doi:10.14720/aas.2023.119.4.15748 Original research article / izvirni znanstveni članek

Influence of mulches on soil moisture and water infiltration in the tomato crop

Imerina TANKEUOO KOPA [1, 2], Mohamed MEDDI [1], Abdelhadi AMMARI [1]

Received August 23, 2023; accepted November 22, 2023.
Delo je prispelo 23. avgusta 2023, sprejeto 22. novembra 2023

Influence of mulches on soil moisture and water infiltration in the tomato crop

Abstract: Soil moisture is a key parameter of soil monitoring for observation of vegetation growth, predicting crop production, and improving water resource management. In this study, the objective is to compare the evolution of soil moisture in different mulches to determine the best mulch and its characteristics of infiltration in the soil. The experiment was conducted during the summer season in July-September 2022 on four different mulches (wood chips, sawdust, straw, mixture), and control at the experimental plot of Blida. The results showed that silt is the main matrix of the soil. The analysis of infiltration data identified modified Kostiakov as the best model of the study site, whose period of plant growth represents the phase during which we have a better infiltration under the mixture. The application of the mulch changes the moisture mainly at 15 cm and the conductivity at 10 cm. In addition, the mixture is the best mulch to conserve moisture in the soil while reducing the frequency of irrigation. The correlation between soil moisture and conductivity was overall very good. This was due to the effect of mulch, soil texture, plant root development, and capillary rise.

Key words: tomatoes, mulching, soil moisture, infiltration, soil electrical conductivity

Vpliv mulčenja na vlažnost tal in infiltracijo vode v nasadu paradižnika

Izvleček: Vlažnost tal je glavni parameter pri spremljanju lastnosti tal pri opazovanju rasti, napovedovanju pridelka in pri izboljševanju upravljanja z vodnimi viri. Predmet te raziskave je bil primerjati razvoj vlažnosti tal pri različnih načinih mulčenja z namenom določiti najboljši način mulčenja za infiltracijo vode v tla. Poskus je potekal v poletni sezoni od julija do septembra 2022 s štirimi načini mulčenja (lesni sekanci, žagovina, slama, mešanica) in kontrolo na poskusnem polju v Blidi, Alžirija. Rezultati so pokazali, da je bil kremenčev drobir glavna sestavina anorganskega dela tal. Analiza podatkov o infiltraciji vode je pokazala, da se je izkazal spremenjen Kostiakov model kot najboljši za preučevanje tal, v katerem predstavlja obdobje rasti rastlin fazo, v kateri je infiltracija vode v tla najboljša pri mulčenju z mešanico. Uporaba mulčenja spreminja vlažnost tal v glavnem na globini 15 cm in prevodnost tal na globini 10 cm. Dodatno je mešanica materialov za mulčenje najboljša, ker ohranja vlažnost tal in hkrati zmanjšuje pogostost namakanja. Korelacija med vlažnostjo in prevodnostjo tal je bila nasplošno zelo dobra kar je bilo posledica mulčenja, teksture tal, razvoja korenin in kapilarnega dviga.

Ključne besede: paradižnik, mulčenje, vlažnost tal, infiltracija, električna prevodnost tal

---

[1] National Higher School of Hydraulics (ENSH), Water and Environmental Engineering Laboratory (GEE), Blida, Algeria
[2] Corresponding author, e-mail: i.tankeuookopa@ensh.dz

1 INTRODUCTION

One of the fundamental soil parameters affecting the life of plants, animals, and microorganisms is soil moisture (Safari et al., 2021). Commonly defined as the amount of water present in the unsaturated zone, it is a key element for predicting agricultural production and improving water resource management. Its measurement in precision agriculture is an essential agronomic component for monitoring crop growth (Goel et al., 2020). Due to the importance of the role played by soil moisture, some scientists have developed different instrumentation observation methods, including the dialectical method by time domain reflectometry (TDR). Indeed, it is a method that cannot be ignored for the quality, ease of use, and accuracy of its measurements (Freire et al., 2020). Other researchers have instead focused on the issue of water conservation in the soil, establishing different techniques, including mulching (Stelli et al., 2018). An old practice (Jacks et al., 1955), consists of covering the soil surface with other materials, called "mulch" (Almetwally et al., 2019; Telkar et al., 2017). They can be applied to perennial or seasonal crops to: conserve water (Zegada-Lizarazu and Berliner, 2011), improve crop performance and wind control (Sharma et al., 2023; Simsek et al., 2017), increase plant health and vitality (Stelli et al., 2018), improve the action of microorganisms in the soil, and increase soil organic matter (Sharma et al., 2023; Simsek et al., 2017). According to an experiment conducted on different organic and inorganic mulches (Safari et al., 2021), the ideal depth is 15 cm with an increase of 2 to 5 % compared to bare soil (control). Organic materials are the most recommended as they can actively promote soil desalination and assist in the degradation of pesticides and other pollutants (Telkar et al., 2017). Several studies have been conducted in semi-arid and arid areas on the effects of mulching in conserving soil moisture (Almetwally et al., 2019; Mkhabela et al., 2019; Stelli et al., 2018; Simsek et al., 2017; Telkar et al., 2017) with interesting results. Some have also tested the effects of mulching on specific crops, such as tomatoes. It's a crop that is widely cultivated for its fruits that are consumed fresh or processed (Chaux and Foury, 1994). Currently, it represents the most cultivated and processed crop in the world (Sharma et al., 2023). Tomatoes play a major role in Algeria's agricultural economy. According to the Ministry of Agriculture and Rural Development (MADR), nearly 33,000 hectares of land are devoted to this crop (horticultural and industrial), with an average production of 11 million quintals and average yields of around 311 Qx ha^{-1} (MADR, 2009 in Tarchag, 2020, MADR, 2011 in Amichi et al., 2015). However, according to Sharma et al. (2023), water is one of the elements that directly affects tomato productivity. In addition to efficient use of available soil moisture, weed control, spacing, timing of planting, and judicious application of manure and fertilizer are all aspects that influence the success of tomato production (Lamont, 2005). The Mitidja, which is heavily dominated by vegetable crops and arboriculture, is one of the most fertile plains in Algeria (Meddi et al., 2013). However, in recent years, this plain is facing a decline in the water table of at least 40 m in some areas. This phenomenon is mainly due to poor water management, overexploitation of the water table by various industries, and drought episodes combined with the importance of irrigated areas (Djouda-Hallah, 2014). Another important process to consider in agriculture is infiltration, as it is one of the important components of the soil water balance in semi-arid areas (Liao et al., 2021). Furthermore, researchers (Oku and Aiyelari, 2011) have shown that soil infiltration properties can be quantified by fitting field infiltration data to model infiltration. Similarly, detailed knowledge of soil infiltration rates and characteristics can increase irrigation water use efficiency and reduce water losses (Haghiabi et al., 2011; Xing et al., 2017). To this end, scientists (Liao et al., 2021; Farid et al., 2019; Vand et al., 2018, Furman et al., 2006; Mishra et al., 2003) have developed several models to determine the infiltration rate and its characteristics.

The most commonly used are Philips, Kostiakov, modified Kostiakov, and Horton because of their performance and efficiency. However, despite all the advantages mentioned, mulching in general and organic mulching in particular is not a common practice in agricultural crops in Algeria. However, this technique can be a design solution to the great theme that is the conservation of moisture to the maximum and with efficiency in the soil, without destructuring and impoverishing it. That is why we studied the effects of mulching on soil moisture and infiltration of the soil in the cultivation of tomatoes. The specific objectives were to (1) characterize the soil of the site where tomato plants were planted; (2) determine the best infiltration model that best fits the study area; (3) study the effects of mulching on soil electrical conductivity, soil moisture retention and identify the best mulch among those studied as well as its ideal depth.

2 MATERIALS AND METHODS

2.1 EXPERIMENTAL SITE

The experiments were carried out in the Mitidja plain, at the experimental site of the National Higher School of Hydraulics (ENSH) of Blida, Algeria (36°30'31" N, 2°53'15" E, 110 m) (Fig. 1), during the period from

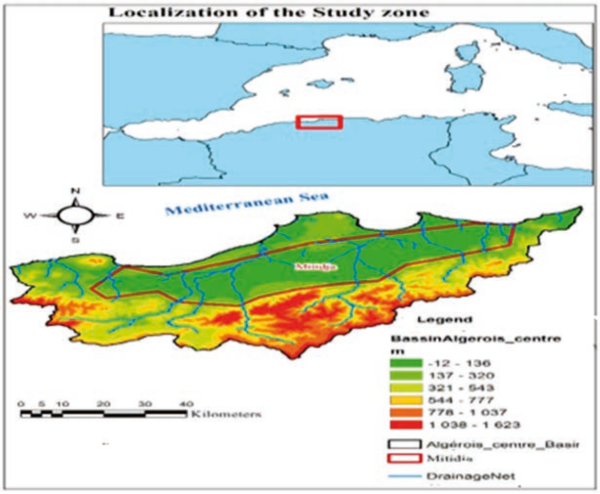

Figure 1: Location map of Mitidja plain

July to September 2022. According to Laribi et al. (2023), this plain extends today over four Wilayas (Blida, Tipaza, Bourmedès and Algiers), with an average annual temperature of 18 °C and a rainfall between 600 mm and 900 mm/year. According to this author, this plain is located in the bioclimatic Mediterranean subhumid area with mild winters. An agro-meteorological station was installed in the plot to obtain data on rainfall, air and soil surface temperature, wind speed, solar radiation and humidity. The data processing for the period July-September 2022 shows that the range of air temperatures varies from 25.25 °C (September) to 50.77 °C (August). On the other hand, on the surface of the ground, the range temperature is about 28.00 °C (September)–54.45 °C (August). The average relative humidity is 64.71 % with a minimum of 33.13 % and a maximum of 75.41 %; solar radiation is 247.70 W m^{-2}, wind speed is 2.54 m s^{-1} and evapotranspiration is 129.95 mm/day. There was no precipitation during this period.

2.2 SITE DESIGN

At this site, five plots of 4 m² were built (Fig. 2) (i.e. a total area of 40 m² with the respective additions of coarse (wood chips) and fine (sawdust) white wood bark mulch, wheat straw (cut to about 5 cm), the mixture of the first three mulches (with the same quantity of each mulch), and bare soil (here referred to as the control). The choice of mulches was based on the availability of inexpensive, abundant, and effective local materials. To monitor moisture until fruiting, 3-week-old 'Bahadja F1' hybrid tomato plants were planted in these plots. The distance between the ramps was 50 cm and 40 cm for the tomato plants and drippers, respectively. Each dripper was placed at the base of each plant and was self-regulating. In total, there were 12 tomato plants and 12 drippers per plot. The plants were irrigated with the surface drip system according to their needs at one-hour (1h) intervals in the evening. For the irrigation control, in addition to the

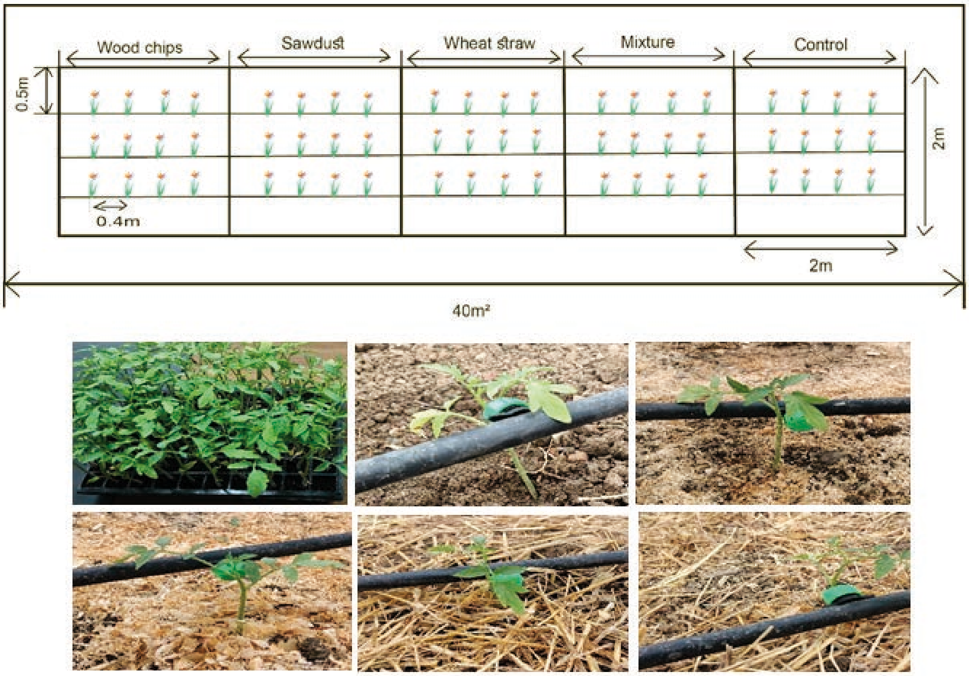

Figure 2: Design of the experimental setup and installation of mulch on tomato plants

literature, we used the template provided by the company responsible for the TDR 150 device, which visualizes the delineation of the moisture at the wilting point (WP) and the field capacity (FC) for each soil type. During this irrigation period, the average flow rate used was 7.72 l h^{-1}.

2.3 SOIL SAMPLING

The soils on which the tomato plants were planted were first physically analyzed to determine soil texture and bulk density. Five samples of disturbed soil, one per plot, were taken with a hand auger from 0 to 30 cm deep. Then five more undisturbed samples (always at the same points and depth) were taken with special samplers (cylinders). The entire sample collection was sent to the Agroecology Laboratory of the National Higher School of Hydraulics (ENSH) for analysis. The international method of Robinson (1949) was used to determine the different proportions of sands, clays, and silts of the reworked samples. Also, the texture of each soil was determined through its texture diagram. To determine the bulk density of each sample, a balance was used for wet and dry weighing, and an oven at 105 °C was used to dry the samples.

2.4 INFILTRATION MEASUREMENT

The double ring infiltrometer with an outer diameter of 32 cm and an inner diameter of 11 cm was installed in the ground to measure the infiltration rate in the field. During our fieldwork, this device was driven into the ground at a depth of 5 cm on a flat surface. The float was placed inside the inner ring to read the amount of water infiltrating into the soil. Measurements were taken at one-minute intervals. Infiltration measurements were taken before sowing tomato plants on bare soil in each plot, during the period of tomato plant growth under mulch, and at the end of crop growth at each soil sampling point. The rest of the experiment continued until the equilibrium infiltration rate was reached. After reaching this equilibrium infiltration rate (mm min^{-1}) in the soil, the experiment was stopped. This experiment was then repeated three times per plot.

2.5 DETERMINATION OF PARAMETERS OF DIFFERENT INFILTRATION MODELS

Philip, Kostiakov, and modified Kostiakov are the three models used in the study due to their popularity, effectiveness, and the type of soil present in the study area (Kostiakov, 1932; Philip, 1957). Experimental field data were used to evaluate these infiltration models and to obtain numerical values of the model hydraulic parameters. The hydraulic parameters of each model were determined using EXCEL software. The equations used for each model are described below.

- Philips model

This model is one of the physical models commonly used to estimate infiltration. Based on Darcy's law and the law of conservation of mass (Vand et al., 2018, Philips, 1957), it has the equation:

$$f(t) = \frac{1}{2}St^{-0.5} + K \qquad (2.1)$$

Where: *f(t)* is the infiltration rate at time *t*, *S* is the soil sorptivity, *K* is the hydraulic conductivity of the soil at saturation, and *t* is the time since infiltration began. In this study, to estimate the values of the parameters *S* and *K*, the infiltration rate data (mm min^{-1}) were fitted as a function of time transformed by least squares regression for all data obtained before sowing, during growth and at the end of fruiting at the five points.

- Kostiakov model

Kostiakov is a model based on the collection of experimental data obtained in the field, as well as in the laboratory. As an empirical model, it allows estimating the infiltration rate according to the equation:

$$f(t) = At^{-B} \qquad (2.2)$$

Where *f(t)* is the infiltration rate at time *t*; *A* and *B* are the parameters of the unknown equation representing the infiltration characteristics of the soil, with *A* the initial measurement of infiltration rate and soil structural condition, and *B* the stability index of the soil structure, *t* the time. To determine its parameters *A* and *B*, the logarithms (*ln*) of the infiltration measurements *f(t)* and time *(t)* were taken.

- Modified Kostiakov model

Also known as Kostiakov-Lewis or Mezencev it is commonly used in the infiltration function for surface irrigation applications (Haverkamp et al., 1988, Furman et al., 2006). Its equation is as follows:

$$F(t) = At^{-B} + f_c \qquad (2.3)$$

Where *F(t)* is the cumulative infiltration rate as a function of time; *A* and *B* are the hydraulic parameters of the equation, *t* is time, and *fc* is the stable infiltration rate. As with Kostiakov, the logarithms (*ln*) of the infiltration *f(t)* and time *(t)* measurements were taken to determine the *A* and *B* parameters.

2.6 SELECTION OF THE INFILTRATION MODEL ACCORDING TO PERFORMANCE CRITERIA

The comparison between the simulated and measured field data was performed according to the selected performance criteria to determine the best - fitting model in the range. The different criteria selected were based on their popularity and efficiency. These include, among others :

- Determination Coefficient (R^2)

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(x_i - y_i)}{\sum_{i=1}^{n}(x_i - \bar{x})} \qquad (2.4)$$

- The Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{1}{n}\left(\sum_{i=1}^{n}(x_i - y_i)^2\right)} \qquad (2.5)$$

- Nash and Sutcliffe efficiency coefficient (NASH)

$$NASH = 1 - \frac{\sum_{i=1}^{n}(x_i - y_i)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad (2.6)$$

- Error Index (PBIAS)

$$PBIAS = \frac{\sum_{i=1}^{n}(x_i - y_i) * 100}{\sum_{i=1}^{n}(x_i)} \qquad (2.7)$$

where *n* is the number of observations, x_i is the observed infiltration depth, y_i is the simulated infiltration depth and $\bar{x}$ is the mean of observed data

The best-fitting model was selected based on the maximum of the coefficient of determination R^2, Nash; the minimum of the root mean square error (RMSE) and the prediction error index (PBIAS), as established by Moriasi et al. (2007).

2.7 MEASUREMENT OF MOISTURE AND ELECTRICAL CONDUCTIVITY IN THE SOIL

The measurement of the amount of water in the soil was carried out throughout the period from the sowing of the tomato plants to the fruiting stage in each of the plots. It was carried out from July to September 2022. In our study, the TDR 150 was used because of its affordability, reliability, accuracy and ease of use. What's special about this device is that it can measure soil moisture, soil electrical conductivity and soil temperature at the same depth and on the same time scale. For this study, we considered only the first two parameters, because of their importance in irrigation and nutrient management. In the field, its spikes were inserted at 5 cm, 10 cm, 15 cm and 20 cm depths next to the tomato plants in each plot. Measurements were taken daily, three repetitions per plot between 4–8 p.m. and reported on data sheets. The data obtained was then processed in Excel software to produce graphs of the evolution of humidity and electrical conductivity at different depths.

3 RESULTS

3.1 PHYSICAL CHARACTERIZATION OF SOIL

The granulometric analysis by sedimentometry carried out according to the method of Robinson (1949) on five (05) samples, made it possible to obtain the percentages of sand (% S), silt (% L), and clay (% A) particles at a depth of 30 cm (Tab. 1). Observation of this table shows that silt is the main matrix of these soils, whose main texture is fine silty. The values of apparent density are between 1.24 and 1.67 g cm^{-3} with an average of 1.33 g cm^{-3}. The water holding capacity varies from 32 to 38 % depending on soil type, wilting point varies from 14 to 17 %, and field capacity varies from 32 to 38 %.

Table 1: Physical analysis of soil samples at 30 cm depth

Samples	Sand %	Clay %	Silt %	Textural Class	Bulk density	WP (%)	FC (%)	SWC (%)
Wood chips	41.7	10.3	49	Loam-Silty Loam-Silty sand	1.24	14	35	35
Sawdust	19.9	8.5	71.5	Silty loam	1.3	17	38	38
Wheat straw	38.1	11	52	Silty loam-loam	1.24	15	36	36
Mixture	21.9	7	70.5	Silty loam	1.18	17	38	38
Control	17.5	6	76.3	Silty loam	1.67	17	38	38

Note: *WP* = wilting point, *FC* = field capacity and *SWC* = Soil water capacity. The value of *WP, FC* and *SWC* were given by the company responsible for the TDR 150 device and the granulometric analysis was performed at the ENSH pedology laboratory

3.2 COMPARISON OF INFILTRATION RATES

Figure 3 shows the evolution of the infiltration rate observed in the field in each mulch and in the control before sowing, during the growth and after the ripening of the tomato plants. The general appreciation of these graphs highlights the rapidity of water infiltration into the soil during plant growth in all mulches and bare soil (control).

However, a closer look at the sawdust graph shows that the infiltration rate is slightly higher after the fruiting phase. In short, it evolves through the different phases. Based on this observation, we can deduce that this mulch improves the humidity of the soil over time, unlike other mulches. In fact, after the growth and fruiting phase, the soil water infiltration behavior of other mulches tends to be similar to that obtained during the pre-sowing phase of tomato plants. This behavior is best illustrated in the mixture. With this in mind, factors such as soil plowing, mulch decomposition and root system development need to be taken into consideration to explain the evolution of the humidity.

3.3 SELECTION OF THE BEST MODEL FOR THE STUDY SITE

The identification of the best infiltration model (Table 2) followed the determination of the hydraulic parameters (Table 2a) and the evaluation of the performance criteria (Table 2b).

3.3.1 Determination of the hydraulic parameters of each model in each mulch before sowing, during growth and after fruiting of tomato plants

Table 2a shows the hydraulic parameters of each model for each mulch before sowing, during growth, and after maturation of the tomato crop. From the annotation of these dashboards, it can be seen that high simulated hydraulic conductivity values are recorded for each model in all three phases during the plant development phase. The mixture also records very high values during this phase.

3.3.2 Evaluation of performance criteria for Philip, Kostiakov and modified Kostiakov models

Table 2b shows the different performance criteria used to determine the best model under each mulch in the study area. Looking at the values obtained from the different performance criteria for different models in each mulch, we note that the modified Kostiakov is the best model in the study area. We also note that the Philip model has the lowest PBIAS value, but unlike Kostiakov, very high RMSE values were found. Overall, these three models are applicable in the area, although modified Kostiakov is the best of the three.

3.4 EFFECT OF MULCH ON SOIL ELECTRICAL CONDUCTIVITY

Daily, soil electrical conductivity data were recorded in each mulch at different depths (Fig. 4). From the general shape of these curves, it can be seen that the highest conductivity values are recorded at 10 cm depth and lower at 5 cm depth at each mulch. However, a difference is observed first in wood chip and sawdust between 08/22/2022 - 01/09/2022, then in control between 16/09/2022 - 26/09/2022, where there is a high peak at 5 cm depth, unlike the rest of the depths. The individual observation of each figure shows that high conductivity rates are recorded within:

- treatments (wood chips, sawdust, straw, and mixture) between 08/22/2022-01/09/2022 and between 11/09/2022-21/09/2022
- bare soil (control) between 27/08/2022-06/09/2022 and between 16/09/2022-26/09/2022

The comparative study of the variation of the electrical conductivity of the soil shows overall very high rates of conductivity between 17/08/2022-06/09/2022.

The overview of Table 3 notices a slightly more pronounced increase in conductivity at 10 cm depth (0.44 µS cm^{-1}). The following classification can be made: 10 cm (0.44 µS cm^{-1}) > 15 cm (0.42 µS cm^{-1}) > 20 cm (0.39 µS cm^{-1}) > 5 cm (0.27 µS cm^{-1}. Also, a more pronounced increase in conductivity at the level of wood chips (0.41 µS cm^{-1}), followed by sawdust (0.37 µS cm^{-1}), straw (0.37 µS cm^{-1}), control (0.38 µS cm^{-1}), mixture (0.36 µS cm^{-1}). The difference between the mulches and the control varied from 0.1 to 0.3 µS cm^{-1}. The standard deviation values for the different mulches at each depth are less than 3 %. The very low deviations indicate that the data points are close to the mean. Showing that the data are homogeneous.

3.5 EFFECT OF MULCH ON SOIL MOISTURE

An overview of the various graphs at 5 cm, 10 cm, 15 cm and 20 cm depth (Fig.5) in each mulch shows that sawdust has a high water content at almost all soil depths,

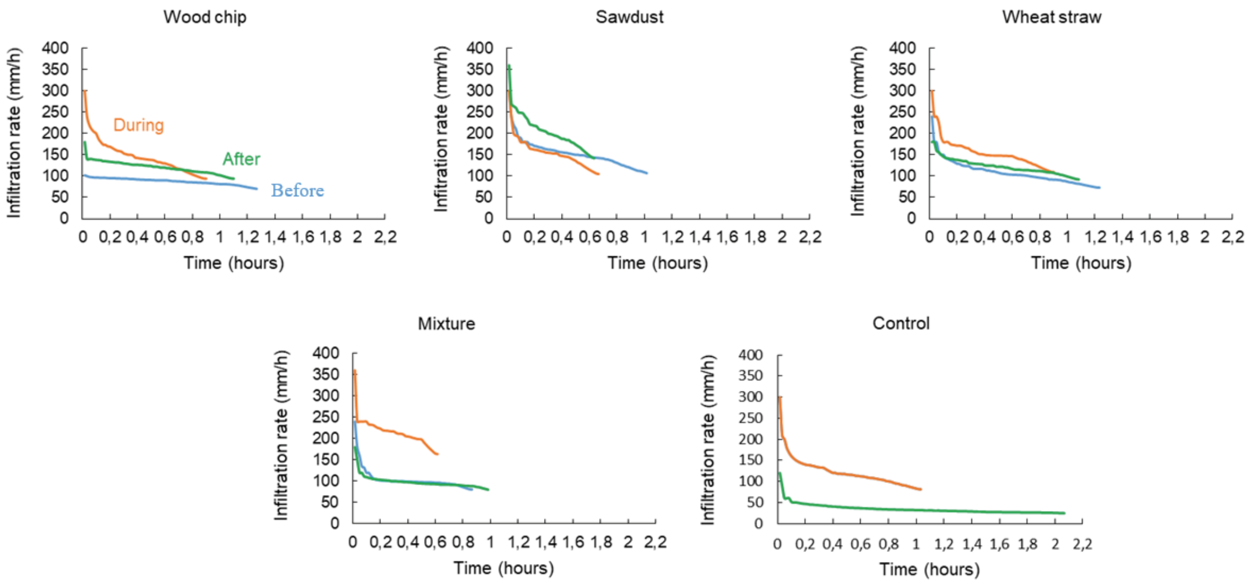

Figure 3: Comparison of infiltration rate (mm h^{-1}) observed before seeding tomato plants (blue color), during plant growth (orange color) and after fruiting tomatoes (green color) in the wood chip, sawdust, wheat straw, mixture and control

Table 2a: Hydraulic parameters of different models before sowing tomato plants, during tomato plant growth and after maturation of tomato plants

Plot	Period	P			K			KM		
		S (mm h^{-1})	K (mm h^{-1})	M	A (mm h^{-1})	B	M	A (mm h^{-1})	B	M
Wood chips	Before	9.27	80.07	87.65	82.47	0.07	87.65	0.63	0.85	1.46
	During	61.73	87.12	146.03	106.87	0.26	146.03	4.19	0.64	2.43
	After	21.35	102.16	120.77	108.34	0.11	120.77	1.41	0.75	2.01
Sawdust	Before	53.13	105.47	153.45	124.22	0.2	153.45	3.68	0.64	2.55
	During	53.54	96.93	155.34	111.34	0.23	155.34	3.59	0.63	2.58
	After	60.81	136.7	204.57	148.65	0.21	204.57	3.98	0.66	3.4
Wheat straw	Before	47.9	68.78	108.4	87.94	0.24	108.4	3.39	0.62	1.8
	During	54.62	103.57	155.69	122.01	0.21	155.69	3.81	0.62	2.59
	After	28.73	97.16	122.38	105.96	0.15	122.38	1.93	0.7	2.03
Mixture	Before	41.03	64.75	104.57	82.83	0.19	104.57	3.18	0.48	1.74
	During	44.02	164.69	214.4	173.55	0.14	214.4	2.95	0.67	3.57
	After	25.05	75.54	98.52	85.52	0.13	98.52	1.84	0.57	1.64
Control	Before	59.07	69.5	122.46	93.11	0.26	122.46	4.23	0.58	2.04
	During	59.07	69.5	122.46	93.11	0.26	122.46	4.23	0.58	2.04
	After	24.83	18.38	34.56	31.05	0.27	34.56	2.11	0.5	0.57
Min		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Max		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Mean		42.94	89.35	130.08	103.80	0.20	130.08	3.01	0.63	2.16

Note. *S*= Sorptivity (mm h^{-1}); *K*= parameter related to saturated hydraulic conductivity (mm h^{-1}); *A* and *B* = hydraulics parameters with *A* measurement initial infiltration (mm h^{-1}) and *B* is index evaluated stability; *P*= Philip model; *K*= Kostiakov model; *KM*= Modified Kostiakov model

Table 2b: Performance criteria and selection of the best model in each mulch (chip, sawdust, wheat straw, mixture) and control

Plot	Soil Texture	Period	R^2			NASH			RMSE			PBIAIS			Best model
			P	K	KM	P	K	KM	P	K	KM	P	K	KM	
Wood chips	L-Ls	Before	0.48	0.70	0.83	0.48	0.69	0.99	5.27	4.03	1.03	0.00	8.33	-13.33	Modified Kostiakov
		During	0.90	0.92	0.96	0.90	0.94	0.99	12.27	8.96	2.21	0.00	3.92	-19.35	
		After	0.70	0.81	0.94	0.70	0.82	0.99	7.82	6.07	1.24	0.00	12.47	-9.57	
Sawdust	lf	Before	0.90	0.91	0.98	0.90	0.94	0.99	9.83	7.82	1.61	0.00	15.42	-12.91	Modified Kostiakov
		During	0.91	0.90	0.98	0.91	0.93	0.99	10.55	9.36	1.11	0.00	23.28	-7.23	
		After	0.87	0.91	0.96	0.87	0.92	0.99	15.05	11.63	1.75	0.00	17.53	-13.29	
Wheat straw	lf	Before	0.91	0.94	0.97	0.91	0.96	0.99	7.88	5.39	1.93	0.00	3.36	-17.24	Modified Kostiakov
		During	0.92	0.92	0.98	0.92	0.94	0.99	9.61	7.85	1.37	0.00	17.35	-12.69	
		After	0.81	0.91	0.94	0.81	0.92	0.99	7.95	5.01	1.45	0.00	5.80	-16.70	
Mixture	lf	Before	0.94	0.86	0.99	0.94	0.84	0.99	5.72	10.13	0.28	0.00	45.45	-2.01	Modified Kostiakov
		During	0.79	0.79	0.98	0.79	0.79	0.99	14.42	14.51	0.82	0.00	42.23	-0.30	
		After	0.95	0.90	0.99	0.95	0.87	0.99	3.24	5.27	0.30	0.00	12.66	-2.04	
Control	lf	Before	0.95	0.95	0.98	0.95	0.96	0.99	7.69	6.96	1.63	0.00	12.22	-12.06	Modified Kostiakov
		During	0.95	0.95	0.98	0.95	0.96	0.99	7.69	6.96	1.63	0.00	12.22	-12.06	
		After	0.96	0.97	0.98	0.96	0.94	0.99	2.17	2.88	1.06	0.00	7.27	-6.60	
Mean			0.86	0.89	0.96	0.86	0.89	0.99	8.48	7.52	1.30	0.00	15.97	-10.49	
Min			0.48	0.70	0.83	0.48	0.69	0.99	2.17	2.88	0.28	0.00	3.36	-19.35	
Max			0.96	0.97	0.99	0.96	0.96	0.99	15.05	14.51	2.21	0.00	45.45	-0.30	

Note. *P* = Philip model; *K* = Kostiakov model; *KM* = Modified Kostiakov model

Table 3: Averages and standard deviations of soil conductivity retained for different mulches (wood chips, sawdust, wheat straw, mixture) and control at 5 cm, 10 cm, 15 cm and 20 cm depths

Mulches	Averages and standard deviations of soil conductivity (µS cm^{-1})					
	5 cm	10 cm	15 cm	20 cm	Mean (%)	SD (%)
Wood chips	0.24	0.5	0.46	0.43	0.41	0.10
Sawdust	0.32	0.41	0.38	0.37	0.37	0.03
Wheat straw	0.26	0.48	0.41	0.34	0.37	0.08
Mixture	0.2	0.39	0.43	0.43	0.36	0.10
Control	0.31	0.44	0.44	0.35	0.38	0.06
Mean (%)	0.27	0.44	0.42	0.39		
SD (%)	0.04	0.04	0.03	0.04		

Note: *SD* = standard deviation, *Mean* = average of soil conductivity in different mulches and depths

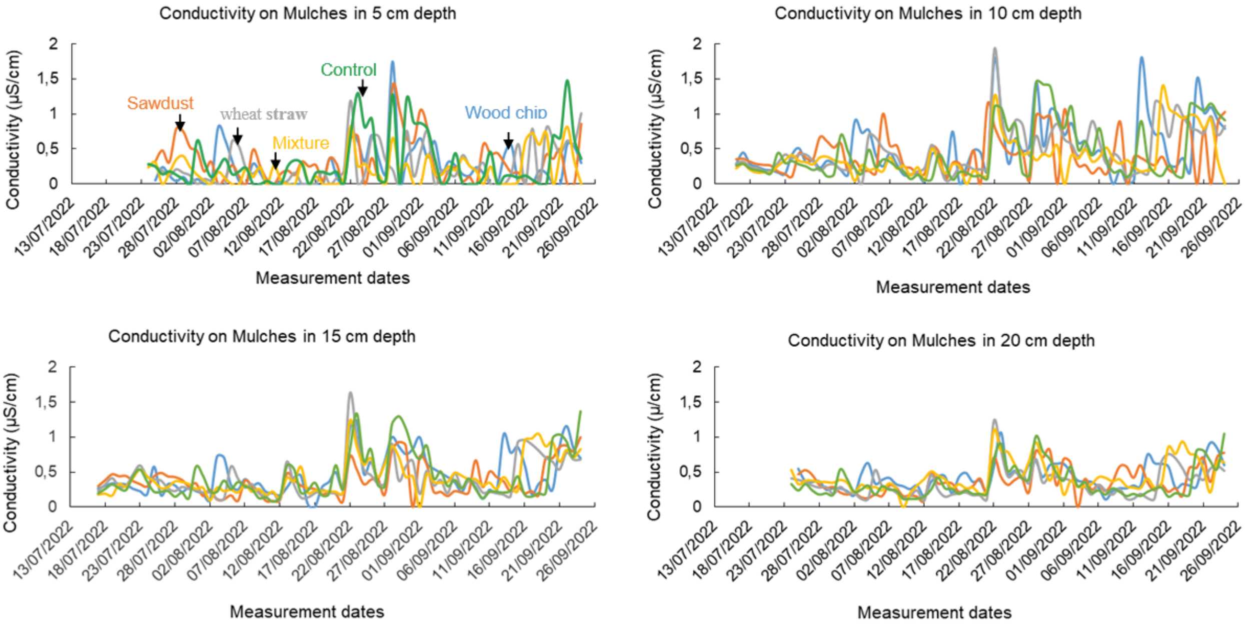

Figure 4: Variation in soil conductivity (µS cm^{-1}) each daily of wood chips (blue color), sawdust (orange color), wheat straw (gray color), mixture (yellow color) and control (green color) at 5 cm, 10 cm, 15 cm and 20 cm depth

while wood chips have a lower water content. However, at a depth of 20 cm, the opposite phenomenon is observed. Wood chips retain more moisture than sawdust.

The moisture data (Fig. 5) obtained on each mulch before and after irrigation allowed us to establish an existing relationship between the parameters: irrigation, moisture, mulch and actual evapotranspiration. The evapotranspiration calculated with the Pennan-Montheih formula was corrected with the crop coefficients of tomato to have plot - specific values. After irrigation under different mulches, the observation is mentioned in the level:

- of the wood chips of great moisture conservation in the soil between the end of August - beginning of September (25/08/2022-09/09/2022), that is 15 days of maximum retention. The observation of the graph shows a particular retention of only three days, justified by a strong increase in real evapotranspiration during this period. In addition, nine irrigation cycles were carried out during the crop.

- of sawdust of a great retention of moisture in the soil of maximum 13 days at the beginning of the growth and flowering stage of the plant (11/07/2022-04/08/2022). Observation of this graph also identifies eight rounds of irrigation during the development of the plant.

- of the straw, the great retention was identified

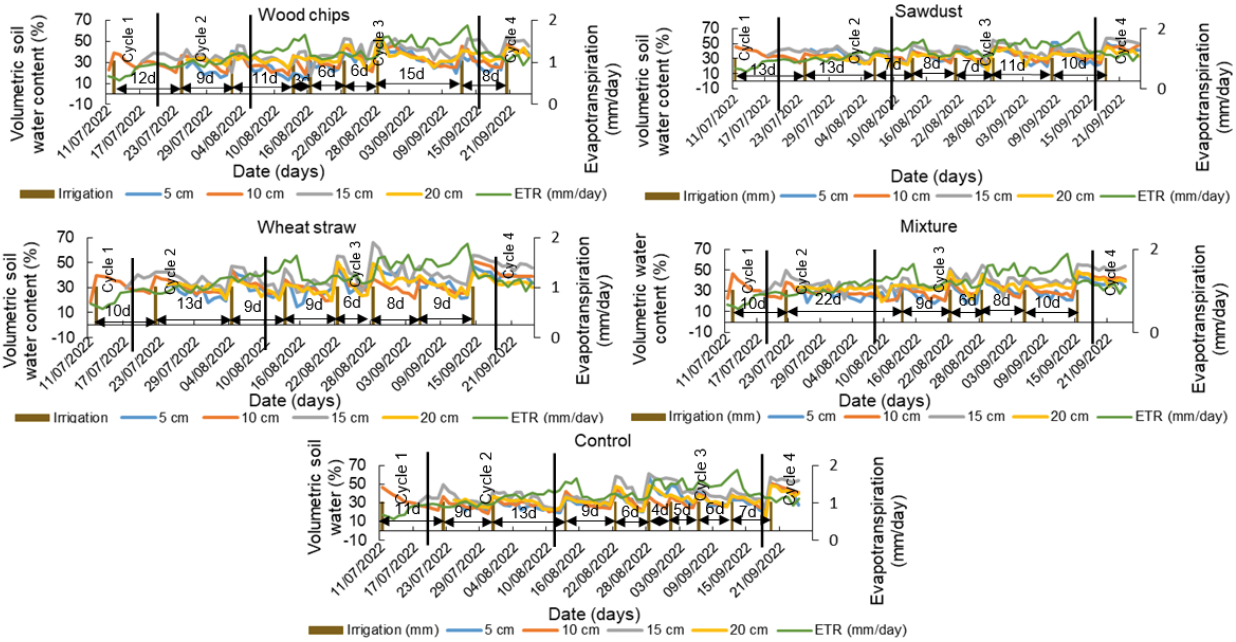

Figure 5: Effects of wood chips, sawdust, wheat straw, mixture, control on moisture at 5 cm; 10 cm; 15 cm and 20 cm depth each daily; relationship between soil moisture (%), irrigation (mm) and reel evapotranspiration (ETR) in mm/day to different mulches and control. The vertical bars represent plant growth stages; the horizontal bars represent the number of days (*d*) of moisture retention in the soil after each irrigation round and the small histograms represents the number of irrigated turns for each treatment

in the second cycle of the plant between 23/07/2022-01/08/2022 which is a maximum of 13 days of conservation. During the growth of the plant, the observation of the graph shows eight rounds of irrigation as the sawdust.

- of the mixture, conservation of humidity in the soil between 20/07/2022-10/08/2022 that is to say a maximum of 22 days. On the graph, we can also see that during the period of growth of the plant, seven rounds of irrigation were carried out.

- of the control, a maximum of 13 days between 07/29/2022-10/08/2022. Also on the graph, we see that during the growth the plants were irrigated 10 times.

Considering the average moisture content data in Table 4, the following classification by the average moisture content obtained in percentages is sawdust (35.6 %) > straw (34.3 %) > mixture (33.9 %) > control (33.8 %) > wood chips (33.7 %). We also note that 15 cm (39.7 %) is the depth at which we record a very high rate of water storage in the soil. In the same table, we observe a slightly significant difference in low water retention in wheat

Table 4: Averages, and standard deviations soil moisture retained for different treatments (wood chips, sawdust, wheat straw, mixture and control) at 5cm, 10cm, 15cm and 20cm depths

Mulches	Averages and standard deviation of soil moisture (%)					
Depths	5 cm	10 cm	15 cm	20 cm	Mean (%)	SD (%)
Wood chips	29.6	31.6	39	34.5	33.7	3.5
Sawdust	34.3	34.5	40.4	33.1	35.6	2.8
Wheat straw	32.4	32.5	40.3	32.1	34.3	3.5
Mixture	29.3	31.5	39.6	34.9	33.9	3.9
Control	31.6	31.4	39.4	33	33.8	3.3
Mean (%)	31.4	32.3	39.7	33.5		
SD (%)	1.8	1.2	0.5	1.0		

Note: *SD* = standard deviation, *Mean* = average of soil moisture in different mulches and depths

Table 5: Correlation between average soil electrical conductivity and soil moisture values at 5cm, 10 cm, 15 cm, 20 cm depths for different treatments

	5 cm	10 cm	15 cm	20 cm
Average humidity (%)	31.40	32.30	39.70	33.50
Average conductivity (µS cm^{-1})	0.27	0.44	0.42	0.39
R^2 Conductivity - Humidity	0.70	0.73	0.91	0.95

Note: R^2 = coefficient of determination

straw and the control; being of the order of 0.3 % (between 20 cm and 5 cm depth) and 0.2 % (between 10 cm and 5 cm depth), respectively. Similarly, indicating the homogeneity of the data, the standard deviation values are low (less than 8 %).

If we make a correlation between the averages of the values of electrical conductivity of the soil and humidity at different depths in different mulches (Tab.5), we obtain good results of coefficient of determination going from 0.70 to 0.95 in almost all the depths.

4 DISCUSSION

The results of the particle size analysis showed that silt is the main matrix of the soils of the different plots, whose main texture is fine silt. These results are consistent with those obtained by Ecrement and Seghir (1971) in the region. According to Skhiri (2019), the average bulk density within the silty soils is 1.3 g cm^{-3}. This result is consistent with that obtained in the study area, which is 1.33 g cm^{-3}. The general observation of the graphs showing the evolution of the infiltration rate observed in the field in each mulch and bare soil, before sowing, during the growth and after the ripening of the tomato plants, allows us to see that the infiltration of water into the soil is more rapid during the period of plant growth. This phenomenon is observed in all the mulches and in the bare soil (control). This can be explained, on the one hand, by the mulching of the soil surface and, on the other hand, by the plowing of the soil before sowing, in addition to the root development of the plant during this period. Several researchers (Liao et al., 2021, Farid et al., 2019) indicate that mulching would facilitate infiltration after irrigation or very heavy rainfall. The hydraulic parameters of each model observed in each mulch before sowing, during growth and after ripening of the tomato crop show that high values of simulated hydraulic conductivity are recorded for each model during the three phases of plant development. The mixture, which is the mulch, records the highest values. Some researchers attribute this increase to the mulching of the soil surface. They consider that mulching improves, if not increases, the rate of hydraulic conductivity in the soil (Mkhabela et al., 2019; Stelli et al., 2018, Simsek et al., 2017). As for the high values of the mixture, according to Bear (1972), they are justified by the very high ability of the soil under this mulch to let water through, unlike other mulches. Based on the evaluation of the selected performance criteria, the modified Kostiakov emerged as the best model in the study area. According to several researchers (Niyazi et al., 2022; Vand et al., 2018; Yuemei et al., 2008), the best model is the one with minimum RMSE and PBIAS, maximum R^2 and NASH. In our study, modified Kostiakov is the best because it has: R^2 equal to 0.996; Nash equal to 0.99997; RMSE equal to 0.279 and PBIAS equal to -19.35. Overall, these three models are applicable in the field, with the best being the modified Kostiakov. This result is similar to that obtained by Smerdon et al. (1988). These researchers have shown that modified Kostiakov is one of the best models to apply in surface irrigation. Thus, from these performance criteria, we can establish the following ranking: modified Kostiakov > Kostiakov≥ Philip. From the research conducted by Zolfaghari et al. (2012) on seven infiltration models, it is found that modified Kostiakov and Kostiakov are the two models with better ranking among all models. Mirzaee et al., (2014) on the one hand state that modified Kostiakov is the best model for fine silty loam soils and on the other hand it is among the best models suitable for loam, silty clay loam and clay loam soils. About the graphs illustrated concerning the simulation of the infiltration rate and the cumulative infiltration, we note that the best simulation is within the soil mulched with the mixture. Likewise, following the values of NASH and R^2 obtained at the level of the mixture, after the stage of maturation of the tomato, we identify very good values and therefore very good simulations, contrary to the first two stages. The plausible explanation is the presence of the mulch, because according to some researchers (Simsek et al., 2017; Zhang et al., 2014), mulching improves infiltration into the soil. As well, as the colored presence of roots in the soil coupled with the soil texture.

The average electrical conductivity values obtained in the soil are, on the whole, very low. Let us remember that electrical conductivity is a very important parameter in agriculture. It is mainly used to determine soil salinity, but it can also be used to estimate other soil properties (soil water content, soil temperature, soil pH, soil texture, organic matter, solution ion concentration, etc.) at the non-saline soil level (Cornwin and Lesh, 2005). According to the range suggested by the NRCS Soil Survey Handbook, we begin to have saline soil when the conductivity value is higher than 2 dS m^{-1} and non-saline soil when the conductivity value is lower than 2 dS m^{-1}. The values obtained in our study are well below the range suggested by the latter for non-saline soils. This is an assurance that the soil quality is ideal for agriculture. Also, a more pronounced increase in conductivity was observed at the level of wood chips (0.41 µS cm^{-1}), followed by sawdust (0.37 µS cm^{-1}), straw (0.37 µS cm^{-1}), control (0.38 µS cm^{-1}), mixture (0.36 µS cm^{-1}). Some authors (Simsek et al., 2017) have shown that mulching does not affect pH, electrical conductivity, bulk density and carbonate content in the soil. On the other hand, others have shown that all types of mulches have a much more positive effect because they maximally reduce the electrical conductivity within the soil properties (Kumar et al., 2012). According to our results, we notice that the electrical conductivity increases in almost all mulches, except at the level of the mixture, where it decreases compared to the control. The low value recorded at the level of the mixture compared to the control is indeed consistent with the results of the authors mentioned above. On the other hand, the opposite phenomenon (increase in conductivity) observed in the other mulches may be due, according to some researchers (Sadek et al., 2019, Pakdel et al., 2013, Chalker-Scott, 2007), to the decomposition of the organic mulch under the effect of appropriate nutrients released in the soil, which become available to plants. But also to the texture and other properties of the soil, which unfortunately we could not study. For example, the level of phosphorus in the soil, as pointed out by Donogemma et al. (2008). The peaks in conductivity observed between 17/08/2022-06/09/2022 could be due to soil moisture. According to the work of (Costa et al., 2014), electrical conductivity is strongly influenced by soil moisture. This is similar to the result obtained in our study during this period. We found during the same period, an increase in soil moisture. The increase in conductivity that is slightly more pronounced at 10 cm depth may be due to the root development of the plants and the texture of the soil.

Synthesizing the moisture data on graphs of each mulch at different depths, it is very clear that the mixture retains more moisture than the rest of the mulch and that the ideal retention depth is 15 cm. According to Dinushika et al. (2019) and Adams (1996), in arid or semi-arid zones, mulching would increase water retention in the soil from 0-40 cm depth. However, Stagnari et al. (2014) state that in a Mediterranean environment, mulching in general and straw in particular would increase the water retention in the soil from 5-15cm depth. According to an experiment conducted on different organic and inorganic mulches (Safari et al., 2021), the ideal depth is 15 cm with an increase varying from 2 to 5 % compared to the control on bare soil. The ideal depth chosen in our study is within the range suggested by the above authors. However, the rate recorded by Safari et al. (2021) is mainly consistent with sawdust. Kumar and Dey, (2011) remind us that the use of mulches on the soil surface would increase water diffusion under the vapor gradient during the growing season. They added by saying that this factor would increase the maximum water absorption under mulch. Next, we note that the mixture was irrigated less than the other mulches. This justifies its low percentage difference in soil water storage (2.3 %) compared to sawdust. Finally, we see that the mixture conserved a lot of soil moisture in the first two cycles. Over time, however, it tends to have the same characteristics as straw in particular. The plausible explanation for this is that the wood chips and sawdust mulch decomposed faster over time than the straw. The work of Kaboneka et al. (2021) and Boyer (2021) emphasizes the fact that these mulches have in common a very slow decomposition. In fact, according to the studies carried out in Burundi by Kaboneka et al. (2021) on the decomposition of wheat straw, it appears that this mulch is characterized by a predominance of substances resistant to decomposition (cellulose, hemicellulose, lignin) and by a very high ratio of carbon to nitrogen (C/N) (76.4), that is, three times higher than the standard (25) ideal for the mineralization of nitrogen and the rapid release of nutrients contained in organic materials. Likewise, the study by Boyer (2021), conducted in Quebec on the bibliographic research of the potential use of organic mulches, showed that the C/N ratio of wood chips is about 39.2; that is, slightly higher than the standard set. Furthermore, Nicolardot et al. (2001) point out that this ratio is considered to be the simplest biochemical indicator of the quality of organic matter, its decomposability and nutrient release potential. According to Kaboneka et al. (2021), its value indicates whether an organic substrate is rapidly or slowly decomposable. Thus, comparing the ratios of the values obtained by their authors shows that wheat straw does indeed take longer to start decomposing compared to wood. This result supports the one obtained in the study area. Furthermore, the straw was the mulch that retained the least amount of water in the soil during the period 13/08/2022-16/08/2022. This can be explained by the peak of water demand observed during the same period. Thus, at the level of mulches, the effective classification is as follows: mixture (07), sawdust (08), straw (08), wood chips (09) and control (10). The fact that the number of irrigated turns is lower for the mulch than for the bare soil control allows us to say that the mulch used allows to reduce the irrigation frequency. This result is in line with the researches carried out by some scientists (Ahmad et al., 2020, Chalker-Scott, 2007, Rasmussen, 1999). The latter emphasize the fact that the application of mulch can significantly reduce the frequency of irrigation and even eliminate the need for irrigation. The choice of mulch is crucial in that some will reduce irrigation more than others, as we observed with the mulches used in the study. During the period from 10/08/2022 to 12/09/2022, when real evapotranspiration was high (marked by two peaks, one on 13/08/2022 and the other on 09/09/2022), we find that the mulched soils were more resistant than the bare soil control because they were less irrigated. This result is consistent with that of Duchaufour et al. (2017), who mention that under the effect of mulching, soil evapotranspiration is reduced. Overall, it is noted that the mulches used retain more moisture in the soil than the control. This result is consistent with the research of Mkhabela et al. (2019) and Telkar et al. (2017), who indicated that soil moisture is retained under mulch. They also indicated that the percentage of water stored in the soil is higher under mulch than under bare soil. However, in our study, this result is not entirely true for the wood chips, which is an exception to the rule. In fact, the difference between the control and the wood chips is slightly higher than that of the wood chips, i.e. 0.1 %. This difference can be explained by the short duration of the study, but also by the nature of the soil. In fact, the wood chips, which are more enriched with sand, retain less moisture due to their texture. Also, since the difference between the two soils is very small, we can take into account the time of the study. Considering the differences that exist between the wood chips and the sawdust in terms of moisture retention and the number of watering cycles, we can explain them by the grinding of the wood. The finer the wood is ground, the more water it retains in the soil.

About the availability of the mulches used in the study, it should be noted that wood waste is widely available in Algeria. Indeed, (Irinslimane, 2007), points out that its recycled waste amounts to 7 to 8 million tons per year, and comes mainly from forestry operations and sawmills. As for (Chachoua, 2015), cereal growing accounts for more than 50 % of useful agricultural areas. The figures given by these researchers reassure us that sufficient water is being used for large areas of irrigation fields in Algeria.

The correlation between the average values of soil electrical conductivity and soil moisture at different depths in different mulches gave good results with coefficients of determination ranging from 0.70 to 0.95 in almost all depths. The strong correlation observed reflects the influence of soil moisture on conductivity. This result is in agreement with the one obtained by Costa et al. (2014) in Brazil.

5 CONCLUSION

In addition to climate change, the overuse of water, chemical fertilizers and pesticides in the cultivation of tomatoes in Algeria has become almost commonplace, in the quest for extreme profitability. Our study is intended to be useful in the sense that, in addition to conserving soil moisture, it can contribute to soil restructuring, as well as enrich the soil with the organic matter and nutrients plants need to grow and produce good yields. In addition, knowledge of the soil's infiltration rate and characteristics enables better irrigation management.

For scientists and researchers, this study contributes to a better understanding of organic mulch and soil moisture in crops. As for legislators, we encourage them to set up a policy to raise awareness among individuals, farmers and water managers of the advantages of organic mulch in agriculture.

Through this study, which aims to be simple in its application, economical and save time and energy, we encourage the above stakeholders to increasingly practice the use of organic mulch in their various crops. This limits weeds, preserves the environment, reduces irrigation requirements, improves water infiltration and conserves soil moisture. What's more, once decomposed, they form compost, ideal for plant growth. This reduces the need for nitrogen fertilizers.

However, if the organic mulch chosen has a positive effect on the various aspects mentioned above, it should be noted that the questions of application density, effect on the growth of tomato crops, and agricultural yield depending on the mulch chosen remain unknown. As is the question of soil temperature and organic matter content. We are currently working on these questions to gain a better understanding them.

6 ACKNOWLEDGMENTS

The study was carried out at the Water and Environmental Engineering Laboratory (GEE) of the Higher National School of Hydraulics (ENSH) of Blida. The study was carried out within the framework of the "AFRICAN WATER RESOURCES MOBILITY NETWORK" (AWaRMN) project funded by the Intra-Africa Academic Mobility Scheme of the European Union. Also, the study is carried out within the framework of the SWATCH project (Prima project) funded by the DGRSDT, Algeria.

7 REFERENCES

Adams J.E. (1966). Influence of mulches on runoff, erosion, and soil moisture depletion. *Soil Science Society of America Journal, 30*, 110–114. https://doi.org/10.2136/sssaj1966.03615995003000010036x

Ahmad, S., Raza, M., A. S., Saleem, M., F., Zaheer, M., S., Iqbal, R., Haider, I., Aslam, M., U., Ali, M., Khan, I., H. (2020). Significance of partial root zone drying and mulches for water saving and weed suppression in wheat. *Journal of Animal and Plant Sciences*, *3,* 154–162.

Almetwally, M., Soussa, H., Fattouh, E. M. (2019). Environmentally friendly soil water conservation techniques. *International Journal of Engineering and Advanced Technology*, *9*(1), 5513–5520. https://doi.org/10.35940/ijeat.A2045.10911

Amichi, F., Bouarfa, S., Lejars, C., Kuper, M., Hartani, T., Daoudi, A., Amichi, H., Belhamra, M. (2015). Des serres et des hommes : Des exploitations motrices de l'expansion territoriale et de l'ascension socioprofessionnelle sur un front pionnier de l'agriculture saharienne en Algérie. *Cahiers Agricultures*, *24*(1), 11–19. https://doi.org/10.1684/agr.2015.0736

Bear, J.(1972). Dynamics of fluids in porous media. *American Elsevier publishing company*, New York, 764 p

Boyer, L. (2021). Revue de littérature systématique sur le potentiel d'utilisation des paillis organiques à améliorer la qualité des sols et de la durabilité des vergers de pommes québécois. *Rapport de fin d'étude, Université de Laval*, 61p.

Chachoua I. (2015). *L'urée dans l'alimentation des ovins : conséquences sur la gestation, la parturition et le croît*. Thèse de Doctorat en sciences, universite el-hadj lakhdar-batna, Algérie. 133p

Chaux, C.L. et Foury, C.L., (1994*). Cultures légumières et maraichères. Tome III : légumineuses potagères, légumes fruit*. Tec et Doc Lavoisier, Paris. 563p.

Chalker-Scott, L. (2007). *Wood chip mulch : Landscape boon or bane ?* 21–23.

Corwin, D.L. and Lesch, S.M. (2005). Apparent soil electrical conductivity measurements in agriculture. *Computers and Electronics in Agriculture*, *46*, 11-43. https://doi.org/10.1016/j.compag.2004.10.005

Costa, M. M., de Queiroz, D. M., de Carvalho Pinto, F. de A., dos Reis, E. F., Santos, N. T. (2014). Efeito do teor de água na relação entre a condutividade elétrica aparente e atributos do solo. *Acta Scientiarum - Agronomy, 36*(4), 395–401. https://doi.org/10.4025/actasciagron.v36i4.18342

Dinushika, W., Mumtaz, C., Raymond, T., Lakshman, G. (2019). Effect of biochar on TDR-based volumetric soil moisture measurements in a loamy sand podzolic soil. *Soil Systems*, *3*(3), 1–12. https://doi.org/10.3390/soilsystems3030049

Djouda-Hallal D. (2014). *Approche méthodologique de la vulnérabilité de la ressource en eau souterraine en milieu fortement urbanisé: exemple en Algérie des plaines littorales (Mitidja*). Thèse de doctorat.USTHB, 157 p.

Donagemma, G. K. et al. (2008). Solution equilibrium phosphorus in clay and silt fractions of oxisols after particle size analysis pre-treatments. *Revista Brasileira de Ciência do Solo*, 32(2-4), 1785-1791. https://doi.org/10.1590/S0100-06832008000400043

Duchaufour, H., M. Bizimana, E. Roose , Mikokoro, C. (2017). Efficacité des haies mixtes, du fumier et du paillage pour la conservation de l'eau et la restauration de la productivité d'un sol ferralitique argileux acide du Burundi. In E. *Roose (edit.) Restauration de la productivité des sols tropicaux et méditerranéens. Contribution à l'agroécologie*. pp. 603-611. https://doi.org/10.4000/books.irdeditions.24492

Ecrement, Y., et Seghir, B. (1971). *Etude agro-pédologique de la plaine de la Mitidja et carte 1/50 000, Alger : Institut Géographique National.*

Farid, H. U., Mahmood-Khan, Z., Ahmad, I., Shakoor, A., Anjum, M. N., Iqbal, M. M., Mubeen, M., Asghar, M. (2019). Estimation of infiltration models parameters and their comparison to simulate the onsite soil infiltration characteristics. *International Journal of Agricultural and Biological Engineering, 12*(3), 84–91. https://doi.org/10.25165/j.ijabe.20191203.4015

Freire, E. R., Almeida, A., & Koide, S. (2020). Avaliação das medições de umidade utilizando sonda de reflectometria no domínio do tempo (TDR) com tubos de acesso em material padrão e alternativo. *Xv Simpósio De Recursos Hídricos Do Nordeste*, 61.

Furman, A., Warrick, A. W., Zerihun, D., & Sanchez, C. A. (2006). Modified Kostiakov Infiltration Function: Accounting for Initial and Boundary Conditions. *Journal of Irrigation and Drainage Engineering*, *132*(6), 587–596. https://doi.org/10.1061/(asce)0733-9437(2006)132:6(587)

Goel, L., Shankar, V., & Sharma, R. K. (2020). Effect of organic mulches on agronomic parameters – a case study of tomato crop (*Lycopersicon esculentum* Mill.). *International Journal of Recycling of Organic Waste in Agriculture*, *9*(3), 297–307. https://doi.org/10.30486/IJROWA.2020.1887263.1015

Irinslimane, H. (2007), Etude de l'adsorption d'un pesticide sur matériaux de récupération (sciure de bois et chutes de liège). *Mémoire de Magister*, *Ecole Nationale Polytechnique*, Alger, 69 p

Jacks, C. V. Brind, W. D. and Smith, R. (1955). Mulching Technology Comm., No. 49, *Common Wealth. Bulletin of Soil Science*, 118p.

Kaboneka, S., Nsavyimana, G., Bizimana, S., Bicereza, D. (2021). *Cinétique de décomposition de la paille de blé dans un sol acide du Mugamba Sud (Burundi): effet du mode d'application*. 10-19.

Kumar, S., and Dey, P. (2011). Effects of different mulches and irrigation methods on root growth , nutrient uptake , water-use efficiency and yield of strawberry. *Scientia Horticulturae*, *127*(3), 318–324. https://doi.org/10.1016/j.scienta.2010.10.023

Kumar D.K., Lal B.R. (2012). Effect of mulching on crop production under rainfed condition: a review. *International Journal of Research in Chemistry and Environment*, *2*(2), 8-20.

Haghiabi, A. H., Abedi-Koupai, J., Heidarpour, J. M., Mohammadzadeh-Habili, J. (2011). A new method for estimating the parameters of Kostiakov and modified Kostiakov infiltration equations. *World Applied Sciences Journal*, *15*(1), 129–135.

Haverkamp, R., Kutilek, M., Parlange, J.-Y., Rendon, L., and Krejca, M. (1988). Infiltration under ponded conditions:

2. Infiltration equations tested for parameter time-dependence and predictive use. *Journal of Soil Science, 145*, 317–329. https://doi.org/10.1097/00010694-198805000-00001

Kostiakov, A N. (1932). On the dynamics of the coefficient of water percolation in soils and the necessity of studying it from the dynamic point of view for the purposes of Amelioration. *Transactions International Society of Soil Science. 6th Commission*, *Moscow*, Part A: 17. (in Japanese)

Laribi S., Boutonnet J.-P., Brabez Fn Adem R. et. Kheffache H. (2023). Les formes d'intégration agriculture -élevage. Le cas des systèmes de polyculture-élevage. *Les Cahiers du Cread, 39*, 307–348. DOI: 10.4314/cread.v39i1.11

Lamont, W.J. A.D. (2005). *Index, Features Plastics: Modifying the Microclimate for the Production of Vegetable Crops, 15*. https://doi.org/10.21273/HORTTECH.15.3.0477

Liao, Y., Cao, H. X., Liu, X., Li, H. T., Hu, Q. Y., & Xue, W. K. (2021). By increasing infiltration and reducing evaporation, mulching can improve the soil water environment and apple yield of orchards in semiarid areas. *Agricultural Water Management, 253*(26), 106936. https://doi.org/10.1016/j.agwat.2021.106936

MADR (2009). *Bilan du programme quinquennal du secteur agricole et rural 2005-2009*, *Rapport interne*, 51 p.

MADR (2011). *Le Renouveau Agricole en chiffres. Rapport d'étape. Contrats de performance 2009- 2010 et prévisions de clôture 2011*, Alger. 116 p.

Meddi, M., Meddi, H., Toumi, S., Mehaiguen, M. (2013). Regionalization of rainfall in north-western Algeria. *Geographia Technica*, *1*, 56–69.

Mirzaee, S., Zolfaghari, A. A., Gorji, M., Dyck, M., & Ghorbani Dashtaki, S. (2014). Evaluation of infiltration models with different numbers of fitting parameters in different soil texture classes. *Archives of Agronomy and Soil Science*, *60*(5), 681–693. https://doi.org/10.1080/03650340.2013.823477

Mishra, S. K., Tyagi, J. V., & Singh, V. P. (2003). Comparison of infiltration models. *Hydrological Processes*, *17*(13), 2629–2652. https://doi.org/10.1002/hyp.1257

Mkhabela, K. T., Dlamini, M. V, & Manyatsi, A. M. (2019). The effect of mulching on soil moisture retention and yield of lettuce (*Lactuca sativa* L .). *International Journal of Environmental & Agriculture Research, 5*(9), 47–50.

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L. et al. (2007). Model evaluation guidelines for sys- tematic quantification of accuracy in watershed simulations. *Trans ASABE*, *50*(3), 885–900. https://doi.org/10.13031/2013.23153

Nicolardot, B., Recous, S., & Mary, B. (2001). Simulation of C and N mineralisation during crop residue decomposition: A simple dynamic model based on the C : N ratio of the residues. *Plant and Soil*, *228*(1), 83–103. https://doi.org/10.1023/A:1004813801728

Niyazi, B., Masoud, M., Elfeki, A., Rajmohan, N., Alqarawy, A., & Rashed, M. (2022). A comparative analysis of infiltration models for groundwater recharge from ephemeral stream beds: A case study in Al Madinah Al Munawarah Province, Saudi Arabia. *Water (Switzerland)*, *14*(11). https://doi.org/10.3390/w14111686

Oku, E., and Aiyelari, A. (2011). Predictability of Philip and Kostiakov infiltration models under inceptisols in the humid forest zone, Nigeria. *Kasetsart Journal*, *45*, 594–602.

Pakdel, P, A. Tehranifar, H. Nemati, A. Lakzian, M., Kharrazi (2013). Effect of different mulching materials on soil properties under semi- arid conditions in north-eastern Iran. Wudpecker, *Journal of Agricultural Research*, *2*(3), 80-85.

Philip, J R. (1957). The theory of infiltration: 4. Sorptivity and algebraic infiltration equations. *Soil Science, 84*, 257–264. https://doi.org/10.1097/00010694-195709000-00010

Rasmussen, K.J. (1999) Impact of ploughless soil tillage on yield and soil quality: A Scandinavian review. *Soil and Tillage Research*, *53*, 3-14. http://dx.doi.org/10.1016/S0167-1987(99)00072-0

Robinson G. W. (1949). *Soils. Their origin, constitution and classification.* London.Thomas Murby & Co, N.Y.J. Wiley & Sons Inc., 573 p

Sadek, I. I., Youssef, M. A., Solieman, N. Y., & Alyafei, M. A. M. (2019). Response of soil properties, growth, yield and fruit quality of cantaloupe plants (*Cucumis melo* L.) to organic mulch. *Merit Research Journal of Agricultural Science and Soil Sciences*, *7*(9), 100–106. https://doi.org/10.5281/zenodo.3463634

Safari, N., Kazemi, F., & Tehrani, A. (2021). Examining temperature and soil moisture contents of mulches in the urban landscaping of an arid region. *Journal of Desert, 26*(2), 139–156. https://doi.org/10.22059/jdesert.2020.256170.1006639

Sharma, S., Basnet, B., Bhattarai, K., Sedhai, A., & Khanal, K. (2023). The influence of different mulching materials on Tomato's vegetative, reproductive, and yield in Dhankuta, Nepal. *Journal of Agriculture and Food Research*, 11(December), 100463. https://doi.org/10.1016/j.jafr.2022.100463

Simsek, U., Erdel, E., & Barik, K. (2017). Effect of mulching on soil moisture and some soil characteristics. *Fresenius Environmental Bulletin*, *26*(12), 7437–7443.

Skhiri, A. (2019). *Les Bases* de *l'Irrigation : Calcul des besoins en eau.* April, 97p.

Smerdon, E.T., Blair, AW. (1988). Infiltration à partir des données avancées d'irrigation. II: Expérimental. *Journal of Irrigation and Drainage Engineering*, *114*(1), 18-30. https://doi.org/10.1061/(asce)0733-9437(1988)114:1 (18)

Stagnari, F., Galieni, A., Speca, S., Cafiero, G., & Pisante, M. (2014). Field crops research effects of straw mulch on growth and yield of durum wheat during transition to conservation agriculture in mediterranean environment. *Field Crops Research*, *167*, 51–63. https://doi.org/10.1016/j.fcr.2014.07.008

Stelli, S., Hoy, L., Hendrick, R., & Taylor, M. (2018). Effects of different mulch types on soil moisture content in potted shrubs. *Journal of Water SA*, *44*(3), 495–503. https://doi.org/10.4314/wsa.v44i3.17

Tarchag, C. (2020). Effet des doses d'irrigation sur la culture de tomate dans la région de Biskra. *Mémoire de Master,* Université de Biskra-Algérie, 51p.

Telkar S. G., Shivkumar & Kant, Kamal & Pratap, Shivendu & Solanki, Shivendu. (2017). Effect of mulching on soil moisture conservation. *Journal of Biomolecule Reports*, 4p.

Vand, A. S., Sihag, P., Singh, B., & Zand, M. (2018). Comparative evaluation of infiltration models. *KSCE Journal of Civil Engineering*, *22*(10), 4173–4184. https://doi.org/10.1007/s12205-018-1347-1

Xing, X., Li Y., Ma X. (2017). Effects on infiltration and evaporation when adding rapeseed-oil residue or wheat straw to a loam soil. *Journal of Water, 9*(9), 700. https://doi.org/10.3390/w9090700

Yuemei, H., Xiaoqin, Z., Jianguo, S., & Jina, N. (2008). Conduction between left superior pulmonary vein and left atria and atria fibrillation under cervical vagal trunk stimulation. *Colombia Medica*, *39*(3), 227–234.

Zegada-Lizarazu and Berliner. (2011). The effects of the degree of soil cover with an impervious sheet on the establishment of tree seedlings in an arid environment. *New Forests*, *42*, 1–17. https://doi.org/10.1007/s11056-010-9233-9

Zhang, J. B., Yang, J. S., Yao, R. J., Yu, S. P., Li, F. R., & Hou, X. J. (2014). The effects of farmyard manure and mulch on soil physical properties in a reclaimed coastal tidal flat salt-affected soil. *Journal of Integrative Agriculture*, *13*(8), 1782–1790. https://doi.org/10.1016/S2095-3119(13)60530-4

Zolfaghari, AA, Mirzaee, S., et Gorji, M. (2012). Comparaison de différents modèles pour estimer l’infiltration cumulée. *Journal International des Sciences du Sol*, *7*(3), 108. DOI : 10.3923/ijss. 2012.108.115.