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Optimizing Greenhouse Productivity: Effective Irrigation and Soil Warming

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Abstract: Enhancing soil heat and its moisture regime will strongly affect different soil processes. Consequently plant growth and yield will be affected. So, modified management of soil warming and irrigation practice could be a successful strategy to achieve the most suitable control for soil temperature and moisture content. Field experiment was carried out in unheated plastic greenhouses. Soil warming treatment was compared with the control. It involved the use of black plastic sheet as soil mulch. Cucumber (*Cucumis sativus*) was cultivated and irrigated with three levels of soil moisture (33, 66 and 100 % of soil field capacity) by means of drip irrigation system. Changes in soil temperature and moisture content were periodically monitored at three different depths: 10, 20 and 30 cm. The obtained results can be summarized as follows: in general, warming treatment had a positive impact on soil temperature, moisture content, plant growth and crop yield. The suitability of appropriate moisture contents and heat in the root zone were not sufficient for good plant growth. Consequently, the change in these variables particularly low reasonable degree of fluctuation is an important factor for plant growth. Decreasing soil moisture fluctuation resulted in reducing soil temperature fluctuations. They played important role in increasing production and vegetative growth of plant.

Key words: Cucumber (*Cucumis sativus*) · Soil temperature · Field capacity · Vegetative growth

INTRODUCTION

Every biological and chemicals processes in soil are accompanied by soil moisture content and the absorption and release of soil heat. These properties are important fertility factors of soil which have a direct influence on plant growth. Soil temperature has close relation with soil moisture content [1-3]. Therefore, changes of soil temperature, along with concomitant changes in soil moisture, will lead to a wide range of soil and plant responses. According to Hillel *et al.* [4] and Sanders [5], cleared and tilled soils which are made warmer, accelerated rate of organic matter decomposition enhanced emitting CO_2 from soil and exacerbate the greenhouse effect itself. Moreover, higher soil temperatures should generally accelerate chemical reaction rates and gaseous components are also affected [6]. Many previous investigations have shown that the plastic film created favorable conditions for increasing temperature in soil and its moisture content compared to bare soil [7-12]. They concluded that the use of plastic mulch would affect soil temperature in three main ways: it would reduce connective heat loss, outgoing radiation and evaporation, thus increasing soil temperature. Soil moisture content is a function of irrigation management, among other factors. It is directly involved with soil temperature. Hassanain and Hokam [13] found that soil and air temperatures were strongly affected by different soil moisture contents. Rycheva [14] reported that podzolic soil thermal conductivity is lower during heating the soil than during its cooling. This effect is probably connected with thermal moisture transfer. This result is similar to that found by Campbell *et al.* [1], they stated that soil thermal conductivity increased dramatically with temperature in moist soils. Their results showed that soil thermal conductivity could be specified as a function of bulk density, temperature and water content.

The present study was carried out on loamy sand soil at Ismailia Governorate, Egypt to evaluate the impact of interaction between irrigation scheduling and soil warming on the balance between soil moisture and temperature, consequently on plant growth and productivity.

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Table 1: Some physical and chemical properties of the experimental site (0-30 cm depth)

Soil characteristics	Values
Texture	Loamy Sand
Sand (%)	81.30
Silt (%)	6.60
Clay (%)	12.10
Bulk density (mg m^{-3})	1.32
Organic matter (%)	1.31
Soil field capacity (g g^{-1} %)	17.50
EC (dS m^{-1})	4.11
pH	6.83

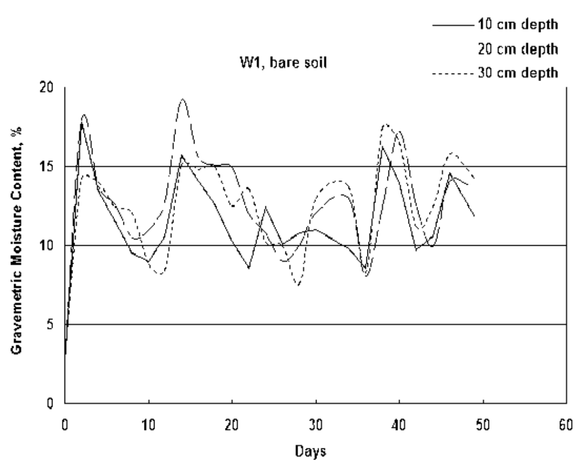
MATERIALS AND METHODS

Field experiment was conducted in three greenhouses at the Experimental Farm, Suez Canal University, Ismailia, Egypt. The soil is well drained loamy sand soil, some physical and chemical properties of the experimental site are given in Table 1. Cucumber was grown on mulched and bare soils located in unheated green house. Black plastic sheet was used for surface soil mulching treatment. Drip irrigation system was used to apply water at three different levels; namely, 100 % of soil field capacity in the first greenhouse (W1), 66 % of soil field capacity in the second greenhouse (W2) and 33 % of soil field capacity in the third greenhouse (W3). These soil moisture levels were interacted with mulched and bare treatments. The emitter used in the irrigation system was online self compensation. Its average rate was 4.26 L h^{-1} under working pressure ranged from 1.0 to 1.5 bars.

Periodically soil samples were collected at 10, 20 and 30 cm depths using a micro soil auger. Moisture contents were determined gravimetrically. Soil temperature was periodically measured every two hours from 8 PM to 6 AM at the same depths using a digital thermocouple. At every two days moisture and temperature measurements were recorded. After harvest, plant height and root depth were measured and total crop yield was weighted.

RESULTS AND DISCUSSION

Irrigation Treatments: Irrigation water was calculated using the equivalent water depth equation. The initial water content was 2.7 % (g g^{-1}) along the 30 soil depth. So, on planting day (6 January 2008) the first amount of applied was to substitute 14.8% moisture content, concerning soil depth as 10 cm for all treatments (this applied water amount was equivalent to 195 m^3 ha^{-1}). On the next days soil moisture contents were determined two days periodically for the three soil depths (i. e. 10, 20 and 30 cm, in which soil temperature was measured every 2 hours at the same day). The results indicated that not only the upper 10 cm, but all three depths were closed to the soil field capacity as shown in Fig. 1, 2 and 3. This finding may resulted because of the calculated water amounts were applied to a limited area (under the emitters) and not for all soil surface, therefore, during the growing season, soil depth involving in equivalent water depth equation was constant and not increased responsible to plant roots development. After that, soil moisture contents along all depths were periodically monitored and the irrigation process has been performed when soil moisture depleted and reached about 8 %. Each greenhouse (included the two different treatments: mulching soil and bare soil) was irrigated separately, where the three greenhouses were brought to different levels of soil field capacity (i. e. up to 100 %, 66 % and 33 % of soil field capacity for W1, W2 and W3, respectively).



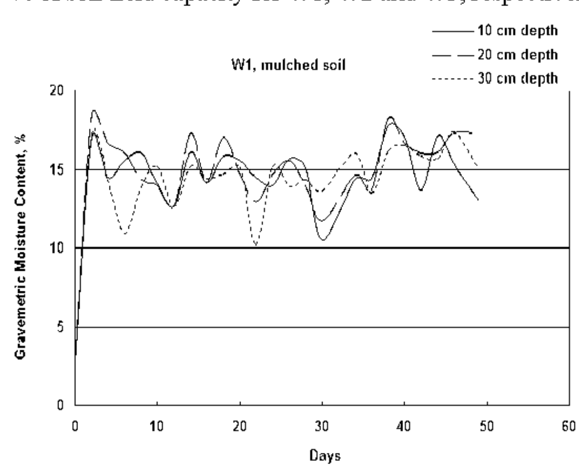


Fig. 1: Soil moisture variability in W1 treatmens at the three soil depths

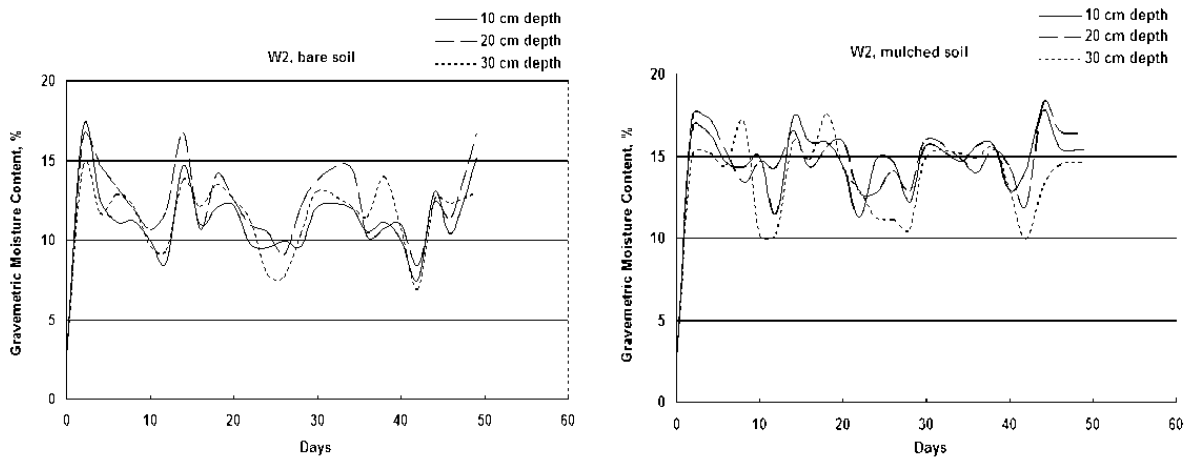


Fig. 2: Soil moisture variability in W2 treatmens at the three soil depths

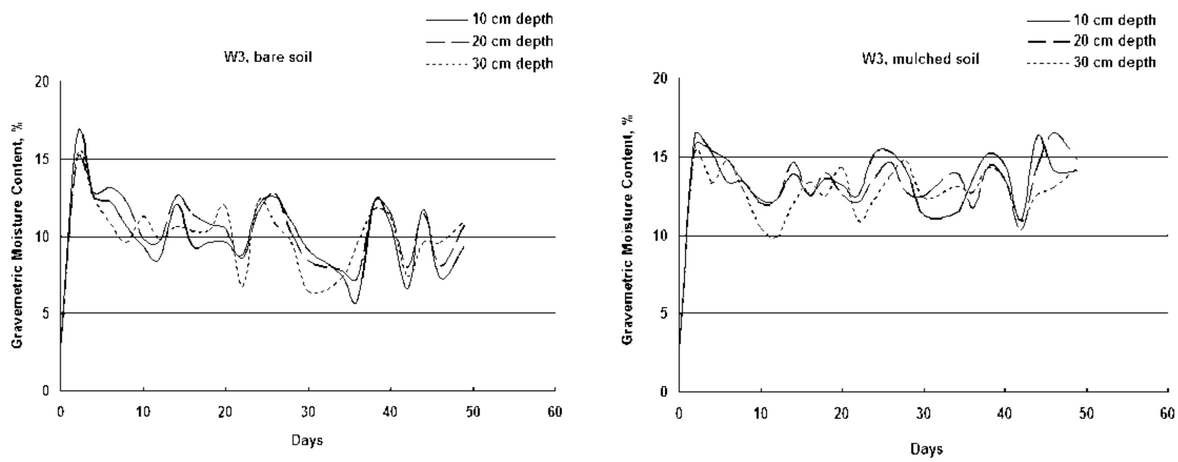


Fig. 3: Soil moisture variability in W3 treatmens at the three soil depths

These different levels of soil field capacity applied in each irrigation treatment were calculated as a ratio of the difference between 8 % and 17.5 %.

Soil moisture distribution, Fig. 1, 2 and 3 indicated that there is an increase in soil moisture content for all treatments with mulching compared to bare soil treatments. This result indicated that plastic mulch had an observed influence on evapotranspiration reduction. The results also indicated that the highest moisture were stored at 20 cm depth, compared to the upper and lower depths. Therefore, it is expected to have a positive impact on root growth and provide it with more available water. Under all treatments the curves show that there was a clear fluctuation in moisture contents which may be owing to the repeated irrigation. Results showed that this fluctuation was greater under the mulching treatments than the bare soil. This means that evapotranspiration was higher in the first case than the second. For example, data shown that soil moisture fluctuations ranged from 7.5 % to 19 % and from 10 % to 18 % under W1 for bar and mulched soil, respectively. The results show that the highest fluctuation occurred under W1 bar soil, while the lowest was under W3, for both mulched and bare soil treatments.

Soil Moisture Distribution: Generally, evapotranspiration was higher under no mulching treatments than under mulch treated soil. This can be noticed from Fig. 1-3 that illustrated the distribution curves of moisture contents for the studied soil under different treatments, similar result was found by Richard [7] and Zhang *et al.* [15]. As shown there are observed clear fluctuations in soil moisture levels, however, the degree of this fluctuation is clustered between the treatment and the other. In general, the fluctuation was arbitrary in treatments without mulching plastic compared to mulching treatments and appears clearly in the W1 and W3. However, it is noticeable that there are some mulching treatments varied also in the degree of moisture content fluctuation, where it was found, for example, this fluctuation as little as possible in the treatment of W3 mulching (which has less moisture contents and may resulted in a relative stress led to the occurrence of fluctuating slightly), followed by W2 mulching (with medium moisture contents), then W1 mulching (with the highest moisture contents). This arrangement consistent in direct correlation with the values of plant height, depth of the root, values of crop production and large amounts of heat stored in the soil. Therefore, it is likely to be the degree of fluctuation in soil moisture content has an influential role in the crop production and not only soil moisture content. Although irrigation treatment in W3 was applied to reach soil moisture content until 33 % of soil field capacity, the best results were recorded under this treatment (with mulching) compared to W2 and W1 which irrigated until 66 % and 100 % of soil field capacity, respectively.

As it is evident from the obtained results it can minimize the fluctuation occurred in soil moisture contents, consequently minimizing heat fluctuations, by reducing or increasing the water amounts added during the irrigation process.

Soil Temperature Distribution: Figures 4, 5 and 6 illustrated the daily changes occurring in soil temperatures at the three different depths: 10, 20 and 30 cm measured at 6 PM. Figures showed that soil temperature with mulching are much higher than those of soil without mulching. This may be owing to mulching prevents cooling of soil surface due to evaporation, in other words the black plastic mulch would reduce connective heat loss, outgoing radiation and evaporation, thus increasing soil temperature. So, mulching finding favorable soil environmental conditions for plant growth.

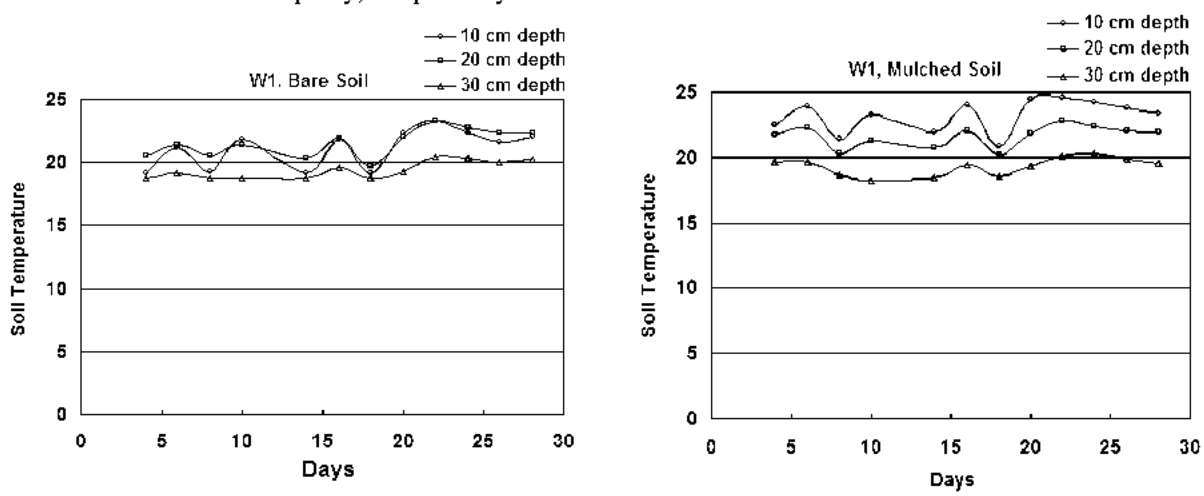


Fig. 4: Soil temperature variability in W1 treatmens at the three soil depths

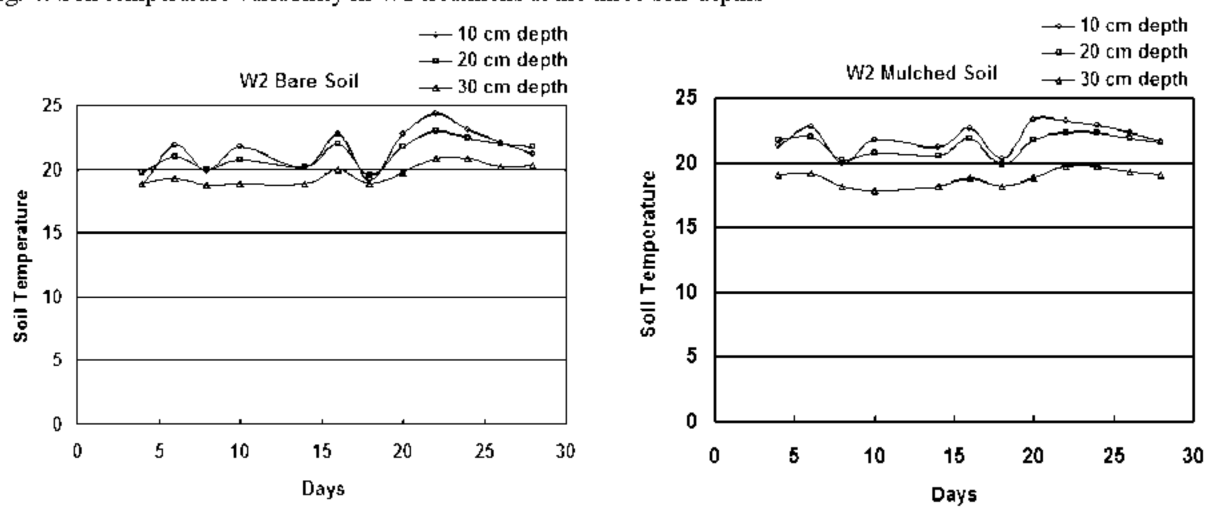


Fig. 5: Soil temperature variability in W2 treatmens at the three soil depths

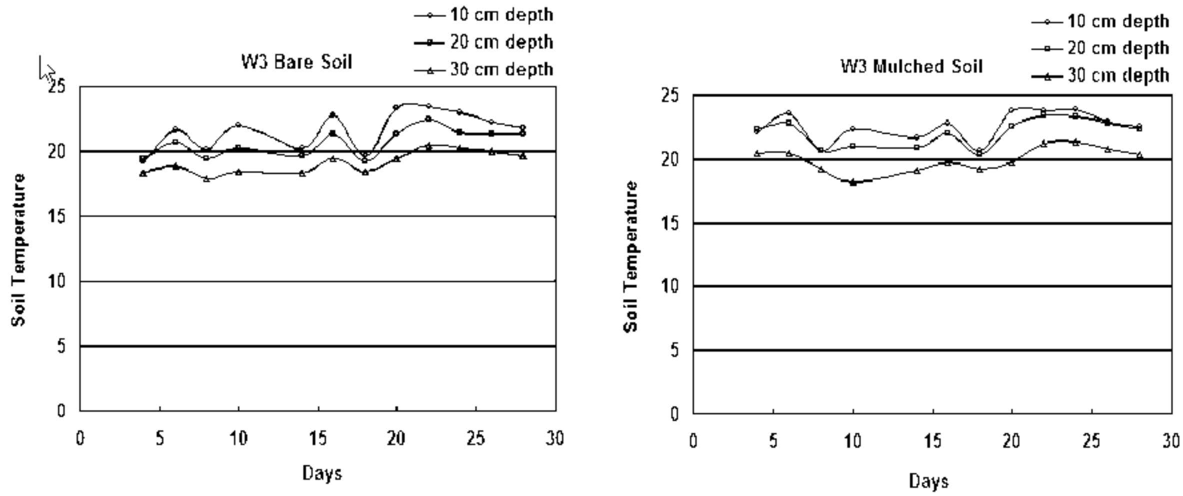


Fig. 6: Soil temperature variability in W3 treatmens at the three soil depths

Generally, all values of soil temperature recorded under each treatments showed that the highest temperatures were obtained at 10 cm depth, followed by 20 cm then 30 cm. Curves also indicate that soil temperatures were higher at the different depths under the mulching treatments than those under treatments without mulch. This observation was found clearly under both depths 10 and 20 cm compared to 30 cm depth. The increasing in soil temperature values fund under mulching treatment in W1 was higher compared to record under mulching treatments in W2 and W3. On the other hand, changes in soil temperatures under treatments without mulch were similar.

Although soil temperatures were measured under all treatments at the same time of day (i. e. 6 AM), the results indicate that there were considerable variations in the maximum temperature to which the upper soil layer of 10 cm has been reached under different irrigation treatments. The maximum temperature in W1 ranged on average from 23.2 °C under mulching treatment to 21.1 °C in treatment without mulch and the corresponding values were ranged from 22.0 to 21.5 °C and ranged from 22.6 to 21.6 °C for W2 and W3, respectively. Increasing of soil under mulching treatment in W1 may be attributed to the interaction between the mulching with black plastic and at the same time increasing soil heat capacity due to increasing its moisture content.

Heat Storage in Soil: One of the major objectives of this study was to maximize the heat storage in the soil root zone. As shown in Fig. 4-6, there were observed variation in soil temperature between the different treatments. The values of soil temperature with mulching are much higher than those without mulch, because mulching could prevent cooling of the soil surface due to evaporation and at the same time absorbs most of the sunlight and becomes greatly warmed and some energy passed to warm the soil. As response, a greater heat storage in soil during daylight and a limitation of cooling during the night-time and consequently producing an important gain of heat during the initial period of growth. Based on the soil thermal regime, soil temperature only is not enough to describe the fate of energy into the soil as affected by its moisture content and its bulk density. So, the quantity of heat flows across a limited area of soil in limited time is a function of soil specific heat, bulk density, moisture content and the change in soil temperature and could be described and calculated according to Hanks and Ashcroft [16] as following:

$$Q_q = \rho_b\ (0.2 + \theta_m)\ V\ (T_1\text{-}T_2) \quad (1)$$

In which volumetric heat capacity of soil, C_v, can be calculated by ρ_b $(0.2 + \theta_m)$, Q_q is the quantity of heat (in calories) flows in a defined volume of soil (this quantity which could flow across a unit area of soil section in cm^2 along 10 cm soil depth to give 10 cm^3 affected volume), ρ_b is soil bulk density, equals 1.32 g cm^{-3} for the studied soil, 0.2 is specific heat in average for mineral soil, in cal. g^{-1} °C^{-1}., V is he affected soil volume in cm^{-3} and $(T_1\text{-}T_2)$ is difference in soil temperature between the beginning and the end of the 10 hours period for each 10 cm soil layer (i. e. ΔT in °C), so equation become:

$$Q_q = (0.264 + \theta_v)\ 10\ (\Delta T) \quad (2)$$

Table 2a: The quantity of heat, in calories, stored in 30 cm soil depth through 10 hours period, from 8 PM to 6 AM in W1 treatment, under bare soil. Data included soil moisture content, θv % and temperature difference, ΔT °C

	Soil depth									
	0-10 cm			10-20 cm			20-30 cm			
Days	θv	ΔT	Q	θv	ΔT	Q	θv	ΔT	Q	Q-Sum
4	17.7	7.5	1347	18.1	6.1	1120	18.5	3	562.9	3030.4
6	15.2	9.2	1423	16.6	6.4	1079	16.4	2.7	449.9	2951.9
8	12.5	8.3	1059	13.9	6.4	906.5	16	2.6	422.9	2388.8
10	11.9	10.3	1253	14.5	7.8	1152	11.6	3.1	367.8	2772.3
14	20.7	6.6	1384	23.8	5.7	1372	19.9	2.8	564.6	3319
16	18.6	7.2	1358	20.6	6.8	1419	19.5	3.4	672	3449
18	16.6	3.5	590.2	19.9	2.6	524.3	19.7	1.2	239.6	1354.1
20	13.6	9.2	1276	19.7	7.4	1477	16.5	3.2	536.4	3289.2
22	11.4	8.3	968.1	15.8	7.8	1253	18	3.8	694	2915.1
24	16.4	5.9	983.2	14.3	5.7	830.1	13.5	2.5	344.1	2157.4
26	13.3	6.2	841	11.9	6.7	815	13.2	2.8	377	2033
28	14.3	7.1	1034	13.2	7.2	969.4	10	3.5	359.2	2362.6

Table 2b: The quantity of heat, in calories, stored in 30 cm soil depth through 10 hours period, from 8 PM to 6 AM in W1 treatment, under mulched soil. Data included soil moisture content, θv % and temperature difference, ΔT °C

	Soil depth									
	0-10 cm			10-20 cm			20-30 cm			
Days	θv	ΔT	Q	θv	ΔT	Q	θv	ΔT	Q	Q-Sum
4	19.1	8.6	1665	22	6.1	1358	18.9	3.1	594.1	3617.5
6	20.5	9.9	2056	21.1	6.5	1389	14.4	2.7	395.9	3840.2
8	21.1	8.7	1859	18.9	5.3	1016	18.3	2.3	427	3301.4
10	18.6	10.3	1943	18.5	7	1314	20.1	2.5	509.1	3765.6
14	21.3	7.7	1660	22.8	5.1	1176	20.1	2.3	468.4	3305.1
16	18.6	8.2	1547	18.7	5	948.2	19	2.7	520.1	3015.1
18	20.9	3.5	740.7	22.4	2.6	589.3	19.4	1.9	170	1500
20	20.5	10.3	2139	19.4	6.5	1278	19.9	2.9	584.8	4001.7
22	19.1	9	1743	17	5.8	1001	13.5	2.6	357.9	3102
24	18.5	6.9	1295	19.4	4.8	943.9	20.1	2.2	448	2686.6
26	20.7	7.9	1656	20.5	5.9	1225	18.3	2.7	501.2	3382.5
28	19.9	8.8	1774	18.5	6.3	1182	18.9	2.5	479.1	3435.6

Table 3a: The quantity of heat, in calories, stored in 30 cm soil depth through 10 hours period, from 8 PM to 6 AM in W2 treatment, under bare soil. Data included soil moisture content, θv % and temperature difference, ΔT °C

	Soil depth									
	0-10 cm			10-20 cm			20-30 cm			
Days	θv	ΔT	Q	θv	ΔT	Q	θv	ΔT	Q	Q-Sum
4	16.5	6.7	1123	19.4	6.1	1199.5	15.4	3.1	485.6	2808.3
6	14.7	9.9	1481	17.6	7	1250.5	17	3.2	552.4	3284.3
8	14.8	8.7	1311	15.7	6.7	1069.6	16	3	488	2868.2
10	13.1	10	1336	14	7.6	1084.1	12.7	3.6	466.7	2887.2
14	19.4	7.2	1416	22	6.1	1358.1	18.2	3.1	572.4	3346.3
16	14.5	7.8	1152	14.1	7.3	1048.6	16	3.9	634.3	2834.5
18	15.8	3.1	498	18.6	2.8	528.2	17.8	1.4	252.9	1279.1
20	16.1	9.7	1587	16.5	7.7	1290.8	16.5	3.6	603.5	3481.6
22	12.8	9.3	1215	14.4	7.8	1143.8	14.8	4	602.6	2961.4
24	12.5	6.6	842.4	13.9	5.8	821.5	10.3	2.9	306.4	1970.3
26	13.1	7.1	948.8	12	6.8	834	10.2	3.1	324.4	2107.2
28	12.7	7	907.5	16	6.7	1089.7	13.7	3.6	502.7	2499.9

Table 3b: The quantity of heat, in calories, stored in 30 cm soil depth through 10 hours period, from 8 PM to 6 AM in W2 treatment, under mulched soil. Data included soil moisture content, θv % and temperature difference, ΔT °C

	Soil depth									
	0-10 cm			10-20 cm			20-30 cm			
Days	θv	ΔT	Q	θv	ΔT	Q	θv	ΔT	Q	Q-Sum
4	21.5	7.4	1611	22.7	6.2	1429.8	20.1	2.6	529.5	3569.8
6	19.3	8.7	1702	20.2	6	1227.8	19.1	2.4	464.7	3394.6
8	18.9	7.4	1418	17.7	5.1	916.2	22.6	1.8	411.6	2745.9
10	16.1	8.7	1424	19.4	6.1	1199.5	13.5	2.1	289	2912.2
14	23	7.1	1652	21.8	5	1103.2	21	2.1	446.5	3201.4
16	21	7.2	1531	18.9	6	1149.8	19.5	2.4	474.3	3155.1
18	20.8	3.3	695.1	20.6	2.2	459	23.2	0.8	187.7	1341.8
20	19	9.3	1792	21	6.6	1403.4	18.9	2.7	517.4	3712.4
22	14.9	7.2	1092	16.9	5.8	995.5	17	2.7	466.1	2553.4
24	19.5	5.7	1127	16.9	4.9	841	14.8	2	301.3	2268.8
26	19.4	6.4	1259	18.6	5.6	1056.4	14.7	2.1	314.2	2629.1
28	16.1	6.6	1080	17	5.9	1018.6	14	2.5	356.6	2455.2

Table 4a: The quantity of heat, in calories, stored in 30 cm soil depth through 10 hours period, from 8 PM to 6 AM in W3 treatment, under bare soil. Data included soil moisture content, θv % and temperature difference, ΔT °C

	Soil depth									
	0-10 cm			10-20 cm			20-30 cm			
Days	θv	ΔT	Q	θv	ΔT	Q	θv	ΔT	Q	Q-Sum
4	16.6	6.9	1163.6	16.9	5.9	1012.7	16.5	3.3	553.2	2729.5
6	16.1	9.1	1489.1	17.4	7	1236.5	14.3	3.5	509.7	3235.3
8	14	8.9	1269.5	16.1	6.4	1047.3	12.7	3.2	414.8	2731.6
10	12.3	10	1256.4	12.9	7.6	1000.5	14.9	3.9	391.4	2648.3
14	16	6.6	1073.4	16.6	5.6	944.4	14	3.1	442.2	246
16	12.4	7.4	937.1	15	6.7	1022.7	13.6	3.9	540.7	2500.5
18	12.7	3.2	414.8	14.3	2.7	393.2	13.7	1.3	181.5	989.5
20	12.7	9.7	1257.5	13.9	7.2	1019.8	15.7	4	638.6	2915.9
22	11.6	7.3	866	11.4	6.6	769.8	9	3.8	352	1987.8
24	15.8	5.9	947.8	15.3	5.3	824.9	16.2	3.2	526.8	2299.5
26	16.5	6.4	1072.9	16.8	6.3	1075	14.3	3.9	568	2715.9
28	14.4	6.7	982.5	13.5	6.7	922.2	12.7	3.9	505.6	2410.3

Table 4b: The quantity of heat, in calories, stored in 30 cm soil depth through 10 hours period, from 8 PM to 6 AM in W3 treatment, under mulched soil. Data included soil moisture content, θv % and temperature difference, ΔT °C

	Soil depth									
	0-10 cm			10-20 cm			20-30 cm			
Days	θv	ΔT	Q	θv	ΔT	Q	θv	ΔT	Q	Q-Sum
4	20.2	7.9	1616.7	20.3	6.2	1275	17.6	3	536	3427.7
6	17.7	9.3	1670.7	19.5	6.7	1324.2	19.5	2.6	513.9	3508.8
8	17.7	7.7	1383.2	17.7	6.5	1006	17	2	345.3	2734.5
10	15.8	9.2	1477.9	16.1	6.3	1030.1	13.7	1.6	223.4	2731.4
14	18.3	7.3	1355.2	19.3	5.2	1017.3	15.8	2.3	369.5	2742
16	16.6	7.2	1214.2	16.5	5.9	989.1	17.7	2.6	467.1	2670.4
18	18	3.6	657.5	18.5	2.6	487.9	16.5	0.9	150.9	1296.3
20	17.4	9.7	1713.4	16.6	6.9	1163.6	18.9	2.7	517.4	3394.4
22	16.5	7.5	1257.3	16	6.6	1073.4	14.4	3.2	469.2	2799.9
24	20.1	6.6	1344	18	5.5	1004.5	16.2	2.3	378.7	2727.2
26	20.2	6.7	1371.1	19.3	6.1	1193.4	18.2	2.7	498.5	3063
28	18.6	7.5	1414.8	16.8	6.3	1075	19.4	2.6	511.3	3001.1

Because of each layer and each treatment has a defined moisture content and temperature changing differ than each other, it is expected to found observed variations among the calculated heat quantities, therefore this property could be taken as good indicator for soil warming. Tables 2-4 included values of soil moisture contents, θv, (for each 10 cm soil layer), temperature difference ΔT for the same layer, during a period of 10 hours daily (from 8 am to 6 am), in addition to heat quantities stored in soil for the same period calculated by equation 2. The results showed that different heat quantities stored in soils are posed by changes in soil temperature and its moisture contents. Generally, those heat quantities are increased as moisture content and soil temperature differences increased. Results recorded in Table 2a indicated that the quantity of heat stored at the end of the 14th day in the depth of 30 cm is equal to almost 565 calories, in which the temperature difference was 2.8°C and moisture content equals to 19.9 %. When this quantity compared with the corresponding quantity stored in the 18th day, we find that it has become almost 240 calories (i.e., less than half the previous value), although the moisture content remained almost unchanged, while the temperature only dropped to 1.2 °C (difference is 1.6 °C). On 26th day, It was found that the change in temperature is the same as that found in 14th day, while soil moisture content decreased sharply to 13.2 % has resulted in a decrease in heat stored, amounting to 377 calories. Conclude from this that the heat quantity stored in soil changed to a low grade when the soil moisture change significantly while the change occurs sharply when small changes in soil temperature, which indicates that the thermal fluctuations in the layers of soil has an influential role in its heat storage.

Tables 2-4 illustrated that the plastic sheet allowed an additional take up of solar energy absorption. Therefore, if the soil warmed up slowly, heating of the same soil mulched with plastic film will be more rapid and this resulted in a greater storage of heat during the day-time and consequently provides a suitable heat exchanger or a limitation of cooling during the night-time. Black plastic mulch absorbs most of sunlight and becomes greatly warmed and some energy passes through to warm the soil. The black plastic mulch resulted in higher soil temperature, therefore the more heat is taken away from soil, which leads to a greater increase of soil heat storage, especially in the upper two depths.

Soil Moisture and Temperature Fluctuations: Based on the thermal inertia concept, Lakshmi *et al.* [17] reported that water soil will exhibit smaller surface temperature amplitude due to the thermal inertia of the water in soil. When comparing the curves of fluctuation of soil moisture with the curves of fluctuation of temperature under different irrigation treatments (i.e. W1, W2 and W3), it is noted that the lowest fluctuation appeared in the soil moisture under treatment W3 compared to W1 and W2 resulted similarly in reducing the fluctuations of soil temperature in W3 treatment comparison to W1 and W2. This result is agreement with those obtained by Fan and Liu [3], they reported that when the initial soil water content increased, soil temperature (through 40 cm soil depth) will change more intensively and rapidly than those when the initial water content is low. This behavior has been appeared in the upper layers, 10 cm and 20 cm and is likely that it may play a significant role also in increasing production and vegetative growth of the plant. The obtained results cleared the treatment W3 with mulch, that the more availability of appropriate content of moisture and heat in the root zone is not alone sufficient for good plant growth, but the stability of these circumstances and not to a reasonable degree of fluctuation is an important factor for plant growth. So, this result has significant practical importance, where the irrigation process can be achieved rely using a limited water source (where it is not necessary that soil reach its field capacity, but sharp enough to reach only one-third) that leads to obtain high production, in addition to reducing of irrigation hours and energy. Cucumber yield, Plant height, root depth and heat stored in soil have been affected by the different treatments (Table 5). Dada showed that the values of the plant parameters and crop yield were increased due to increasing in soil moisture content cased by losses of evaporation of soil water and increasing the heat quantities stored in soil under mulching treatment compared to bar soils. Similar results were reported by Gajri *et al.* [18], Jain *et al.* [19], Khurshid *et al.* [20] and Seyfi and Rashidi [21]. Data also showed that W3 mulched soil treatment had the highest value of crop yield (0.875 kg plant^{-1}) compared to all treatments.

As shown from Table 4, Fig. 1-3 and Fig. 4-6, plant height, root depth and crop yield obtained from W1 mulched soil treatment were higher than all treatments except for W3 mulched soil. This result may be explained based on the concept that reported by Campbell *et al.* [1], who stated that soil thermal conductivity increases dramatically with temperature in moist soils.

Table 5: Plant height, root depth, crop yield and heat storage in average (calculated from Tables 1-3)

W3		W2		W1		
Bare	Mulched	Bare	Mulched	Bare	Mulched	Parameters
60	142	102	145	100	131	Plant height, cm
14	21	19	23	18	26	Root depth, cm
0.12	0.875	0.281	0.435	0.246	0.524	Crop yield, kg/plant
2284	2841	2694	2828	2669	3246	Heat Storage, cal.

The obtained data for root depth, listed in Table 4 showed that warmer temperatures under mulched treatments tend to accelerate and encourage plant root growing and distribution and probably was the most important process for nutrients uptake resulted in high plant height and crop yield. On the other hand, data indicated that treatment W3 of bare soil has been recorded with the least heat storage and the highest moisture fluctuations compared to the other treatments as shown in Fig. 1-6, so it may be associated with its low yield production. Also data showed that bare soil treated with irrigation treatments in W3 and associated with high soil temperature has increased the evaporation from soil and thus contribute to drier soil moisture.

CONCLUSION

Generally, soil temperature at different soil depth changed periodically with the periodic changes of soil moisture contents, all mulching treatments lead to increasing of soil moisture content and temperature compared to the bare soil. During the most parts of the day, soil temperature in the upper layers are higher than those in the deeper layer, which leads to a greater increase of soil heat storage in the upper two depths. The obtained results could be used to guide soil management strategies for local and other regions which have such conditions. It recommend to apply the management of treatment W3-mulched soil followed by W1 or W2 (both for mulched soil), under which plant roots could be provided with the best conditions of temperature and moisture distribution and at in the same time have the lowest fluctuation in both moisture and temperature levels, in turn resulted in the optimum conditions for vegetative growth and production.

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