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Effect of Organic Soil Amendment and Deficit Irrigation on Yield and Irrigation Efficiency of potato (*Solanum Tuberosum* L.)

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Abstract: A field experiment was conducted during 2016/2017 growing seasons in Hout Research Station, General Commission for Scientific Agricultural Research, Syria, to study the effect of improving soil physical properties with compost of town refuse (CTR) and deficit irrigation on potato crop yield and water use efficiency and compare its effect with common mineral fertilizer. Three levels of CTR amendments in addition to mineral treatment were applied to potato crop, crop was also exposed to three levels of irrigation i.e., deficit irrigation I3(50% of crop evapotranspiration (ETc) requirement), I2(75% of ETc), and full irrigation treatment 100% of ETc. Data regarding soil organic matter (SOM) content, total available water (TAW), crop actual evapotranspiration (Eta), final crop yield, irrigation water use efficiencies (WUE – IWUE), and crop response factor to deficit irrigation (Ky) were recorded. The results showed a significant improvement in soil physical properties on crop tolerance of water stress and recorded values of crop response factor to deficit irrigation Ky= 0.24, WUE=8.45, IWUE=9.41 in I2F1(75% irrigation and double amount of CTR) with 25% reduction in irrigation water requirement (469.72 mm) and crop yield of 35.28 ton/ha during the second year of study. Soil organic amendment ensures the potential of applying deficit irrigation technique on sensitive crops and CTR as beneficial and cost-effective recycling organic amendment. In addition, results of this research have widened the possibilities for farmers in potato growing according to locally available resources.

Keywords: Compost of town refuse, Deficit irrigation, Readily Available water, water stress.

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1. Introduction

Deficit irrigation techniques have spread widely and attracted great attention during recent years (Ding et al., 2021; Giordano et al., 2021; Hakeem et al., 2016). Especially with the decreased resources of irrigation water available for the agricultural sector, along with the increased population worldwide and the stresses it put on the agricultural sector from competition on freshwater to achieve food security (Awaad et al., 2020; Darko et al., 2016). With a deeper look, it is obvious that climate change and temperature fluctuation make it challenging to apply deficit irrigation on most vegetable crops (Mehmood et al., 2015; Yu et al., 2020).

Grown in more than 125 countries (Mullins et al., 2006) with global production of 388 million tons (FAOSTAT, 2019), potato tubers are considered among the most consumed vegetable. But its dependence on sufficient irrigation and soil suitability limited its expansion in regions with water shortage and heavy soils (Djaman et al., 2021). Therefore, to meet the agenda of the SDGs, it is essential to adopt modern irrigation techniques in deficit irrigation for sustainable water use and food security (Jägermeyr et al., 2017; Taka et al., 2021).

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Stewart et al., (1977) used the following liner equation to determine crop yield response factor K_y under water stress conditions:

$$\frac{Ya}{Ym} = 1 - Ky\left[1 - \frac{ETa}{ETm}\right] \quad \text{[Eq 1]}$$

or Yd= K_y. ETd.

Which indicates the predicted reduction of relative yield (Yd) according to relative reduction (ETd) of ET_c related to deficit irrigation level (Allan et al., 1998). Previous studies classified potatoes as a sensitive crop for water stress (Hassan et al., 2002; Shock, 2004; Thornton, 2002). Other studies reported a significant reduction in quantity with negative effects on the quality of potato tubers even after brief periods of water stress (Shock and Feibert, 2000). The studies of Mohsin Iqbal et al., (1999), Doorenbos and Kassam (1979), and FAO (2002) estimated Ky_{potato} = 1.1, which reached 1.61 for full deficit irrigation in Ayas and Korukcu (2010) and 1.12 in Fatih et al (2006); which means a significant yield reduction for each unit of irrigation water below ETc.

Researchers are working to reduce the yield gap by using the partial deficit irrigation method, which applies water stress in certain growing stages, but results were not better than Ky = 0.909 in Ayas and Korukcu (2010) for 50% water reduction of ETc during early vegetative growth period. Others like King and Stark (1997) found that even a 10% decrease of irrigation water during the initiation stage caused a significant decrease in potato yield (which considered in several studies the less demanding period of potato growing stages) (Liu et al., 2006). Crop response factor (Ky) value differs according to several factors: climate, variety, evapotranspiration, irrigation practices, and soil properties (Doorenbos and Kassam, 1979).

Previous experiments tried to influence the Ky factor by changing varieties or planting conditions, as reported by Pejie et al. (2015) but results were not better (Ky=1.14). Soil physical conditions were rarely given importance to study irrigation efficiency and potato tolerance to deficit irrigation. Costa et al., (2007) stressed the need for further studies on factors influencing deficit irrigation efficiencies like soil conditions and soil-plant relationships. Moreover, Ahmadi et al., (2010) found a significant interaction between deficit irrigation and soil texture. Therefore, the objective of this study is to verify the effect of improving soil physical conditions by using unconventional organic amendment as compost of town refuse on water use efficiency of deficit irrigation technique.

2. Materials and Methods

The research was conducted during summer seasons of 2016 and 2017 at the Hout Research Station (32.47 latitude- 36.60 longitude – 1050 Altitude) with an average of 250mm annual precipitation. The soil is heavy clay and Table 1 describes its chemical and physical characteristics.

Compost of town refuse (CTR) was analyzed before adding to estimate the correct amounts that should be added to each treatment, Table 2 describe its chemical content, physical characteristics and added amounts of F_2 treatment (base treatment).

The trial was designed as split plots with completely random distribution for the three replications of each treatment. The main plot was irrigation treatment: three levels of irrigation (main treatment) I_1:100% of ETc; I_2: %75 of the applied amount in I_1 treatment; I_3: %50 of I_1. Within each irrigation level, there were four fertilizing treatments (sub treatment): F_1: 200% crop nitrogen requirement as CTR (after analyzing the soil and compost content of nitrogen); F_2: 100% crop nitrogen requirement as CTR; F_3: Nitrogen: 50% as CTR, 50% as urea; F_4: 100 Nitrogen as urea.

Each plot of 36 plots was 3m×3m= 9m^2 with 2m as a buffer zone to separate two different treatments, to limit nutrient movement with water. Irrigation lines were placed at a distance of 0.8m. These plots received the estimated amounts of different fertilizers at the beginning of each growing season and adjusted during the two seasons, which started with sowing on 1st of April 2016 and 2017, with (35-45g on average/ Spunta Cultivar) tubers, to study the accumulative effects of these additions.

Water added with planting to make Soil water content reach Field capacity level. Deficit irrigation started after completion of potato tuber germination (15 days after planting). Then irrigation water amounts were estimated based on daily measurements of soil moisture by using the gravimetric method at 0.2m depth for the beginning of the growing season then 0.5m at late stages.

Plants irrigated with drip irrigation system (8L h^{-1}: dripper per plant) according to measured soil moisture content and water balance equation (Allen et al.,1998).

Table 1. Physico-chemical properties of experimental soil

		Soil Depth	
		0-30 cm	**30-60 cm**
N	%	0.023	0.019
P	ppm	3.5	3.3
K		350	325
OM	%	0.5	0.39
pH	Saturated paste	7.5	7.4
EC $_{dS/m}$		0.4	0.39
$CaCO_3$	%	0.83	0.83
clay	%	58	60
Silt		23	21
Loam		19	19
ρb	g cm^{-3}	1.15	1.19
ρd		2.76	2.77
Fc	%	0.36	0.36
Po		58.15	57.64
Infiltration	cm h^{-1}	1.5	

$$ETa = M+10P + (W_1-W_2) + Rf + Dp + CR \quad [Eq\ 2]$$

Where, Eta, actual crop evapotranspiration; M: irrigation amount (mm); P, precipitation amount (mm); Rf, Runoff from the soil surface (mm); Dp, Water loss out of root zone by deep percolation (mm); CR, capillary rise from groundwater table (mm); W1-W2: available soil water content at the beginning and end of the measured period. Values of Rf, Dp, and CR were zero in the studied area.

Irrigation amounts calculated by the Eq 3 (Allen et al.,1998)

$$M= 10.h.a. (B_1-B_2) \quad [Eq\ 3]$$

Where h, root depth (m); a soil bulk density (g cm^{-3}); B_1, soil moisture at field capacity; B_2, soil moisture at 65% for potato (before starting irrigation event) (Allen et al., 1998).

The equation of (Allen et al., 1998) was used to calculate the Soil content of total available water:

$$TAW= 1000(\theta_{FC} - \theta_{Wp})\times Z_e. \quad [Eq\ 3]$$

Where θ_{FC}: soil moisture content at field capacity ($m^3\ m^{-3}$); θ_{Wp}: soil moisture content at wilting point ($m^3\ m^{-3}$); Z_e: depth of soil susceptible to evaporation (m).

Crop response factor to water stress calculated by:

$$\frac{Ya}{Ym} = 1 - Ky\left[1 - \frac{ETa}{ETm}\right] \quad [Eq\ 4]$$

Where Y_a: actual yield under deficit irrigation treatment (kg ha^{-1}); Ym: maximum yield in full-irrigated treatment (kg ha^{-1}); ET_a: actual evapotranspiration under deficit treatment (mm); ET_m: Maximum evapotranspiration in full-irrigated treatment (mm).

Water use efficiency WUE and irrigation water use efficiency were calculated by using Eq 5 & Eq 6 (Ibrahim, 2009),

$$WUE = \frac{Yield\ (kg)}{ETa\ (m3)}, \quad [Eq\ 5]$$

$$IWUE = \frac{yield\ (kg)}{Total\ water\ applied\ (m3)} \quad [Eq\ 6]$$

Soil organic matter (SOM) was measured by method described by Walkely and Black (1934). Potato tubers were harvested after 3.5 months after planting date. Yield data was collected from three random plants $plot^{-1}$. Then the collected data subjected to analysis of ANOVA2 using GenStat12, and test of Duncan (1995) at 0.05 probability level was used to indicate the significance of differences between treatments.

3. Results and Discussion

3.1. Soil organic matter content and total available water

High levels of CTR had a significant influence on increasing soil organic matter (SOM) content, which explained the superiority of F_1 level within each irrigation level comparing with other fertilizing treatments (reached 376% in I_1F_1 by the end of the second season). Generally, SOM is derived from organic inputs and organic residuals after harvesting. Growth differences with the increase of irrigation water and their effects on plant's residuals amounts, explained the significant increase in F_1 level under I_1 irrigation level, in comparison with its effect under water stress treatment I_2 and I_3. Similar behavior was found for each level of organic fertilizing for both seasons. These results agree with the findings of (Adunga, 2016; Blanchet et al., 2016; Chatterjee et al., 2017).

Table 2. Physical, chemical characteristics of CTR and added amounts for F2 treatment

Season	ρb	SC	Po	OM	pH	EC dS m^{-1}	N	P	K	Moisture	CTR Added amount F_2
	g cm^{-3}	(g_{water} / $g_{dry\ compost}$)	%		(1:10) suspension		%			%	ton ha^{-1} (wet weight)
Season1	0.577	3.4	65.13	37.8	7.80	0.29	0.5	0.22	0.33	15.3	40
Season2	0.583	3.2	63.44	36.9	8.07	0.30	0.5	0.21	0.38	16.1	31

Pb, bulk density (g cm^{-3}); Sc, saturated capacity (g water / g dry compost); Tp, total porosity (%)

Studies from literature proved SOM as a key factor for soil moisture characteristics, like total water amount and available water for plants absorption. Increased SOM content of 376% in I1F1 raised its content of TAW by 87% comparing with mineral treatment I1F4, in other words, TAW can be multiplied with a proper organic amendment of dryland soils. This effect tends to increase with increased amounts of CTR under each irrigation level, even at severe deficit treatment, which is due to the important role of CTR in absorbing higher amounts of irrigation water (3.3g water/ g dry compost – Table 2, and enhancing soil water characteristics like FC and WP which determine the range of soil available water. Characteristics of CTR in Table 1, can explain its effect on improving soil water holding capacity, total porosity, bulk density and infiltration of clay soil when mixed, and these results are in agreement with the finding of earlier reports (Garcia-Gil et al., 2004).

Previous studies used small amounts of the organic amendment, but achieving effective impact on soil physics and TAW needs larger amounts, that is why best physical benefits were obtained in F1 treatments, and his result agree with (Kowaljow et al., 2017).

3.2. Actual crop evapotranspiration

According to Table 4, crop water consumption did not exceed standard values (500- 700mm / summer season/) for potatoes in the studied region. Water consumption is affected by climate and soil conditions: differences in ETa (I_1F_4) between seasons represented climate conditions effect, which was no more than 3% between 2016 and 2017, due to temperature fluctuation during summer months.

Table 3. Soil organic matter and total available water under different irrigation and regimes

Irrigation Treatment	Fertilizer Treatment	2016 OM%	2016 TAW%	2017 OM%	2017 TAW%	%Increase (as compared to F_4) 2016 OM%	2016 TAW%	2017 OM%	2017 TAW%
I_1	F_1	3.08a	57.06a	4.24a	67.97ab	295	76	376	87
	F_2	2.30c	45.29ab	3.43c	56.12ab	195	39	285	55
	F_3	1.29f	37.45b	2.37f	50.28bc	65	15	167	38
	F_4	0.78i	32.52b	0.89j	36.33c	-	-	-	-
I_2	F_1	2.95ab	56.96a	3.56b	69.05a	273	76	351	90
	F_2	1.93d	45.02ab	2.87e	56.59ab	144	39	263	56
	F_3	1.15g	37.05b	1.99h	50.11bc	46	14	152	38
	F_4	0.79i	32.41b	0.79k	36.35c	-	-	-	-
I_3	F_1	2.86b	57.06a	3.22d	68.16ab	271	74	308	88
	F_2	1.76e	45.26ab	2.21g	56.03ab	129	38	180	54
	F_3	1.00h	37.12b	1.54i	50.19bc	30	13	95	38
	F_4	0.77i	32.79b	0.79k	36.30c	-	-	-	-
	$LSD_{0.05}$	0.069	7.81	0.035	9.76				

I_1:100% of ETc; I_2: 75% ETc; I_3: %50 ETc; F_1: 200% crop nitrogen requirement as CTR; F_2: 100% crop nitrogen requirement as CTR; F_3: 50% nitrogen as CTR + 50% as urea; F_4: 100 Nitrogen as urea; * different letters indicate significant differences.

Table 4. Seasonal ETc of potato (mm)and Yield of potato tubers (t ha^{-1})

Treatment		ET_a		Yield		Yield Increase (%) during second season
		2016	2017	2016	2017	
I_1	F_1	551.04	469.72	29.7a	35.28a	19
	F_2	513.74	492.13	25.19c	29.53c	17
	F_3	434.85	429.99	19.90e	23.22e	17
	F_4	458.36	447.14	15.99gh	16.69g	4
I_2	F_1	413.28	352.28	27.17b	33.14b	22
	F_2	385.31	369.09	21.86d	26.55d	22
	F_3	326.14	322.49	17.12fg	20.25f	18
	F_4	343.77	344.35	11.33i	12.39h	10
I_3	F_1	275.53	234.86	17.78f	21.87e	23
	F_2	256.87	246.07	14.62h	17.58g	20
	F_3	217.43	216.50	10.74i	12.87h	20
	F_4	229.18	223.57	7.03j	7.69i	9
$LSD_{0.05}$				1.69	1.62	

I_1:100% of ETc; I_2: 75% ETc; I_3: %50 ETc; F_1: 200% crop nitrogen requirement as CTR; F_2: 100% crop nitrogen requirement as CTR; F_3: 50% nitrogen as CTR + 50% as urea; F_4: 100 Nitrogen as urea; * different letters indicate significant differences.

Higher levels of CTR reduced water consumption under each level of irrigation by 15% (F1), 4% (F2), and 1% in F3 in 2017 compared to the 2016 season. This indicates the soil improvement effect of CTR and its strong relation (r =0.96) with TAW (Table 3).

3.3. Potato Yield

Mixing clay soil with CTR improved its physical as well as its chemical properties. When combining chemical effects with physical improvements along with CTR slow mineralization, organic amended treatments provides nutrients for an extended period, meeting plant growth requirements for a longer period and gave better potato yields than common mineral treatments F_4. This result agrees with the findings of (Omidire et al., 2015). In addition, higher levels of CTR increased soil water holding capacity WHC, decreased the potential risk of losing water with its load of dissolved nutrients beyond the effective root zone. CTR also increased water contribution in plants growth and added more essential nutrients to soil fertility and plant growth, which was the best in F_1 treatments, and in agreement with the results of (Franzluebbers, 2002).

By adding the irrigation level effect, I_1F_1 had superiority among all applied treatments. Treatment I_2F_1 was only (9%-6%) less productive than I_1F_1 for potato seasons respectively, with 25% water savings. On the other hand, I_2F_1 was significantly superior to I_1F_2 with 8%-12% potato yield increase. Similar results were noticed for I_3F_1 with (11%-31%) increase compared to the mineral nutrient treatment I_1F_4 despite the 50% reduction in irrigation water allocation.

Table 5. Ky values for potato crops, WUE and IWUE under deficit irrigation levels

Treatment		Ky		2016		2017	
		2016	2017	WUE	IWUE	WUE	IWUE
I_2	F_1	0.34	0.24	5.88	6.57	8.45	9.41
	F_2	0.53	0.40	5.03	5.67	6.49	7.19
	F_3	0.56	0.51	4.60	5.25	5.62	6.28
	F_4	1.17	1.12	2.95	3.3	3.22	3.6
I_3	F_1	0.80	0.76	5.48	6.45	7.96	9.31
	F_2	0.84	0.81	4.78	5.69	6.15	7.15
	F_3	0.92	0.90	4.08	4.94	5.06	5.95
	F_4	1.12	1.08	2.61	3.07	2.92	3.44

I_1:100% of ETc; I_2: 75% ETc; I_3: %50 ETc; F_1: 200% crop nitrogen requirement as CTR; F_2: 100% crop nitrogen requirement as CTR; F_3: 50% nitrogen as CTR + 50% as urea; F_4: 100 Nitrogen as urea; IWUE, irrigation water use efficiency; WUE, water use efficiency.

Moreover, replacing mineral fertilizers with CTR in I_3F_2 gave better results than I_1F_4 with the possibility to save 50% of irrigation water. Organic amendment improved soil TAW and had a significant role in potato drought tolerance under water stress conditions. It increased potato yield in the range of (20-23%) in I_3 amended treatments compared with (17-19%) under full irrigation by the second season (Table 4).

3.4. Crop response factor to deficit irrigation (Ky)

As it was mentioned before, potato is a sensitive crop for water stress, that is why Ky values were (Ky>1) for I_2F_4 and I_3F_4 in both seasons. Reduction percentage increased with CTR decreased amounts and higher levels of water stress. Amending soil with CTR had accumulated importance so only a reduction of 24% was recorded in I_2F_1 during the second season after 25% shortage of irrigation water allocation. All values of Ky for both seasons were better than all results of previous studies, which emphasize the importance of organic physical improvements of clay soil.

With partial deficit irrigation and water stress applied during the initial, less potato growth affecting period, Ayas and Korukcu (2010) reported a value of (Ky=0.909). But, in this research, the smallest studied amount of CTR under severe deficit irrigation (I_3=50%), resulted in Ky value of 0.9 in I_3F_3 (Table 5). We can conclude that the soil organic physical amendment rises the potential of practicing full deficit irrigation resulting in large amounts of saved water compared with the saving of small amounts in partial deficit irrigation.

Values of WUE and IWUE are the practical indices of efficient and profitable irrigation water use and can be considered as more important indicators than ETc and Yield net values under water shortage conditions. During two years of study, WUE and IWUE values were higher in organic amended treatments with CTR (the increase of IWUE reached 99% in I_2F_1 and 110% for I_3F_1 compared with the mineral treatment of the same irrigation level). Better results were obtained in the second season compared with the first one (39% and 44% increase in IWUE in 2017 and 2016 for I_2F_1 and I_3F_1 respectively) (Table 5), while this improvement was only 9% and12% for I_2F_4 and I_3F_4 respectively. It is a clear output of CTR effects on both ETa requirements and final yield, CTR altered soil physical properties, increased its ability for water assurance, and raised its resilience to water stress. Side by side to its common nutritional benefits.

5. Conclusion

The obtained results allow providing farmers with a wide range of possibilities and choices that can be helpful to decide what level of CTR organic soil amending to apply and what level of deficit irrigation to use depending on locally available resources. The saved amounts of water could be transformed to other social needs or used to irrigate the additional area with other crops or to expand the irrigated area to meet the challenges of food security. Physical amendment with CTR helps to grow potatoes in heavy soils like the soil in this study, so this important crop could be planted in new regions. Soil conservation practices can be followed to enhance carbon sequestration and adapt to climate change.

List of abbreviations: $CaCO_3$, calcium carbonate; CTR: compost of town refuse; EC, electrical conductivity; Fc, soil field capacity; Infil, soil infiltration; K, potassium; N, nitrogen; P, phosphorous; pH, soil pH; PO, total soil porosity; SC, compost saturated capacity; SOM, Soil organic matter; Pb, soil bulk density; Pd, practical density.

Competing Interest Statement: The authors declare that they have no conflict of interest.

Author's Contribution: R. Zahalan designed, conducted the experiment, and wrote the manuscript, while M.M. Alzoubi performed the statistical analysis, read and approved the final manuscript.

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