Study The Thermal Properties of The Soil Under Systems Irrigation and Mulching Different

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Abstract: **A field experiment was carried out in the field of the Faculty of Agriculture / University of Wasit located at a longitude 45° 50' 33.5''east and N 29° 36' 49.8'' norths for the 2019 growing season, with the aim of studying thermal properties under different irrigation and mulching systems. The study was carried as factorial experiment in RCBD design with three replications, the first factor was mulching (control, wheat straw, palm fronds, and black nylon), and the second factor was irrigation methods (basin, and furrow). Maize crop was planted on 20/7/2019, and harvesting was completed on November 20, 2019. The thermal properties were estimated using equations (thermal conductivity, heat flow, volumetric heat capacity, thermal diffusion), the results showed the following:**

1. It is noticed that superiority of the treatment of mulching with black nylon at the beginning and end of the season by obtaining the highest thermal conductivity of the soil, followed by the treatment of straw and fronds compared to the treatment without mulching, as it reached at the beginning of the season 0.830, 0.769, and 0.752 W·m^{-1}·K respectively, and reached at the end of the season 0.772, 0.813, and 0.834 W·m^{-1}·K respectively, while the thermal conductivity of the control was 0.665, 0.746 W·m^{-1}·K at the beginning and end of the season respectively.
2. The basin irrigation method outperformed the furrow irrigation method in the thermal conductivity values at the beginning and the end of the season, reaching 0.733 and 0.775 W·m^{-1}·K respectively at the beginning of the season and 0.785 and 0.797 W·m^{-1}·K respectively at the end of the season.
3. The black nylon mulch treatment outperformed the rest of the treatments at the beginning of the season, followed by the non-mulched treatment, then the frond mulching and straw mulching treatment by obtaining the highest heat flux rate of 2.96, 3.30, 4.47 and 6.80 W/m^2, respectively.
4. The basin irrigation method outperformed the furrow irrigation method by obtaining the highest heat flux at the beginning of the season, reaching 5.99, and 2.77 W/m^2, respectively, but the opposite happened at the end of the season where the furrow irrigation method outperformed the basin irrigation method, reaching 3.99, and 3.85 W/m^2 respectively.
5. The mulching treatment with black nylon exceeded by obtaining the highest values of volumetric heat capacity, then followed by the treatment of mulching with straw and fronds, and then treatment without mulching at the beginning and end of the growing season, reaching 1.61, 1.53, 1.49, and 1.39 MJ / m^3 respectively at the beginning of the season and 1.52, 1.54, 1.54 and 1.63 respectively at the end of the season.
6. The basin irrigation method outperformed the furrow irrigation method in that it obtained the highest values of volumetric heat capacity which were 1.48 and 1.53 MJ / m^3.K respectively at the beginning of the season and 1.57 and 1.54 MJ / m^3.K respectively at the end of the season.
7. The treatment of mulching with black nylon outperformed by obtaining the highest value of thermal diffusivity, followed by the treatment of mulching with fronds and straw, compared to a treatment without mulching at the beginning of the season, which amounted to 5.18x10^{-7}, 5.06x10^{-7}, 5.01x10^{-7}, and 4.79x10^{-7} m^2 / sec respectively.
8. The basin irrigation method achieved the highest rate of thermal diffusivity compared with the furrow irrigation method at the beginning of the growing season, reaching 5.09 x10^{-7}, and 4.94x10^{-7} m^2 / sec respectively.

Keywords: **thermal properties; mulching; systems irrigation; mulching; soil.**

I. Introduction

Soil temperature is one of the most important physical properties of soil, and researchers have been interested in studying its changes due to its effect on many of the chemical, physical and biological processes that occur near the root zone of the plant and the layer of air surrounding the soil surface [1]. The thermal properties of the soil are dynamic, because they depend on external factors such as weather conditions, tillage, and physical properties of the soil such as

moisture content, temperature, bulk density, etc. [2], In view of the climatic conditions that our country and the countries of the Middle East region are exposed to due to global warming and the unprecedented rise in temperatures and their rates exceeding more than 50° C and the accompanying evaporation of the soil and plant surface due to the high temperatures of the soil surface and the heat flow through the soil bed, which calls for the need to the use of some ways to manage the soil, which is the use of mulching materials, which are the remnants of crops after harvest, palm leaves (fronds) and some industrial coverings such as polyethylene of different colors and others, used for the purpose of reducing the effect of solar radiation and the accompanying high soil temperatures that in turn affect plants. It also works on changing the soil moisture and thermal system, and changing the conditions surrounding plants by maintaining soil moisture and reducing the amount of water used in irrigation due to reducing the rate of evaporation from the soil surface, increasing soil fertility and reducing soil erosion, improving the biological system of the soil [3].

Maize (*Zea mays*, L.) is one of the most important strategic and economic crops in the world, and it ranks third in importance after wheat and rice. Iraq cultivates maize on a large scale, with the area cultivated for the year 2016 about 76,000 hectares, with a production rate of 3,416 µg. hectare^{-1} [4]. Maize crop is one of the most important cereal crops for the production of fodder, starch, oil and fuel, and its economic importance has increased at the therapeutic level, the production of dyes, or its use as a promising alternative to traditional auto fuel or other uses [5].

From this standpoint, this study came for the purpose of achieving the following goals: Study the effect of different types of soil mulching on the thermal properties of the soil.

II. Materials and Methods

The experiment was conducted in sandy loam soil. A factorial experiment was implemented according to the RCBD with three replications. The experiment land was plowed, smoothed, amended, and divided into 24 experimental units with dimensions 4 x 3.75 m, leaving a distance of 1 m between blocks and 1 m between the experimental units. Some physical and chemical properties of the field soil were measured before planting (Table 1 and 2), as well as the chemical properties of irrigation water (Table 3). The experiment consists of the following factors:

A. Soil Mulching: Three types of mulching have been used, namely:
1. Black mulching, the plots were completely covered with black nylon, and as for the furrows, it was completely covered with black nylon, leaving the bottom of the furrow uncovered.
2. Mulching Fronds, the plots were covered with fronds, and as for the furrow, the side facing the sun was covered with palm fronds where the crop was grown.
3. Straw mulching, the plots were covered with straw and, for furrow, the side facing the sun on which the crop was grown.
4. Without Mulching (Control).

B. Irrigation method: It includes two types of irrigation methods, namely:
1. Basins Irrigation (B)
2. Furrow Irrigation (F)

The eight treatments were allocated randomly to the experimental units of each block. The planting was carried out on July 20, 2019 in lines in basins (plots) and in the upper third in furrow, the distance between furrow was 75 cm, and in the hole, the distance between one hole and another 25 cm^3 seeds were placed in each hole. thinning was carried out two weeks after planting and the plants were reduced to one plant per hole. After reaching a height of 15-20 cm. Weeding was carried out according to the needs of the plants, and urea was added before planting as a first batch, the second batch after two months of planting, and potassium sulfate and triple superphosphate before planting according to the recommendations of the Ministry of Agriculture. The corn stalk borer insect was controlled by using the granular pesticide of diazinon (10%) by placing it in the apical meristem of the plant. The first irrigation (the germination irrigation) was given immediately after planting on 7/20/2019, all the experiment treatments were irrigated equally until germination, after which the irrigation was done on the basis of depletion of 50% of the available water for the plant. Where the depth of water required to reach soil moisture to the field capacity limits was added based on soil moisture tension curve data.

$$d=(\Theta_{f.c}-\Theta_w) \times D \dots\dots\dots (1)$$

d = depth of irrigation water to be added (cm)
$\Theta_{f.c}$ = volumetric moisture at field capacity cm^3 / cm^3
Θw = volumetric moisture before subsequent irrigation cm^3 / cm^3
D = soil depth (cm), where a depth of 10 cm was used for the stage of germination and vegetative growth, then it was increased to 20 cm for the stage of flowering, then it was increased to 30 cm in the stage of maturity and harvesting, depending on the field follow-up to deepen the root system of the crop.

The volume of added water (V) was calculated for each experimental unit and the irrigation time (T) according to the equations in [6] and [7] as follows:

$$V = d \times A \ .... \ (2)$$
$$T = V / Q \ .... \ (3)$$

d = depth of irrigation water (m)
A = The area of the experimental unit (plots or furrows) m^2
Q = discharge (liters / s)
Soil bulk density was measured for all experiment treatments before planting and at the beginning, mid and end of the season and at five depths (0-10) (10-20) (20-30) (30-40) (40-50) cm from the soil surface using the method of Cylinder Core Sample. The soil water conductivity was measured for all the experiment treatments at the end of the season and at five depths (0-10) (10-20) (20-30) (30-40) (40-50) cm from the soil surface using a constant water column on non-disturbed soil according to the method [8] and according to the following equation:

$$K = \frac{V \ L}{At \ \Delta H} \ .... \ (4)$$

As: _
K: saturated hydraulic conductivity (cm h^{-1}).
V: The volume of leachate (cm³).
L: Length of the column of soil (cm).
A: The area of the running section (cm²).
t: water collection time (hour).
Δh : The change in the water voltage between its entry and exit point (cm).

Soil temperature was measured for all experiment treatments throughout the growing season and at depths of 0-30-20-20-10 cm from the soil surface by electronic thermometers every 6 hours on a daily basis throughout the experiment period.
Thermal characteristics were calculated for all experiment treatments, including:
1. Calculating the thermal conductivity of the soil according to [9], using the following equation:

$$K = (0.9 \log W - 0.2) 10^{0.01yd} \ .... \ (5)$$

Where W = gravimetric moisture content%
    Yd = soil bulk density Mg / m^3
2. Soil heat flux is calculated from (Fourier) equation in [10] and as follows:

$$qh = -K \frac{dT}{dx} \ .... \ (6)$$

qh = heat flux (w / m^2)
k = thermal conductivity (w / m.k)
T = temperature (K)
X = vertical distance (m)
3. Estimation of the volumetric heat capacity (Cv) is calculated from the equation given in [10] following:

$$Cv = \frac{2.01 * 10^6 pb}{2.65} + 4.19 * 10^6 \ \theta \ .... \ (7)$$

Cv = volumetric heat capacity (J / m^3.k)
Pb = bulk density (Mg / m^3)
Θ = volumetric soil moisture content (m^3 m^{-3})
4. Estimation of thermal diffusivity (D) according to the following equation in [11]:

$$DH = K/CV \ .... \ (8)$$

DH = thermal diffusivity m^2 / sec
K = thermal conductivity w / m.k
CV = volumetric heat capacity J / m^3.k
Statistical analysis: The data were analyzed statistically according to the method of analysis of variance and comparisons were made between the arithmetic averages according to the test of the least significant difference (L.S.D) at a probability level of 0.05.

Table 1. physical characteristics of the study soil before planting.

water conductivity cm sec^{-1}	Porosity%	True density μg m^{-3}	bulk density μg m^{-3}	Texure	Particle Size distribution			Soil Depth (cm)
					Clay gm Kg^{-1}	Silt gm Kg^{-1}	Sand gm Kg^{-1}	
0.00291	55.9	2.63	1.16		63	360	577	0 -10
0.00288	54.5	2.64	1.20		76	375	549	10-20
0.00283	53.6	2.65	1.23	Sandy loam	89	360	551	20-30
0.00279	52.1	2.65	1.27		93	350	557	30-40
0.00272	52.4	2.67	1.27		95	335	570	40-50

Table 2. Chemical properties of field soil before planting.

Organic matter %	C mol/l								(pH)	Ec (dsm^{-1})	Soil depth (cm)
	SO_4^{-2}	HCO_3^-	Cl^-	CO^{-2}	K^+	Na^+	Mg^{+2}	Ca^{+2}			
0.65	1.31	4.8	12.8	0	2.2	3.11	4.4	9.2	7.15	1.89	0 -10
0.58	1.28	4	12.5	0	2.0	2.92	3.8	8.9	7.13	1.79	10-20
0.58	1.1	3.6	10.6	0	1.81	2.70	3.1	7.7	7.11	1.49	20-30
0.55	1.4	3.1	10	0	1.63	2.63	2.6	6.4	7.09	1.34	30-40
0.53	1.2	3.0	10	0	1.62	2.61	2.6	6.3	7.11	1.32	40-50

Table 3. Chemical properties of irrigation water.

SO_4^{-2}	Cl^-	HCO_3^-	CO^{-2}	K^+	Na^+	Mg^{+2}	Ca^{+2}	PH	Ec
C mol/l									(dsm^{-1})
1.5	7	5	0	0.641	3.6	4	5.6	6.76	1.4

III.   Results and Discussions

1.   Thermal conductivity
1.1.   The effect of mulching on the thermal conductivity

There are significant differences in the mulching treatments on the values of the thermal conductivity of the soil during the growing season of the crop (Figure 1), where it is noticed that the treatment black nylon mulching at the beginning and end of the season has the highest thermal conductivity of the soil, and then comes the treatment of straw and fronds compared to the control treatment, as it reached at the beginning of the season 830, 0.769, and 0.752 W·m^{-1}·K respectively, and at the end of the season it reached 0.772, 0.813, and 0.834 W·m^{-1}·K respectively, and the reason for this is due to the high moisture content of these treatments where the treatment mulched with black nylon had a high moisture content, followed by a Straw and frond mulching treatments compared to a non-mulching treatment (control). The reason is due to the mulching with black nylon led to less evaporation of water from the soil, as well as mulching with straw and fronds preserving soil moisture for a longer period, as a result, these treatments obtained the highest thermal conductivity compared to control treatment, as the thermal conductivity is higher under wet conditions compared to dry conditions because the highest thermal conductivity of the soil is obtained after irrigation and this is in agreement with [12] and[13]. The reason may also be attributed to the fact that increasing the soil moisture content increases the contact between soil particles, which increases the thermal conductivity and diffusivity of the soil [14]. It is also noticed that the thermal conductivity increases at the end of the season compared to the beginning of the season for all treatments, due to the increase in the moisture content as the growing season progresses, as well as the increase in the bulk density of most transactions with the advancement of the growing season, whereas, increasing the bulk density leads to a decrease in porosity and an increase in the state of contact between soil particles, thus increasing the thermal conductivity of the soil [14].
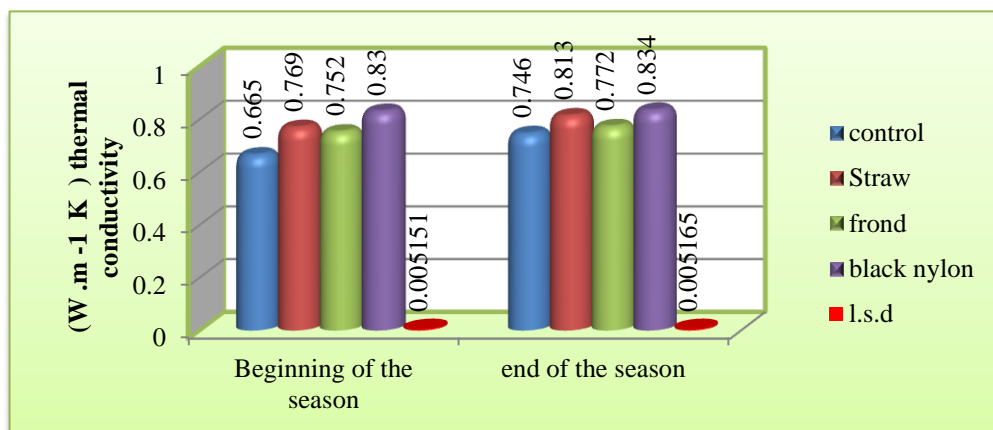
Fig.1. The effect of mulching on the thermal conductivity values of the soil at the beginning and end of the crop growing season

2.1. The effect of irrigation method on thermal conductivity

Figure 2 shows a significant effect of the irrigation method factor on the values of the thermal conductivity of the soil during the growing season of the crop, as the basin irrigation method significantly outperformed the furrow irrigation by means of increasing the thermal conductivity at the beginning and end of the season, reaching 0.733 and 0.775 $W \cdot m^{-1} \cdot K$ respectively at the beginning of the season, and 0.797 and 0.785 $W \cdot m^{-1} \cdot K$, respectively, at the end of the season. The reason for this is that the quantities of water added in the basin irrigation method are more than the furrow irrigation method. Where the percentage of the area wet by the basin irrigation method was 100% while the percentage of the area wet by the furrow irrigation method was 93%, which led to an increase in the soil moisture content, which has a major role in increasing the thermal conductivity of the soil, as the water displaces the air on the one hand and works as bridges link between solid particles on the other hand, thus raising the thermal conductivity values of the soil significantly compared to soils with low moisture [15]. Different irrigation methods lead to the entry of different quantities of irrigation water into the soil, which leads to a change in the distribution of water in the soil, and thus a difference in the soil moisture content, and an appropriate amount of water can increase the thermal capacity of the soil and reduce the loss of soil temperature [16]. The thermal conductivity and heat distribution are affected by the moisture distribution of the soil, as moisture is transferred from hot to cold regions in the soil body [17].

Fig.2. The effect of irrigation method on soil thermal conductivity values at the beginning and end of the crop growing season

Heat flux
1.2.1. Effect of Mulching on Heat Flux

Figure 3 shows a significant effect of the covering factor on the heat flux values of the soil during the growing season of the crop, where the treatment of mulching with black nylon surpassed the rest of the treatments at the beginning of the

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season, followed by the treatment without coverage, then the treatment of mulching with fronds and straw mulching, reaching 6.8, 4.47, 3.30, and 2.96 W·m^{-2}, respectively, and the reason for this is due to the fact that nylon absorbs a greater amount of solar radiation, and then increases the heating of the soil surface, which leads to higher soil temperatures, in addition to an increase in the moisture content as nylon works to reduce water evaporation from the soil [18], as the soil temperature under the black nylon was 2-5 ° C higher than the straw-mulched soil, and this is consistent with [19]. A treatment without mulching was recorded the highest heat flux values after treatment with black nylon, and the reason for this is the high temperature of the soil at the beginning of the season, which caused its moisture content to decrease. This, in turn, has an effect on the thermal conductivity compared to the rest of the treatments, and the reason may be due to the surface of the soil if it is dry, then the thermal energy will heat the surface of the soil and the product will be a relatively large thermal gradient that causes a reasonable thermal flow to the soil bed [20]. Whereas, the frond and straw mulching treatment obtained lower values of heat flux compared to the control treatment. The reason for this may be attributed to the lower soil temperature of these two treatments compared to the two treatments of nylon mulched and without mulching, and this is consistent with what was found by [21], as the soil temperature under the influence of mulching with wheat straw was less than the temperature of the non-mulched soil by 5°C. Also, the reason for the decrease in the heat flux of the two treatments of straw and frond mulching may be attributed to the fact that covering the surface of the soil with straw and fronds reduces the transfer of heat to the soil bed as a result of absorbing most of the solar radiation energy and reversing it to the atmosphere again due to its transparent color, thus reducing the heat energy transferred to the depths of the soil [22]. As for the heat flux at the end of the growing season, it was noticed that the treatment of black nylon, followed by the frond mulching and straw mulching, amounted to 3.43, 4.61, and 4.71 W.m^{-2}, respectively, due to its high moisture content and increased bulk density at the end of the season, which led to increase its thermal conductivity, as the thermal flow affects the ability of the soil to store heat, and it determines the depth of the wave that penetrates the soil profile when exposed to sunlight, and this depends on the soil moisture content, heat capacity and thermal conductivity [23], but the treatment without mulching obtained the lowest heat flux compared to the rest of the mulched treatments with straw and fronds, which reached 2.95 W. m^{-2} due to the low temperatures of the air and soil at the end of the season. Likewise, the heat flux in wet soils is higher than in dry soils due to filling the pores with air [24]. As the soil temperature under mulching (black nylon) is 2-5 degrees Celsius higher than the soil temperature without mulching, and this is consistent with what was found by [25]. Also, it is noticed that the heat flow decreases at the end of the season for some treatments compared to the beginning of the season. The reason for this is the decrease in air temperature, which in turn affects the soil temperature.
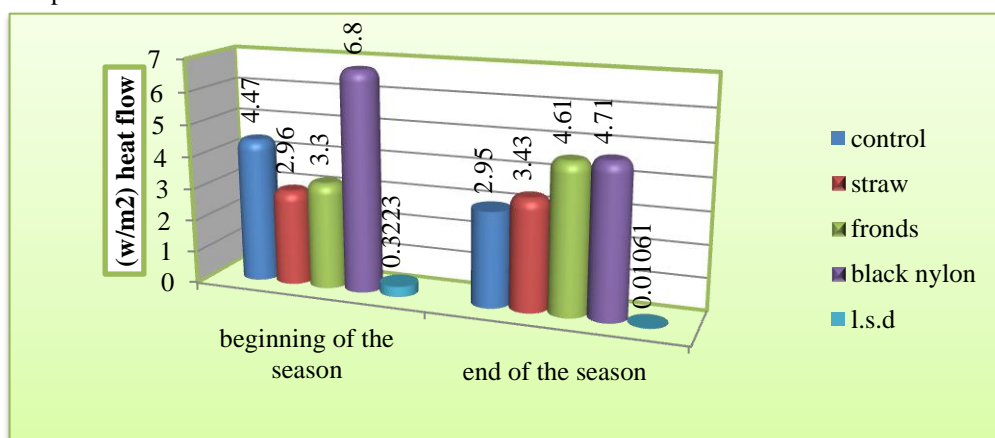

Fig.3. The effect of mulching on heat flow values at the beginning and end of the crop growing season.

2.2. Effect of irrigation method on heat flux

There is a significant effect of the irrigation method factor on the heat flow values of the soil during the growing season of the crop (Figure 4), as it is noticed that the basin irrigation method is superior to the furrow irrigation method by obtaining the highest heat flux at the beginning of the season as it reached 5.99 and 2.77 W. m^{-2} respectively. However, the opposite happened at the end of the season, where the furrow irrigation method surpassed the basin irrigation method, reaching 3.85, and 3.99 W. m^{-2}. The reason for the variation in the heat flux values at the beginning and end of the season may be due to the soil temperature and the soil moisture content, as the soil temperature was high at the beginning of the season, reaching (35.2, 33.82, 30.72, 34.36) degrees Celsius for the basins mulched with nylon, fronds and straw without mulching,

respectively. It reached (36.06, 30.76, 32.3, 33.8) degrees Celsius for furrows mulched with nylon, fronds and straw and without mulching. However, there was a decrease in the average temperature at the end of the season, which amounted to (20.64, 21.54, 18.5, 23.92) degrees Celsius for the basins covered with nylon, fronds and straw and the control respectively, and it reached (20.98, 21.3, 19.8, 21.08) degrees Celsius for the furrows mulched with nylon, fronds and straw and control). The average moisture content was low at the beginning of the season as it reached (0.1638, 0.1455, 0.1374, 0.1227) for basins mulched with nylon, straw and fronds and control respectively, and it reached (0.1589, 0.1409, 0.1294, 0.0938) for furrows mulched with nylon, straw and fronds and control respectively, but the average moisture content increased at the end of the season, reaching (0.1657, 0.1497, 0.1438, 0.1408) for basins mulched with nylon, straw and fronds and control respectively, and it reached (0.1607, 0.1498, 0.1377, 0.1279) for furrows mulched with nylon, straw and fronds and control respectively. In addition, the wetted area of the basins was 100%, but the furrows were 93%, which reduced the moisture content of the furrows, and thus reduced the thermal conductivity of the furrows, and this in turn affected the heat flux of the furrows ng compared to the heat flux of the basins. But, at the end of the season, the temperatures were low and the moisture content was high for the basins and the turquoise, so there was a slight increase in the heat flow between the basins and the furrows, and these factors have a great influence on the thermal characters, as mentioned by [26] and [27], that the heat flux is proportional with thermal conductivity and temperature, as the mulching increases the thermal conductivity, the soil temperature also increases, by increasing the moisture content, which increases the heat flux.
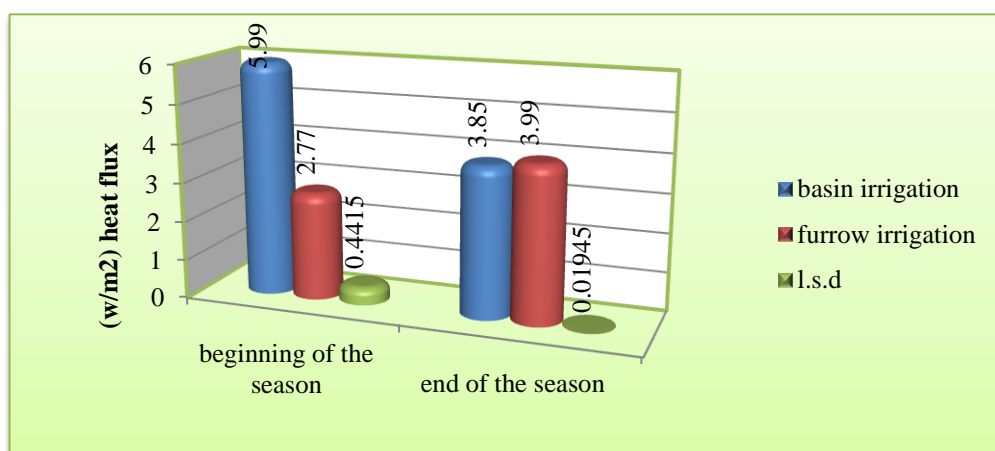

Fig.4. The effect of irrigation method on the heat flux values of the soil at the beginning and end of the crop growing season

1.3. Volumetric heat capacity
1.3.1. Effect of Coverage on Volumetric Heat Capacity

It is noticed from Figure 5 that there is a significant effect of the mulching on the values of the volumetric heat capacity of the soil during the growing season of the crop. The treatment of mulching with black nylon outperformed by obtaining the highest values of the volumetric heat capacity, then comes the two treatments of mulching with straw and fronds, and then the control treatment at the beginning and end of the growing season It was 1.61, 1.39, 1.49, 1.53 MJ. m^{-3}. K respectively at the start of the season and 1.63, 1.54, 1.49, and 1.39 MJ. m^{-3}. K respectively at the end of the season, the reason for this is due to the role of mulching in reducing evaporation and maintaining the amount of water added during the irrigation process for a longer period, which increases its moisture content [28]. This in turn increases the volumetric heat capacity of the soil, and the reason for the increase in the heat capacity of the straw treatment may be attributed to the fact that the heat capacity of the soil is the sum of the heat capacities of mineral materials, organic matter and water, and since the heat capacity of the organic matter is 0.60 cal. cm^{-3} K, and this is the higher heat capacity than quartz and other minerals with a capacity of 0.48 and air 0.003, and this in turn increases the specific heat capacity of the treatment [29]. As the black nylon mulch has the greatest ability to increase the moisture content of the soil, and then the wheat straw mulch, followed by the palm frond mulch, and this increase in the soil moisture content compared to the control soil, is a result of the ability of these mulching to reduce the evaporation of water in the soil and its permeability to air [19]. It is noticed that the volumetric heat capacity has increased at the end of the growing season compared to the beginning of the growing season,

and this may be due to the increase in the moisture content and the bulk density of some treatments at the end of the season compared to the beginning of the season as shown, where the volumetric heat capacity increases when the volumetric humidity and bulk density increase This is due to the role of mulching the soil surface, which helps to increase the ability of the soil to hold water compared to uncovered soils, and this in turn leads to an increase in soil moisture, which increases the storage of the soil heat capacity [26].
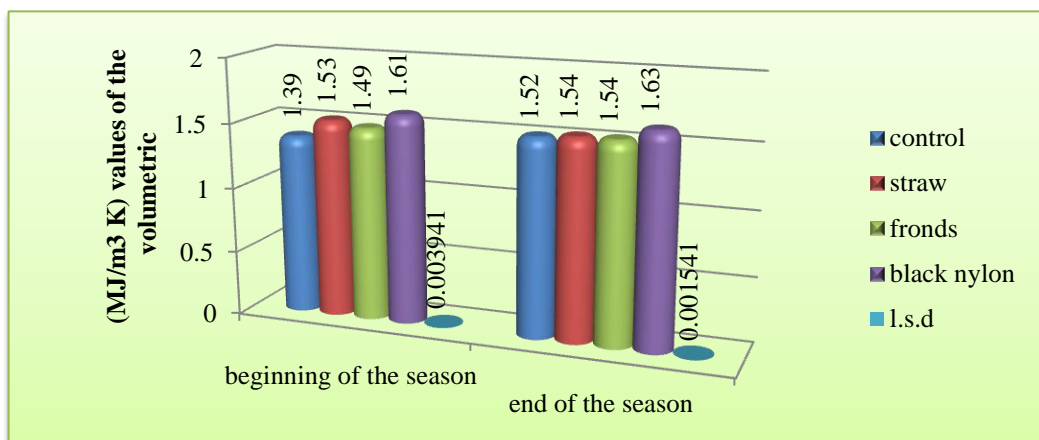
Fig.5. The effect of mulching on the values of the volumetric heat capacity of the soil at the beginning and end of the crop growing season

2.3.1. Effect of irrigation method on volumetric heat capacity

It is noticed from Figure 6 the effect of the factor of the irrigation method on the values of the volumetric heat capacity of the soil during the growing season of the crop, where it is noticed the superiority of the basin irrigation method over the furrow irrigation method in that it obtained the highest values of the volumetric heat capacity, reaching 1.53, 1.48 MJ.m^{-3}K, respectively at the beginning of the season and 1.57 and 1.54 MJ.m^{-3}K respectively at the end of the season, and the reason for this may be due to the fact that the amount of water added by the basin irrigation method is more than the furrow irrigation method, as irrigation increases the heat capacity of the soil, raises the relative humidity of the air over the soil and increases the thermal conductivity and this reduces changes daily soil temperature [14]. Also, a slight increase in the bulk density values was observed when using the basin irrigation method compared to the furrow irrigation method, and this leads to an increase in the heat capacity as the volumetric heat capacity value depends on the solid soil components (the existing mineral and organic matter), bulk density, soil moisture and porosity [30], the heat capacity increases with increasing soil moisture content after rains and the irrigation process. Volumetric heat capacity depends on the volumetric moisture content and the bulk density [31].

Fig.6. The effect of irrigation method on the values of the volumetric heat capacity of the soil at the beginning and end of the crop growing season.

1.4. Thermal diffusivity
1.4.1 The effect of coverage on thermal diffusivity

It is noticed from Figure 7 the effect of the mulching factor on the thermal diffusivity values of the soil during the growing season of the crop. The black nylon mulching treatment outperformed by obtaining the highest thermal diffusivity value, followed by the frond mulching and straw mulching treatment compared to control treatment at the beginning of the season, reaching 5.18x10-7, 5.06. 10-7, 5.01x10-7, x10-7 4.79 m^2. sec^{-1}, respectively, and the reason for this is due to the high moisture content of the black nylon mulch treatment compared with the rest of the treatments, as it improved the thermal conductivity between soil and air particles. Thermal diffusivity is directly proportional to the thermal conductivity, so the thermal diffusivity increases linearly with the increase in soil moisture content [30,31]. However, the straw-mulching treatment, followed by the black nylon and the fronds, outperformed control treatment at the end of the season, reaching 5.24x10-7, 5.13x10-7, 5.01x10-7, and 4.95x10-7 sec. m^{-2} respectively. Whereas, the straw mulching treatment had a high thermal conductivity of 0.806 W. m^{-1}. K and a volumetric heat capacity less than that of nylon mulching, reaching 1.55 and 1.64 MJ .m^{-3} K, respectively, as the thermal diffusivity is D = K / cv, this led to an increase in the thermal diffusivity of straw mulching treatment at the end of the season, the reason may also be attributed to their higher moisture content as mulching can be beneficial in reducing soil moisture loss, and thus soil temperature [33,34]. Thus preserving its moisture, which in turn affects the thermal diffusivity of the soil. This is in agreement with a study of [35], stated that organic fertilizers can increase thermal diffusivity of soil by increasing the thermal conductivity and volumetric heat capacity of the soil, through changes in soil bulk density and moisture content. However, it is not clear whether this is the case for all types of soil and crops. The decrease in the thermal diffusivity of a non-mulching treatment is due to the high soil temperature at the beginning of the season, which increases the evaporation of water from the soil and thus reduces the soil moisture content, and this greatly affects the thermal properties of the soil.
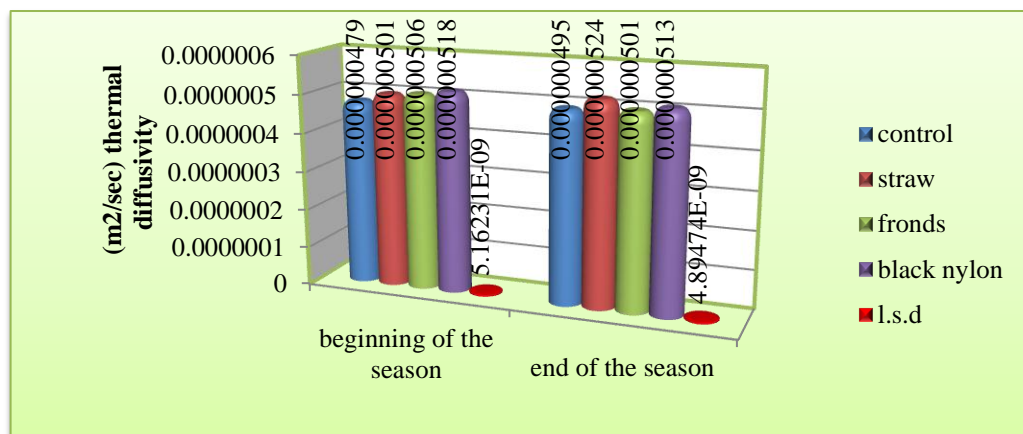

Fig.7. The effect of mulching on the thermal diffusivity values of the soil at the beginning and end of the crop growing season

2.4.1 The effect of the irrigation method on the thermal diffusivity

It is noticed from Figure 8 the effect of the irrigation method on the thermal diffusivity values of the soil during the crop growing season. The basin irrigation method achieved the highest thermal diffusivity rate compared with the furrow irrigation method at the beginning of the growing season, as it reached 5.09x10^{-7} and 4.94x10^{-7} m^2 sec^{-1} respectively. The reason for this may be due to the fact that the added irrigation water depths are more in the basin irrigation method compared to the furrow irrigation, where the area of the basin was covered with water by 100%, but in the furrows the percentage of wet area is 93%.This, in turn, affects the moisture content of the soil, so the moisture content in the basin was higher than it is in the furrows, and this directly affects the thermal conductivity and the volumetric heat capacity and indirectly the thermal diffusivity, and since the coverage increases the moisture content, therefore the thermal properties of the mulched soils increase compared to non-mulched soils [33]. A slight variation is observed in the thermal diffusivity values at the end of the season between irrigation methods reaching 5.09x10^{-7}, 5.08x10^{-7} m^2. Sec^{-1} for furrow irrigation and

basins irrigation, respectively. The reason for this is due to the difference in the values of the moisture content and the bulk density, some treatments decreased their bulk density and others increased their bulk density at the end of the season compared to the beginning of the season. As the high moisture content leads to an increase in contact between soil particles and therefore the thermal conductivity increases on the one hand. On the other hand, increasing the bulk density of some treatments reduces porosity and increases contact between soil particles, thus increasing the conductivity as well as thermal diffusivity of the soil [14].
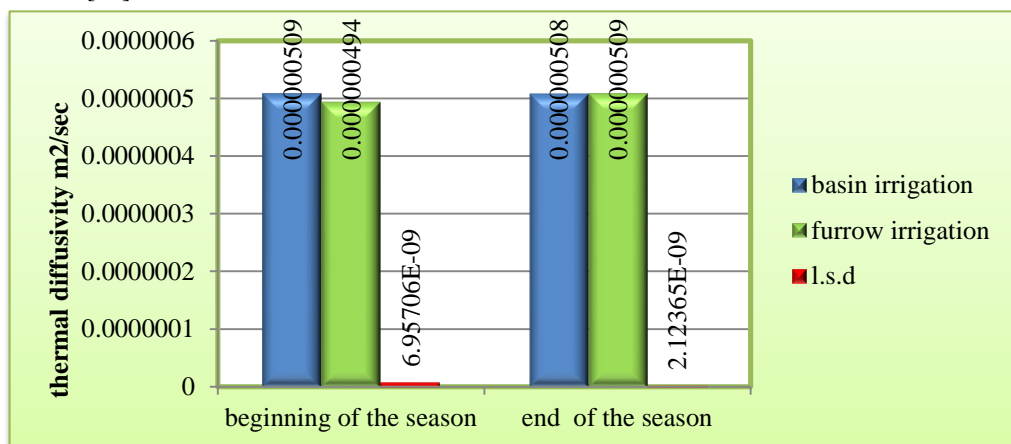

Fig. 8. The effect of irrigation method on the thermal diffusivity values of the soil at the beginning and end of the crop growing season

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