Water magnetization and phosphorus transport parameters in the soil

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A B S T R A C T

There are scientific studies describing changes in properties of the water when subjected to the action of a magnetic field, which may favor the availability of some nutrients in the soil solution. Some nutrients, although they are essential to the process of crop development, can be sources of pollution for watercourses and soil. The aim of this study was to evaluate the effect of water magnetization on transport parameters of the phosphate ion in a Red Latosol (RL) and in a Quartzarenic Neosol (QN). Saturated leaching columns were connected to bottles containing KH_2PO_4 solutions. In RL, there were significant differences in phosphorus (P) transport parameters, related to the retardation factor (R) and distribution coefficient (K_d). For the others, Peclet number (Pe), dispersive-diffusion coefficient (D) and dispersivity (λ), there were no significant differences in the comparison between the treatments with magnetized and non-magnetized water. In QN, there were statistical differences in R and K_d. For the other parameters, Pe, D and λ, there were no statistical differences between treatments.

Magnetização da água e os parâmetros de transporte de fósforo no solo

R E S U M O

Existem trabalhos científicos que descrevem alterações nas propriedades da água quando submetida à ação de um campo magnético, podendo vir a favorecer a disponibilidade de alguns nutrientes na solução do solo. Alguns nutrientes, apesar de serem essenciais ao processo de desenvolvimento das culturas, podem ser fontes de poluição para os cursos hídricos e para o solo. Objetivou-se, neste estudo, avaliar o efeito da magnetização da água nos parâmetros de transporte do íon fosfato em um Latossolo Vermelho (LV) e em um Neossolo Quartzarênico (NQ). Foram usadas colunas de lixiviação saturadas e conectadas a frascos contendo soluções de KH_2PO_4. No LV, foram encontradas diferenças significativas para os parâmetros de transporte do fósforo (P), relacionados ao fator de retardamento (R) e coeficiente de distribuição (K_d); para os demais, número de Peclet (Pe), coeficiente dispersivo-difusivo (D) e dispersividade (λ) não houve diferenças significativas quando comparados aos tratamentos com água magnetizada e não magnetizada. No NQ, ocorreram diferenças significativas no R e no K_d; para os demais parâmetros Pe, D e λ não foram verificadas diferenças estatísticas entre os tratamentos.

Introduction

Most nutrients necessary to plant metabolism are absorbed from the soil solution. Some of them are strongly retained to mineral particles of the soil or are found in forms that are not readily assimilable (Putti, 2014). To improve yield and quality of agricultural products, some studies have used water subjected to magnetic field in irrigation.

Maheshwari & Grewal (2009) noted that the magnetized water for irrigation sometimes tended to alter soil pH, electrical conductivity, available P and potassium (K) extractable by the crop, compared with the control treatment. Tai et al. (2008) concluded that magnetized water increased the concentration of available nutrients in the soil solution such as P, K and Zn. Other researchers, such as Alkhazan & Saddiqm (2010), using magnetic field in different intensities in sewage water, observed, among other factors, increase in pH and decrease in electrical conductivity.

Some of these studies suggest greater availability of soil nutrients to the crops in comparison to irrigation using conventional water. The explanation for such effect could be supported in studies such as those of Xiaofeng & Bo (2008), who reported alterations in properties like surface tension and infrared and ultraviolet absorption of the water, under the action of magnetic fields.

Phosphorus (P), despite being important in the photosynthetic process of the plants, is one of the main contributors to the pollution of watercourses. The supply of this nutrient in the soil constitutes an interesting tool for the adequate management of fertigation. Analyses of this nature can be performed according to Alcântara & Camargo (2010), who aimed to understand the movement of nutrients and heavy metals in the soil.

Based on these facts, this study aimed to evaluate the effect of water magnetization on transport parameters of the phosphate ion in two different types of soil.

Material and Methods

The study was carried out at the Laboratory of Soil Physics of the Agricultural Engineering Department of the Federal University of Viçosa (UFV), with the objective to observe the effects of magnetized water on P transport parameters in the soil. The experiment used a Quartzarenic Neosol (QN), occurring in Mocambinho, in the municipality of Jaíba, situated in the state of Minas Gerais, and Red Latosol (RL), from the city of Sete Lagoas, also in Minas Gerais.

The physical analyses were performed at the Laboratory of Soil Physics of the Soil Department of the UFV using the methodology of EMBRAPA (1997), adapted by Ruiz (2005), for granulometric analysis, and the methods listed by EMBRAPA (1997) for the other physical determinations. The chemical analyses were performed at the Laboratory of Routine Chemical Analyses of the Soil Department of the UFV, according to the methods presented by Defelipo & Ribeiro (1997) (Table 1). The samples were air-dried and sieved through a 2-mm mesh.

The leaching columns were made of PVC tubes, with internal diameter of 47 mm and length of 20 cm. The internal

Table 1. Physical and chemical characterization of both types of soil used

Characteristic	QN	RL
Coarse sand[1] (g kg^{-1})	530.00	80.00
Fine sand[1] (g kg^{-1})	370.00	30.00
Silt[2] (g kg^{-1})	50.00	80.00
Clay[2] (g kg^{-1})	50.00	810.00
Soil bulk density[3] (g cm^{-3})	1.52	1.00
Soil particle density[4] (g cm^{-3})	2.67	2.19
Total porosity[5] (cm^3 cm^{-3})	0.43	0.54
Hydraulic conductivity[6] (cm h^{-1})	15.00	9.50
pH in water (1:2.5)	6.17	4.76
P (mg dm^{-3})	31.00	3.20
K (mg dm^{-3})	63.00	31.00
Ca^{2+} (cmol$_c$ dm^{-3})	1.60	1.80
Mg^{2+} (cmol$_c$ dm^{-3})	0.32	0.12
Al^{3+} (cmol$_c$ dm^{-3})	0.00	1.40
H + Al (cmol$_c$ dm^{-3})	2.80	10.60
SB (cmol$_c$ dm^{-3})	2.08	2.00
CEC (t) (cmol$_c$ dm^{-3})	2.08	3.50
CEC (T) (cmol$_c$ dm^{-3})	4.88	12.60
V (%)	42.60	15.90
m (%)	0.00	41.20
Organic matter (g kg^1)	7.90	60.80
N (g kg^{-1})	0.80	2.40

[1]Through sieving; [2]Pippete method; [3]Graduated cylinder method; [4]Volumetric flask method; [5]Calculated: PT = 1-ρs/ρp; [6]In saturated medium, constant-load permeameter; P-Na-K - Extractor: Mehlich 1; Ca-Mg-Al - Extractor: 1 mol L^{-1} KCl; H+Al - Extractor: 0.5 mol L^{-1} Calcium acetate - pH 7.0; SB - Sum of bases; CEC (t) - Effective cation exchange capacity; CEC (T) - Cation exchange capacity at pH 7.0; V - Base saturation index; m - Aluminum saturation index; OM = Organic C x 1.724 - Walkley-Black; P-rem - Remaining phosphorus; N - total N - Sulfuric digestion - Kjeldhal distillation

part of the tubes was coated with sand and paraffin to avoid preferential flow along the walls. The bottom part was covered with a fine mesh screen (≤ 2 mm). The samples of QN and RL were used to fill the columns.

The amount of soil added to each column was the one that promoted the bulk density closest to the actual value found at the field (Table 1) for all columns that had soil with the same characteristics. These amounts were added in the columns in layers of approximately 2.0 cm, always mixing the previous layer with the subsequent layer until obtaining a column of 15 cm.

The volume of pores for each column was estimated using the following relationship:

$$V_0 = V_T \varepsilon = \pi r^2 L \left(1 - \frac{\rho_s}{\rho_p} \right) \qquad (1)$$

where:

V_0 - volume of pores in the column (cm^3);

V_T - total soil volume in the column (cm^3);

ε - soil porosity (cm^3 cm^{-3});

r   - internal radius of the column (cm);

L   - soil height in the column (cm);

ρ_s - soil bulk density (g cm^{-3}); and,

ρ_p - soil particle density (g cm^{-3}).

The columns were ascendingly saturated for a minimum period of 24 h, using a 0.005 mol L^{-1} CaCl$_2$ solution, to minimize clay dispersion. The saturated soil hydraulic conductivity (K_0) was measured in the leaching columns using the method of constant-load permeameter (EMBRAPA, 1997). The obtained

means of K_0 were used to establish the different flows in the leaching columns. The values of flow were used to determine the hydraulic gradients to be applied.

After saturation, the columns were connected to Mariotte bottles containing $CaCl_2$ solution until the flow reached the condition of permanent equilibrium. After the equilibrium was achieved, the bottles containing $CaCl_2$ solution were disconnected and bottles containing solutions with different concentrations of KH_2PO_4 were connected.

Solutions with the same solute concentration were prepared adopting 2 treatments: one with common distilled water and another with magnetized distilled water. The electrical conductivity was measured in both types of water and the magnitude of the alterations in this property were the threshold values to establish the treatments.

Porto (1998) reported that the water exposed to magnetic field has higher electrical conductivity compared with non-treated water. This author cites mean values of eight measurements of electrical conductivity (k) of the water exposed to the magnetic field (k = 2.60 ± 0.30 µS cm⁻¹) and the control (k = 1.50 ± 0.18 µS cm⁻¹) obtained at temperatures between 22 and 24 ºC.

The water was magnetized by introducing a domestic magnet (Sylocimol), internally constituted of oriented permanent magnets and stainless steel, with magnetic field of 3860 Gauss, indicated by the manufacturer, in the solution prepared with common distilled water. The magnet was removed in successive intervals of 20 min. The solution was agitated with a glass rod and placed back in the container until achieving 3 h of treatment for a volume of 1 L. The common distilled water showed hydraulic conductivity values of 0.40 and 8.73 µS cm⁻¹, measured before and after treatment with magnetic field, respectively.

The tests with P solution were performed for 3 different initial concentrations for QN (C_1 = 20 mg L⁻¹, C_2 = 72 mg L⁻¹ and C_3 = 115 mg L⁻¹ of P), established based on the recommendations of EMBRAPA (2004), and 3 for RL (C_1 = 230 mg L⁻¹, C_2 = 326 mg L⁻¹ and C_3 = 405 mg L⁻¹ of P), based on the values adopted by Valeri et al. (2003), for both conditions, normal and magnetized water. These solutions were applied until the infiltrated volume corresponded to 13 pore volumes, totaling 1820 mL of solution applied in the RL and 7 pore volumes, totaling 784 mL of solution applied in the QN.

At the bottom of the column, samples of the solution were collected in varied intervals of pore volumes, divided in 14 intervals (4 of 0.50; 4 of 0.75; 4 of 1.25 and 2 of 1.50), totaling 13 pore volumes for RL and 12 intervals (4 of 0.25; 4 of 0.50 and 4 of 1.0), totaling 7 pore volumes for QN. When the effluent reached the pre-established volume in the collecting container, an aliquot was collected, placed in hermetically closed glass container and maintained under refrigeration for later quantification of the concentration of the effluent solute (C) and relative concentration (C/C₀).

The samples of the P effluent solution were analyzed through molecular absorption colorimetry, thus obtaining the concentration of P effluent (C) and the relative concentration (C/C₀). The relative concentrations and the respective pore volumes were used as input data to obtain the transport parameters.

The transport parameters relative to Pe, R and D were obtained using the computational program Disp (Borges Júnior & Ferreira, 2006), which fits the transport parameters comparing the experimental values of the solute concentration with those simulated using the solution of the differential equation of transport of solutes in the soil. The adopted mathematical solution was the A-1 model of the Disp program, which considers the concentration in the solution flow. The program considers linear sorption isotherm.

The λ was estimated using Eq. 2 and considering n (parameter dependent on the geometry of the medium) equal to 1, due to the conditions of saturated soil. For ξ (tortuosity factor), a value equal to 1 was used.

$$D = D_0\xi + \lambda v^n \tag{2}$$

The value of D_0 for P diffusion in pure water, according to Costa et al. (2006), is 0.03204 cm² h⁻¹, at 25 ºC. K_d was estimated using Eq. 3 and considering the soil water content (θ) as equal to the total porosity, since the soil was completely saturated.

$$R = 1 + \frac{\rho_S K_d}{\theta} \tag{3}$$

The experiment used 36 columns, corresponding to 2 types of soil (QN and RL), 3 concentrations of P for QN and 3 concentrations of P for RL, 2 types of water (magnetized and non-magnetized), with 3 replicates. The experimental design was completely randomized in a 3 x 2 factorial scheme (3 concentrations combined with 2 types of water), with 3 replicates.

The values of flow, D, R, K_d, λ and P_e, relative to each soil, under 3 different solute concentrations and 2 water treatments, were subjected to analysis of variance and Tukey test at 0.05 probability level to test if there was difference between the means of the treatments, using the software Assistat 7.7

Results and Discussion

Table 2 shows the P transport parameters comparatively obtained for RL when the solutions were treated with common and magnetized distilled water, evaluated for 3 different solute concentrations.

There was no statistical difference between the P transport parameters Pe, D and λ, for RL (Table 2) in the comparison between common and magnetized water, at any of the 3 concentrations. However, at the concentration of 405 mg L⁻¹, there were significant differences for the parameters associated with the mobility of the ion in the soil profile, R and K_d.

The mobility of solutes in the soil is inversely correlated with their sorption to the solid fraction or with the conditions of the medium, since they favor the precipitation of the ions. The ionic sorption to the soil exchange complex causes the ions to maintain an exchange with the soil solution, promoting their retention to the solid fraction and availability in the aqueous medium (Tagliaferro et al., 2011).

The magnetized water may have interfered with the phenomenon of ionic exchange due to the rearrangement of

Table 2. Phosphorus transport parameters in Red Latosol (RL)

Parameters	Concentrations (mg L^{-1})					
	230		**326**		**405**	
	[2]**CW**	[3]**MW**	**CW**	**MW**	**CW**	**MW**
Flow (cm h^{-1})	[1]14.95 a	15.25 a	13.40 a	14.61 a	13.15 a	12.28 a
Pe	3.84 a	5.65 a	7.29 a	7.40 a	6.69 a	4.08 a
R	13.35 a	11.70 a	8.32 a	8.64 a	7.57 b	8.69 a
K_d (cm^3 g^{-1})	6.67 a	5.78 a	3.95 a	4.13 a	3.55 b	4.15 a
D (cm^2 h^{-1})	146.71 a	107.51 a	52.96 a	55.97 a	57.10 a	93.59 a
λ (cm)	5.13 a	3.78 a	2.20 a	2.13 a	2.40 a	4.74 a
Electrical conductivity (µS cm^{-1})	692. 9	719.5	1013	1025	1430	1447

[1]Means followed by the same letter for the same parameter and same concentration, in the same row, do not differ statistically; [2]CW - Common water; [3]MW - Magnetized water

spatial charges in the colloidal micelles of the soils and to the alterations in the charges of the clays, as claimed by Lopes et al. (2007). Thus, the high clay content present in this soil may have reflected these changes in the process of adsorption of the solute in its matrix. Higher solute concentrations seem to favor this phenomenon.

Costa & Prunty (2006) found statistically different performances for rose cultivars irrigated with magnetically treated and common solutions. Similar results were found by Putti (2014), who reported more favorable results for the production variables of lettuce irrigated with magnetically treated water. The opposite was observed. Under conditions of higher solute concentration for this soil, the magnetized water influenced the reduction in the availability of the ion in the profile.

Table 3 shows the P transport parameters obtained for QN comparatively for solutions treated with common and magnetized water, evaluated for three different solute concentrations.

The analysis of the results for the P transport parameters obtained in the absence and presence of the magnetic field for the three concentrations applied in soil with predominantly sandy characteristics showed differences between the treatments for R and K_d at the lowest concentration, 20 mg L^{-1}. The lower values of R for the magnetically treated water represent greater movement of the solute in the soil profile and, for this situation, the magnetization may have caused changes in the behavior and in the clusters. Thus, there might have been structuration of the liquid water. The electrical conductivity increased in the common water that subsequently suffered the action of the magnetic field, so that the availability of the ions in the soil would be more evident, leading to greater movement in the soil profile.

The results were the same found by Pang & Shein (2013), who obtained magnetized water from pure water exposed to magnetic field and observed that the electrical conductivity of the magnetized water is higher than that of pure water, and these values increase over time and frequency of magnetization. In addition, sandy soils tend to have greater availability of P, because the adsorption is smaller, due to the low concentration of clays; however, excessive doses may lead to losses of the nutrient (Machado et al., 2011).

Porto (1998) claims that the amount of water adsorbed by the different surfaces depends on the intensity of the magnetic field and time of exposure. Assuming this, the magnetic field to which the water was subjected may have been insufficient to cause substantial changes in the behavior of the magnetized water in sandy soils.

For the K_d coefficients, there was also a variation for the solution with lowest P application. There was lower K_d in the treatment subjected to the magnetic field, reflecting higher values of the solute present in the liquid phase of the soil, indicating its greater availability in the movement along the profile, making it more prone to the leaching process.

There were no statistical differences in Pe or D between the treatments, in any of the evaluated concentrations. This observation leads to the assumption that the magnetic field did not influence the speed of flow or the degree of P movement in this type of soil. Similar analysis can be observed for λ.

For having larger particles and lower CEC, sandy soils have lower forces of adsorption with the solute, compared with clayey soils, which, associated with the reduced P doses, favors the action of the magnetic field, contributing to the increase in solute movement. On the other hand, clayey soils have smaller particles and high CEC, and these characteristics may be intensified in the process of solute adsorption to the soil, when influenced by the action of the magnetic field and higher doses of the solute. This phenomenon results in greater retention of the ions to the solid particles and lower availability and mobility in the profile.

Table 3. Phosphorus transport parameters in Quartzarenic Neosol (QN)

Parameters	Concentrations (mg L^{-1})					
	20		**72**		**115**	
	[2]**CW**	[3]**MW**	**CW**	**MW**	**CW**	**MW**
Flow (cm h^{-1})	[1]44.03 a	39.94 a	35.36 a	31.24 a	43.63 a	31.24 a
Pe	5.15 a	7.81 a	14.84 a	10.79 a	24.51 a	20.60 a
R	1.95 a	1.72 b	1.74 a	2.03 a	1.62 a	1.52 a
K_d (cm^3 g^{-1})	0.27 a	0.20 b	0.21 a	0.3 a	0.17 a	0.15 a
D (cm^2 h^{-1})	329.5 a	178.8 a	96.74 a	101.3 a	70.83 a	53.48 a
λ (cm)	3.14 a	1.93 a	1.33 a	1.40 a	0.71a	0.74 a
Electrical conductivity (µS cm^{-1})	81.7	90	235	242	381	390

[1]Means followed by the same letter for the same parameter and same concentration, in the same row, do not differ statistically; [2]CW - Common water; [3]MW - Magnetized water

Conclusions

1. In the Red Latosol (RL), the magnetized water showed, for the applied P solution, greater retention of this ion to the soil particles at the highest dose of the solute, and did not show statistical difference between the treatments for the lower doses.

2. In the Quartzarenic Neosol (QN), there was greater availability of P in the soil profile, with effect of the magnetic field when reduced doses of the solute were applied; for the other doses, there were no statistical differences between the treatments.

3. The electrical conductivity increased in all treatments using magnetized water, in comparison to the samples without the application of the magnetic field.

4. The intensity of the magnetic field used in the present study may have been insufficient to show differences in the mobility of phosphorus in the evaluated sandy and clayey soils.

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