EVALUATION OF NUTRIENTS AVAILABILITY BY APPLYING FERTILIZER AT DIFFERENT DOSES IN SOIL COLUMN

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Abstract

The issue of exchange processes, retention and leaching of ions in soil is far from being completely elucidated, most of the researches being conducted on pure materials and the organic-mineral complexes from soil differs significantly from those. In addition, details of soil nutrients availability rate are unknown, requiring fundamental research studies for each type of soil. In order to study the retention and migration processes it was developed an experiment on epicalcaric chernozem soil from Scânteia, Ialomiţa County for a number of cations and anions involved in plant nutrition. The retention and migration in soil of ammonium, nitrate, phosphate and potassium nutrient ions have been experimentally investigated by providing an experimental device that consisted in a series of glass columns filled with 100 g of soil air dried. A solution containing investigated ions, in different doses, was applied in soil by percolation. The soil columns experimental method allows us to determine the equations that describe the availability of nitrogen forms (ammonium and nitrate), phosphorus and potassium based on applied dose of fertilizer. The relation between the content in soil of mineral nitrogen (N-NH_4^+ and N-NO_3^-), potentially available phosphorus and potassium and applied dose of N, P and K indicate a highly significant correlation. Nutrient retention and leaching simulation processes by applying different doses of chemical fertilizers in soil allowed us to establish the available and accessible quantities, and to obtain the optimal levels of fertilizer required by crops.

Key words: *fertilizer doses, nutrients availability, retention, soil column.*

INTRODUCTION

Researches concerning retention and migration processes of nutritive species in different experimental conditions are scarce in literature (Heckrath et al., 1995; Madjar et al., 2004), so this concern is far of being solved and may be subject of many fundamental research studies developed for each type of soil. Column sorption experiments confirmed the pH influence in the amounts of metals mobilised (Anderson et al., 2000). Understanding of these processes may have an important influence on soil fertility management and provide useful information regarding agricultural practices that could improve this feature. Leaching can play an important role in agricultural nutrients losses when fertilizers are applied to the soil. Estimation of nitrogen, phosphorus and potassium leaching from soil is necessary in sustainable agriculture (Jalali et al., 2008). A series of leaching column experiments were set-up to investigate the effects of increasing and decreasing the sulphate of an acidified podzolic soil (Hodson et al., 1999).

Moreover, it is outstanding to identify the specific equations which describe the retention and migration of interest nutritive ions in order to obtain proper rates of fertilizers that are required by crops. This is useful for economical use of fertilizers but also to prevent environmental pollution caused by their use.

In the case of pollutant species, knowledge of migration and retention processes are fundamental for comprehension of movement in contaminated soils for a preventive environment control. Therefore, these processes regarding heavy metals (Selim et al., 1992; Zhang et al., 2006; Zhao et al., 2009; Ramachandran et al., 2013; Selim et al., 2013) and organic pollutants (Acher et al., 1989; Jackson et al., 1990; Conte et al., 2001) are intensively studied through experiments that are carried out in soil columns. The potential risk of heavy metal in soil depends on their mobility and of the release of metal cations to the water phase (Xu et al., 2005)

Considering the scientific evidence that fertility is a soil feature that must be maintained through proper agricultural practices including judicious use of fertilizers, we developed an experiment with the aim to investigate the retention and migration processes on epicalcaric chernozem soil from Scânteia, Ialomiţa County for some nutritive species (NH_4^+, NO_3^-, PO_4^{3-} and K^+) involved in plant nutrition. In order to evaluate the species mobility, the soils should be representative of agricultural area (OPPTS 835.1240, 2008). The main objective of the research is to determine the specific equations which describe the retention and migration of studied ions in soil column experiment by applying graduated concentrations of the nutrients.

MATERIALS AND METHODS

Studied area

The investigated soil in retention and migration process research was epicalcaric chernozem from Scanteia, Ialomita County.

Scanteia village is situated in the north-east part of Ialomita County at the edge with Braila County. The position of Scanteia on Romania map is presented in Figure 1. The main activity of inhabitants is agriculture.

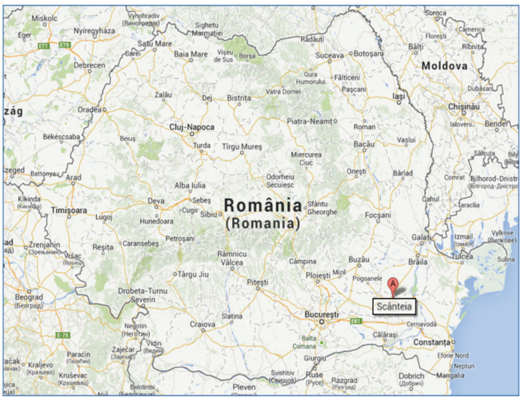

Figure 1. The position of Scanteia on Romania map

Agrochemical characteristics of the soil indicate at the start of the experiments a pH value of 7.48, a very slightly alkaline soil reaction. The total soluble salts content of 0.11488% indicates a low saline soil (situated in interval of 0.100 to 0.250%).

Mineral nitrogen content of the soil is the sum given by the ammoniacal and nitric nitrogen accessible forms. The result (12.75 ppm N) indicates normal mineral nitrogen supply (9.1 - 14 ppm N) for analyzed soil sample.

Mobile phosphorus soil content extractable in ammonium acetate lactate (P_{AL}) is 73.2 ppm and this value indicates a very high level (P_{AL} > 72 ppm), meanwhile soluble phosphorus content of 2.3 ppm P-PO_4^{3-} is low ($P_{soluble}$ <7 ppm), its availability being conditioned by soil pH.

Soil potentially available potassium content of 240 ppm K_{AL} is high (201-265 ppmK_{AL}), and the soluble potassium content of 20 ppm $K_{soluble}$ is low ($K_{soluble}$ <40 ppm).

Humus content of 3.09% indicates a medium supply soil level (2.1 to 4.0% humus).

Experimental device

The experiments are performed to determine the leaching potential of the test nutritive species in soils under controlled laboratory conditions (OECD, 2004).

Soil processes of retention, migration, and retrogradation were experimental investigated for the ions with nutritive role: N-NH_4^+, N-NO_3^-, P- PO_4^{3-} and K^+.

The experiments were conducted in an experimental device that consisted in a series of glass columns with a diameter of 3.5 cm. In each column was introduced 100 g of soil air dried, the soil column height being of 20 cm. In each column, the soil was brought to saturation humidity with 50 ml of distilled water so that the moisture of the soil to be uniform. A solution containing investigated ions, in different doses, was applied in soil by percolation, in three repetitions for each graduated concentrations. The ratio between the soil and the leaching solution was of 1/5 (w/v), and the percolation solution volume was of 500 ml. The solution flow rate was adjusted to have a constant liquid column height at 10 cm.

The solutions used in the experiment were prepared starting from the following chemical fertilizers: ammonium nitrate (35% N), superphosphate (18% P_2O_5), and potassium chloride (63.08% K_2O). The concentrations of the percolating solutions correspond to the doses of nitrogen, phosphorus and potassium applied to the soil in kg N, P_2O_5, K_2O/ha (Table 1).

Chemical analyses and analytical methods

After percolation, the soil from columns was air-dried, milled and sieved with 2 mm mesh size. The following soil analyses were performed:

- *soil pH* in aqueous suspension (1/2.5) by potentiometric method;
- *the total soluble salts content* in aqueous extract (1/5) by conductivity method;
- *soluble forms of* $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, PO_4^{3-}, K^+ in aqueous extract (1/5);
- *potentially available or mobile forms of* P_{AL} *and* K_{AL} in ammonium acetate lactate (1/20).

The levels of phosphate nitrate and ammonium species were assessed by spectrophotometric means. Phosphate was quantified as molybdenum blue, meanwhile for nitrate was used phenoldisulphonic acid in basic medium and for ammonium determination was used Nessler reagent. The potassium content was quantified by flame photometry.

Experimental scheme

The following experimental schemes were performed based on the nutrients ions, applied fertilizers and doses:

Table 1. The amounts of N, P and K applied by leaching in chernozem epicalcaric soil from Scânteia, Ialomiţa County

Nitrogen experimental scheme			**Phosphorus experimental scheme**			**Potassium experimental scheme**		
Column no.	**Experimental variant**	**kg N/ha**	**Column no.**	**Experimental variant**	**kg P_2O_5/ha**	**Column no.**	**Experimental variant**	**kg K_2O/ha**
$1_{(R11R12R13)}$	V1 (N_0)	0	$1_{(R11R12R13)}$	V1 (P_0)	0	$1_{(R11R12R13)}$	V1 (K_0)	0
$2_{(R21R22R23)}$	V2 (N_{50})	50	$2_{(R21R22R23)}$	V2 (P_{50})	50	$2_{(R21R22R23)}$	V2 (K_{50})	50
$3_{(R31R32R33)}$	V3 (N_{100})	100	$3_{(R31R32R33)}$	V3 (P_{100})	100	$3_{(R31R32R33)}$	V3 (K_{100})	100
$4_{(R41R42R43)}$	V4 (N_{150})	150	$4_{(R41R42R43)}$	V4 (P_{150})	150	$4_{(R41R42R43)}$	V4 (K_{150})	150
$5_{(R515R52R53)}$	V5 (N_{200})	200	$5_{(R515R52R53)}$	V5 (P_{200})	200	$5_{(R515R52R53)}$	V5 (K_{200})	200
$6_{(R61R62R63)}$	V6 (N_{300})	300						

RESULTS AND DISCUSSIONS

Availability and leaching of nitrogen in the chernozem epicalcaric soil from Scanteia

The application of nitrogen in increasing doses determined a different content of mineral nitrogen in soil. In the control variant V1 (N0), without applied fertilizer, the mineral nitrogen content, which represent the sum of $N\text{-}NH_4^+$ and $N\text{-}NO_3$, indicates a value of 8.5 ppm, a moderate nitrogen supply (6-9 ppm N) (Madjar, 2008).

The results obtained in variants V2 (N50), V3 (N100) and V4 (N150) reveal a normal mineral nitrogen supply in soil (9.1 - 14 ppm N). Applying a dose of 200 kgN/ha lead to 15.75 ppm nitrogen available in soil, indicating a high nitrogen supply class (14.1-18 ppm N), and for 300 kgN/ha applied was obtained 22.25 ppm, a very high nitrogen supply (> 18 ppm N) (Figure 2).

The experiment allows determining the equations of ammoniacal, nitric and mineral nitrogen availability depending on the fertilizer applied doses.

The equation that describes the amount of soil available ammonium nitrogen in ppm (mg N/kg soil) depending on the applied quantities, called dose (**D**), in kg N / ha, is:

$$N\text{-}NH_4^+, \text{ppm} = 0.0001D^2 + 0.0029D + 6.4462$$

The relation between the content of ammoniacal nitrogen in the soil and the applied dose as ammonium nitrate shows a highly significant correlation (R = 0.9261 ***).

Similar, was calculated the regression equation between nitric nitrogen, in ppm (mg N/kg soil), and applied fertilizer dose (**D**), in kg N / ha:

$$N\text{-}NO_3^-, \text{ppm} = -1E\text{-}05D^2 + 0.023D + 2.080$$

The correlation coefficient is very significant ($R = 0.9375^{***}$).

The sum of ammoniacal and nitric nitrogen gives the amount of soil available mineral nitrogen and the equation that describes the nitrogen content in ppm (mg N/kg soil) depending on the applied quantities as dose (**D**) in kg N / ha is:

$$N_{mineral}, \text{ppm} = 0.0001D^2 + 0.0263D + 8.5266$$

The relation between soil mineral nitrogen content and the applied dose indicates a highly significant correlation ($R = 0.9731^{***}$) (Figure 3).

The experiment allows determining the equations of ammoniacal, nitric and mineral nitrogen availability depending on the fertilizer applied doses.

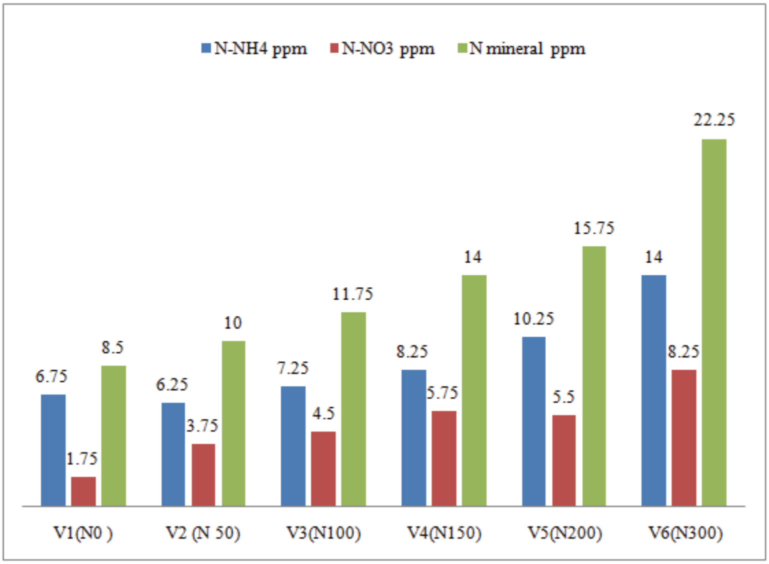

Figure 2. The content of ammoniacal, nitric and mineral nitrogen in soil

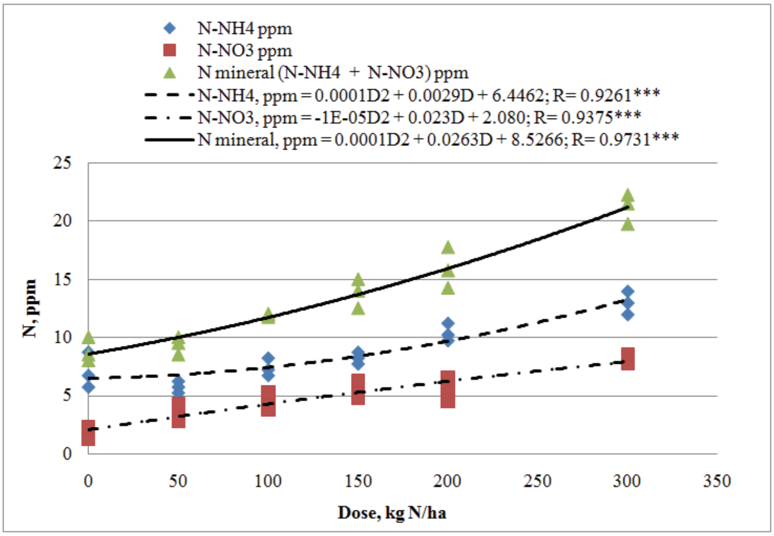

Figure 3. Dose influence on soil nitrogen availability

The equation that describes the amount of soil available ammonium nitrogen in ppm (mg N/kg soil) depending on the applied quantities, called dose (**D**), in kg N / ha, is:

$$N\text{-}NH_4^+, \text{ppm} = 0.0001D^2 + 0.0029D + 6.4462$$

The relation between the content of ammoniacal nitrogen in the soil and the applied dose as ammonium nitrate shows a highly significant correlation (R = 0.9261 ***).

Availability, leaching and retrogradation of phosphorus in the chernozem epicalcaric soil from Scânteia

The soil reactions that lead to the phosphorus retrogradation process are influenced by pH values > 7.3 when results calcium compounds with low solubility but also by pH values < 5.5 that favour obtaining of iron and aluminium poorly soluble compounds. Maintaining soil pH between 6 and 7 determine the highest availability of phosphorus in the soil. Study regarding the intensity of phosphorus retrogradation and leaching processes on the basis of the soil column method also need a further investigation on more soils with a wide range of physical and chemical properties (Li et al., 2013).

At the control variant V1, without applied phosphorus fertilizer the obtained value of 65.2 ppm P indicates a high level of mobile P supply. Experimental variants of V_2 (P50), V3 (P100), V4 (P150) and V5 (P200) indicates a very high level of potentially available phosphorus with values >71 ppm (Madjar, 2008) (Figure 4).

The equation that describes the influence of fertilizer doses on potentially available phosphorus content in soil is:

$$P_{AL}, \text{ppm} = -0.0007D^2 + 1.0206D + 68.2057$$

The relation between the content of phosphorus in soil and applied dose as superphosphate with 18% P_2O_5 indicate a very significant correlation *** R = 0.9957 (Figure 5).

Retention and leaching of potassium in the chernozem epicalcaric soil from Scanteia

Part of the potassium quantities from percolated solution was retained by various processes, mainly through cation exchange, or fixed between clay minerals, some remained in the soil solution, and the rest passed in percolate.

By applying increasing doses of potassium was obtained different potassium content in the soil. The obtained results indicate in all fertilized variants a very high supplied of potentially available potassium (K_{AL} > 266 ppm), and in the case of soluble potassium the soil analysis reveals low soluble potassium ($K_{soluble}$< 40 ppm) (Madjar, 2008) (Figure 6).

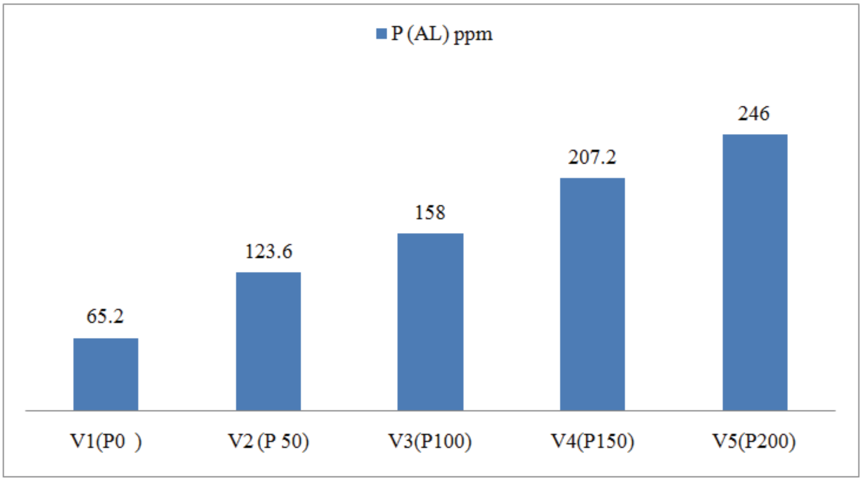

Figure 4. The content of potentially available phosphorus in soil

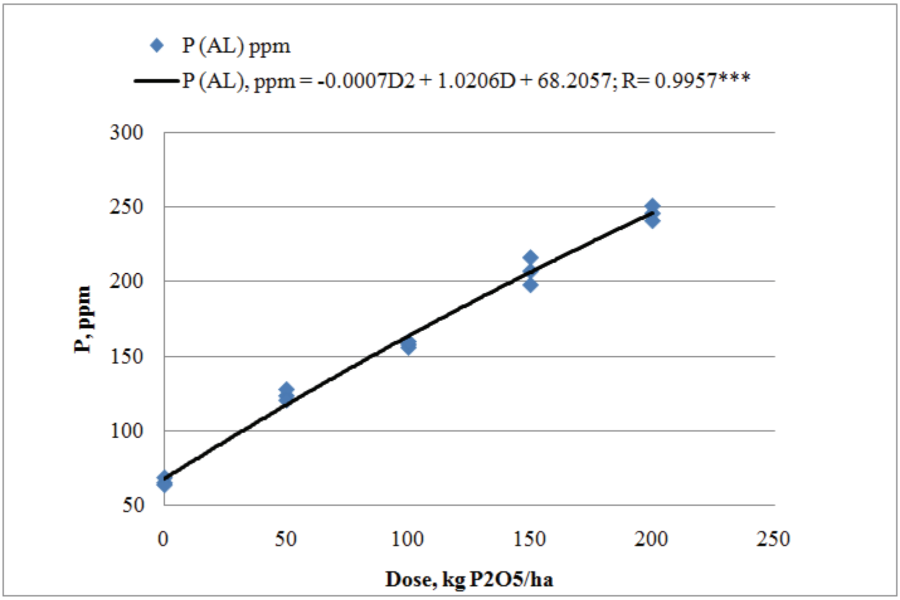

Figure 5. Dose influence on soil potentialy available phosphorus

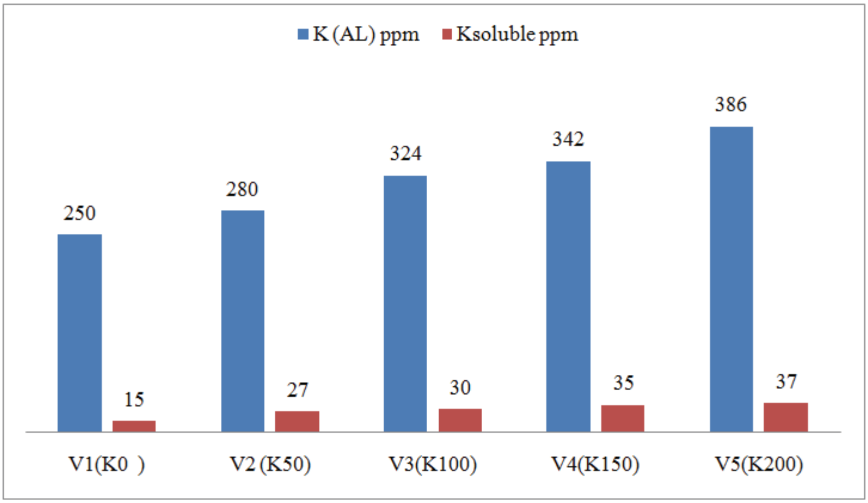

Figure 6. The content of potentially available potassium in soil

The regression equations that determine the potassium availability in soil as mobile and soluble forms depending on applied fertilizer doses are the results of the potassium cation exchange in retention simulation process achieved by soil columns experiment.

The mathematical relations between available potassium quantities and applied fertilizer dose (**D**) are:

$$K_{AL}, \text{ppm} = 0.0001D^2 + 0.6566D + 249.8857$$
$$K_{soluble}, \text{ppm} = -0.0005D^2 + 0.2069D + 15.8286$$

A highly significant correlation R = 0.9860 ***, respectively R=0.9477*** was calculated between mobile and soluble potassium content in soil and applied dose as KCl indicates (Figure 7).

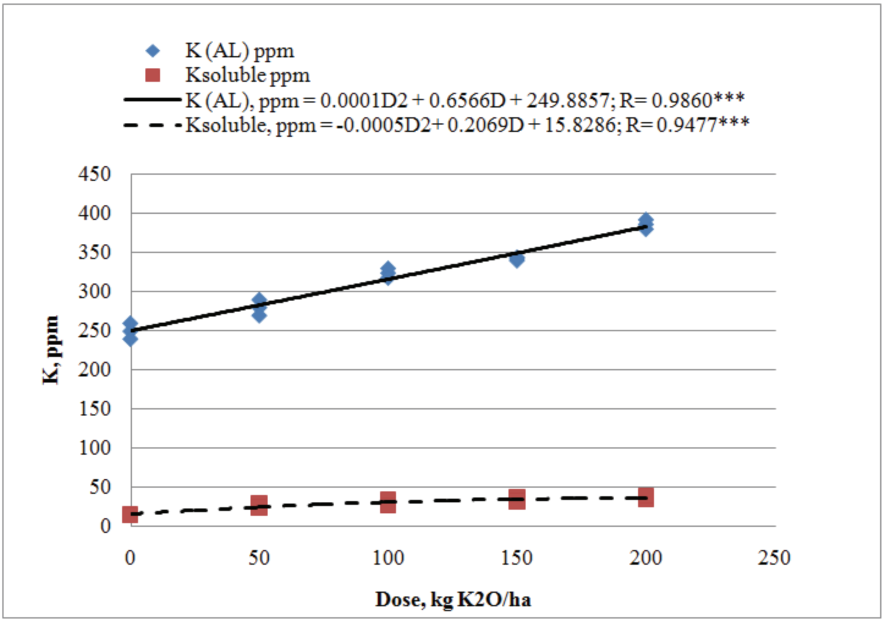

Figure 7. Dose influence on soil potentialy available potassium

CONCLUSIONS

Simulation processes of nutrient retention and leaching by applying fertilizer at different doses on soil chernozem epicalcaric from Scânteia, Ialomiţa County allowed us to determine the plant available quantities, to obtain optimal fertilizing levels to achieve a soil nutrients supply required by the crops.

For unilateral application of nitrogen as ammonium nitrate, phosphorus as superphosphate and potassium as potassium chloride revealed the following:

1. Soil fertilization with doses of nitrogen between 50 kg N/ha and 150 kg N/ha determined a mineral N ($N\text{-}NH_4^+ + N\text{-}NO_3^-$) content that ensures normal soil nitrogen supply. A high supply of mineral N is supported by a dose of 200 kg N/ha (V5).
2. Research regarding the nitrogen availability and leaching processes at the increasing doses of nitrogen as ammonium nitrate allows us to calculate the regression equations that describe the influence of applied fertilizer dose on soil nitrogen content.
3. Soil column experiment with superphosphate applied achieves a very high potentially available phosphorus supply of 123.6 ppm P_{AL} at minimum dose of variant V2 (P50). Higher doses than 50 kg P_2O_5/ha are not justified, soil being assured in mobile phosphorus reserves by applying the referred dose. Due to the slightly basic pH the soluble phosphorus form not pass in soil solution, even if the soil is very high supplied in potentially available phosphorus.
4. Potassium fertilizer doses between 50 and 200 kg K_2O/ha lead to low supply in soluble potassium ($K_{soluble}$ <40 ppm) and very high content in potentially available potassium (K_{AL} > 266 ppm).

REFERENCES

Acher A.J., Boderie P., Yaron B., 1989. Soil pollution by petroleum products, I. Multiphase migration of kerosene components in soil columns. Journal of Contaminant Hydrology, 4(4), p. 333-345.

Anderson P., Davidson C.M., Duncan A.L., Littlejohn D., Ure A.M., Garden M., 2000. Column leaching and sorption experiments to assess the mobility of potentially toxic elements in industrially contaminated land. J. Environ. Monit., 2, p. 234-239.

Conte P., Zena A., Pilidis G., Piccolo A., 2001. Increased retention of polycyclic hydrocarbons in soils induced by soil treatment with humic substances, Environmental Pollution, 112(1), p. 27-31.

Heckrath G., Brookes P.C., Puolton P.R., Goulding K.W.T., 1995. Phosphorus leaching from soils containing different concentrations in the Broadbalk experiment. Journal of Environmental Quality, 24(5), p. 904-910.

Hodson M.E., Langan S.J., 1999. A long-term soil leaching column experiment investigating the effect of variable sulphate loads on soil solution and soil drainage chemistry. Environmental Pollution, 104 (1), p. 11-19.

Jackson D.R., Bisson D.L., 1990. Mobility of polychlorinated aromatic compounds in soils contaminated with wood-preserving oil. Journal of the Air & Waste Management Association, 40(8), p. 1129-1133.

Jalali M., Kolahchi Z., 2008. Ability of sorption–desorption experiments to predict potassium leaching from calcareous soils. Journal of Plant Nutrition and Soil Science, 171 (5), p. 785-794.

Madjar R., 2008. Agrochimie. Ed. INVEL – Multimedia, p. 92 -95.

Madjar R., Davidescu V., 2004. Retention and migration process of potassium in an organic substrate for horticulture. Acta Horticulturae, 663, p. 309-314.

OECD Guidelines for the Testing of Chemicals, 2004. Degradation and Accumulation Test No. 312: Leaching in Soil Columns, ISSN: 2074-577x, DOI: 10.1787/2074577x, p. 5-7.

OPPTS 835.1240, 2008. Fate, Transport and Transformation Test Guidelines Leaching Studies, United States Environmental Protection Agency (EPA 712-C-08-010), p. 6.

Ramachandran V., D'Souza S.F., 2013. Adsorption of nickel by Indian soils. Journal of Soil Science and Plant Nutrition, 13(1), p. 165-173.

Selim H.M., Buchter B., Hinz C., Ma L., 1992. Modeling the transport and retention of cadmium in soils: multireaction and multicomponents approaches, Soil Sci.Soc.Am.J., 56, p. 1004-1015.

Xu J., Han S., Sun S., Meng F., Dai S., 2005. Leaching behavior of Copper (ii) in a soil column experiment. Bull. Environ. Contam. Toxicol., 75 (5), p.1028-1033.

Zhang H., Selim H.M., 2006. Modeling the transport and retention of arsenic (V) in soils. Soil Sci.Soc.Am.J., 70, p. 1677-1687.

Zhao L.Y.L., Schulin R., Nowack B., 2009. Cu and Zn mobilization in soil columns percolated by different irrigation solutions. Environmental Pollution, 157, p. 823-833.