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AN IMPROVED METHOD TO STUDY SOLUTE LEACHING IN LARGE UNDISTURBED SOIL COLUMNS NEAR FIELD CAPACITY TOWARD THE GROUNDWATER IN VARIOUS ENVIRONMENTS

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Abstract: Water flow in soil is a complex environmental process, which is very important not only for soil formation conditions in the nature, but also for plant development and leaching of nutrients and pollutants toward groundwater. The purpose of this work is to develop a research device intermediary between small-sized soil columns and lysimeters, as well as an adequate research method, to determine soil water permeability and flow conditions in undisturbed soil columns aiming to find out the maximum steady-state water flow values under continuous water supply in order to help investigate the movement of pollutants and fertilizers toward groundwater. The study was carried out in undisturbed soil columns, 0.3 m in diameter and 1 m length, in various environments: loamy Cambic Chernozem (CZca), a loamy-clayey chernic-argic phaeozem (FZce-ar) and a sandy textured eutric psamosol (PSeu). Water was applied according to the soil infiltration rates, and it was found that the steady-state effluent rate (Vef, mm h^{-1}) under continuous water application, as a product of hydraulic conductivity and gradient, and existing in nature after long rainy periods, is generally lower than the saturated hydraulic conductivity (Ks, mm h^{-1}) of all soil horizons, including the most compacted or clayey horizons, due to the different flow type, the unsaturated type for the columns' Vef and the saturated one for small cylinders' Ks, respectively. In the case of high clay-content, swell-shrink compacted soils (FZce-ar), there is water infiltration until the soils get wet to values higher than field capacity, then the flow ceases due to clay swelling. The steady-state Vef, achieved after important amounts of continuous water application and practically equal to the steady-state infiltration rate, is the maximum value of soil water flow in the column, because it occurs under submersion conditions at the soil surface, but in unsaturated soil conditions deeply in the column. After cessation of water application, redistribution between the soil horizons occurs for a longer period, and Vef slowly decreases and finally ends after 3-10 days, depending on soil texture and porosity. This flow type is specific for wet and cold seasons when there is a predominantly descendent water movement. Normally, in the other seasons with high evapotranspiration, lower rainfall, and when water infiltration occurs occasionally in the field, Vef would present lower values. The experiments could also involve plants grown under controlled atmospheric conditions. Leaching of soluble nutrients and pollutants depends on the magnitude of Vef, because the movement of these substances cannot exceed the steady-state Vef for all soil columns, and also for subsoil and the underlying geological deposits, simply because the water is their transport agent. Thus, Vef might be an important variable in modeling the leaching of some substances from the soil.

Keywords: saturated hydraulic conductivity rate (Ks), effluent rate (Vef), cambic chernozem, chernic-argic phaeozem, eutric psamosol

1. INTRODUCTION

Water flow is a complex, very important process for the soil formation conditions in the nature, and also for plant growth and leaching of nutrients and pollutants toward the groundwater. Studies on soil water flow were performed both under field and laboratory conditions, and simulation models were usually based on such studies.

Interactions between the soils and groundwater or surface waters have been previously studied in many countries, for instance in some areas of France (Canoğlu et al., 2019), in some central parts of Romania (Ispas et al., 2018) or in western regions of the country (Martonos & Sabo, 2017); the chemical soil composition and water quality were also examined in various regions of Romania by other scientists (Lăcătușu 2017, Lăcătușu et al., 2019a and 2019b). Other parts of the country affected by pollution with heavy metals in soils were investigated by Damian F. et al., (2019) and Damian G. et al., (2019).

In most of the situations, the water coming from precipitations infiltrates into the soils, and from here deeper to the groundwater. Thus, water is one of the most important transport agents in the environment. The most representative experimental studies were carried out on large drained land plots hydrologically isolated and having areas of some hundreds of square meters using soil matric potential sensors installed at various depths (Catt, 1991, Păltineanu et al., 2013) and also on lysimeters (Chaozi et al., 2019) or using macroplots that allow the use of natural porous structure and cracks of the soils (Păltineanu et al., 2001). The soil columns present the disadvantage of experiment simplification by investigating only one or a few essential factors. However, they have the advantages of researcher's permanent control concerning the application of a continuous leaching treatment, as well as an easy effluent collecting and emphasizing the influence of the studied factors on the investigated object.

More recently, following an increase in environmental pollution, leaching studies regarding nutrients and pollutants in soil columns and lysimeters grew. Thus, groundwater pollution with various substances like nutrients (nitrate, phosphorous, etc.), pesticides, heavy metals, mine seepage, petrol derivatives, etc. was studied experimentally through different methods and was simulated using various experimental procedures and/or specific models (Stagnitti et al., 2001). Liu et al. (2018) investigated acid mine drainage solute in soil columns made of glass using specific fluids of various concentrations and collecting the effluent, while Vitale et al. (2018) developed a soil column experiment on leaching of polychlorinated biphenyls (PCBs) using a solution of water and dissolved organic carbon and analyzing the effluent collected in time.

In the same manner, Riyadh et al. (2018) investigated movement of petrol derivatives toward groundwater, and López-Piñeiro et al. (2014) developed undisturbed soil column studies on pesticide movement and sorptivity in loamy-clayey-sandy soils amended on the surface with soil-incorporated residues from olive oil factories for many years versus not amended soils.

Sohaib et al., (2018) studied pesticide movement (Glyphosate and s-metolachlor) in soil columns toward the groundwater, and Elke & Vogeler (2018) also used soil columns to examine ethylene-diaminetetra-acetic acid solutions on the movement of some heavy metals (Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sn, Zn) under unsaturated soil conditions. Zhilong et al. (2018) also investigated heavy-metals' movement in soil columns by using acid-rain simulating solutions and analyzed periodically the concentration of Cu, Cd, Pb in the effluent. Similarly, Jiangbo et al., (2017) studied the movement of Pb and Cd in soil columns, while Wang et al., (2018) examined Cd mobilization in the soil and its uptake by the roots of some groundnut crops. Zhao et al., (2009) and Chatain et al., (2013) investigated total phosphorous movement in soil columns, and Li et al. (2013) and Nest et al., (2014) also studied total phosphorous leaching under unsaturated conditions.

Although the use of lysimeters containing undisturbed soils is very precise and recommended in many cases, their cost is high. Many of the above-presented studies were carried out either in small-scale columns with 0.07 to 0.15 m diameters and 0.50 to 0.75 m lengths, or in disturbed soil conditions that are much different from the natural, environmental conditions and do not comply with the requirements of a minimum representative volume.

The purpose of this paper is to propose an improved method to investigate soil permeability for water and solute leaching in large columns of undisturbed soil, near field capacity (FC), allowing thus to determine the maximum, steady-state water and solute flow under continuous water application and the volume and quality of the effluent toward the subsoil and groundwater.

2. MATERIAL AND METHODS

2.1. The studied soil material and taking undisturbed soil samples

The soil cover has differently been spread over the globe according to the environmental factors, and the first 1 m depth is the most important soil part containing the major plant roots and being subject to severe human pollution.

Because the particle-size distribution generally determines soil permeability, three different-textured soil types have been studied: 1) a cambic chernozem (CZca) from Grindu village, Ialomita county, with the geographical coordinates of 44.790°N and 26.939°E, and 62 m altitude above sea level, characterized by a loamy texture in the topsoil and a sandy-loamy one in the subsoil, 2) a chernic-argic phaeozem (FZce-ar) from Draganesti village, Teleorman county, having the geographical coordinates of 44.09337°N, 25.54698°E, and altitude of 89 m, with a clayey-loamy texture in the topsoil and a loamy-clayey one possessing swell-shrink properties in the subsoil, and 3) a sandy-textured, eutric psamosol (PSeu), with high permeability. The geographical coordinates of PSeu are: 43.779°N, 24.2078°E and altitude of 61 m, being located in Potelu-Ianca village, Olt county.

The climate of the investigated southern part of Romania is temperate-continental, a Dfb category after Köppen-Geiger climate classification (Geiger 1961), and is characterized by mean annual temperatures of 10.5-11.0°C and precipitation between 500 and 600 mm, and solar radiation favorable for many crops (Păltineanu et al., 2000, 2002). A trend of increasing temperature, reference evapotranspiration and crop evapotranspiration has recently been reported for the area (Paltineanu et al. 2011, 2012).

Soil profiles were dug up in three different-cropped fields: sun-flower (CZca), chick pea (FZce-ar), and water melon (PSeu), and their morphological aspect is shown in figure 1.

Disturbed soil samples were taken to analyze particle-size distribution and chemical analyses, and undisturbed samples were sampled in metal rings of 0.05-m diameter and 0.05-m height for determination of bulk density, hydraulic conductivity and penetration resistance (Dumitru et al., 2009).

The compaction degree of the intensely-worked soils (CZca and FZce-ar) is high in the hardpan that is just below the upper Ap horizon. Bulk density (BD) as mean weighted values over the length size (1 m) of the soil columns is 1.58 kg dm^{-3} for CZca and 1.40 kg dm^{-3} for FZce-ar (Paltineanu et al., 2019), while for PSeu it is 1.56 kg dm^{-3}. The soil compaction of the CZca hardpan, and especially the high (over 48%) swell-shrink clay content from the Bt horizon of FZce-ar, induce negative physical properties of these two soil types, mainly through the low saturated hydraulic conductivity (Ks), low porosity and high resistance to penetration (RP), Table 1.

In the case of CZca, Ks presents high values over the entire soil profile, in accordance with the loamy soil texture, except the hardpan where it is low. Both Ks and RP are intensely correlated with BD, inversely and directly, respectively (Păltineanu et al., 2016c). There are extreme values of these two properties within the hardpan, where BD is 1.85 kg dm^{-3}, Ks is 5.05 mm h^{-1}, and RP is 10.25 MPa, versus the other soil horizons.

In the case of FZce-ar, Ks is strongly different within the soil horizons, showing minimum values in the Bt clayey horizon (1.21 mm h^{-1}), while in the case of PSeu, Ks is excessively high (over 206 mm h^{-1}) within the entire profile. The extremely high Ks values for PSeu can be attributed to the total sand content that is 97%, while the clay content is only 0.51%.

The Ks weighted harmonic means for the column length (1 m) are as much as 17.04 mm h^{-1} for CZce, 2.44 mm h^{-1} for FZce-ar and 201.5 mm h^{-1} for PSeu, respectively.

a b) c)

Figure 1. Morphological aspects of the soil profiles studied: a) CZca of Grindu, b) FZce-ar of Draganesti, c) PSeu from Potelu-Ianca

Table 1. The main soil physical and chemical properties for CZca, FZce-ar and PSeu

Soil type	Horizon	Depth	pH	Humus content	Clay content	Bulk density	Ks	Porosity	RP
	Simbol	(cm)	units	(%)	(% <0.002 mm)	(kg dm^{-3})	(mm h^{-1})	(%)	(MPa)
CZca	Ap	0-17	5.63	2.67	30.3	1.25	33.17	52.9	1.03
	Ap hard	17-29	6.27	2.43	16.6	1.85	5.05	30.4	10.25
	Am	29-42	6.50	2.49	19.5	1.66	11.90	37.4	2.7
	A/B	42-54	6.65	2.07	18.7	1.63	24.52	38.5	3.14
	Bv1	54-72	6.84	1.60	19.7	1.57	34.25	40.8	2.16
	Bv2	72-89	7.00	1.36	16.7	1.67	23.80	37.0	1.91
	B/C	89-109	8.40	1.01	17.2	1.52	68.86	42.9	1.42
	Cca1	109-124	8.72	0.77	16.2	1.62	20.55	38.9	4.86
	Cca2	124-137	8.74	0.50	12.2	1.62	38.9	2.55	2.55
	Mean*	**0-100**	**6.24*** **	**1.95**	**20.2**	**1.58**	**17.04****	**40.5**	**3.0**
FZce-ar	Am1	0-10	5.05	4.62	48.8	1.10	25.43	58.5	1.77
	Am2	10-23	5.55	3.67	43.5	1.56	4.50	41.0	7.26
	AB	23-51	6.57	3.44	47.2	1.37	18.68	48.4	5.30
	Bt1	51-93	6.89	2.25	48.2	1.42	1.21	46.5	6.86
	Bt2	93-118	7.02	1.72	48.9	1.50	4.67	43.6	5.98
	Bt3	118-143	7.12	1.07	48.4	1.59	0.17	40.1	9.32
	BC	>143	8.41	0.77	46.1	1.10	25.43	58.5	1.77
	Mean*	**0-100**	**5.86*****	**2.97**	**47.42**	**1.40**	**2.44****	**47.31**	**5.90**
PSeu	Ao	0-31	6.20	1.30	0.70	1.50	197.15	43.6	0.59
	Cn1	31-52	6.55	1.36	0.40	1.55	247.47	41.6	0.59
	Cn2	52-84	6.80	0.83	0.50	1.60	219.11	39.5	0.88
	Cn3	84-106	6.94	0.53	0.30	1.58	147.87	40.5	0.78
	Cn4	> 106	6.65	0.30	0.40	1.58	77.87	40.6	0.98
	Mean*	**0-100**	**6.49*****	**1.04**	**0.51**	**1.56**	**201.5****	**41.37**	**0.71**

Note: Symbol * shows the weighted arithmetic mean for the 0-1 m columns' depth, and ** shows Ks harmonic weighted mean over the same depth, while *** shows the weighted antilog mean for pH

The studied soils present an increasing chemical reaction (pH) from the surface to the depth, from slightly acid in Ap to alkaline (> 8) values deep in the soils, except PSeu, slightly acid, Table 1. The humus content is higher for FZce-ar and slightly decreases for CZca, being very low for PSeu. It also decreases strongly with depth for all soils.

2.2. Sampling soil columns in the field

Stainless steel columns of 0.3 m in diameter and 1 m in length were inserted in soil by pressing with the help of a mechanical equipment or by hitting with a 10 kg mass hammer in a circular, thick metal cylinder laid over the columns until penetrating about 0.05-0.10 m depth; afterwards the soil outside the column was removed by digging with a spade in order to minimize the external friction and to allow soil sampling in the column in the least invasive possible way, (Fig. 2a). The operation was repeated until the entire column was inserted in the soil. The hard, clayey FZce-ar soil was wetted to FC before sampling in order to facilitate columns' pressing and penetration. After the insertion of the entire column, the soil was cut off at the column bottom, and double-layer plastic sheets were used to isolate the columns at both sides, (Fig. 2b).

After the soil columns were transported into the laboratory, they were laid over special stainless steel, circular holders provided with drainage system consisting of two layers: 1) one of 1-cm height coarse and fine sand at the intimate contact with the soil to allow a low hydraulic resistance when the soil solution gets out of the columns, and 2) a 4-cm height gravel 3-7 mm sized below the sand. Beneath the drainage layers there is a stainless steel sieve containing 50 holes of 1.5 mm diameter over a tap-outlet device to collect the effluent, Figure 3a.

In the laboratory, the manipulation of the soil columns of cca. 120-140 kg mass was performed by help of a mobile crane and two fastening belts (Fig. 3b). In total, six soil columns with CZca, three with FZce-ar and three with PSeu were sampled for water infiltration and leaching investigation.

a)

b)

Figure 2. Sampling undisturbed soil columns by using a sampling steel cylinder above for pressing or hitting (a) and binding the ends of columns with double-layer plastic sheets (b)

a)

b)

Figure 3. Stainless steel circular holders provided with the lower drainage layer, a 3-7 mm sized gravel (a), the crane manipulating a soil column with tow fastening belts above a holder with both drainage layers – the upper one seen, the sand (b)

2.3. Preparation of the soil columns in the laboratory for water application

A soil volume of 1.5 cm height at the columns' top was removed to create space for application of water that was poured as flooding according to the soil infiltration rate (Vi) until the effluent rate (Vef) was equal to the steady-state Vi under continuous water application. The height of water above the soil columns ranged between 14.2 mm at the moments of 1 L of water application and 0 mm when the whole water amount infiltrated. Beneath the outlets of the soil columns, glass recipients were placed to collect the effluent for both quantitative and qualitative determinations (Fig. 4).

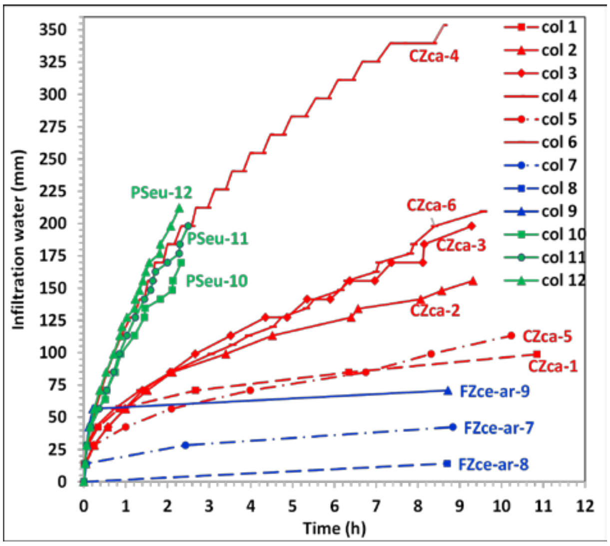
The air temperature in the laboratory was between 20 and 22°C. The evaporated water amount from pots of similar diameter with the columns was determined by a daily basis to correct the infiltration amount. The effluent from each soil column was periodically collected in thin-mouth bottles to minimize evaporation and error determinations.

A drip irrigation system was installed in the lab to apply water in every soil column for percolation studies. The method allows to study the movement of any pollutant in the soil toward the groundwater.

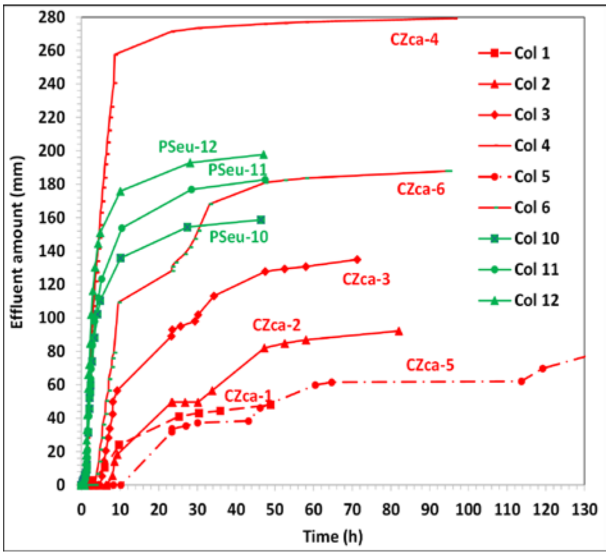
Figure 4. Water infiltration under flooding in the soil columns set above the stainless circular holders provided with drainage systems in the laboratory and collecting the effluent in bottles

3. RESULTS

The cumulative values of infiltration and effluent water are presented in Figure 5. The antecedent soil moisture content in the case of CZ and PS was near the management allowable depletion values (at about half of the available water capacity); it can be noted that in these soils in the first few hours from the start of determinations the water infiltrated rapidly, yet not homogeneously among the columns within the same soil type.



a)



b)

Figure 5. Cumulative infiltration (a) and effluent water (b) in the soil columns studied, from column 1 to 12

Thus, six hours following the onset of water application, the CZca columns with the numbers 1 and 5 presented the lowest values, cca. 75 mm, and columns 2, 3 and 6 presented moderate values of 125-150 mm, while in column 4 the infiltrated water was 300 mm (Fig. 5a). Regarding the PSeu soil type columns one can note that the infiltration occurred relatively uniform, and two hours after the onset of water application this one was about 175-220 mm. These two soil types do not present problems for irrigation application.

The loamy-clayey textured FZ - soil columns 7, 8 and 9 - presented a totally different pattern versus the other two, and the infiltration was very low here due to the fine texture, compacted state and fine porosity, and also due to the antecedent soil water content (SWC) that was near FC here, because soil column sampling could not be performed at any other water contents. Thus, in column 9 the infiltration water only was 60 mm, and then the infiltration water almost stopped after nine hours. In the other two columns the infiltration was much lower, of 10-30 mm. These results confirm once again that the fine-textured soils containing smectite-like, swell-shrink minerals can be wetted when dry, but after swelling the infiltration drops and finally ceases.

The infiltration process lasted differently as a function of the antecedent SWC and permeability, depending on the biological activity of the plants and animals. After the soil columns were wetted to FC within the whole 1 m depth, the effluent started to appear at the columns' bottom. Water application continued until the effluent rate (Vef) equaled the infiltration rate (Vi), and these moments came across after a few hours in the PS soil type columns, and until a few days in the CZ columns. Practically, there was no effluent water in the FZ soil columns, even if there was a permanent water layer above the soils in these columns for at least 1.5 months.

Figure 5b presents the cumulative effluent water from the studied soil columns, except the FZ ones. The steady-state Vef under continuous water application was rapidly reached in the PS soil columns as close values, and non-uniformly in the CZ columns. At the end of determinations there was a water amount of 50-60 mm effluent for columns 1 and 5, between 80-190 mm in columns 2, 3 and 6, and about 280 mm in column 4.

After the cease of infiltration, the water was redistributed between the soil horizons, and the effluent gradually ceased after various periods among columns. Vef as steady-state average values for the investigated soil type columns under continuous water application along with the standard deviations (SD) and the variation coefficients (VC) are shown in Table 2, versus the mean values of Ks over the soil horizons from the 1 m length columns.

In the case of CZ, the mean Vef was 5.57 mm h^{-1}, and VC presented high values (126%). The Ks weighted harmonic mean over the column depth was much higher, 17.04 mm h^{-1}, and the minimum Ks value in the most compacted horizon was 5.05 mm h^{-1}, this value being of the same magnitude order as Vef mean. In the case of FZ, the mean and minimum Ks values were 2.44 and 1.21 mm h^{-1}, respectively, while Vef was 0. In the case of PS, the mean Vef was 49.7 mm h^{-1}, being much lower than the mean or minimum Ks values, while VC shows a relatively homogeneous value, 18.5%. The conclusion drawn from this section is that the weighted harmonic means of Ks overestimates the mean Vef values found for the

Table 2. Mean, standard deviation (SD) and variation coefficient (VC) values for the steady-state effluent rate (Vef) under continuous water application above the soil columns studied versus the harmonic weighted means of Ks

Soil type	Steady-state effluent rate (Vef)			Saturated hydraulic conductivity Ks (mm h^{-1})
	Mean (mm h^{-1})	SD (mm h^{-1})	VC (%)	Harmonic Means over 0-1 m depth
CZca	5.57	7.02	126.1	17.04
FZce-ar	0	0	-	2.44
PSeu	49.69	9.18	18.5	201.5

investigated soil columns, and that the less permeable soil horizons govern the soil water and solute flow in the undisturbed soils. Consequently, the weighted harmonic mean of Ks over a certain depth is thus not useful for further calculations.

4. DISCUSSION

According to the calculations based on the antecedent SWC, the soil was not saturated with water when the effluent appeared at the column bottom, and then there were pores free of water. How it was previously reported, water flow from one soil horizon to another does not only occur at saturation, but also before this state was attained, at a SWC value approaching or exceeding field capacity (FC); soil wetting usually does not occur uniformly, but as vertical fingers through macropores (Hillel, 1980, Paltineanu et al., 2001). The antecedent SWC values influences water infiltration in the first period of this process, but counts less to its steady-state reaching (Canarache, 1990). Vi and Vef are soil water fluxes, as products between Ks (which in turn is a function of SWC or potential) and the hydraulic gradient with its components: a) submersion, b) matric or suction the last being important in the first periods of soil wetting, and c) gravity that is always unitary; in the last wetting hours when SWC increases the soil suction decreases to its end (Hillel, 1980).

In the present experiment, when Vi and Vef were equal and became relatively constant, the total hydraulic gradient approached unity. Based on such assumption, if Ks from the soil horizons are compared with the steady-state Vef values under continuous water application, although a rigorous comparison may only be done at unitary gradients, it can be noted that the Vef values are generally lower than Ks, including Ks values from the less permeable horizons where Ks is minimum and which practically govern water and solute flow (Tables 1 and 2).

The main difference consists in the flow regime; Ks is determined at saturation on small-sized cylinder samples from single soil horizons, while Vef is determined at a lower-than-saturation SWC, yet being higher than FC because there was effluent. Another difference is the size of the columns containing more soil horizons, while Ks values are measured on small-volume samples, with a less representative area. The prolonged effluent following the water and soil solute vertical redistribution among the soil horizons confirms once again the difficulty of defining FC (field capacity), according to which the effluent would have ceased after 1-2 days from the end of water application. As already shown, the effluent continued many days following the end of water application within the permeable CZ and excessive permeable PS. The unsaturated K probably declines at SWC values that are lower than saturation but higher than FC. From a practical view point the question is if the effluent water can be used by the crop roots, or its rate is too high for plant absorption.

The determination of Vef is important for natural drainage studies and to estimate soil water and solute flow toward the groundwater, or vertically inside the soil and geological deposits beneath them. Such substances may be soluble or suspension nutrients or pollutants. Vef can be used in simulation models, because Ks only offers comparative data between the soil horizons, and water infiltration and solute movement in the field does not happen under saturated conditions, except some rare cases in the very wet and cold seasons.

Thus, the steady-state Vef values under continuous water supply practically represent the maximum water flow rate that is specific to each soil, in this particular case for 1 m depth. However, during the growing seasons the water flow into the soils occurs occasionally, from precipitation or irrigation, and Vef presents such values that are lower than those shown in this experiment. The wetting front usually depends on the annual time distribution of the precipitation and crop evapotranspiration, without taking into account the changeable climate conditions, including the crop water uptake, as described, among others by Păltineanu et al. (2011), or the roots distribution in the soils (Păltineanu et al., 2016a, 2016b), with the complex process of absorption capacity of the roots.

The effluent movement into the soil toward the groundwater is also a function of the permeability of the subsoil and the underlying geological deposits. The leaching of nutrients and pollutants that are soluble in water or are in suspension depends on the steady-state Vef, which is practically the higher flow rate occurred naturally under the existence of a continuous descendent flux. The concentration of some substance in the groundwater, e.g. nitrates in the Glavacioc catchment, is the result of all the above factors (Lăcătușu et al., 2019a, 2019b).

The soils and environments investigated here are not specific only to Romania, but also in many other countries. For instance, chernozems and phaeozems are spread over large parts of Europe, i.e. Moldova, Ukraine, Hungary, Bulgaria, etc. (Jones et al. 2010); they can also be found in other continents (USA, Argentina, China, etc. ***). Sandy soils (psamosols) are specifically in the great deserts of the world and also in some temperate-continental climates in Europe.

As a matter of fact, the improved method presented in this paper can be used in a wide range of soil textures, from sandy to clayey-loamy, in any environment in the world, with the note that very fine-textured (clayey) soils combined with high-compaction states are mostly impermeable for water after getting wet and the effluent might be missing. Such experiments could also involve plants grown under controlled atmospheric conditions. Leaching experiments using nutrients (nitrate, phosphate, potassium, etc.), petrol contaminants, pesticides, heavy metals, etc. can be carried out next using and the drip irrigation system to determine their movement in the soil toward the subsoil and the groundwater.

5. CONCLUSIONS

The devices and the improved method presented in this paper are designed to investigate the flow of water and leaching of nutrients and pollutants, either soluble or in suspension.

The steady-state effluent rate Vef obtained under continuous water application, existing after important precipitation amounts, is generally lower than the saturated hydraulic conductivity Ks of the soil horizon with minimum permeability, due to the different flowing regime, which is saturated and determined on small-sized samples for Ks, and unsaturated and for all the horizons from the 1 m depth for Vef. For the compacted clayey soils containing swell-shrink minerals, the soil columns showed no effluent after long periods of time (months).

The steady-state effluent rate Vef represents the maximum value of water and solute flow within the 1 m depth soil profile, and can be an important variable for their transport modeling. These Vef values can occur in wet and cold seasons, when most of the movement of nutrients and pollutants usually happen in the environment. This movement also depends on the physical properties of the subsoil and geological deposits toward the groundwater.

Such experiments could also involve plants grown under controlled atmospheric conditions.

The next research step is to study the transport of various substances, e.g. nutrients, pesticides, heavy metals, petrol derivates, into the soil toward the groundwater, depending on the precipitation and reference evapotranspiration, in any environment characterized by various climates and soil textures, except swell-shrink compacted clayey soils where there is a risk as the effluent might not exist.

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References

Canarache A. 1990. *Physics of agricultural soils.* Editura Ceres. 268 pages (in Romanian).

Canoğlu M. C., Kurtulus B. & Razack M. 2019. *Soil–aquifer interactions and vadose zone modeling: An example from marais Poitevin (Western France),* Carpathian Journal of Earth and Environmental Sciences, Vol. 14, No. 1, p. 171 - 180; DOI: 10.26471/cjees/2019/014/069.

Catt J. 1991. *The Brimstone Experiment - Collaborative Work by ADAS' Field Drainage Experimental Unit and Rothamsted Experimental Station*-Conference Proceedings (Paperback). Book.

Chaozi W., McNew C.P., Lyon S.W., Walter M.T., Volkman T.H.M., Abramson N., Sengupta A., Wang Y., Meira Neto A.A., Pangle L., Troch P.A., Kim M., Harman C. & Dahlke H.E. 2019. *Particle tracer transport in a sloping soil lysimeter under periodic, steady state conditions.* Journal of Hydrology 569 (2019) 61–76.

Chatain V., Benzaazoua M., Cazalet L.M., Bouzahzah H., Delolme C., Gautier M., Blanc D. & de Brauer C. 2013. *Mineralogical study and leaching behavior of a stabilized harbor sediment with hydraulic binder*. Envir. Sci. Poll. Res., DOI 10.1007/s11356-012-1141-4.

Damian F., Jelea S.G., Lăcătușu R. & Mihali C. 2019. *The treatment of soil polluted with heavy metals using the sinapis Alba L. and organo zeolitic amendment,* Carpathian Journal of Earth and

Environmental Sciences. 14(2):409-422; DOI:10.26471/cjees/2019/014/090.

Damian G., Szakacs Z., Iepure G. & Damian F. 2019. *Distribution of heavy metals in granulometric fractions and on soil profiles*. Carpathian Journal of Earth and Environmental Sciences. Vol. 14(2): 343 - 351; DOI:10.26471/cjees/2019/014/085.

Dumitru E., Calciu I., Carabulea V. & Canarache A. 2009. *Methods of analyses used in soil physics laboratories*. Ed. Sitech, Craiova, 341 pages (in Romanian).

Elke B. & Vogeler I. 2018. *Influence of graded EDTA applications on mobilization and translocation of trace elements—a soil column experiment*. J. Plant Nutr. Soil Sci., 181: 220–230, DOI: 10.1002/jpln.201700353.

Geiger R. 1961. *Überarbeitete Neuausgabe von Geiger, R.: Köppen-Geiger / Klima der Erde*. (Wandkarte 1:16 Mill.) – Klett-Perthes, Gotha.

Hillel D. 1980. *Applications of soil physics*. Academic Press. New York. USA.

Ispas G., Roba C., Bălc R., Coadă M. & Gligor D. 2018. *The quality of water and soil in Haneș mining area, Alba County, Romania*. Carpathian Journal of Earth and Environmental Sciences, Vol. 13(2): 505-514; DOI:10.26471/cjees/2018 /013/043.

Jiangbo Q., Sun H., Luo X., Zhang W., Mathews S. & Yin X. 2017. *EDTA-assisted leaching of Pb and Cd from contaminated soil*. Chemosphere 167: 422-428.

Jones A., Montanarella L., Micheli E., Spaargaren O. & Jones R.J.A. 2010. *Major soil types of Europe*. EC JRC, EU Publication Office, Luxembourg.

Lăcătușu R. 2017. *Agrochemistry*, Terra Nostra Publisher, Iasi, 440 pp. (in Romanian).

Lăcătușu R., Paltineanu C., Vrinceanu A. & Lăcătușu A. R. 2019a. *Influence of domestic activity on the quality of groundwater and surface water in the rural built-up area of the southern Romanian Danube Plain–a case study in the Glavacioc catchment.* Carpathian Journal of Earth and Environmental Sciences, Volum 14(2): 323-334. DOI:10.26471/cjees/2019/014/083.

Lăcătușu R., Paltineanu C., Lăcătușu A.R., Rizea N. & Dragomir S. 2019b. *Nitrate pollution of groundwater from built-up areas of the Glavacioc catchment.* 19 International Multidisciplinary Scientific GeoConference SGEM2019, Section of Hydrology and water resources, vol. 19: 419-426, doi.org/10.5593/sgem2019/3.1

Li Y., Gao R., Yang R., Wei H., Li Y., Xiao H. & Wu J. 2013. *Using a Simple Soil Column Method to Evaluate Soil Phosphorus Leaching Risk.* Clean – soil air water.

Liu F., Qiao X., Zhou L., & Zhang J. 2018. *Migration and Fate of Acid Mine Drainage Pollutants in Calcareous Soil*. International Journal of Environmental Research and Public Health, 15, 1759.

López-Piñeiro A., Peña D., Albarrán A., Sánchez-Llerena J. & Becerra D. 2014. *Long-term effects of olive mill waste amendment on the leaching of herbicides through undisturbed soil columns and mobility under field conditions*. Soil & Tillage Research, 144: 195–204

Martonos I. M. & Sabo H. M. 2017. *Quality of drinking water supplies in Almaşu rural area (Salaj county, Romania).* Carpathian Journal of Earth and Environmental Sciences, Vol. 12(2): 371 – 376.

Nest T. Vanden, B. Vandecasteele, G. Ruysschaert, & Merckx R. 2014. *Incorporation of catch crop residues does not increase phosphorus leaching: a soil column experiment in unsaturated conditions*. Soil Use and Management, September 2014, 30, 351–360.

Păltineanu C., 2001. *Nutrient leaching in a cracked vertisol in Romania*. Agronomie 21(5), July-August, An international Journal in Agriculture & Environment, INRA, EDP Sciences, France, https://doi.org/10.1051/agro:2001135.

Păltineanu C., Chitu E. & Mateescu E. 2011. *Changes in crop evapotranspiration and irrigation water requirements*. International Agrophysics. 25(4), pp. 369-373.

Păltineanu C., Chitu E. & Mateescu E. 2012. *New trends for reference evapotranspiration and climatic water deficit*. 2012. International Agrophysics. 26(2), pp. 159-165.

Păltineanu C., Septar L. & Moale C. 2013. *Crop Water Stress in Peach Orchards and Relationships with Soil Moisture Content in a Chernozem of Dobrogea*. J. Irrig. Drain Eng. 139(1): 20–25. doi: 10.1061/(ASCE)IR.1943-4774.0000492.

Păltineanu C., Mihailescu I.F, Torica V. & Albu A.N. 2002. *Correlation between sunshine duration and global solar radiation in south-eastern Romania*. Int Agrophys. 16(2): 139-145.

Păltineanu C., Chitu E., Tanasescu N., Apostol G. & Pufu M.N. 2000. *Irrigation water requirements for some fruit trees specific to the Arges-Vedea river basin, Romania*. Acta Hort. 537:113-119.

Păltineanu C., Lăcătuşu R., Vrinceanu A., Vizitiu O. & Lăcătuşu A. R. 2019. *Comparing soil physical properties in forest soils and arable soils within heavy-clay Phaeozems: an environmental case study in Romania*. Agroforestry Systems. Volume 92, DOI: 10.1007/s10457-019-00373-9.

Păltineanu, C., Septar, L., Gavat C., Chitu E., Iancu M., Oprita A., Moale C., Lamureanu G., Calciu I. & Stroe V.M. 2016a. *Spatial distribution of apricot roots in a semi-arid environment.* Agroforestry Systems. Volume 90 (3): 469-478. DOI: 10.1007/s10457-015-9869-8.

Păltineanu C., Septar L., Gavat C., Chitu E., Oprita A., Moale, C., Calciu I., Vizitiu O. & Lamureanu G. 2016b. *Characterizing Root Density of Peach Trees in a Semi-arid Chernozem to Increase Plant Density*. International Agrophysics, Volume 30(1): 67–74, DOI:10.1515/intag-2015-0079.

Păltineanu C., Tanasescu N. & Chitu E. 2016c. *Pattern* *of soil physical properties in intensive plum and apple orchards on medium and course textured soils*. Soil & Tillage Research. 163(C): 80-88. DOI: 10.1016/j.still.2016.05.013.

Riyadh Al-R., Ngueleu S., Rezanezhad F., Van Cappellen Ph. 2018. *Groundwater pollution by petroleum-derived contaminants in coastal semiarid environment. Energy and Environment-Poster Display*. doi.org/10.5339/qfarc.2018.EEPD709.

Sohaib A., Iqbalb A., Lafoliec F., Recousb S., Benoita P. & Garniera P. 2018. *Mulch of plant residues at the soil surface impact the leaching and persistence of pesticides: A modelling study from soil columns.* Journal of Contaminant Hydrology: www.elsevier.com/locate/jconhyd.

Stagnitti F., Li L., Barry A., Allinson G., Parlange J.Y., Steenhuis W. & Lakshmanan E. 2001. *Modelling Solute Transport in Structured Soils: Performance Evaluation of the ADR and TRM Models*. Mathematical and Computer Modelling 34: 433-440.

Vitale C.M., Terzaghi E., Zati D. & Di Guardo A. 2018. *How good are the predictions of mobility of aged polychlorinated biphenyls (PCBs) in soil? Insights from a soil column experiment*. Science of the Total Environment 645: 865–875.

Wang K, Wang F, Song N, Liu J, Zhang T, Wang M. & Wang Y. 2018. *Contribution of root uptake to cadmium accumulation in two peanut cultivars: evidence from a split-column soil experiment*. Environmental Science and Pollution Research. 25:15036–15043, https://doi.org/10.1007/s11356-018-1719-6.

Zhao M., Chen X., Shi Y., Zhou Q. & Lu C. 2009. *Phosphorus vertical migration in aquic brown soil and light chernozem under different phosphorous application rate: a soil column leaching experiment*. Bull Environ Contam Toxicol 82:85–89, DOI 10.1007/s00128-008-9586-3.

Zhilong P., Wen J., Liu Y., Zeng G., Yi Y., Fang Y., Zhang S., Deng J. & Cai X. 2018. *Heavy metal leachability in soil amended with zeoliteor biochar-modified contaminated sediment*. Environ Monit Assess 190: 751, https://doi.org/10.1007/s10661-018-7124-2.

***http://www.fao.org/fileadmin/templates/nr/images/resources/images/SoilMap_hires.pdf. accessed in October 9, 2019.

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