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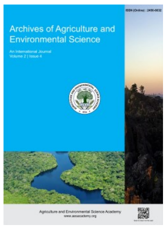

ORIGINAL RESEARCH ARTICLE

CrossMark

Effect of soil mulching on growth, productivity, and water use efficiency of potato (*Solanum tuberosum* L.) under deficit irrigation

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ABSTRACT

Two field studies were conducted consecutively in the summer season of 2015 and 2016 to investigate the effect of different soil mulching materials (bare soil: BS as a control, white plastic: WP, black plastic: BP and rice straw: RS) on growth, productivity, and water-use efficiency (WUE) of potato under three levels of irrigation (I_{100}=100%, I_{80}=80%, and I_{60}=70% of crop evapotranspiration). Growth characteristics, yield and its components, and WUE were significantly ($P \leq 0.05$) affected by both irrigation level and mulching materials. All mulching materials effectively enhanced growth and productivity when compared to bare soil. Potato plants grown under BP and WP as well as RS showed higher mean values of large size (> 60 mm) tubers and WUE compared to non-mulched treatment (BS) in both seasons. Mulching treatments noticeably increased tuber yield in the order of BP > RS > WP. Results displayed that, under different soil mulching materials, the I_{80} strategy studied here could be successfully applied during summer season in commercial potato production allowing water savings of 20% without any detrimental effect on plant growth or productivity.

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INTRODUCTION

Potato (*Solanum tuberosum* L.) is the most main of crop contributing to world's food after maize, rice and wheat (Barakat *et al.*, 2016; Karam *et al.*, 2009). It is not only a cash crop but also a cash crop to increase income through its exportation (Kandil *et al.*, 2011). Potato is grown during summer season in El-Fayoum Governorate; Egypt where soil temperature is low as well as rainfall is scarce. At all stages of potato growth, deficit irrigation during the periods of tuber initiation and bulking has the most drastic effect on yield tubers (Yuan and Kang, 2003). Therefore, irrigation water is an essential component in commercial potato production system. This can be achieved by introducing advanced irrigation water methods and improved agriculture management practices (Rady *et al.*, 2017; Semida, 2016; Semida and Rady, 2014; Yaghi and Naoum, 2013; Zaman and Saleem, 2001).

Drought and salinity are the main limiting factors destructively affect crops growth and productivity (Abd El-mageed *et al.*, 2020; Desoky, El-sayed *et al.*, 2020; Desoky, El-sayed *et al.*, 2020; Rady *et al.*, 2020; Semida *et al.*, 2019, 2020). The soil surface application with different soil mulching materials is a corner stone in sustainable agriculture. There are two types of mulches; organic and inorganic. Organic mulches as rice straw and inorganic mulch as white and black plastic. There are multifarious benefit effects of using different soil mulching types i.e., reducing weeds growth, raising soil temperature by absorbing warmth in soil (Abd El-Mageed *et al.*, 2016; Teasdale and Mohler, 1993), soil reducing evaporation and thus more maintained water available to plant, eliminate soil erosion by protecting soil surface (Bot and Benites, 2005), reducing nutrients loss by run off and leaching (Olasantan, 1999) and maximizing quantitative and qualitative of grown crop (Chakraborty *et al.*, 2008; Ravi and Lourduraj, 1996). Hence, two experiment fields were conducted to assess the effect of soil mulching materials under deficit irrigation on potato growth and productivity during the summer seasons.

MATERIALS AND METHODS

Farm site and experimental layout

Two similar field experiments were imposed at a private farm in El-Fayoum Governorate, Egypt during the summer season of 2015 and 2016. The scope of two trials to investigate the main and interaction effects of irrigation rates; 60, 80 and 100% ET_C under different mulch types ; bare soil, rice straw, white and black plastic on soil temperature during seeds germination, seeds germination rate index, vegetative growth traits and total tubers yield and its components of potato (*Solanum tuberosum* L.). Soil samples at 25 cm depth were collected to identify some the physical and chemical properties of experimental site and these soil samples were analyzed at Soil Laboratory Test, Faculty of Agriculture, El-Fayoum University according to standard published methods (Soil Survey Staff USDA, 1999). The results of physical and chemical analyses were shown in Tables 1 and 2.

Imported potato seeds cv. Spunta class E was used. Weight seeds either wholes or pieces ranged between 55– 60 g. During the preparation of experimental site, farmyard manure at 20 m^3 fed^{-1} was broadcasted and properly leveled with intra-row spacing 0.70 m. A drip irrigation network was designed for this study; main drip line contained three main valves to control irrigation rates and lateral drip line was set over row far away 5 cm from planting hole. Distance between drippers was 25 cm and dripper discharge was 4 liter $hour^{-1}$. Potato seeds were planted on January 22 and 23 in 2015 and 2016, consecutively at in-row spacing of 25 cm. After immediately seeds planting; rice straw was at 500 g m^2 and white and black plastic at 40 μm thickness were performed. Edges white and black plastic was held tightly under every row. Small holes in white and black plastic at a proper spacing were made. The first irrigation of potato seeds was adequately ordinary water and irrigation treatments were initiated one week after full germination. Potato plants at 3 days interval by different irrigation treatments. Irrigation samples water were taken and analysed at Soil Laboratory Test, Faculty of Agriculture, El-Fayoum University. The results of samples of irrigation water were shown in Table 4.

Table 1. Physical properties of the studied soil.

Particle size distribution				FC (%)	WP (%)	AW (%)
Silt (%)	Clay (%)	Sand (%)	Texture			
22.0	33.0	45.0	Clay loam	34.19	16.13	18.06

FC = Field capacity, WP = wilting point, and AW = Available water.

Table 2. Chemical properties of the studied soil.

Properties	Value
pH	7.61
ECe (dS m^{-1})	1.80
$CaCO_3$ (%)	4.3
Co^{-3} (Meq L^{-1})	0.00
Hco^{-3} (Meq L^{-1})	2.10
So^{-4} (Meq L^{-1})	6.20
Organic matter (%)	1.32
Avalable nutriments: (mg kg^{-1} soil)	
N (%)	0.04
P	589.0
K (Meq L^{-1})	1.52
Ca^{++} (Meq L^{-1})	7.70
Mg^{++} (Meq L^{-1})	4.70
Na^{+} (Meq L^{-1})	4.58
Cl^{-} (Meq L^{-1})	10.20

Tables 3. The scheduling nutrition of potato cv. Spunta through drip irrigation system during the summer season of 2015 and 2016.

Weeks after planting	Ammonium nitrate 33% N (Kg)	Phosphoric acid 80% P (Liter)	Potassium sulfate 48% K_2O (Kg)	Magnesium sulfate 16% MgO (kg)
5^{th}	24	4.5	15	8
6^{th}	30	4.5	15	8
7^{th}	36	4.5	15	8
8^{th}	42	4.5	18	8
9^{th}	48	4.5	18	10
10^{th}	36	4.5	18	10
11^{th}	30	4.5	15	6
12^{th}	24	4.5	15	4
13^{th}	21	3.0	15	3

Table 4. Chemical composition of irrigation water.

Ionic concentration (ppm)								EC^a (dS m^{-1})	pH	SAR^b
CO_3^{--}	HCO_3^-	SO_4^{--}	Cl^-	Mg^{++}	Ca^{++}	Na^+	K^+			
0.00	1.85	2.12	4.13	1.54	3.21	2.83	0.52	0.82	7.25	1.88

[a]EC: is the electrical conductivity, and [b]SAR : sodium adsorption ratio.

Table 5. Monthly weather data at Fayoum, Egypt as average for 1998-2015.

Month	T_{max} (°C)	$^aT_{min}$ (°C)	T_{avg} (°C)	RH_{avg} (%)	U_2 ms^{-1}	ETo mmd^{-1}
January	9.2	22.1	15.65	58.6	3.2	1.8
February	9.9	25.8	17.85	59.2	3.7	1.90
March	13.4	28.0	20.7	56.7	4.2	2.99
April	17.0	36.1	26.55	53.2	5.0	4.18

$T_{max,}$ T_{min} and $T_{avg.}$ = maximum, minimum and average temperatures, respectively. RH_{avg} = average relative humidity. U_2 ms^{-1} = average wind speed. ETo = average potential evapotranspiration (Allen *et al.*, 1998).

Irrigation water applied (IWA) was specified as a percentage of the crop evapotranspiration (ETc) representing one of the following three treatments: I_{100} = 100%, I_{80} = 80% and I_{60} = 60% of ETc. The daily ETo was computed according to the Equation 1 (Allen *et al.*,1998) as follows:

$$ETo = Epan \times Kp \quad (1)$$

Where, ETo is the reference evapotranspiration (mm day^{-1}), Epan is the evaporation from a class A and Kp is the pan coefficient.

Average daily *ETo* in Fayoum region was estimated using the monthly mean weather data for a 15-year period (January 1998 – December 2015) of Etsa station. The average of daily ETo in El -Fayoum was 1.8, 1.9, 2.99, and 4.18 mm day^{-1} in January, February, March, and April respectively Supplementary Table 5. The crop water requirements (ETc) were estimated using the crop coefficient according to Equation 2.

$$Et\,c = ETo \times Kc \quad (2)$$

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

The amount of IWA to each treatment during the irrigation regime was determined by using the Equation 3 as follows:

$$IWA = \frac{A \times ETc \times Ii \times Kr}{Ea \times 1000} \quad (3)$$

Where, IWA is the irrigation water applied (m^3), A is the plot area (m^2), ETc is the crop water requirements (mm day^{-1}), Ii is the irrigation intervals (day), Ea is the application efficiency (%) (Ea = 85), Kr is the covering factor

All the experimental unites received identical rates of 96.03 N, 31.20 P_2O_5, 69.12 K_2O and 10.40 $MgSO_4$ fed^{-1}. The respective forms fertilizer of N, P_2O_5, K_2O and $Mgso_4$ were ammonium nitrate (33% N), phosphoric acid (80% P), potassium sulfate (48% K_2O) and Magnesium sulfate (16% MgO), one by one, as illustrated in Table 3. All other agro-management practices such as cultivation and pests control were achieved whenever it was necessary and as recommended in the commercial production of potato production. Irrigation water was stopped after 105 days from seeds planting and 5 days later canopy was manually removed. Harvesting total tubers yield after 115 days from seeds sowing.

The experimental layout was a split-plot based on Randomized Complete Blocks Design with four replications. Irrigation water rates and mulch types were randomly distributed as main and sub-plot, respectively. The buffer strip between main plots was 1.5 m. wide. The experimental unit area included two rows with 12.5 m length and 0.7 m width. In each experimental unit; first row was allocated to measure vegetative growth and second row was to determine total tubers yield and its components.

Growth traits and yield measurements

In each experimental unit, four random plants were chosen after 90 days from seeds planting and the following measurements were measured; Plant height; measured from starting ground surface till the tallest of leaf and main stems plant^{-1}, Shoots, leaves and canopy dry weights plant^{-1}; the fresh of shoots and leaves samples were placed in a forced oven at 70 °C till weights became constant and canopy dry weight by the summation dry weights of shoots and leaves. Leaves area plant^{-1}; estimated by the relationship of fresh leaves weight plant^{-1} and area of 20 disks by a borer known its diameter (Semida *et al.*, 2017).

Tubers number and tubers yield plant^{-1}; performed by dividing total tubers number and tubers weight plot^{-1} by total plants existed plot^{-1}, orderly. Tuber weight; attained by dividing tubers number plot^{-1} by total plants existed plot^{-1}. Total tubers yield fed^{-1}; expressed as total tubers weight plot^{-1}and converted to total tubers yield fed^{-1}. Tuber size grading plot^{-1}; tubers size plot $^{-1}$ into three grading sizes according to their diameter; small (< 30 mm), medium (30 – 60 mm) and large (> 60 mm) (Al-Moshileh *et al.*, 2005). Each tuber grade size was weighed and the percentage of total tubers yield plot^{-1} was performed. Water use efficiency (kg tuber m^3); describe the relationship between production plot^{-1} (kg) and dividing the amount of water plot^{-1}(kg).

Statistical analysis

All data of two field experimental seasons were analyzed by the analysis of ANOVA using Genstat statistical software (version 11; VSN International Ltd, Oxford, UK). Differences between the treatments means were separated by Duncan's Multiple Range at 5% level ($P \leq 0.05$).

RESULTS AND DISCUSSION

Growth characteristics

Water scarcity is a crucial abiotic environmental stress influencing plant growth and physiological processes (Abd El-Mageed *et al.*, 2018; Huang *et al.*, 2009; Loutfy *et al.*, 2012). Data in Table 6 showed that, the effect of irrigation rate from $I_{60}$to $I_{80}$and further to I_{100} on plant height were significantly increased. While, the effect of I_{100} and/or I_{80}on leaves area plant^{-1}, intrinsically, increased compared to I_{60}, during both seasons. Nevertheless, main stem number plant^{-1} were augmented under I_{100} relative to $I_{80}$and/or I_{60}, in 2016 season only. The main effect of soil mulching materials showed that, plant height and leaf area plant^{-1} under black plastic were significantly increased. Whilst, no considerable effect was observed on main stem number plant^{-1} between different mulching materials (i.e., white and black plastic as well as rice straw) when compared to bare soil, in both seasons. Potato plants grown under I_{100}× black plastic mulch showed the maximum mean value of plant height and leaves area plant^{-1} in both seasons. Whereas, under $I_{80}$and/or I_{100} × black and/or white plastic mulch, main stem number plant^{-1} were significantly higher in both seasons.

Data in Table 7 showed that DI negatively affected the investigated growth characteristics of potato plants in terms of leaves and main stems dry weight (DW) plant^{-1}as well as canopy dry weight plant^{-1}. Increasing the DI from 20% (I_{80}) to 40% (I_{60}) further decreased significantly or insignificantly the former growth traits in both growing seasons. Similarly, leaves and main stems dry weight plant^{-1}in addition to canopy dry weight plant^{-1} was also significantly affected ($P < 0.05$) by mulching materials. For both seasons, leaves, stems, and canopy DW of potato plants were much higher under mulched treatments (BP, and WP) than that under RS and/or non-mulched treatment (BS). Potato plants grown under I_{100} and/or I_{80}× BP showed the maximum mean value of stems and canopy DW plant^{-1} in both seasons. Whereas, under I_{80} and/or I_{100} × BP and/or RS, leaves DW plant^{-1}were significantly higher in both seasons.

Although maximum values of the different growth characteristics were obtained with I_{100}× BP and/or RS soil mulching, potato plants grown under I_{80}× BP and/or RS soil mulching enabled plants to enhance growth characteristics more than, or in a similar way with, the plants grown under full irrigation conditions (I_{100}) as shown in Table 7. The undesirable effect of deficit irrigation on different growth characteristics can be attributed to slower cell division, decreased photosynthetic pigment especially leaf total chlorophyll content and decreased enzymes activity consequently, reflected on the studied growth parameters. Similar results were also reported by (Abd El-Latif *et al.*, 2011; Abd El-Mageed *et al.*, 2016; Abd El-Mageed and Semida, 2015; Abd El-Mageed *et al.* 2016; Abd El-Mageed *et al.*, 2017; Tolessa *et al.*, 2016). Potato plants grown under moderate (80% pan evaporation) and/or severe (60% pan evaporation) DI were negatively affected in terms of plant height, branches number and above ground biomass plant^{-1} when compared to un-stressed plants (Kumar *et al.*, 2007).

The observed positive effect of BP soil mulching on plant height, leaves area and leaves, shoots and canopy dry weight plant^{-1} might be due to the enhanced soil temperature, adequate plant microclimates, the absence of light under black plastic mulch, depressed weeds growth and other metabolic activities led to growth characters. Similar kind of observations with respect to plant growth parameters were reported by Coling (1997), Hooks and Johnson (2003), Assi and Rayyan, (2007) and Muhammad *et al.* (2009) and Singh and Ahmed (2008) who proved that, growing potato plants under black plastic mulch caused the highest plant height, leaf area index and main stems number hill^{-1}.

Table 6. The main and interaction effects of irrigation rates and mulch types on plant height, main stem number and leaves area plant-1 during the summer season of 2015 and 2016.

Irrigation level (I)	Type of soil mulching	Plant height (cm)		Main stem number plant-1		Leaves area plant^{-1} (dcm^2)	
		2015	2016	2015	2016	2015	2016
I_{100}		70.05^{A*}	53.09^{A}	1.88^{A}	1.34^{A}	133.9^{A}	89.66^{A}
I_{80}		64.91^{B}	43.78^{B}	2.02^{A}	1.14^{B}	137.7^{A}	64.52^{B}
I_{60}		58.75^{C}	38.19^{C}	1.75^{A}	1.11^{B}	113.4^{B}	39.98^{C}
	BS	59.98^{C}	40.06^{D}	1.77^{A}	1.21^{A}	113.7^{A}	62.33^{BC}
	WP	66.33^{AB}	43.92^{C}	1.91^{A}	1.25^{A}	142.3^{A}	57.11^{C}
	BP	68.33^{A}	49.46^{A}	2.00^{A}	1.17^{A}	144.8^{A}	73.39^{A}
	RS	63.62^{B}	46.65^{B}	1.83^{A}	1.17^{A}	112.7^{B}	66.05^{B}
I_{100}	BS	63.75^{cd}	46.44^{cd}	1.75^{ab}	1.38^{ab}	121.3^{b-e}	88.02^{ab}
	WP	72.19^{a}	51.50^{b}	2.00^{ab}	1.44^{a}	151.2^{ab}	79.10^{bc}
	BP	74.75^{a}	60.19^{a}	1.81^{ab}	1.31^{a-c}	150.4^{a-c}	98.12^{a}
	RS	69.50^{ab}	54.25^{b}	1.94^{ab}	1.25^{a-d}	112.7^{de}	93.39^{a}
I_{80}	BS	59.50^{de}	39.88^{ef}	1.75^{ab}	1.00^{e}	118.2^{c-e}	61.28^{de}
	WP	64.44^{b-c}	42.88^{de}	2.25^{a}	1.19^{b-e}	136.0^{a-d}	57.07^{ef}
	BP	69.69^{ab}	47.31^{c}	2.31^{a}	1.19^{b-e}	161.9^{a}	73.84^{cd}
	RS	66.00^{bc}	45.06^{cd}	1.75^{ab}	1.19^{b-e}	134.8^{a-d}	65.90^{de}
I_{60}	BS	56.69^{e}	33.88^{g}	1.81^{ab}	1.25^{a-d}	101.4^{e}	37.69^{g}
	WP	62.37^{cd}	37.38^{fg}	1.50^{b}	1.13^{c-e}	139.5^{a-d}	35.17^{g}
	BP	60.56^{de}	40.88^{ef}	1.87^{ab}	1.00^{e}	122.1^{b-e}	48.22^{fg}
	RS	55.37^{e}	40.62^{ef}	1.81^{ab}	1.06^{de}	90.8^{e}	38.85^{g}

I100 = irrigation with 100% of ETc, I80 = irrigation with 80% of ETc and I60 = irrigation with 60% of ETc; BS = bare soil, WP = soil mulching with white plastic, BP = soil mulching with black plastic, RS = soil mulching with rice straw; *Values marked with the same letter(s) within the main and interaction effects are statistically similar according to Duncan's multiple range test at ($P \leq 0.05$). Uppercase and lowercase letter(s) refer to differences within the main and interaction effects.

Table 7. The main and interaction effects of irrigation rates and soil mulching types on leaves, stems, and canopy dry weights during the summer season of 2015 and 2016.

Irrigation level (I)	Type of soil mulching	Leaves dry weight plant^{-1} (g)		Stems dry weight plant^{-1} (g)		Canopy dry weight plant^{-1} (g)	
		2015	2016	2015	2016	2015	2016
I_{100}		22.12^{A*}	13.52^{A}	31.80^{B}	24.08^{A}	53.91^{A}	37.60^{A}
I_{80}		20.18^{AB}	8.98^{B}	36.67^{A}	18.08^{B}	56.85^{A}	27.07^{B}
I_{60}		17.15^{B}	5.09^{C}	26.39^{C}	12.84^{C}	43.54^{B}	17.93^{C}
	BS	16.72^{B}	7.25^{B}	26.42^{C}	16.34^{B}	43.14^{C}	23.59^{C}
	WP	22.97^{A}	7.99^{B}	30.69^{BC}	18.28^{AB}	53.66^{B}	26.27^{B}
	BP	22.03^{A}	10.83^{A}	37.54^{A}	19.97^{A}	59.57^{A}	30.80^{A}
	RS	17.54^{B}	10.73^{A}	31.82^{B}	18.74^{AB}	49.37^{B}	29.47^{A}
I_{100}	BS	19.16^{b-d}	10.51^{b}	24.54^{cd}	21.99^{b}	43.70^{ef}	32.49^{bc}
	WP	24.29^{ab}	10.73^{b}	35.40^{b}	24.02^{ab}	59.69^{ab}	34.75^{b}
	BP	26.14^{a}	15.66^{a}	35.92^{b}	26.98^{a}	62.06^{ab}	42.64^{a}
	RS	18.88^{b-e}	17.18^{a}	31.32^{bc}	23.34^{ab}	50.20^{c-e}	40.51^{a}
I_{80}	BS	16.82^{c-g}	7.29^{cd}	31.98^{bc}	15.62^{d-f}	48.80^{c-e}	22.91^{de}
	WP	21.24^{a-c}	8.94^{bc}	34.91^{b}	16.92^{c-e}	56.15^{b-d}	25.86^{d}
	BP	21.08^{b-c}	10.63^{b}	45.74^{a}	19.47^{b-d}	66.82^{a}	30.10^{c}
	RS	21.56^{a-c}	9.08^{bc}	34.06^{b}	20.32^{bc}	55.62^{b-d}	29.39^{c}
I_{60}	BS	14.18^{d-g}	3.94^{e}	22.73^{cd}	11.42^{f}	36.91^{f}	15.36^{g}
	WP	23.38^{a-c}	4.29^{e}	21.77^{d}	13.91^{ef}	45.15^{d-f}	18.21^{fg}
	BP	18.86^{b-f}	6.18^{de}	30.96^{b-d}	13.47^{ef}	49.82^{c-e}	19.66^{ef}
	RS	12.19^{eg}	5.94^{de}	30.10^{b-d}	12.56^{ef}	42.29^{ef}	18.51f^{g}

I100 = irrigation with 100% of ETc, I80 = irrigation with 80% of ETc and I60 = irrigation with 60% of ETc; BS = bare soil, WP = soil mulching with white plastic, BP = soil mulching with black plastic, RS = soil mulching with rice straw; *Values marked with the same letter(s) within the main and interaction effects are statistically similar according to Duncan's multiple range test at ($P \leq 0.05$). Uppercase and lowercase letter(s) refer to differences within the main and interaction effects.

Table 8. The main and interaction effects of irrigation rates and soil mulching types on tubers number plant^{-1}, tubers yield plant^{-1}, tuber weight and total tubers yield fed^{-1} during the summer season of 2015 and 2016.

Irrigation level (I)	Type of soil mulching	Tubers number plant^{-1}		Tuber weight (g)		Tubers yield plant^{-1}		Total tubers yield fed^{-1}	
		2015	2016	2015	2016	2015	2016	2015	2016
I_{100}		7.28^{A*}	4.85^{A}	149.6^{A}	207.2^{C}	1.08^{A}	0.97^{A}	19.00^{A}	18.10^{A}
I_{80}		6.74^{AB}	3.44^{B}	142.9^{A}	280.9^{B}	0.94^{B}	0.93^{A}	16.69^{B}	17.71^{A}
I_{60}		6.49^{B}	2.78^{B}	118.5^{B}	338.5^{A}	0.74^{C}	0.92^{A}	13.36^{C}	17.26^{A}
	BS	6.57^{A}	3.54^{A}	131.9^{A}	261.5^{A}	0.85^{B}	0.87^{B}	15.01^{B}	16.54^{B}
	WP	6.67^{A}	3.74^{A}	145.3^{A}	304.0^{A}	0.96^{A}	0.95^{A}	16.85^{A}	17.70^{A}
	BP	6.95^{A}	3.86^{A}	139.8^{A}	259.5^{A}	0.96^{A}	0.98^{A}	17.29^{A}	18.42^{A}
	RS	7.15^{A}	3.63^{A}	130.9^{A}	276.6^{A}	0.91^{A}	0.95^{A}	16.25^{AB}	18.09^{A}
I_{100}	BS	7.30^{a}	4.44^{ab}	142.4^{a-c}	199.1^{f}	1.03^{ab}	0.88^{bc}	17.86^{ab}	17.13^{ac}
	WP	7.31^{a}	5.72^{a}	150.7^{ac}	197.1^{f}	1.09^{ab}	1.01^{ab}	19.34^{a}	18.55^{ab}
	BP	7.20^{a}	4.62^{ab}	155.8^{ab}	223.7^{ef}	1.11^{a}	1.03^{a}	19.58^{a}	18.95^{a}
	RS	7.30^{a}	4.62^{ab}	149.4^{ac}	208.7^{f}	1.08^{ab}	0.94^{ac}	19.23^{a}	17.78^{ab}
I_{80}	BS	7.17^{a}	3.64^{bc}	129.1^{bd}	235.3^{df}	0.89^{c}	0.85^{c}	16.16^{bc}	16.06^{c}
	WP	6.38^{ab}	3.08^{bc}	159.8^{a}	331.2^{ab}	1.0^{ab}	0.94^{ac}	17.54^{ab}	17.75^{ac}
	BP	7.11^{a}	3.87^{bc}	141.7^{a-c}	253.0^{cf}	0.99^{b}	0.97^{ac}	17.54^{ab}	18.69^{a}
	RS	6.28^{ab}	3.18^{bc}	140.7^{a-c}	304.2^{ae}	0.88^{cd}	0.97^{ac}	15.50^{bd}	18.34^{ac}
I_{60}	BS	5.22^{b}	2.55^{c}	124.2^{c-d}	350.3^{ab}	0.63^{f}	0.89^{bc}	11.00^{e}	16.45^{bc}
	WP	6.33^{ab}	2.40^{c}	125.0^{c-d}	385.1^{a}	0.77^{e}	0.91^{ac}	13.66^{d}	16.80^{ac}
	BP	6.55^{ab}	3.11^{bc}	122.0^{c-d}	301.8^{be}	0.79^{de}	0.92^{ac}	14.75^{cd}	17.63^{ac}
	RS	7.87^{a}	3.08^{bc}	102.6^{d}	316.8^{ad}	0.77^{e}	0.95^{ac}	14.03^{cd}	18.16^{ac}

I100 = irrigation with 100% of ETc, I80 = irrigation with 80% of ETc and I60 = irrigation with 60% of ETc; BS = bare soil, WP = soil mulching with white plastic, BP = soil mulching with black plastic, RS = soil mulching with rice straw; *Values marked with the same letter(s) within the main and interaction effects are statistically similar according to Duncan's multiple range test at (*P*≤0.05). Uppercase and lowercase letter(s) refer to differences within the main and interaction effects.

Tuber yield and its components

Data of yield components in terms of tubers number plant^{-1}, tuber weight, tubers yield plant^{-1} and total tubers yield fed^{-1} of potato plants grown under DI and different mulching materials and there interactions are shown in Table 8. Potato yield was significantly affected (P < 0.05) by irrigation quantity and mulching materials in both growing seasons. Our results collectively showed that gradual increase in DI, significantly, decreased tuber yields, particularly under I_{60}. Increasing the DI from 20% (I_{80}) to 40% (I_{60}) further decreased tuber yield in terms of tubers number plant^{-1}, tuber weight, tubers yield plant^{-1} and total tubers yield fed^{-1}. Likewise, tubers number plant^{-1}, tuber weight, tubers yield plant^{-1} and total tubers yield fed^{-1} were also significantly affected (P < 0.05) by mulching materials. For both seasons, tubers yield plant^{-1} and total tubers yield fed^{-1} was much higher under mulched treatments (BP, WP, and RS) than that under non-mulched treatment (BS). However, no significant effect of the mulching materials was observed on tubers numbers plant^{-1} and tuber weight plant^{-1}. Potato plants grown under I_{100} × BP, WP, and/or RS showed the maximum mean values of tubers yield plant^{-1} and total tubers yield fed^{-1} in both seasons when compared with non-mulched treatment (BS) under the same level of irrigation. Even though maximum values of the tubers yield plant^{-1} and total tubers yield fed^{-1} were obtained with I_{100} × BP, WP, and/or RS soil mulching, potato plants grown under I_{80} × BP and/or RS soil mulching enabled plants to enhance tuber productivity more than, or in a similar way with, the plants grown under full irrigation conditions (I_{100}) as shown in Table 8.

Data listed in Table 9 show the effects of DI and different mulching materials and there interactions on small (< 30 mm), medium (30 – 60 mm), large (> 60 mm), in diameter, potato tubers and water use efficiency, during the summer season of 2015 and 2016. Potato plants grown under I_{100} showed the maximum mean values of small size (< 30 mm) tubers compared to I_{80} and I_{60} in 2016 season. However, no significant effect of the irrigation level was observed on small size tubers in 2015 season. Plants grown under I_{60} gave the maximum mean values of medium (30 – 60 mm) and large (> 60 mm) size tubers compared to I_{80} and I_{100} in both seasons. However, no appreciable effect of the irrigation level was observed on medium size tubers in 2016 season. Concerning the effect of DI on WUE, the averages of WUE in both seasons respectively were 7.92, 8.69, 9.35, and 7.75, 9.48, 12.32 kg m^{-3} for I_{60}, I_{80}, and I_{100}, respectively, indicating that the average value of WUE of I_{60} and/or I_{80} was higher than those of I_{100} (Table 9). Grown potato plants under BS and/or RS mulching showed the maximum mean values of small size (< 30 mm) tubers compared to BP and WP in both seasons. No significant effect of mulching materials was observed on medium size (30 – 60 mm) tubers in both seasons. Potato plants grown under BP and WP as well as RS showed higher mean values of large size (> 60 mm) tubers and WUE compared to non-mulched treatment (BS) in both seasons. Potato plants grown under I_{100} and/or I_{60} × RS mulching showed the maximum mean values of small size (< 30 mm) tubers and medium size (30 – 60 mm) tubers. However, under I_{60} × RS and/or BP mulching showed the maximum mean values of large size (> 60 mm) tubers and WUE compared to other mulching treatment in both seasons.

Table 9. The main and interaction effects of irrigation rates and soil mulching types on tubers small size (%), tubers medium size (%), tubers large size (%) and Water use efficiency (WUE) during the summer season of 2015 and 2016.

Irrigation level (I)	Type of soil mulching	Tubers small size (%)		Tubers medium Size (%)		Tubers large size (%)		WUE (kg tuber m^3)	
		2015	2016	2015	2016	2015	2016	2015	2016
I_{100}		4.50^{A}	4.03^{A}	3.14^{B}	0.92^{A}	7.92^{B}	7.75^{C}	7.92^{B}	7.75^{C}
I_{80}		4.56^{A}	3.09^{B}	4.03^{B}	0.90^{A}	8.69^{A}	9.48^{B}	8.69^{A}	9.48^{B}
I_{60}		5.25^{A}	3.27^{B}	8.03^{A}	0.92^{A}	9.35^{A}	12.32^{A}	9.35^{A}	12.32^{A}
	BS	5.29^{A}	3.70^{A}	6.37^{A}	0.96^{A}	7.92^{B}	9.22^{B}	7.92^{B}	9.22^{B}
	WP	4.06^{B}	2.63^{B}	4.72^{A}	0.91^{A}	8.90^{A}	9.81^{A}	8.90^{A}	9.81^{A}
	BP	4.38^{AB}	3.44^{B}	4.41^{A}	0.89^{A}	9.18^{A}	10.24^{A}	9.18^{A}	10.24^{A}
	RS	5.35^{A}	4.09^{A}	4.77^{A}	0.89^{A}	8.61^{AB}	10.13^{A}	8.61^{AB}	10.13^{A}
I_{100}	BS	4.56^{ab}	4.25^{ab}	4.56^{ab}	4.25^{ab}	7.44^{d}	7.33^{f}	7.44^{d}	7.33^{f}
	WP	3.73^{b}	3.06^{bc}	3.73^{b}	3.06^{bc}	8.06^{cd}	7.94^{ef}	8.06^{cd}	7.94^{ef}
	BP	4.27^{ab}	3.85^{ac}	4.27^{ab}	3.85^{ac}	8.16^{cd}	8.12^{ef}	8.16^{cd}	8.12^{ef}
	RS	5.44^{ab}	4.98^{a}	5.44^{ab}	4.98^{a}	8.01^{cd}	7.61^{ef}	8.01^{cd}	7.61^{ef}
I_{80}	BS	5.34^{ab}	3.59^{ac}	5.34^{ab}	3.59^{ac}	8.42^{bd}	8.60^{de}	8.42^{bd}	8.60^{de}
	WP	4.43^{ab}	2.69^{bc}	4.43^{ab}	2.69^{bc}	9.14^{a-c}	9.50^{cd}	9.14^{a-c}	9.50^{cd}
	BP	4.05^{ab}	3.06^{bc}	4.05^{ab}	3.06^{bc}	9.14^{a-c}	10.01^{c}	9.14^{a-c}	10.01^{c}
	RS	4.42^{ab}	3.00^{bc}	4.42^{ab}	3.00^{bc}	8.07^{cd}	9.82^{c}	8.07^{cd}	9.82^{c}
I_{60}	BS	5.96^{ab}	3.25^{ac}	5.96^{ab}	3.25^{ac}	7.91^{cd}	11.74^{b}	7.91^{cd}	11.74^{b}
	WP	4.03^{ab}	2.15^{c}	4.03^{ab}	2.15^{c}	9.49^{a-c}	11.99^{ab}	9.49^{a-c}	11.99^{ab}
	BP	4.83^{ab}	3.40^{ac}	4.83^{ab}	3.40^{ac}	10.25^{a}	12.58^{ab}	10.25^{a}	12.58^{ab}
	RS	6.19^{a}	4.30^{ab}	6.19^{a}	4.30^{ab}	9.74^{ab}	12.96^{a}	9.74^{ab}	12.96^{a}

I100 = irrigation with 100% of ETc, I80 = irrigation with 80% of ETc and I60 = irrigation with 60% of ETc; BS = bare soil, WP = soil mulching with white plastic, BP = soil mulching with black plastic, RS = soil mulching with rice straw; *Values marked with the same letter(s) within the main and interaction effects are statistically similar according to Duncan's multiple range test at (P≤0.05). Uppercase and lowercase letter(s) refer to differences within the main and interaction effects.

In the present study, it was noticed that drought stress, generated from DI, reduced tuber yield and its components of potato plants (Tables 8 and 9). The enhanced effect of I_{100} on tubers yield plant^{-1} and total tubers yield fed^{-1} can be attributed to better moisture availability in root zone during potato growth. Water plays a crucial role in nutrients uptake and transportation which favoured the growth and consequently reflected gradually on tubers yield plant^{-1} and total yield fed^{-1}. Similar findings were reported by Yuan *et al.* (2003), Kumar *et al.* (2007), Abou EL-Khair *et al.* (2011) and Abou EL-Khair *et al.* (2011) on potato .The negative effect of I_{80} and/or I_{60} on tubers small size compared to I_{100} can attributed to the decrease of irrigation water in roots zone during potato growth and development, therefore increased tubers small size than tubers large and medium size. General agreements was noticed between these results and those reported by Karafyllidis *et al.* (1996) and Amer *et al.* (2017) who reported that, increasing irrigation amount water from 45 to 60 and further to 75 % from available water, significantly decreased small size potato tubers whilst, increased large size tubers. Similar results were reported by Yuan *et al.* (2003) who indicated that, increasing irrigation level at up to 1.25 pan evaporation, significantly, gradually increased tubers number plant^{-1}. Kumar *et al.* (2007) reached the same conclusion. The synergetic of irrigation amounts at 80 and/or 60 % ET_C on water use efficiency compared to irrigation rate at 100 % ET_C. Reversely, Kumar *et al.* (2007) showed that, irrigation rates at 0.80, 1.00 and 1.20 pan evaporation on water use efficiency, truly, increased in comparison with 0.60 pan evaporation.

The current study showed a pronounced effect of artificial (white and black polyethylene) and organic (rice straw) soil mulching materials on tubers yield plant^{-1}, total tubers yield fed^{-1}, tubers large size and water use efficiency than bare soil. These results are in parallel with those of, (Burgers and Nel, 1984), (Mahmood *et al.*, 2002), and Azad *et al.* (2015) who indicated that, potato plants under white, black and transparent plastic mulch have a higher total tubers yield ha^{-1} when compared with bare soil. Grown potato plants under bare soil and/or rice straw mulch showed a positive effect on small size tubers compared to white and/or black plastic mulch. Similar findings were reported also by Sadawarti *et al.* (2013) and Pulok *et al.* (2016).

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