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UTILIZATION OF SOIL MULCH FOR INCREASING SURFACE IRRIGATION PERFORMANCE AND WATER PRODUCTIVITY

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Abstract

Maximizing water productivity is one of the most important strategies in arid and semi-arid regions. Therefore, the aim of this study was to investigate the using of plastic mulch at field scale for improving the performance of surface irrigation in contrast to conventional practices in irrigated agriculture. The experiment was laid out in furrow and border irrigation system with three main treatments namely non-mulched furrows (NMF) (as control), plastic mulched furrows (FM) and plastic mulched-hole border (MB), and the sub main treatments were three lengths (15, 30 and 40 m). Each of the three main plots consisted of 9 irrigation parts each three of them represent one of the sub main treatments (furrow and border lengths). The spacing was 0.7m between all treatments. Squash crop was planted in April for two successive seasons. The results indicated that applied water was low in case of MB where the mulch effect reduced the number of irrigation times to the half. The maximum total yield was obtained from treatment with 30m length under MB (31.89 t/ha) followed by 15 m under MB (30.46 t/ha). As regard different irrigation practices with plastic mulch, maximum irrigation water productivity (8.33 to 9.15 kg/m^3) was measured in MB for all lengths, followed by MF (5.11 to 5.41 kg/m^3). The water saving was thus 10.44% and 46.3% under treatments MF and MB, respectively, when compared to NMF. The result of this study indicates that, using hole-mulching resulted a corresponding increasing of water productivity and water saving.

Key words: *plastic mulch, surface irrigation, squash, water productivity*

INTRODUCTION

Optimized water management techniques at the farm level are required in view of increasing water demand and limited resources. Flood irrigation method is the most effective and ready to adopt surface irrigation system and widely used for all crops [9]. Basin, border and furrow are the traditional surface irrigation methods, which are used to irrigate crops in Egypt. Closely related furrow irrigation is the surface irrigation which utilizes the water for irrigation more efficiently as compared to other surface irrigation methods [4].

At present, the effects of plastic film mulching technology are mainly on border irrigation and furrow irrigation. In border irrigation, the membrane is laid on the border fields, where crops are grown. In furrow irrigation, crops are planted on groove slope or ridge back, while membrane is tiled on the bottom of the ditch, groove slope and part of the ridge back [18, 20].

Mulching is one management method that can be used to conserve water by preventing surface evaporation, controlling weeds, regulating soil surface temperature, improving overall soil quality by increasing soil organic matter, stimulating soil activity, increasing nutrient availability and increase crop yield [12]. Likewise, mulching is an economical and effective management method for controlling the moisture of the soil in root zone of crop [7, 13].

Under mulched furrow experiment done by Shelemew et al. [14], total yield harvested of head cabbage from black plastic mulch were 9.33ton/ha. High yield of 16.60 ton/ha was recorded from full irrigation that is 100%ETc and when half of irrigation water applied the yield were 9.4 ton/ha which showed significant difference between the two irrigation level. Water productivity of 4.3kg/m^3 and 3.8kg/m^3 were produced under 50%ETc and 100%ETc or full irrigation water respectively. The effects of mulching materials and furrow irrigation techniques on maize yield and water productivity under semiarid conditions indicate that both grain yield and water productivity were affected by the main effect of furrow irrigation techniques and mulching materials ($P \leq 0.05$) [2]. The conventional furrow irrigation (8,193 kg/ha) and white plastic mulch (7,930 kg/ha) resulted in the maximum grain yield.

The grain yield and nitrogen fertilizer utilization under border with 40 m length irrigation were significantly higher than those under irrigation of other border lengths and was considered as the best border irrigation length [21]. The saving percentages of water under treatments were 52.22% and 31% under furrow bottom with plastic sheet without plastic Sheet respectively, as compared to the saving of water under traditional irrigation practice [10]. Overall, better performance, in terms of crop production and water saving, was obtained with use of plastic sheet integrated with bottom of furrows. Hence, it is suggested that the furrow irrigation method with plastic sheet may be used to preventing moisture and minimize deep percolation losses from furrow bottom. The overall objective of the study was to investigate the using of plastic mulch of furrow and border irrigation on squash crop yield and its water productivity, as well as on improving the performance of irrigation method and its water distribution uniformity.

MATERIALS AND METHODS

Site Description

Field experimental study was conducted in private farm at Minya Alqamh, Sharkia governorate, Egypt - during two summer seasons of 2021 and 2022 from mid-April to end July. The location represents clay soil conditions of the Nile Delta region. The dominant soil of the experimental site was clay textured throughout the profile (5.4% coarse sand, 10.2% fine sand, 14.2% silt and 70.2% clay). The field capacity, wilting point and electrical conductivity values were 38%, 18.7% and 2.1 dSm^{-1} respectively.

Experimental layout and design

The experiment was laid out in furrow and border irrigation system with three main treatments namely non-mulched furrows (NMF) (as control), plastic mulched furrows (FM) and plastic mulched-hole border (MB), and the sub main treatments were three lengths (15, 30 and 40 m) as in Fig (1). Each of the three main plots consisted of 9 irrigation parts each three of them represent one of the sub main treatments (furrow and border lengths). The spacing was 0.7m between all treatments.

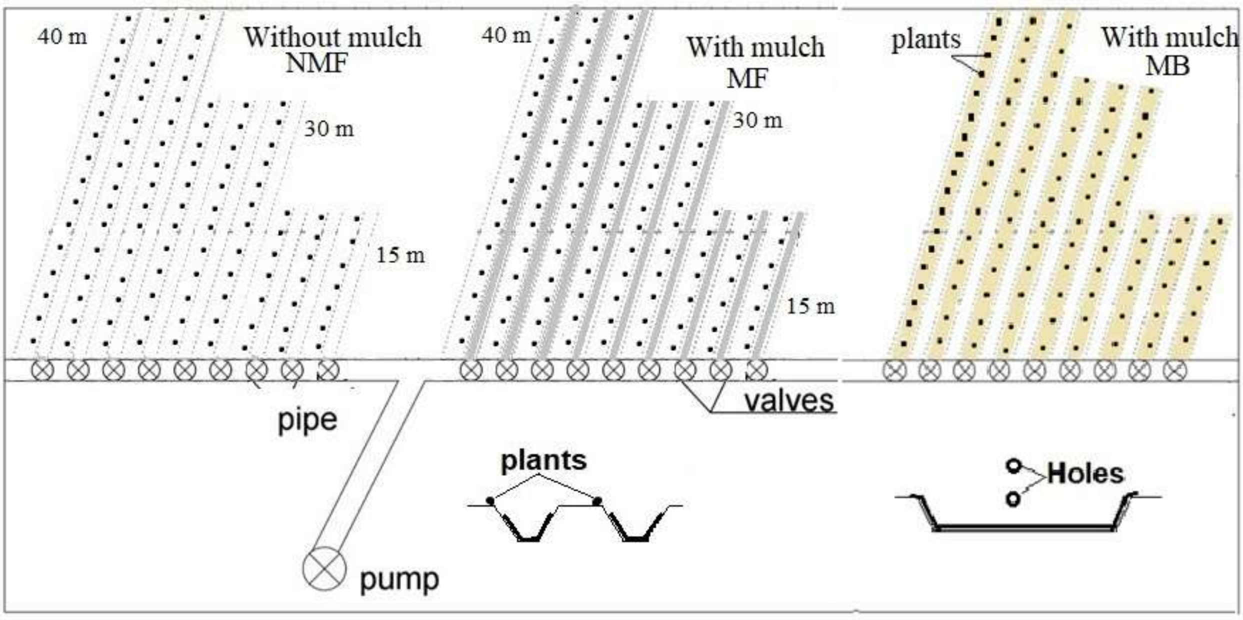

Fig. 1. A schematic diagram of the experimental treatments and the irrigation network components
Source: Authors' determination.

The experimental irrigation network consisted of (i) 6.5 HP gasoline engine water pump, (ii) Main lines of 75 mm diameter P.V.C pipes (iii) the pipe was provided with several 1 inch valves to control the amount of water add to each furrow or border. In the mulched furrow treatments, black polyethylene sheet of 0.08 mm thickness was manually laid out on the furrow bottom and fixed at sides of furrow to two third of the ridges for sowing the crop. The process of supplying the plant with water was based on filling the furrow with water to the level of the plastic cover, then the water will infiltrate into the furrow sides. In the mulched-hole border treatment, the surface of the borders was covered with plastic sheet and the edges were well fixed with the edges of the raised borders manually. The planting holes were performed in the sheet-hole with the help of 5 cm diameter pipe with sharpen edge [16]. The plant to plant spacing and row to row width was set as 70 cm (planting distance). After the cultivation process, water was added using the valves.

Type of crop under study

The selected crop for experimentation was squash (zucchini) (Aziad Hybrid F1) variety. It was sown by seeding rate of (8 kg/ha) in April of the two seasons. Two seeds were sown in each hole with 70 cm between holes and 70 cm spacing between furrows and border. After full germination, the best plant has been selected to be left in each hole for production. Fertilizer requirements for zucchini have been applied according to the recommendations of Agricultural Research Center, ARC.

Irrigation management

The amount of irrigation requirement for squash crop was calculated according to the climatic balance irrigation that established with numerical models by Central Laboratory for Agricultural Climate (CLAC), Ministry of Agriculture and Land Reclamation for experiment location. Water consumptive use (ETo, mm/day) was calculated according to the climate data using the Penman-Monteith method [5]. The crop water requirements (ETc) were estimated using the crop coefficient according to following equation:

ETc= ETo x Kc..................................(1)

where:
ETc is the crop water requirement (mm day^{-1}), and Kc is the crop coefficient.

The duration of the different crop growth stages were 20, 35, 20, and 15 days for initial, crop development, mid-season and late season stages, respectively and the crop coefficients (Kc) of initial, mid and end stages were 0.60, 1.00 and 0.75, respectively [3].

Soil moisture was monitored gravimetrically through soil depths (0-20, 20-40 and 40-60cm) layers. Soil samples were taken from each 20cm layer up to 60cm soil depth at four points along each furrow.

For high yield, soil water depletion should not exceed 65% of the total available water (p=65%) [1]. Soil moisture depletion (SMD) at any soil moisture level was observed with the following expression as:

SMD= (FC- MC) x Dzr........................(2)

where:
FC = Volumetric soil moisture content at field capacity (%), MC = Volumetric moisture content at time of irrigation (%) and Dzr = Depth of effective root zone (mm).

Regular soil samples were collected from experimental plots before and after irrigation for gravimetric soil moisture determination. The gravimetric soil moisture is then determined using the expression:

MC (%) = [(Ww - Wd)/ Wd]. 100.........(3)

where:
MC is the soil moisture content at time of sampling (%), Ww is weight of wet soil (gm) and Wd is weight of dry soil (gm).

Water distribution uniformity of furrow irrigation

To fully express the efficiency of an irrigation system, the distribution uniformity of water applied needs to be evaluated. Distribution Uniformity (Du) is the ratio of minimum infiltrated amount to the average infiltrated depth over the field [19]. DU was directly measured from soil moisture content difference before and after irrigation of the soil along the furrow and border length, and the root depth of the crop was taken as zone of distribution and finally it was computed by equation given below:

$$D_u = \frac{Z_{min}}{Z_{Av}} * 100 \quad \text{..........................(4)}$$

where:

Du is distribution uniformity (%), Z_{min} is the minimum infiltrated depth, and Z_{Av} is the mean of depths infiltrated over the length.

Soil moisture distribution

For each treatment, four locations were taken along the row of plants. The soil water content was determined using the gravimetric method. Moisture content for each treatment was measured at 0.2 m increments to a depth of 0.60 m before irrigation and 48 hours after irrigation.

Growth parameters of squash (zucchini) crop

Three vegetative samples were taken during the growth period at the middle and end of the growing seasons. The following characteristics were measured:

1. Germination ratio (the germinated plants were counted along with non-grown plants. On the basis of numbers of grown and non-grown plants, germination percentages were determined).

2.Vegetative growth (length, weight, number and area of leaves, and root length and weight)

3.Productivity (The fruits were harvested by collecting in the appropriate phase for fresh consumption and the consumer's taste. They are easy fruits that are quick to perish, and trained workers collected them).

Irrigation water productivity (WP)

Irrigation water productivity is an indicator of effective use of irrigation unit for increasing crop yield. WP was calculated from following equation [5]:

$$WP\ (kg/m^3) = \frac{yield\ (kg/ha.)}{Total\ applied\ irrigation\ water\ (m^3/ha)}$$

....(5)

Data Analysis

The least significant difference (LSD) test was applied at 5% level of significance to compare means showing significant differences.

RESULTS AND DISCUSSIONS

Effect of plastic mulch on soil moisture Content and water distribution uniformity

The average values of moisture amount for each replication of the treatments and soil depth (0-60 cm) in mid-season of squash under different systems of planting with and without polythene mulch are shown in Figures 2, 3 and 4 between to irrigations. The mulched furrow planting system (MF) recorded significantly (P< 0.05) high moisture content over without mulched furrow (NMF) treatment as shown in Figures 2 and 3. However, there is no significant difference among the mulched furrow lengths. Before irrigation, the highest moisture content was 26.7 % under MF as an average for the three lengths. The moisture content directly before the irrigation in MF planting system registered 17.4 % increase over NMF.

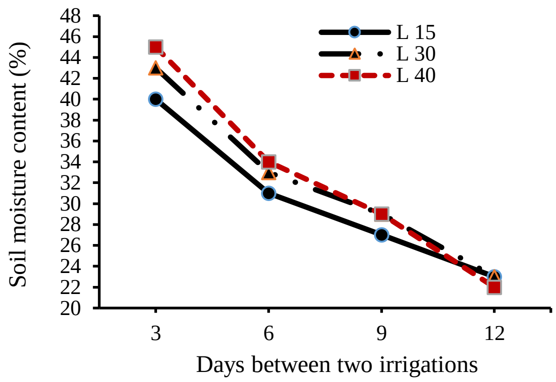

Fig. 2. Moisture content between two irrigations for NMF under different lengths
Source: Authors' determination.

The MB recorded significantly (P < 0.05) high moisture content. However, there is no significant difference among the MB lengths but there is significant difference among NMF lengths.

Before irrigation, furrow treatments required to irrigate after 12 days where soil moisture content reached 24.6% and (soil water depletion should not exceed 65% of the total

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available water (p=65%)) while MB treatments continued to 25 days to soil moisture content reach 25.7% as an average for the three lengths (Fig 4).

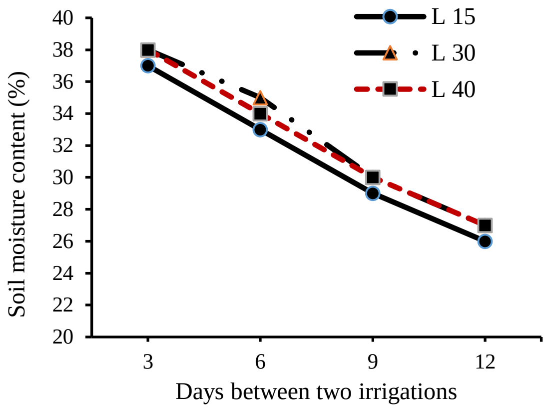

Fig. 3. Moisture content between two irrigations for MF under different lengths
Source: Authors' determination.

From the above observation on moisture content, it can be said that the plastic mulches are effective in water storage. Mulches were increasing the stored water in root zone than without mulched treatments and it could be inferred that the plastic mulches are competent enough to reduce evaporation loss there by effective in conserving moisture as a result moisture is available to meet the water requirement of the crop [17].

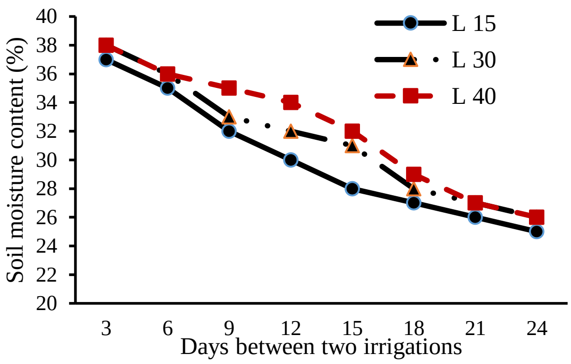

Fig. 4. Moisture content between two irrigations for MB under different lengths
Source: Authors' determination.

To determine the moisture uniformity, soil samples were collected from the head, middle and tail reaches of the field from mulched and conventional plots two days after irrigation. The field results are given in Table (1). It is clear from the table that moisture percentage is high at head and gradually decreased to the tail of the field with mulched and conventional irrigation. For border, it was observed that moisture level was high at head and gradually decreased to the tail with differences of 3 – 4% under mulched-hole border for all lengths. It is fact that in open field opportunity time was more as compared to tail of the field but in mulched border case due to covered surface of the field water moved rapidly to the downward direction, therefore moisture level differences was less than non-mulched furrow.

Distribution uniformity (Du) calculated for NMF were 79%, 75.2% and 70.3% at 15, 30, and 40 m, respectively, as shown in Table (1). For MF, calculated Du increased to 87.2%, 85.1% and 84.3% at 15, 30, and 40 m, respectively. The MB was more effective and homogenous that recorded 88.3%, 86.4% and 85.9% at 15, 30, and 40 m, respectively. Soil water storage in the 0–40 cm layer decreased in conventional treatments while in mulched treatments slightly increased in case of MF and high increase for MB. This was mainly because plastic mulch reduced the soil water evaporation. The integrative effect of plastic film mulch on soil water retention was better than the non-mulched treatments [6]. Furthermore, we found that soil water storage also varied between different lengths, where was no significant difference among 30 m and 40 m but 15 m treatment was less in water storage in all treatments.

Table 1. Moisture distribution and distribution uniformity (Du) for mulched and conventional treatments

Field Location	Length (m)	NMF (%)	MF (%)	MB (%)
Head	15	39	39	37
	30	43	40	38
	40	47	40	38
Middle	15	37	38	36
	30	41	38	36
	40	38	38	37
Tail	15	36	38	35
	30	37	38	34
	40	35	37	35
DU	15	79	87.2	88.3
	30	75.2	85.1	86.4
	40	70.3	84.3	85.9

Source: Authors' determination.

Irrigation water application

The total depths of irrigation water applied in mm through both irrigation methods were varied (Table 2). The gravimeter soil moisture content revealed that the total net of irrigation water determined in mm for each treatment were 525.7, 470.8 and 348.8 mm for NMF, MF and MB respectively, at the entire growing of the crop as it was determined from multiplication of total available water and depletion fraction (p=65%). The variation of application depth occurred between these irrigation methods were due to presence of plastic mulch except in sowing irrigation, the applied water was almost the same because the initial soil moisture content was the same for all experimental area.

Table 2. Total seasonal water application for mulched and non-mulched treatments

Number of irrigation	The amount of applied water (mm)		
	NMF	MF	MB
Sowing irrigation	110	110	110
1	78.6	70.7	Not irrigated
2	50.0	45.0	78.6
3	70.7	57.9	Not irrigated
4	63.2	53.6	81.2
5	94.3	76.8	Not irrigated
6	58.9	56.8	79
Total	525.7	470.8	348.8

Source: Authors' determination.

Applied water value was low in MF by 10%, than NMF may be due to the higher moisture content (26.6%) before irrigation than NMF (22.7%) as a direct effect of mulch.

The difference in applied water was higher in case of MB by 33.6% than NMF, where the mulch effect reduced the number of irrigation times to the half.

Effects of mulching on squash growth parameters

The germination of squash seed in mulched and conventional plots under different lengths are shown in Figure 5. It was observed that seed germination rate was 92 to 98% and mortality rate was 2-8% of MF. On the other hand the seed germination rate was observed as 80 to 89% and mortality rate was noted only as 11-20% in case of NMF. It was observed that germination rate was higher in the short furrows (15 m) in NMF, due to the low moisture uniformity in long furrows, while in MF, there was no significant difference between different lengths. It was also noted that moisture level remained more mulch treated furrows because of less evaporation and continuously soil moisture available in contrast to conventional furrows. Seed germination rate was 97 to 100% and mortality rate was 0-5% in MB with no significant difference between different lengths.

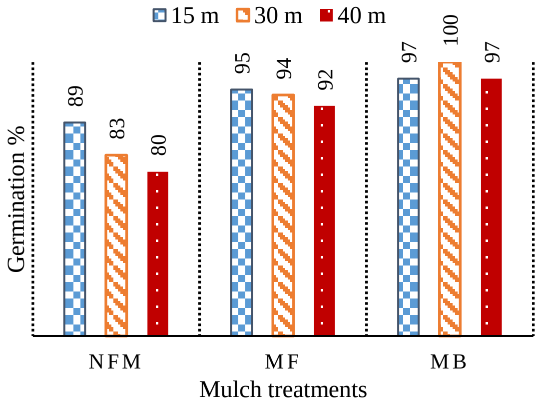

Fig. 5. Effect of different treatments on germination percentage after sowing squash
Source: Authors' determination.

The analysis of variance ($p<0.05$), showed that the plant heights and plant weight for selected 10 different plants were significantly changed by using plastic hole-sheet at border (MB) (Table 3). It was determined that the average values of plant height were noted 81, 80.5 and 79.4 cm were recorded for the treatment MB with increasing 44.1, 50.7 and 52.4% than NMF for 15, 30 and 40 m respectively. It was determined that the average values of plant height were recorded for MF an increase with 3.7, 8.2 and 3.2% more than NMF for 15, 30 and 40 m respectively. The increase in plant height under MB might be due to more availability of soil moisture in the root zone and better nutrient use efficiency and their uptake by plants as reported by [1]. MB treatments showed an increase in plant weight with average of 38.6% as compared to those under NMF (Table 3). In case of using plastic sheet at furrow bottom, the changes were moderate. It was determined that the average values of plant weight were increased by 0.01, 4.6 and 3.8 % under treatment MF as compared to those under NMF for 15, 30 and 40 m respectively. For mulching treatments, results are in line with those of [22] who reported that, plant weight were significantly affected by the mulching treatments.

Table 3. Effect of irrigation techniques on squash growth and yield parameters

Treat.	Length (m)	Plant high (cm)	Plant weigh (g)	Leaves area (cm^2)	N. Leaves
NMF	15	56.2	910	403.3	34.1
	30	53.4	900	384.4	34.4
	40	52.1	896	371.3	33.2
MF	15	58.3	919	470.4	35.2
	30	56.4	942	465.9	35.2
	40	55.1	930	465.0	35.3
MB	15	81.0	1261	627.2	38.2
	30	80.5	1249	622.3	37.1
	40	79.4	1240	618.0	36.2

Source: Authors' determination.

Plant leaf area was significantly affected by mulching in both MF and MB. In contrast, number of leaves per plant were not significantly affected by mulching on MF but was significantly affected by mulching at MB. Between the mulched treatments, number of leaves per plant under (MF) increased by 3% as an average than those under NMF, while it was increased under MB by 9 % in comparable with NMF. The difference in plant leaf area either between the mulched and non-mulched treatments or between the mulched treatments was significant.

The MF treatment showed good performance for root length and weight with non-significant effect in comparable with NMF (Table 4). These results are supported by [1] who reported same root growth, and root weight in furrow method. This may be due to availability of more soil moisture and soluble nutrients in the root zone where plastic sheets were used, facilitating it to uptake and stopping leaching.

Hence, it created better conditions for the growth and a well development of plant root system. These results are supported by [15], which stated that the higher crop production with mulched method, it might be the reason that more moisture and nutrient contents in the leaves, roots, and grains in mulched treatments.

Table 4. Effect of irrigation techniques on root length and weight

Parameters	Length m	Irrigation Techniques			LSD
		NMF	MF	MB	
Root length (cm)	15	46.2^{bc}	49.1^{b}	58.8^{a}	4.5
	30	46.3^{bc}	49.2^{b}	54.5^{a}	
	40	44.7^{bcd}	48.3^{b}	55.1^{a}	
Roots weight (g)	15	25.2^{c}	26.2^{bc}	29.2^{a}	2.1
	30	23.3^{c}	27.0^{bc}	28.1^{ab}	
	40	25.0^{c}	26.0^{bc}	27.2^{ab}	

Source: Authors' determination.

Effect of mulching on yield and water productivity (WP)

The yield of squash was significantly affected by mulched irrigation techniques.

Table (5) revealed that, the application of furrow plastic mulch, and mulch-hole border showed a significant increase in total yield of the crop as compared to non-mulched treatment for all different lengths.

However, total yield were not affected within the same length under plastic mulch. The maximum total yield was obtained from treatment with 30m length under MB (31.89 t/ha) followed by 15 m under MB (30.46 t/ha) while, the 40 m showed a little decrease total yield (29.04 t/ha).

There was also significant difference observed under MF with increase of 31.2 % and 40.2 % more than NMF in 30 and 40 m respectively, but there was no observed effect in yield on 15 m length for both NMF and MF.

Based on the results, MB method was resulted in increased yield by 50.6 % and 23.1% as compared to NMF and MF, respectively.

There was also significant difference observed between mean at ($p < 0.05$). These results are in agreement with those reported by [11].

The data related to the effect of different irrigation practices with plastic mulch on water productivity (WP) of squash are given in Figure 6. This figure clearly indicates that different irrigation practices with plastic mulch had significant effect on WP of squash.

Table 5. Effect of mulch on yield

Parameters	Length (m)	Irrigation Techniques			LSD
		NMF	MF	MB	
Yield (kg/ha)	**15**	24.95 ^{c}	25.47^{c}	30.46 ^{ab}	2.64
	30	19.04 ^{d}	24.95 ^{c}	31.89 ^{a}	
	40	17.14 ^{de}	24.04 ^{c}	29.04 ^{b}	

Source: Authors' determination.

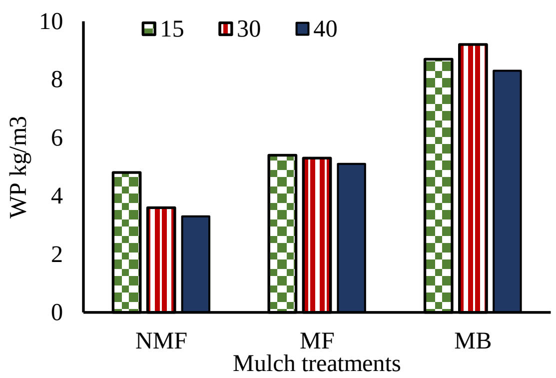

Fig. 6. Effect of irrigation techniques on WP
Source: Authors' determination.

As regard different irrigation practices with plastic mulch, maximum WP (8.33 to 9.15 kg/m^3) was measured in mulched-hole border for all lengths, followed by furrow irrigated sowing with plastic mulch (5.11 to 5.41 kg/m^3). In general, WP values decreased with increasing amount of irrigation applied. Mulching increased WP and yield due to reduction in evaporation, enhanced transpiration and deep percolation, leading to increased yields and WP [23]. Soil mulching with plastic reduced water loss, conserve soil moisture and more even regulated soil temperature.

Effect of mulching on water saving

The water saving was thus 10.44% and 46.3% under treatments MF and MB, respectively, when compared to NMF (Fig. 7).

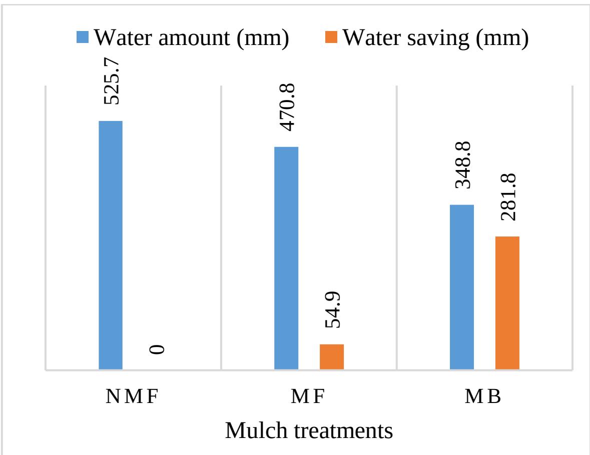

Fig. 7. Effect of mulch treatments on water saving
Source: Authors' determination.

These results are matching with [15] who reported that placing a plastic sheet on the bottom of the furrow prevents direct vertical infiltration from the bottom of the furrow which increase the water saving efficiency of furrow irrigation method.

These results are also similar to [8] who reported 22.73%-40.38% increase in water saving efficiency with plastic sheet mulching in furrow irrigation method.

CONCLUSIONS

Generally, mulching showed significant effect on soil moisture conservation and agronomic parameters.

According to the findings of this experiment, the highest soil water content was obtained using plastic mulch in border followed by mulched furrow bottom. In this experiment, application of mulch played a greater role in distribute water uniformly, due to this available water to plants root not varied appreciably. Therefore, the total yield of squash was increased by 38% and 49.7% for MF and MB respectively, while water saving was thus 10.44% and 46.3% under treatments MF and MB, respectively, when compared to NMF. The availability of high soil moisture resulting in increases in photosynthetic rate and thereby increasing vegetative growth such as plant height, leaf area, and root length. The increment in number of leaves must have led to an increment in leaf area; hence, increased light interception and photosynthesis. These effects are translated in terms of total fresh weights of fruits, which showed a positive response to increasing moisture conservation practice and total yield.

Finally, the use of plastic mulch on the border produced the best performance in reducing water losses. Moreover, considering the soil moisture storage, the use of plastic mulch treatment in furrow irrigation was suggested as a favorable approach in water and soil management as well as increasing crop yield and water productivity.

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