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SOIL SOLUTION IS A KEY FACTOR OF SOIL NUTRITION

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Abstract

It is highlighted the dynamics features and the importance of soil solution in plant nutrition in the main genetically contrasted soil kinds of Ukraine. It is shown that soil solution is the most sensitive indicator of plant nutrition and changes in reaction and in concentration of nutrient elements in it make quick impact on plant growth. Optimal concentration of phosphorus and potassium ions in soil solution was revealed in set of vegetation experiments with oat and barley. Soils with high buffer mobilization capacity can compensate the deficit of a large part of these ions while mineral nutrition of plants is ongoing. In contrast, soil solution becomes poor on biogenic elements in soils with low buffer capacity. Processes of immobilization and mobilization of biogenic elements are regulated by bio-organo-mineral complex, which specifies a dynamics pattern of the fertility element concentration in soil solution. This pattern is described by buffer curve in relation to the curve of bufferless substrate. The more distance between these curves the higher buffer capacity in investigated soil.

Key words*: buffer ability, models of fertility.*

INTRODUCTION

Due to a wide range of scientific works (Gynzburg, 1975; Kanunnikova et al., 1981; Khristenko, 2016; Paul et al., 2010) it was proved that diagnostics and agroecological assessment of soil nutrient regime only by the level content of mobile forms of biogenic elements at the moment of measurement is not enough. Therefore, there is a necessity to determine a criteria for functional diagnostics, which would take into account the dynamics of the concentration (activity) of the most accessible forms of the main plant nutrients in soil ("intensity factor" - IF).

There are many different methodological approaches and techniques for the diagnostics of nutrient regime. However, a close correlation between the content of mobile forms of nutrients in soils and yield, as a rule, was not observed (Nay et al., 1980; Khristenko, 2016). Low correlation or its absence is caused by not only the antagonism-synergism between nutrients in soil solution during the process of water-mineral nutrition of plants (Fateyev et al., 2020), but also by the functioning of soil processes of natural regulation - natural and acquired soil ability to place and maintain the IF value at a constant level. This ability is considered (Truskavetsky, 2003; Truskavetsky et al., 2016) one of the most important factors that determine the soil conditions for mineral nutrition of plants.

The patterns of IF changes are reflected by the buffer curve, the shape of which depends on the functioning of soil mechanisms of natural regulation.

Unfortunately, "buffer" issues are poorly understood in soil science, except of the acid-base buffer ability of soils (pH-buffer), which is covered in a number of scientific papers (Nadtochiy, 1993; Philep et al., 1989). But only several scientific works are devoted to other types of soil buffer ability, such as nitrogen, phosphate, potassium, hydro-, thermo- and redox-buffering as well as soil buffer ability to heavy metals and microelements (Kanunnikova et al., 1981; Savich et al., 1980; Beckett, 1964).

Analysis of literature sources (Nay et al., 1980; Shakhparonov, 1976) shows that soil solution is the most influential factor on crop formation.

In laboratory and analytical practice, soil solution is studied by simulating it with various soil extracts - water, acid-free, as well as with soil pastes, suspensions, centrifuges etc. The closest to the natural conditions ones are such with the "soft" impact on soil - water and acid-free extracts (Gynzburg, 1975; Nay et al., 1980;

Beckett, 1964), which do not ravage the soil solid phase and thus do not cause significant changes in chemical composition of the soil solution. However, using methods with acid-free and water extracts you cannot determine the ability of soil to provide plants with nutrients, which was called "capacity factor" (CF) (Beckett, 1964). In agrochemical practice, CF is determined using more aggressive extragents - acid and alkaline solutions, but it is not usually possible to assess the actual agroecological condition of the soil solution because of its compositional disorder caused by the destructive (aggressive) action of acid and alkaline to the soil substrate.

A great number of researchers (Khristenko, 2016; Nosko, 2017) say in their methodological works about the futility of using "hard" chemical reagents for the functional diagnostics and optimization of soil fertility. Currently, methods with acid and alkaline soil extracts could determine CF, which is the first reserve for the reduction of IF deficit during the process of plant nutrition. These factors (CF and IF) are in thermodynamic equilibrium (Cheshko, 2015), which is varied in parameters and depends on the buffer properties of each soil kind.

The ability of soil to compensate partly the content of a nutrient in the soil solution during plant nutrition was defined as its potential buffer capacity (PBC) (Beckett et al., 1964). These authors worked out methods for determination PBC of soil to both phosphorus (PBC_P) and potassium (PBC_K) and mentioned them as important diagnostic criteria.

Thus, it should be used two main diagnostic indicators as criteria for the optimization of the fertility elements - the concentration (activity) of nutrients in soil solution (IF) and the ability of soil to store and maintain IF in optimal parameters (buffer capacity). This theoretical conclusion formed the basis of our research.

Motivation for the writing this article was an attempt by its authors to put scientists of foreign countries next to the results of author's long-term research on soil "buffer" issues and their use in the practice of soil nutrient management.

MATERIALS AND METHODS

The methodology of functional diagnostics and optimization of soil fertility was worked out by studying the behavior of phosphate and potassium ions in soil solution of genetically contrasted soils in Ukraine.

For the study, samples were taken from the 0-25 cm arable layer of the main soil types in the Polessye and Forest-Steppe zones of Ukraine, the characteristics of which are given in Table 1. Samples were taken on control (long-term unfertilized) variants of stationary field trials of research institutions of Ukraine. Soil mass was also taken from the arable layer of unfertilized variants for vegetation experiments.

Soil samples were analyzed for: pH of the soil-water extract (according to UNS ISO 10390:2007), granulometric texture (according to UNS 4730:2007), bulk density (according to UNS ISO 11272:2001), organic carbon content (according to UNS 4289:2004), mobile forms of phosphates and potassium (according to UNS 4405:2005); phosphate and potassium buffer ability according to our modernized methods (UNS 4724:2007 and UNS 4375:2005, respectively). In peat samples it was determined the ash content and peat decay degree according to UNS 7942:2015 and UNS 7829:2015, respectively.

Phosphate (IF_P) and potassium (IF_K) intensity factors and their dynamics under the increasing additives of calcium monophosphate [$Ca(H_2PO_4)_2$] and potassium chloride (KCl) in soil samples were determined by the method of Scofield using 0.01n and 0.001n $CaCl_2$ solutions according to the instructions (Beckett et al., 1964).

Optimal parameters of phosphate and potassium IF were determined earlier (Truskavetsky, 2003) by conducting a series of vegetation experiments with cereals. Experimental schemes included variants with progressive increased doses of phosphorus and potassium fertilizers single (pre-sowing) application at the time when moisture and nutrients are optimized.

Table 1. Characteristics of the studied soils in the 0-25 cm arable layer

MINERAL SOILS				
		Chernozem podzolized heavy-loamy (Left-bank Forest-Steppe zone of Ukraine)	Light-gray forest light-loamy soil (West Forest-Steppe zone of Ukraine)	Sod-podzolic sandy-loamy soil (Central Polessye zone of Ukraine)
pH_{water}		6.2	5.2	4.9
$C_{org.}$, %		2.2	1.1	0.7
Total content, %	Nitrogen	0.21	0.23	0.06
	Phosphorus	0.10	0.12	0.07
	Potassium	2.10	1.70	1.10
Content of particles, %	<0,01 mm	42.2	23.3	16.4
	<0,001 mm	12.8	7.8	7.8
PEAT SOILS				
		Peat eutrophic mesotrophic soil	Silty-peat ash-rich soil	Peat alcalitrophic ash-rich soil
$pH_{water.}$		5.4	6.5	7.1
Ash content, %		12.0	41.0	25.0
Peat decay degree, %		30.0	46.5	57.0

Optimal minimum of IF was at a dose of fertilizer, above which the efficiency of fertilizer decreases rapidly, and the optimal maximum of it was when negative impact of fertilizer on yield could be seen with its total decrease of 15-25%. Optimal limits (minimum and maximum) of phosphate and potassium ions concentration in soil solutions of different soils (Table 2) were determined in vegetation experiments.

Table 2. Soil gradation by phosphate and potassium buffer capacity (BCp)
and by mini-optimum of IF

Soil gradation	BCp, points		Mini-optimum of IF	
	phosphate	potassium	pP	pK
Low buffer capacity	< 5	< 3	< 4.35	< 3.85
Medium buffer capacity	5-15	3-8	4.35-4.65	3.85-4.25
High buffer capacity	15-35	8-16	4.65-4.90	4.25-4.45
Very high buffer capacity	> 35	> 16	> 4.90	> 4.45

The upper limit of the concentration of nutrients in soil solution with a single application of increasing doses of fertilizers was basically the same apart from the buffer capacity of studied soils: for phosphate and potassium ions it was at the level of 3.25 and 3.15, respectively (pP and pK) and fluctuations did not exceed 0.20 units (delta pP and pK).

The mini-optimum for pP and pK in soil solutions is the most important parameter that should be achieved and kept in the soil root layer for the maximum yield. There was found a significant correlation between soil immobilization buffer capacity and the optimal minimum of pP and pK in soil solutions with the coefficients for phosphate ions - Rp = 0.88 and potassium - Rk = 0.72 and described by the following equations:

$$pP = 3.77 + 0.066*X_P - 0.001*X_P^2$$
$$pK = 3.79 + 0.023*X_K - 0.0003*X_K^2$$

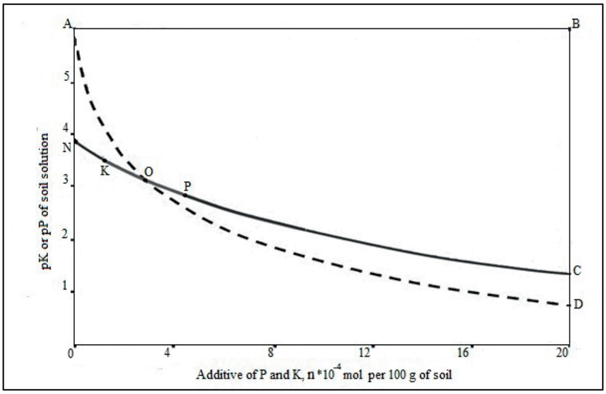
where: X_P and X_K are immobilization buffer capacities to both phosphate and potassium ions, points (on a 100-point scale).

The more immobilization buffer capacity of the soil the less use efficiency of fertilizers because soil absorbs nutrients from soil solution and they become unavailable for efficient plant nutrition.

RESULTS AND DISCUSSIONS

Soil buffering to nutrients is its ability to resist changes in concentrations (activities) of these elements in the soil solution (IF). Buffer curve characterizes the dynamics of IF changes in different kinds of soils under the influence of increasing fertilizer additives and shows in fact the strength of fertility elements fixation by the soil bio-organo-mineral complex, and on the other hand, the easiness of their release from it. The concentration (activity) of nutrients in the soil solution (IF) may be low, but optimal functioning of soil buffering mechanisms makes favorable conditions for mineral nutrition of plants as opposed to high, but unstable IF, which is in soils with low buffer capacity. It is clear that instability of plants mineral nutrition is due to the deficit of IF in the soil solution and to the inability of the soil mass to make it up in time from the potential reserves of the fertility element in the soil solution.

Buffer capacity is the rate of deviation of the soil-buffering curve from the "zero-buffering" curve. "Zero-buffering" curve is the curve of change in the concentration (activity) of phosphate and potassium ions with their increasing additives in the bufferless substrate or in pure aqueous solution (hydroponics). General view of the graphical model for the diagnostics and optimization of soil phosphate and potassium regimes is shown in Figure 1. This author's model is presented for the first time in foreign publications.



buffer curve of bufferless substrate (pure sand) - AD; buffer curve of some soil - NC

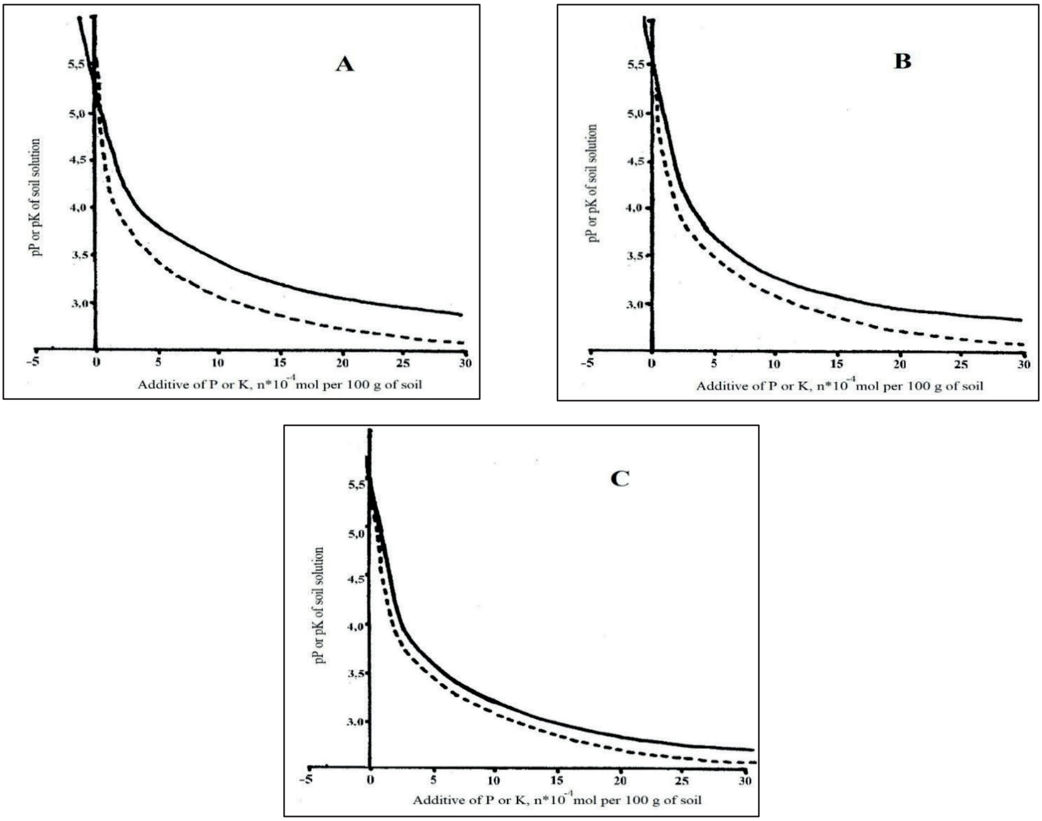
N - initial condition of fertility element; O - thermodynamic equilibrium of turnover;
ABD - buffer capacity standard area (100 points); OCD - mobilization buffer capacity area;
AON - immobilization buffer capacity area; KP - optimal parameters of intensity factor

Figure 1. Graphical model of diagnostics and optimization of phosphate and potassium condition of some soil

Thus, our research on "buffer" issues was aimed at improving the methodology of functional diagnostics. It is important to assess the level of deviation of the actual state of the fertility element from its genetic parameter as well as the dynamics of the transition and stable retention of the fertility element in optimal parameters for plant growth (segment KP on the buffer curve, Figure 1). External influences significantly change soil functioning and the line of the flow of biological cycle processes. However, due to buffer mechanisms, these changes are in the appropriate parameters for a particular soil.

Therefore, we formalized obtained results of experimental studies related to the determination of soil buffer parameters into integrated diagnostic and optimization (management) graphical models. In summary, optimal IF values (minimum and maximum) obtained for each studied soil are plotted on their buffer curves and, thus, we obtain an integrated graphical model that optimizes phosphate and potassium regimes of the studied soils and assesses the dynamics of their state.

Unfortunately, it is not possible to disclose all our created models for different soils of Ukraine in this article. At the same time, we consider it necessary to show and describe phosphate and potassium models for three soils that sharply contrasted by buffer properties and fertility and dominate in the Polessye and in the Forest-Steppe zone of Ukraine, such as sod-podzolic sandy, light-gray forest light-loamy and chernozem podzolized heavy loamy (Figure 2).

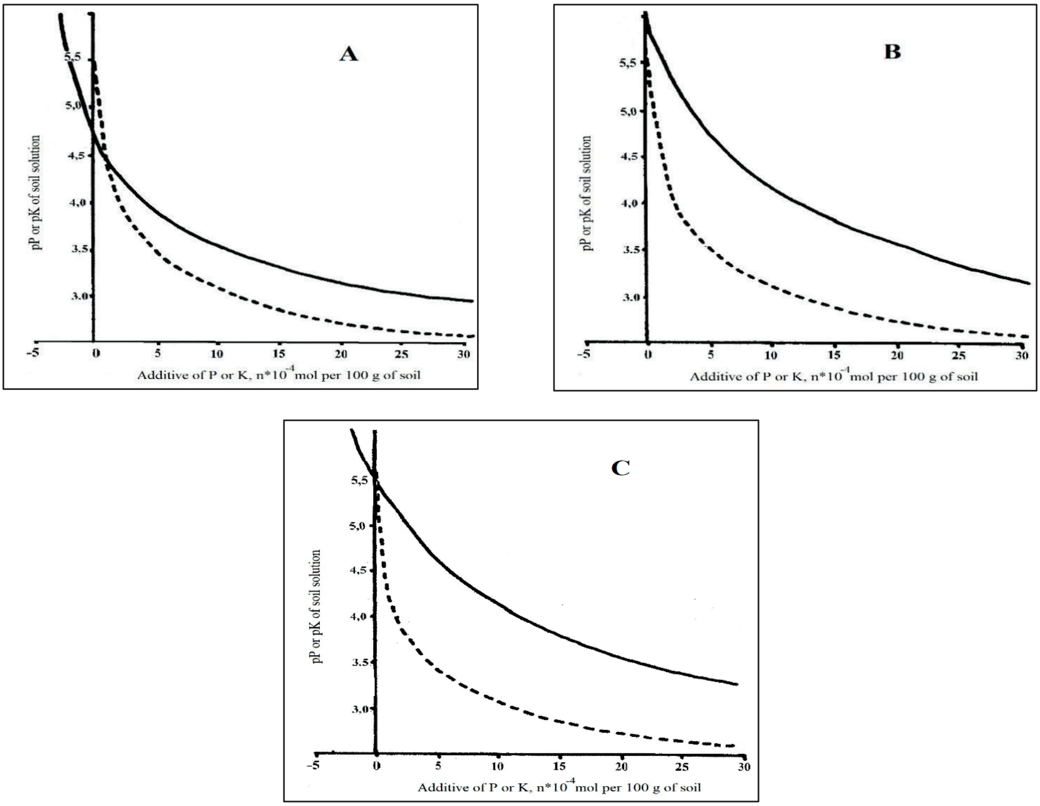


- - - - - buffer curve of bufferless substrate (pure sand); A - buffer curve of chernozem podzolized heavy loamy; B - buffer curve of light-gray forest light-loamy soil; C - buffer curve of sod-podzolic sandy soil

Figure 2. Graphical model of phosphate and potassium buffer ability of different mineral soil types

As shown in Figure 2 buffer curve of chernozem significantly deviate from the buffer curve of bufferless substrate ("zero-buffering" curve). Instead, a deviation of buffer curve of sod-podzolic soil from "zero-buffering" curve is not significant and indicates its low buffer capacity, which is expressed in points on a 100-point scale of the author's computer programs (pP-buff and pK-buff). At the moment, buffer curve of light-gray soil is in the mean position between mentioned soils, which is a natural phenomenon.

Our models for three types of peat soils (peat eutrophic mesotrophic soil, peat alcalitrophic (carbonate) ash-rich soil and silty-peat ash-rich soil) are also demonstrative (Figure 3).



- - - - - buffer curve of bufferless substrate (pure sand); A - buffer curve of peat eutrophic mesotrophic soil; B - buffer curve of peat alcalitrophic (carbonate) ash-rich soil; C - buffer curve of silty-peat ash-rich soil

Figure 3. Graphical model of phosphate and potassium buffer ability of different peat soils

Indeed, buffer curve of peat eutrophic mesotrophic soil should be etalon for the susceptibility to optimization of the phosphate regime and the easiness of its control and silty-peat ash-rich soil one - should be the same in relation to the management of plant potassium nutrition. Instead, alkalitrophic (carbonate) peat soils require appropriate reclamation techniques (including gypsum and acid clay application) to improve their phosphate and potassium regimes.

CONCLUSIONS

Soil solution is the most influential factor in crop formation and sensitive to changes in the soil environment. Objective agroecological diagnostics of soil solution is impossible without taking into account its dynamics.

The effectiveness of the main sources of making up for the deficiency of nutrients in the soil solution (capacity factor and fertilizers) is closely related to the functioning of soil buffer mechanisms.

Methods of "hard" chemical diagnostics (acid and alkaline extracts) cannot be criteria for optimization of soil nutrient regime.

Author's graphical models of soil nutrient management (on the example of phosphate and potassium regimes) integrate diagnostics and optimization into one whole and are based on the patterns of intensity factor dynamics (indicators of concentration (activity) of phosphate and potassium ions in the soil solution) under the increased doses of fertilizers and experimentally proved optimal parameters of IF.

Author's graphical diagnostic and optimization models allow to assess the initial state and conditions of phosphate and potassium nutrition of plants in soils; set doses of fertilizers to achieve optimal parameters of concentration (activity) of phosphate and potassium ions in the soil solution, depending on the methods of their application and the duration of their aftereffects; ground the choice of effective ways to use phosphorus and potassium fertilizers and reclamation techniques aimed at improving the conditions of mineral nutrition of plants.

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