable as high alkalinity (pH_{KCl} 8.0 or pH_{water} 8.5 and higher) is frequently due not only to the presence of calcium carbonates, but also to the presence of Na. The latter compound is detrimental to the growth and development of many agricultural crops, which abruptly decreases the efficiency of fertilizers applied.

Mathematical models and the corresponding software were developed by the authors for the determination of the actual supply of alkaline soils with available P depending on the pH_{KCl} or pH_{water} values (Khristenko, 2009). The use of these mathematical models or software, as well as the improved scale for soil P supply, will contribute to the optimization of fertilizing systems and, hence, expenditures per ha of fertilized area. For example, finding that the supply of soil P is 25 mg P_2O_5/kg (medium P supply) rather than 5 mg P_2O_5/kg (low P supply), the farmer can significantly reduce fertilizer application without fear of crop yield reductions. BC

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