Variation of sprinkler irrigation in relation to water infiltration and distribution in soils of western of Romania

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Abstract. This study reports the development and testing of a model which relates yield to irrigation amount and uniformity. Required input data are the Christiansen uniformity coefficient (CUC) and a parameter describing the sensitivity of crop yield to water deficits obtained from empirical relationships between evapotranspiration and crop yield. The model was used to determine optimum irrigation amounts for forestry nursery under sprinkler irrigation in soils of western Romanian. The research was carried out in the Iarac forestry nursery in the Iuliu Moldovan Forest District during 2012-2014, on an alluvial soil (the vertical-gleyed subtype). The placement of the sample markets was carried out according to the "divided parcels method" in two repetitions, and the surface of a parcel was 450 m^2. At the time when the measurements were taken, the meteorological conditions were: temperature of 23°C; wind speed of 1.5 m s^{-1}; total nebulosity 3; and relative humidity 47. The paper work displays the results obtained after the sprinkler irrigation, when we determined the quantity of water spread by the 6 sprinklers on a 15 m-radius, placed on the direction of the cardinal points and values of water infiltration after 24 hours by sprinkler irrigation. The purpose of this research is to emphasize the variation of the water infiltration after sprinkler irrigation correlated with the uniformity coefficient (Cristiansen) and the soil granulometry of the experimental field. This correlation is important, because the soil moisture values measured at a certain time frame after irrigation consists in an important parameter for the optimal amount of water supplied per unit area assessments. The results show that the optimum irrigation amount depends on irrigation uniformity, and on agronomic and physical properties of soil.
Key Words: sprinkler irrigation, uniformity of sprinkling, water infiltration, soil moisture.

Aims and background. In the quantitative study of infiltration, two indicators are used: the quantity of water infiltrated in a certain period of time, called accumulated infiltration (infiltration) and the speed at which the water infiltrates in a time unit, called infiltration speed (Cazacu 1989).

The soil permeability for water is measured with the aid of some indicators, among which we use the indicator - the infiltration speed of the water in the soil - for practical purposes related to the application of the irrigation water. We determine the volume of the water infiltrated in the surface unit and in the time unit (Vlad 1982).

The infiltration speed depends not only on the soil texture, but also on other factors like: the soil structure at the surface, the presence of the soil crusts, the type of coverage of the green soil, the compaction degree and the soil compaction, the content of humidity, the water temperature and the irrigation method (Plesa & Burchiu 1986).

The penetration of the water in the soil, also called infiltration, is of utmost importance for forestry, especially for the process of procurance of saplings in the forestry nurseries (Popescu & Popescu 2000).

With regards to the influence of the irrigation method on the infiltration speed of the water in the soil, the distinction results from the way in which infiltration occurs: vertically with aspersion and laterally with furrow irrigation (Grumezea & Kleps 2005).

The fluctuation of the infiltration speed is considerable: the coarse soils and the loose soils have the highest values, while the fine soils and compacted soils or the crusted soils at the surface have the lowest values (Trifu 1973).

With the exception of extreme cases, this hydro-physical indicator has values between 1 to 50 mm h^{-1}, as it follows: under 10 mm h^{-1} for the heavy soils, between 10 and 20 mm h^{-1} for the medium soils and above 20 mm h^{-1} for the light soils (Nedelcu 2004).

The values of the infiltration speed are used for the irrigation technique in order to establish the irrigation method, to calculate the technical elements of the watering or to choose the right type of sprinkling device, etc. (Sisesti 1971).

The infiltration speed at a certain time (instantaneous) is determined as a ratio between the water infiltrated in the soil (as water layer) and the duration of the infiltration (Mihai 1970).

In the case of the vast majority of irrigable soils in the country, we have to deal with the problem of increasing the infiltration speed of the water in the soil so that we could reduce the duration of irrigation. This aspect can be achieved through different means (Sabau et al 2011).

The determination of the infiltration speed on the irrigated fields must be acquired in very similar conditions to those in which the irrigation is done: the coverage type, the content of humidity, the type of water infiltration in connection with the irrigation method, etc. (Doneva 2010; Kirkova 2010; Kukali et al 2012).

Measurements of pore characteristics are becoming more and more used to characterize soil structure since they influence numerous functions in soils. One important function of soil is transmission of water, which directly affects plant productivity and the environment. Infiltration of water increases water storage for plants and groundwater recharge and reduces erosion. The rate of infiltration is controlled by the pore size distribution and the continuity of pores or pathways. The relations between soil pore structure induced by tillage and infiltration play an important role in flow characteristics of water and solutes in soil (Kutílek 2004).

Infiltration is the phenomenon by which water on the ground surface enters the soil in an aeration zone (soil, sediment or permeable rock), followed by a descendent movement that ends in the saturation zone. Loosely, the infiltration phenomenon has two distinct phases:

- the penetration of water on the ground surface and its entrance in the soil, under the topographic surface;
- the descendent movement with a rather vertical component, in an unsaturated area, from the surface of the ground to the first piezometric level, which marks the superior limit of the phreatic water bed.

The process of infiltration contributes to the transformation of the precipitations both in the retention water and the actively hydrodynamic water which generate the hypodermic drainage, the subsurface drainage and the recovery of the aquifer reserve.

In longer periods of time, the infiltration acts as a regularizing process of the hydrologic regime, making a part of reservation out of the atmospheric water, returned afterwards, more slowly, to the stream.

The physical process of water infiltration is dominated by complex interactions between the three present phases:

- the solid phase represented by the mineral matrix of the formations in the unsaturated zone through which the infiltration occurs;
- the liquid phase represented by the water derived from precipitations;
- the gaseous phase represented by the air present in the porous space unsaturated by water.

The forces occurring in the case of infiltration are gravity and capillarity, which put water in motion from the more humid zones towards those with a lower degree of humidity. The resistance forces that occur are: the friction of the surface water on the mineral particles and the counter-pressure exercised by the air existent in the ground. Among secondary factors, we can mention the viscosity of the water influenced by temperature and mineralization (the content of dissolved salts) of the water.

In the initial state of infiltration, the action of capillary forces is much more important than gravity, which is why the lines of current that indicate the drift track of water can be deviated in all directions. The capillary effect decreases as the humid front advances, insomuch that at a one-meter depth, the gravitational infiltration becomes dominant, developing in depth at a relatively uniform speed.

An important role in the infiltration dynamic is played by the air in the ground. At the beginning, the humid front advances non-uniformly, the air is evacuated in different directions and the infiltration speed decreases because of the consumption of energy. If the process of infiltration continues, a part of the air is dissolved and a certain increase of infiltration speed can be recorded.

Experimental. The research was carried out in the Iarac forestry nursery (Figure 1) in the Iuliu Moldovan Forest District (Arad County Branch) during 2012-2014, on an alluvial soil (the vertical-gleyed subtype). At the time when the measurements were taken, the meteorological conditions were: temperature of 23^{o}C; wind speed of 1.5 m s^{-1}; total nebulosity: 3; and relative humidity 47. The placement of the sample markets was carried out according to the “divided parcels method” in two repetitions, and the surface of a parcel was 450 m^2.

Figure 1. The placement of the Iarac nursery.

The present paper displays the results obtained after the sprinkler irrigation, when we determined the quantity of water spread by the 6 sprinklers on a 15 m-radius, placed on the direction of the cardinal points and values of water infiltration after 24 hours by sprinkler irrigation.

Thus, we established two surfaces for the sampling of the observational data, in a rectangular form, with a 450 m^2 (30 x 15 m) surface, among which one was the witness sample –the un-irrigated soil, and the other surface suffered successive modifications through the sprinkler irrigation. At each surface, we sampled 60 primary data, placed on the direction of the cardinal points (N, S, E, W) for each of the six sprinklers henceforth abbreviated (A1…A6) (Boja et al 2013).

In order to assess the impact of the irrigation through sprinkling on the water quantity in the soil, we had to determine the soil moisture at a 24-hour interval after the irrigation. The determination of the soil humidity was effectuated in the same points used for the determination of the sprinkling uniformity, but at a different depth (0-10 cm, 10-20 cm, 20-30 cm).

In order to determine the quantity of water in the soil which had been distributed by the sprinkling device, we effectuated soil profiles at a 30-cm depth, each and every meter, on two diagonals (the cardinal points: N, S, E, W), until a 15-m distance, for all the sprinkling devices included in the experiments. The gathered information appears in tables 4-6.

For the expedite determination of the soil moisture, we used a digital thermometer, Blumat Digital, which is an accurate tool for the measurement of the level of soil moisture, both for the inside and the outside, and for all the types of soils, even for the claylike fields.

As the water consumption of the saplings is concerned, it is necessary to be in the know of the quantity of water existent in the soil layer (Doneva 2010), because it constitutes the water reserve and it is expressed in m^3 ha^{-1} or in t ha^{-1}.

Knowing the soil moisture is of utmost importance for the orientation of the water reserve in the soil which is at the disposal of the saplings, for the establishment of the optimal moment of execution of the soil works and the determination of the moment and norm of watering.

Radial basis function interpolation. Radial basis function (RBF) interpolation consists in finding the coefficients, $\lambda = (\lambda_1,...,\lambda_n)$, for a base of radial functions and the coefficients, $c = (c_1,...,c_l)$, for a set of fitting polynomial, $p = \{p_1,..., p_l\}$, so that this interpolation function $s(x)$ defined below (Boer et al 2007):

$$s(x) = p(x) + \sum_{i=1}^{n} \lambda_i \cdot \phi(|x - x_i|) \ , \ x \in R^n \tag{1}$$

has to pass through the values of definition

$$s(x_i) = y_i \ , \ i = \overline{1,n} \ \text{ and } \sum_{j=1}^{n} \lambda_j \cdot p(x_j) = 0 \ , \tag{2}$$

where $(x_i; y_i)$ are the coordinates of N known points.

The thin plate radial function, $\phi(r) = r^2 \cdot \ln(r)$, was chosen for the studied case. These conditions, under the matrix form, can be written the following form (Carr et al 2003):

$$\begin{pmatrix} R & P \\ P^T & 0 \end{pmatrix} \begin{pmatrix} \lambda \\ c \end{pmatrix} = \begin{pmatrix} Y \\ 0 \end{pmatrix} \tag{3}$$

where we have: $R_{i,j} = \phi(|x_i - x_j|)$, $P_{i,l} = p_l(x_i)$, $Y_i = y_i$, $i, j = \overline{1,n}$, $l = \overline{1,m}$. The generated equations system has the solution given by Boja et al (2013), Modog et al 2010; Prada et al 2009.

$$\begin{aligned} c &= \left[(P^T \cdot R^{-1} \cdot P)^{-1}\right] \cdot (P^T \cdot R^{-1} \cdot Y) \ , \\ \lambda &= (R^{-1} \cdot Y) - (R^{-1} \cdot P) \cdot [(P^T \cdot R^{-1} \cdot P)^{-1} \cdot (P^T \cdot R^{-1} \cdot Y)] \ . \end{aligned} \tag{4}$$

In order to find out the granulometric structure of the soil from the parcels included in the experiment, we firstly determined their granulometry fractionally. This is strictly necessary because of the rapports existent between the granulometric fractions and other physical-mechanical properties. The coarse-grained part of the soil particles were determined through sieving, while the fine parts (dust, clay) trough sedimentation. The attempts were done in the Agro-Pedological Laboratory from the Department of Agriculture from Arad.

Results and Discussion

Granulometric analysis. The knowledge about the granulometric composition of a soil is extremely important because on one hand, it is in a direct connection with the water infiltration, and on the other hand, together with other constituents, it offers the soil better or worse biological valences.

From the analysis of the values gathered from the participation quotas of the granulometric fractions (Figure 2), we infer some interesting differences, as it follows:

- the soil presents a relatively close mixture, but in different proportions from the three granulometric fractions (Table 1), as it follows: sand 39.4%, dust 36.9% and clay 23.6%;
- the sand fraction (coarse and fine) is predominant (39.4%), with a heavy weight of fine sand (37.6%);
- in the case of the granulometric component of dust, the ratios change in the sense that the highest percentage belongs to the dust II (0.01-0.002 mm) 23.1%, and the lowest one is dust I (0.02-0.01 mm) 13.8%.
- the participation quotas of the clay granulometric fraction are the lowest, 23.6%, occupying a medial position between the other two.

The determination of the soil granulometry is essential so that we could refer to the quantity of water that infiltrates after 24h from the irrigation with sprinkling.

Table 1

Average values of the granulometric analysis at different depths of prelevation

Depth of prelevation of the sample	*Sand*		*Dust*		*Clay*
	Coarse	*Fine*	*I*	*II*	
(cm)	(%)				
0-10	1.6	36.8	13.2	23.8	21.8
10-20	1.7	37.1	13.8	23.1	23.8
20-30	2.2	38.8	14.5	22.5	25.2
Average per profile	1.8	37.6	13.8	23.1	23.6

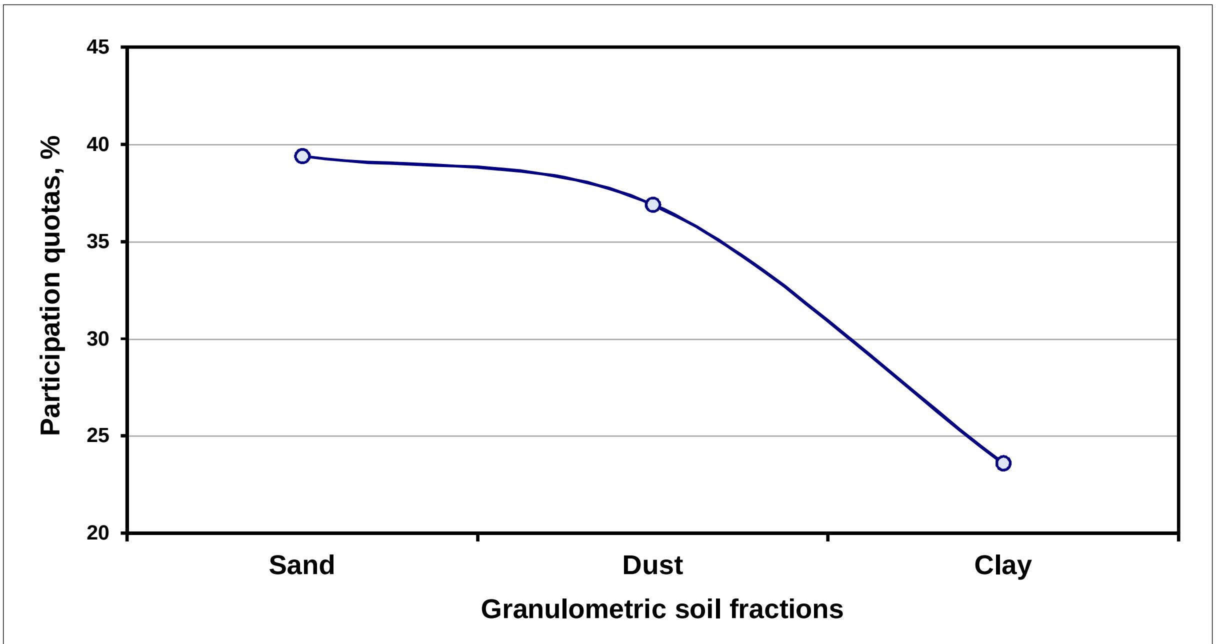

Figure 2. Granulometric curve analysis of the nursery soil.

Christiansen coefficient of uniformity

$$C_u = 100\left(1 - \frac{\sum |a|}{m \cdot n}\right) \quad (5)$$

where:

$\sum a$ represents the sum of the partial deflections from the average volume of water collected in pluviometers, in cm^3;

m - the average volume of water collected in pluviometers, in cm^3;

n – number of pluviometers (Popescu & Popescu 2000; Grumezea & Kleps 2005).

The condition of a good uniformity is: Cu > 80-85%. The distribution scheme of the water sprinkled on the surface of the soil is of great importance for the acknowledgement of the quality of watering. This distribution, expressed through the coefficient of uniformity, has deep implications on the development of cultures and, thus, on the productions obtained.

In the experiments of both our Romanian and foreign researchers, the coefficient mostly used is that of uniformity (Cu (%)), after Christiansen (Grumezea & Kleps 2005).

$$C_u = 100\left[1 - \frac{\sum(h - \overline{m})}{\overline{m} \cdot n}\right] \quad (6)$$

with:

h is the height of the water in each pluviometric box, in mm;

$\overline{m}$ - average height of water fallen in pluviometers, mm;

n – number of pluviometers.

For the interpretation: when Cu=100-85% good and very good uniformity, Cu=85-75% average uniformity, Cu=75-65% weak uniformity, Cu=65% inadequate uniformity (Popescu & Popescu 2000; Grumezea & Kleps 2005).

The values obtained for the Christiansen coefficient of uniformity are presented in Table 2.

Table 2

Values of the Christiansen coefficient of uniformity (%) determined for the six sprinklers according to the cardinal points

Sprinkler	*Cardinal points*			
	North	*East*	*South*	*West*
A1	84.262	99.777	110.655	105.305
A2	98.497	102.741	93.192	105.570
A3	92.490	107.949	98.463	101.098
A4	78.125	101.042	112.083	108.750
A5	75.158	98.795	111.876	114.171
A6	79.732	104.899	104.899	110.469

Pernes coefficient of uniformity (%)

$$C_u = 100\left(\frac{H_o}{H_m} \cdot \frac{s}{S}\right) \quad (7)$$

with:

H_o – is the minimum height of the rain fallen on the irrigated surface, in mm;

H_m – is the average height of the fallen rain, in mm;

s – the irrigated surface which received from 80% to 120% from the height of the average rain in m^2 ;

S – the total surface watered, in m^2.

The interpretation of the results is made as it follows: Cu < 50% - inadequate uniformity; Cu < 75% - medium uniformity; Cu > 75% - very good uniformity (Popescu & Popescu 2000; Grumezea & Kleps 2005) (Table 3).

Water infiltration. The results gathered appear in Tables 4-6 for the average values of the quantity of water stored in the soil at a distance from the sprinkling device, at the sample depth with the purpose of emphasizing the variation of the soil humidity after the irrigation (Figure 3).

Table 3

Values of the Pernes coefficient of uniformity grouped according to the distance to sprinkler

Distance from the sprinkler (m)	*Coefficient of uniformity*
1	76.50
2	72.73
3	78.18
4	66.43
5	63.05
6	58.14
7	60.37
8	69.98
9	59.77
10	49.67
11	44.14
12	29.70
13	37.65
14	43.64
15	46.83

Table 4

Average values of the soil moisture grouped by cardinal points on 0-10 cm depth

Distance from the sprinkler (m)	*Average values (%)*			
	North	*East*	*South*	*West*
1	25.83	25.33	25.22	25.73
2	24.08	24.77	23.62	24.10
3	23.82	23.82	23.90	24.23
4	23.85	24.55	23.08	22.65
5	23.47	23.95	22.78	22.07
6	23.63	23.72	23.10	21.77
7	24.33	22.97	22.88	21.87
8	23.45	21.97	22.55	21.97
9	22.63	20.73	21.72	21.10
10	22.48	19.92	20.38	20.73
11	20.45	19.22	19.68	20.37
12	19.85	18.73	19.25	19.80
13	19.02	18.62	18.85	19.23
14	18.65	18.48	18.62	18.68
15	18.57	18.45	18.53	18.60

Table 5

Average values of the soil moisture grouped by cardinal points on 10-20 cm depth

Distance from the sprinkler (m)	*Average values (%)*			
	North	*East*	*South*	*West*
1	22.80	22.30	22.18	22.70
2	21.05	21.73	20.58	21.07
3	20.78	20.78	20.87	21.20
4	20.82	21.52	20.05	19.62
5	20.43	20.92	19.75	19.03
6	20.60	20.68	20.07	18.73
7	21.30	19.93	19.85	18.83
8	20.42	18.93	19.52	18.93
9	19.60	17.70	18.68	18.07
10	19.45	16.88	17.35	17.70
11	17.42	16.18	16.65	17.33
12	16.82	15.70	16.22	16.77
13	15.98	15.58	15.82	16.20
14	15.62	15.45	15.58	15.65
15	15.53	15.42	15.50	15.57

Table 6
Average values of the soil moisture grouped by cardinal points on 20-30 cm depth

Distance from the sprinkler (m)	*Average values (%)*			
	North	*East*	*South*	*West*
1	20.77	20.27	20.15	20.67
2	19.02	19.70	18.55	19.03
3	18.75	18.75	18.83	19.17
4	18.78	19.48	18.02	17.58
5	18.40	18.88	17.72	17.00
6	18.57	18.65	18.03	16.70
7	19.27	17.90	17.82	16.80
8	18.38	16.90	17.48	16.90
9	17.57	15.67	16.65	16.03
10	17.42	14.85	15.32	15.67
11	15.38	14.15	14.62	15.30
12	14.78	13.67	14.18	14.73
13	13.95	13.55	13.78	14.17
14	13.58	13.42	13.55	13.62
15	13.50	13.38	13.47	13.53

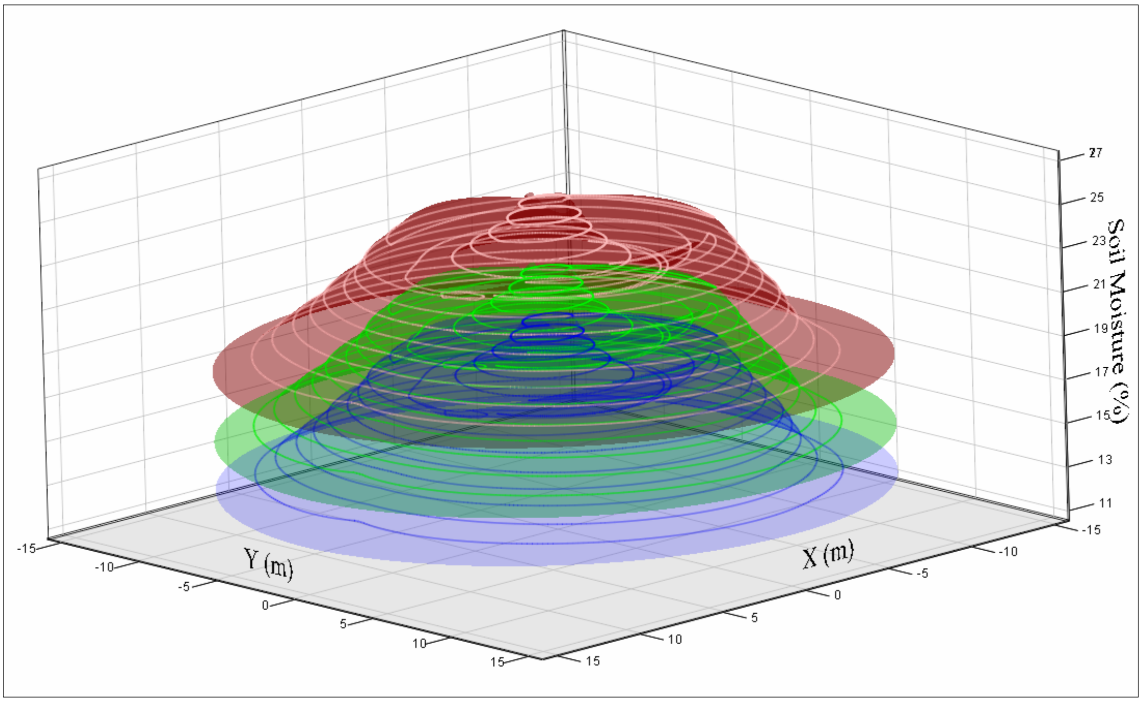

Figure 3. Variation of average values of the soil moisture for three sampling depths (red: 0-10 cm; green: 10-20 cm; blue: 20-30 cm).

We can draw the following conclusions after analysing the data in Tables 7-10, which gather average values of the soil moisture recorded at the cardinal points, at certain distances from the sprinkling device and at the sample depth (Figure 4):

- the largest quantity of water accumulated in the soil after the irrigation is recorded at a 0-10 cm depth;
- high values of soil moisture in the 0-10 cm blanket are recorded until a 10 m distance from the sprinkling device (humidity above 20%);
- normal values of soil moisture in the 10-20 cm blanket are recorded until a 6 m distance from the sprinkling device, because at greater distances we inferred oscillations of humidity;
- the soil moisture determined at a 20-30 cm depth presents quite sizeable variations, dependent on the distance of determination from the sprinkling device; these

variations are due to the relatively short amount of time of the water infiltration from the irrigation.

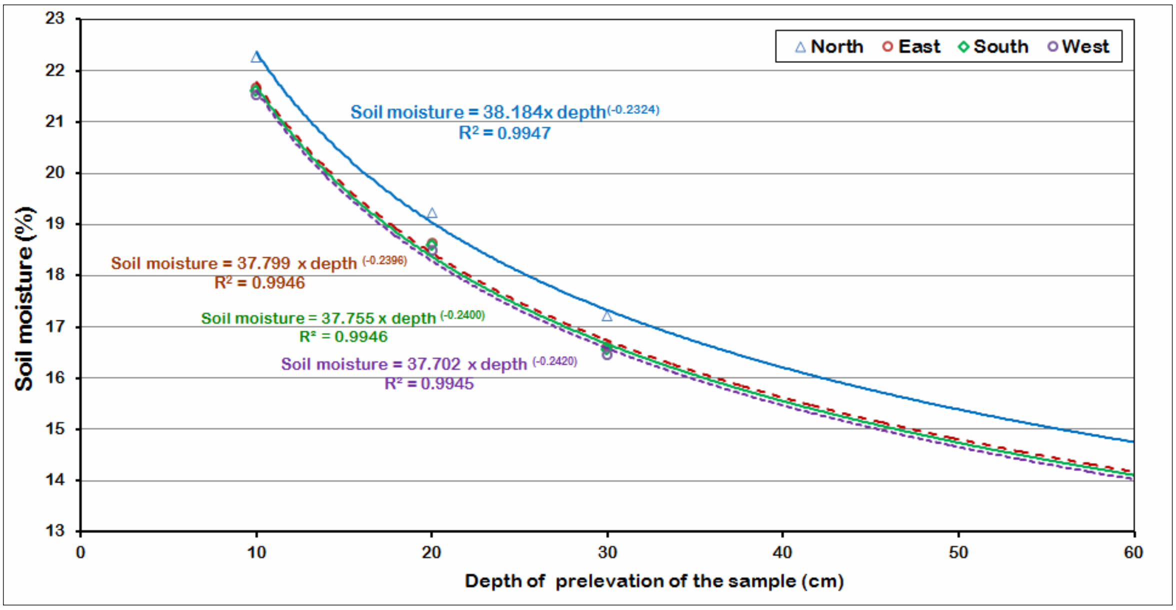

Figure 4. Variation of average values of the soil moisture on the direction of the cardinal points.

Table 7

Average values of the soil moisture on the direction of the cardinal points

Depth (cm)	*Cardinal points*			
	North	*East*	*South*	*West*
10	22.27	21.68	21.61	21.53
20	19.24	18.65	18.58	18.49
30	17.21	16.61	16.54	16.46

Table 8

Variance of some statistical indexes of the average values of the soil moisture in connection with the cardinal points on 0-10 cm depth

Statistical indexes	*Cardinal points*			
	North	*East*	*South*	*West*
Mean	22.27	21.68	21.61	21.53
S.E.M. (Average standard error)	0.60	0.67	0.57	0.54
Standard deviation	2.34	2.61	2.19	2.08
Coefficient of variation	0.10	0.12	0.10	0.10
Minimum	18.57	18.45	18.53	18.60
Maximum	25.83	25.33	25.22	25.73
The number of feature values (N)	15	15	15	15
Skewness	-0.46	-0.04	-0.15	0.37
Curtosis	-1.14	-1.64	-1.34	-0.59
Mean deviation	2.12	2.52	2.05	1.74
Median	23.45	21.97	22.55	21.77
Range	7.26	6.88	6.69	7.13
Confidence level (0.95)	1.29	1.45	1.22	1.15
Lower confidence limit	21.67	21.01	21.04	20.99
Upper confidence limit	22.88	22.36	22.18	22.06

Table 9

Variance of some statistical indexes of the average values of the soil moisture in connection with the cardinal points on 10-20 cm depth

Statistical indexes	*Cardinal points*			
	North	*East*	*South*	*West*
Mean	19.24	18.65	18.58	18.49
S.E.M. (Average standard error)	0.60	0.67	0.57	0.54
Standard deviation	2.34	2.61	2.19	2.08
Coefficient of variation	0.12	0.14	0.12	0.11
Minimum	15.53	15.42	15.50	15.57
Maximum	22.80	22.30	22.18	22.70
The number of feature values (N)	15	15	15	15
Skewness	-0.46	-0.03	-0.15	0.38
Curtosis	-1.14	-1.64	-1.34	-0.59
Mean deviation	2.12	2.52	2.05	1.74
Median	20.42	18.93	19.52	18.73
Range	7.27	6.88	6.68	7.13
Confidence level (0.95)	1.29	1.45	1.21	1.15
Lower confidence limit	18.64	17.97	18.01	17.96
Upper confidence limit	19.85	19.32	19.14	19.03

Table 10

Variance of some statistical indexes of the average values of the soil moisture in connection with the cardinal points on 20-30 cm depth

Statistical indexes	*Cardinal points*			
	North	*East*	*South*	*West*
Mean	17.21	16.61	16.54	16.46
S.E.M. (Average standard error)	0.60	0.67	0.57	0.54
Standard deviation	2.34	2.61	2.19	2.08
Coefficient of variation	0.14	0.16	0.13	0.13
Minimum	13.50	13.38	13.47	13.53
Maximum	20.77	20.27	20.15	20.67
The number of feature values (N)	15	15	15	15
Skewness	-0.46	-0.03	-0.15	0.38
Curtosis	-1.14	-1.64	-1.34	-0.59
Mean deviation	2.12	2.52	2.05	1.74
Median	18.38	16.90	17.48	16.70
Range	7.27	6.89	6.68	7.14
Confidence level (0.95)	1.30	1.45	1.21	1.15
Lower confidence limit	16.60	15.94	15.98	15.92
Upper confidence limit	17.81	17.29	17.11	17.00

In order to synthetize more efficiently the data and to describe more accurately the intrinsic characteristics of the sample, we proceeded to the statistical processing with the aid of the KyPlot (Kyplot Version 5.0.2) program (http://www.kyplot.software.informer.com).

Without insisting on all the interesting aspects contained as informational messages in the values of the statistical indicators, we have to point out, though, that the average values of humidity are very close at the level of distances from the sprinkling device, especially in the case of the sample depth.

We can also notice the values of the coefficient of variation of the geometric means, which are below 1, for both determinations, which indicates a severe homogeneity of sampled data.

Conclusions. From the analysis of the values gathered from the participation quotas of the granulometric fractions, we infer some interesting differences: the soil presents a relatively close mixture, but in different proportions from the three granulometric fractions, as it follows: sand 39.4%, dust 36.9% and clay 23.6%.

Values of the Christiansen coefficient of uniformity determined for the six sprinklers according to the cardinal points indicates a very good uniformity (Cu > 75%).

Values of the Pernes coefficient of uniformity grouped according to the distance to sprinkler indicates a medium uniformity (50% > Cu < 75%) up to a distance of 10 m from sprinkler.

The average value of soil moisture for the six sprinklers and all cardinal points measured in the 0-10 cm depth is 21.77%. The average value of soil moisture for the six sprinklers and all cardinal points measured in the 10-20 cm depth is 18.74%. The average value of soil moisture for the six sprinklers and all cardinal points measured in the 20-30 cm depth is 16.71%.

Christiansen uniformity coefficient high values (Cu > 75%) resulted from the research analysis. This indicates very good sprinkler water distribution uniformity. Furthermore, as reflected by high soil moisture values measured after 24 hours from irrigation. Thus, in order to achieve an efficient management of water resources in the area, we recommend reducing the dispersed water flow up to 15%.

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