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Effect of Water Stress and Levels of Bio-Organic Fertilizers on Water Productivity and Potato *Solanum tuberosum* L. Yield

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Abstract: A field experiment was conducted at the University of Baghdad, Al-Jadriya in the spring season of 2021 for the potato crop under the influence of organic biofertilizers and water stress. Three levels of bio-organic fertilizers were used 0 (OM0), 1 (OM1) and 1.5 (OM2) ton.ha-1 and three levels of irrigation 30 (I-30), 50 (I-50) and 75 (I-75) % water depletion were available to evaluate the role of bio-organic fertilizer and water stress in production functions and water use efficiency. I-30 treatment showed the highest water consumption ranging between 468 and 486 mm.season^{-1} and decreased to 355-436 mm with water stress treatments I-75. The values of water consumption varied according to the levels of bio-organic fertilizer. The percentage of decrease in water consumption was 1.49 and 3.66% at low stress and reached 6.37% at high stress (I-75) compared to OM0. Both treatments I-30 and I-50 gave the same yield. Bio-organic fertilization led to an increase in the average yield of tubers 32.8 and 41.9% for both OM1 and OM2 compared to OM0. The production functions indicate that the yield increases by 0.057 ton.ha^{-1}.mm^{-1} of added water, and the water depth must be greater than 64.2 mm to obtain a yield that is 1.96 ton.ha^{-1} more (significant limit) than the treatments in the experiment (1.96=0.057(Irr.).)-1.70). Fertilizer levels are higher than 1.9 ton.ha^{-1} to obtain a higher yield of tubers by 26.29 tons.ha^{-1} and the efficiency of water use is nil according to the water use function when the water consumption is higher than 692.7 mm. The response factor decreased when adding bio-organic fertilizer compared to OM0, which means that plants were not affected significantly under water stress conditions.

Keywords: Bio-Fertilizers, Drip irrigation, Potato yield, Production functions, Response factor, Water consumption.

Introduction

Iraq is exposed to severe environmental stress due to a lack of water supply and climate change (Masood & Shahadha, 2021), so it requires focusing on increasing the efficiency of water use by adopting multiple methods (Al-Lami *et al.*, 2023), including the use of drip irrigation systems and appropriate irrigation scheduling, which have higher water use efficiency, in addition to the use of organic fertilizers that improve soil fertility (Singh *et al.*, 2020) and physical and biological activities which enhances root growth (Lal, 2006; Bhatt *et al.*, 2019) and thus increases production. Bio-organic fertilizers were used to reduce the application of mineral fertilizers (Zhao *et al.*, 2016), which promote plant growth, increase plant stress resistance and release nutrients (Ye *et al*., 2020). It improves the activity of microorganisms, and soil enzyme activity as well as it mitigates the effects of soil salinity (Wang *et al*., 2013; Li *et al*., 2017; Mao *et al*., 2022) and enhances crop growth and soil fertility (Densilin *et al*., 2010; Chen *et al*., 2021, Cui *et al*., 2021). Potato is an economically important crop and food resource all over the world, and this crop is grown in several regions of Iraq, and due to the scarcity of water has led to the decline and reduction of its cultivation areas recently, which has negatively affected production quantities. The application of adding bio-organic fertilizer enhances soil fertility and may provide a sustainable method, increase water use efficiency and increase production. Therefore, this study was conducted to investigate the role of bio-organic fertilizers and water stress on potato productivity, water use and preservation of water resources from waste and waste.

Materials & Methods

This experiment was conducted in Al-Jadriya region during the spring season of 2021. The region is located in the center of Baghdad, Iraq at latitude 33°16'N and longitude 44°22E. The region is characterized with semi-arid climate, and the region receives an annual rainfall of 122 mm (Fig. 1).

The region's soil is well drained, with a clay loam texture.. A field experiment was conducted in the fields of the College of Agricultural Engineering Sciences, University of Baghdad, Al-Jadriya on the spring season of 2021 in soil texture a clay loam, tillage and leveling operations were conducted. Samples of depth 0-30 cm were taken before cultivation for the purpose of determine physical and chemical analyzes of the soil. Characteristics were determined according to the methods in Black (1965) and Page *et al*. (1982) (Table 1).

The irrigation water was obtained from the Tigris River, and irrigation water had a pH of 7.6 and an electrical conductivity (EC) of 1.2 dS m^{-1}. The experiment included three treatments of water stress I-30, I-50 and I-75, which represent the depletion of 30, 50 and 75% of the available water, respectively. Three levels of organic fertilizer were added 0 (OM0), 1 (OM1) and 1.5 (OM2) tons and their specifications are shown in Table 2, with three replicates for each treatment. Irrigation is conducted to reach the field capacity of the above water stress factors. The gravimetric method was used to determine the level of depletion and irrigation time, and then the water depth was added using the following equation (Allen *et al*., 1998).

$$d = \left(\theta_{fc} - \theta_{w}\right) \times D \quad (1)$$

Where d: the depth of water applied (mm), θfc the volumetric moisture at field capacity (cm^3 cm^3), θw the volumetric moisture before irrigation (cm^3 cm^3), D the soil depth, which is equal to the effective roots depth (mm).

Phosphorous fertilizer was added during soil preparation at average 100 kg ha^{-1} and potassium fertilizer at 200 kg ha^{-1}. Nitrogen fertilizer were added at an average of 200 kg ha^{-1}. The area of the experimental plot was 2m × 3m. On January 25, 2021, potato tubers (*Solanum tuberosum* L.), and cultivar Rivera (cultivar Rivera), were planted at a depth of 10 cm, with a spacing of 75 cm between the lines and 30 cm between plants. Using the sprinkler system at the beginning of planting and change to drip irrigation later. The distance between the furrow is 90 cm. The Furrow is generally V-shaped, 25 cm deep and 40 cm wide at the top. The irrigation system consists of a pump, filter, and control valves; the main line is a polyvinyl chloride (PVC) pipe, which transports water to key points in the field. Sub-main lines connected to the 75 mm main line were used, 63 mm polyethylene pipes connected to the main line and control valves installed on the branch pipes were used. The emitters discharge was 8 liters per hour, and the spacing between emitters was 30 cm.

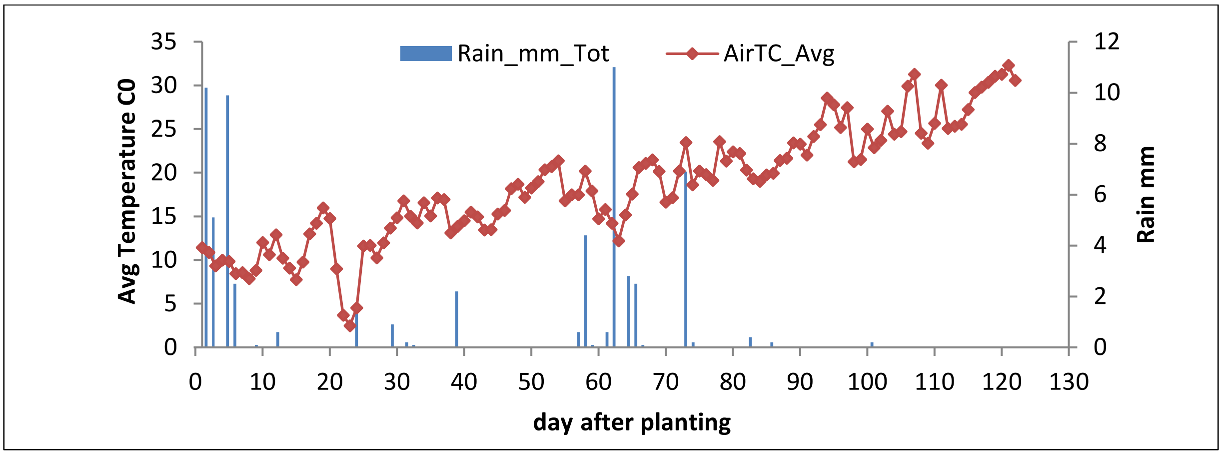

Fig. (1): Temperature and rainfall during the growing season.

Table (1): Physical and chemical analysis of soil

Properties	Soil Depth (0.0 -0.30) m
Sand (gm kg^{-1} soil)	277
Silt (gm kg^{-1} soil)	433
Clay (gm kg^{-1} soil)	290
Soil Texture	Clay loam
Bulk Density (μg m^{-3})	1.5
Moisture content at saturation (cm^3 cm^{-3})	0.47
Moisture content at 33 kPa (cm^3 cm^{-3})	0.29
Moisture content at 1500 kPa (cm^3 cm^{-3})	0.13
$EC_{1:1}$	1.2
HCO_3^- (meq L^{-1})	2.2
Cl (meq. L^{-1})	5.2
SO_4^{2-} (meq. L^{-1})	10.1
Ca^{++}(meq. L^{-1})	4.1
$K^{+\ ++}$(meq. L^{-1})	0.7
Mg^{++} (meq. L^{-1})	5.6
Na^+ (meq. L^{-1})	7.1
OM (gm kg^{-1})	12.2

Table (2): Chemical analysis of Bio–Organic fertilizer

Chemical analysis:	
Organic matter	45%
Beneficial Microb	≥20 million.g^{-1}
Amino acid	5%
Humic acid	10%
$N+P_2O_5+K_2O$	5%

The actual evapotranspiration of the potato crop (ETa) was estimated by the following water balance equation:

$$ETa = I + P \mp \Delta S - R - D \qquad (2)$$

As the actual evapotranspiration ETa (mm), I depth of irrigation water added (mm). P rainwater depth (mm). D: depth of piercing water (zero), R runoff, ΔS change in soil moisture storage. Crop data was recorded on plot basis and extrapolated to hectare basis. The yield of tubers (Mg.ha^{-1}) was estimated from the average yield of the experimental unit, and the response coefficient of the yield Ky was estimated according to the following equation:

$$Ky = \frac{1 - Ya.Ym^{-1}}{1 - ETa.ETm^{-1}} \qquad (3)$$

Ya: is the actual yield of water stress treatment and Ym is the maximum quotient of the comparison treatment (μg.ha^{-1}), ETa is the actual evapotranspiration (mm) and ETm is the maximum evapotranspiration (mm). The irrigation water productivity or water use efficiency WUEETa (kg.ha^{-1} mm^{-1}) was estimated from the following equation:

$$WUE_{ETa} = \frac{YIELD(Kg/ha)}{ETa(mm)} \qquad (4)$$

Statistical analysis was conducted according to the GENSTAT statistical program, the experimental data were analyzed with a randomized complete block design (RCBD), and the average difference was estimated using the least significant difference (LSD) compared. These treatments were assigned in Randomized factorial treatment design with three replications.

Results & Discussion

Fig. (2) show the actual water consumption of the plant during the different stages of growth, where it is noticed that there is a increase in the values of water consumption during growth stages, and the emergence stage take lowest value of water consumption compared to other stages, due to low temperatures at the beginning of the agricultural season. The values of water consumption increased in the stage of vegetative growth and flowering, as a result of the increasing of leaf area and the increase in the plant's need for water and nutrients. The percentage of water consumption for the complete irrigation treatment in the seedling stage was about 8% of the total water consumption, it increased to 18% in the vegetative growth stage and 50% in the flowering, then it decreased to 24% in the stage of crop formation. Table (3) shows the actual water consumption (ETa) for the different irrigation treatments of the potato crop. I-30 treatment showed the highest water consumption (468 and 486 mm season^{-1}) and decreased to 355-436 mm when water stress treatments I-75. The values of water consumption varied according to the levels of bio-organic fertilizer.

The difference in water consumption is due to the variation in soil moisture content at the levels of organic biofertilizer. As the levels of bio-organic fertilizers (Ton.ha^{-1}) in the soil led to a reduction in water consumption as a result of soil water retention, the following function was taken:

$$ETa = 12.79\ OM + 435.3 \qquad R^2 = 0.88$$

At the same time, the values of water added for the I-30 treatment increased compared to the water stress factors, and this is due to the soil moisture available at low stress being exposed to evaporation higher (Ati *et al.*, 2017). The crop did not have time to consume some of the water available in the root zone, which ranged between 31-70 mm, due to the organic matter that has the ability to store water (Table 3). Irrigation treatments led to differences in the stored soil water, due to its depletion in the root zone. To avoid water stress, good management practices were used, namely, the addition of bio-organic fertilizers to keep soil moisture in the root zone under specific water stress. Irrigation parameters also led to differences in water consumption values and the depth of seasonal water added below organic matter levels. Seasonal values of ET at I-30 were higher and soil evaporation increased due to more wetting of the soil surface in irrigation at 30% depleted of the available water. No deep percolation occurred during the study for any of the treatments because we used the irrigation scheduling for root depth during irrigation.

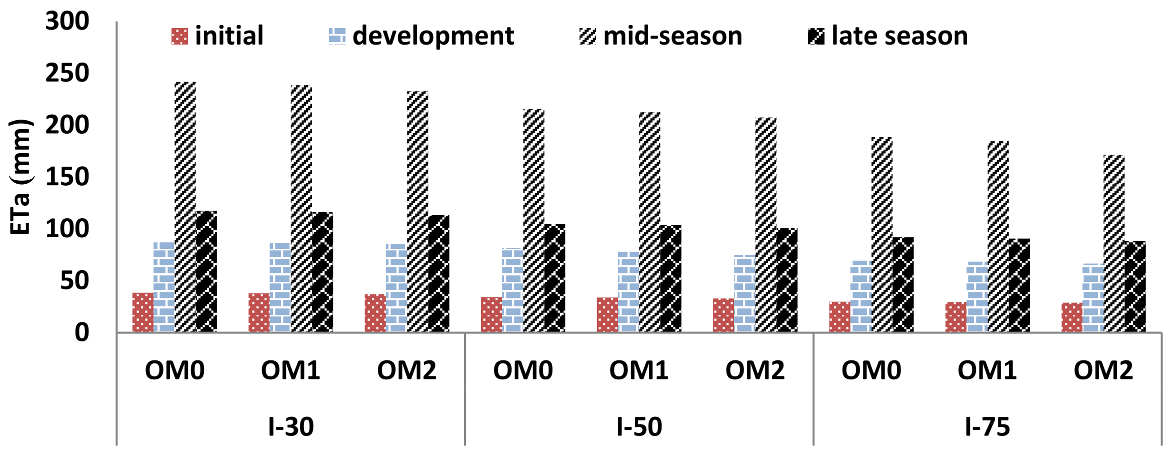

Fig. (2): Effect of water stress and bio-organic fertilizers (levels of organic fertilizer added 0 (OM0), 1 (OM1) and 1.5 (OM2) tons) on water consumption during plant growth stages.

Table (3): Effect of water stress and bio-organic fertilizers (levels of organic fertilizer added 0 (OM0), 1 (OM1) and 1.5 (OM2) tons) on water depth, water consumption and stored water depth.

Water stress	OM	Irr. mm	p. mm	ETa . mm	Δs mm
I-30	OM0	475	63	486	52
	OM1	475	63	479	59
	OM2	475	63	468	70
I-50	OM0	401	63	436	28
	OM1	401	63	428	36
	OM2	401	63	416	48
I-75	OM0	348	63	380	31
	OM1	348	63	373	38
	OM2	348	63	355	56

Most of the water consumption used in the middle of the growing season when there was canopy cover and the plant was needed for growth. Water requirements for potatoes are from 500 to 700 mm depending on the climate (Pereira & Schock, 2006). Low and moderate water stress treatments led to a significant increase in the average total yield of tubers (irrespective of the biological organic matter treatments) compared to the high-stress treatment (75% depletion of prepared water). I-50 treatment with a 49.9% increase in yield compared to I-75. Both treatments I-30 and I-50 produced the same yield (Table 4), although

I-50 received 74 mm of irrigation less than I-30 (Table 3).

Table (4): Effect of water stress and bio-organic fertilizers (levels of organic fertilizer added 0 (OM0), 1 (OM1) and 1.5 (OM2) tons) on potato yield (µg.ha^{-1}

Irrigation levels	OM			mean
	OM0	OM1	OM2	
I-30	18.42^{b} ±1.05	25.96^{a} ±1.61	27.19^{a} ±2.89	23.86^{a} ±1.85
I-50	19.47^{b} ±0.69	26.14^{a} ±1.52	26.98^{a} ±2.54	24.20^{a} ±1.58
I-75	13.51^{c} ±1.32	16.14^{bc} ±2.49	18.77^{b} ±3.08	16.14^{b} ±2.29
mean	17.13^{b} ±1.02	22.75^{a} ±1.87	24.32^{a} ±2.84	

Note: Values in a column followed by the same letter are not statistically different at p≤0.05 (Mean± SD)

The bio-organic fertilization led to an increase in the average yield of tubers from 17.13 to 22.75 µg.ha^{-1} when adding 1 ton.ha^{-1}, with an increase of 32.8% compared to the treatment without fertilization at the second level of bio-organic fertilizer (OM2), the increase in yield was 41.9%. The interaction between bio-organic fertilization and water stress led to a significant increase in yield at levels of addition compared to control treatment. The effect of the interaction between irrigation levels and the addition of bio-organic fertilizer, where it gave OM2 the highest production of 27.19 ton.ha-1, with a significant increase, compared to all treatments of no addition as well as the level of irrigation 75% at the levels of organic matter 1 and 1.5 ton. The production function gave a highly significant correlation coefficient. Referring to the above function, and through the least significant difference, it can be predicted about the moral value of adding bio-organic fertilizer at a level of 1.9 ton.ha^{-1}, in order to obtain a yield of tubers of 26.29 ton.ha^{-1} (positive significant). The contents of bio-organic fertilization of macro and microelements have an important role in improving the physical, chemical, biological and fertility properties of the soil (Bhatt *et al*., 2019), in addition to the presence of organic acids and their role in improving and processing nutrients (Ye *et al*., 2020). In addition to the role of microorganisms in the provision and availability of nutrients through the secretion of organic acids, growth regulators and chelating compounds. At the same time, there were no significant differences between OM2-I-75 with I-30 and I-50 treatments in the case of OM0, this confirms the importance of adding organic matter to the soil in cases of high-water stress. The production decreased when the organic matter was not added at the high levels of depletion compared to another treatments. The actual water consumption was best correlated with the yield of tubers (R^2 = 0.74), and the production function at the water consumption levels gave the following function:

$$\mathbf{YIELD} = 0.072\mathbf{ETa} - 9.36 \qquad R^2 = 0.74$$

It is clear from the above relationship that the production is after 130 mm (9.36/0.072 = 130 mm) of water consumption, assuming that the production is equal to zero Ton.ha^{-1}, at the same time, it indicates that the yield of potato tubers increases by 0.072 Ton.ha^{-1}.mm^{-1} (µg.ha^{-1}.mm^{-1}).

$$\mathbf{YIELD} = 0.057\ \mathbf{Irr} - 1.70 \qquad R^2 = 0.63$$

The above equation indicates that the yield increases by 0.057 Ton ha^{-1} mm^{-1} water added, and this represents the slope value in the equation. Table (4) explained that the significant value of the irrigation treatments was 1.96 Ton ha^{-1}, which means the amount of water should increase by 64.2 mm (1.96 = 0.057 (Irr)-1.70) to obtain a yield greater than 1.96 Ton ha^{-1}on the treatments. In the experiment, this addition must be during the growing season to obtain the appropriate yield that significantly increases the yield of tubers, but the important question is when this quantity is added and at what stage, and this needs a more detailed study .

It is possible to quantitatively express the effect of water stress on potato yield (plant sensitivity to water stress) by finding the value of the relationship (Table 5) between the relative decrease in yield and the relative decrease of evapotranspiration (Equation 3). When the plant is suffered to water stress, the relative decrease in evaporation of transpiration is higher than the relative decrease in the yield and thus high values of the crop response coefficient (Ky). That is, where the value is greater than one, it means that the loss in the quotient is more important than the decrease in ET (table 5) that shows the difference in the values of the potato response coefficient (Ky) with the different water stress factors and the levels of organic biofertilizer. This means that plants are not significantly affected under water stress conditions. These parameters seem to suggest that the potato's response to water can change with organic matter levels, irrigation depth and improved management practices. This means all the Ky values were less than unity, indicating that a unit water deficit resulted in a less than one unit reduction in fresh yield.

Table (5): Effect of water stress and bio-organic fertilizers (levels of organic fertilizer added 0 (OM0), 1 (OM1) and 1.5 (OM2) tons) on the response factor.

Irrigation levels	OM	Ya/Ym	ETa/ETm	Ky
I-30	OM0	0.32	0.00	-
	OM1	0.05	0.01	3.03
	OM2	0.00	0.04	0.00
I-50	OM0	0.28	0.10	2.74
	OM1	0.04	0.12	0.32
	OM2	0.01	0.14	0.05
I-75	OM0	0.50	0.22	2.29
	OM1	0.41	0.23	1.75
	OM2	0.31	0.27	1.15

Water use efficiency or water productivity

The results of the effect of water stress and bio-organic matter and their interactions on water use efficiency (WUE) are shown in Table 6. I-50 treatment gave the highest values of water use efficiency 56.9 $kg.ha^{-1}$ mm-1, with a significant increase of 13.8 and 29.6% compared to treatments I-30 and I-75, respectively. This is due to an increase in production in this treatment.

$$\mathrm{WUE} = -0.18\mathrm{ETa} + 124.7 \qquad R^2 = 0.93$$

The addition of the bio-organic matter OM2 led to a significant increase, as the average water use efficiency was 58.6 $kg.ha^{-1}$ mm^{-1} with an increase of 48.7% compared to OM0, at the same time OM1 excelled with a significant increase of 34.3% compared to OM0. It is noted that the water use efficiency function that took the following relationship:

$$WUE = 12.9OM + 39.6 \quad R^2 = 0.99$$

In order to achieve a significant increase according to the production function (63.46 kg $ha^{-1}.mm^{-1}$) for the other assumed level of bio-organic fertilizers, the addition level must be more than 1.9 $ton.ha^{-1}$. The bio-organic matter promotes the growth of leaves and roots increases the efficiency of photosynthesis, in addition to increasing the availability and absorption of nutrients from plants, this means the number of leaves and root growth is one of the morphological responses to water stress and bio-organic fertilizers (Ati *et al*., 2017).

Table (6): Effect of water stress and bio-organic fertilizers (levels of organic fertilizer added 0 (OM0), 1 (OM1) and 1.5 (OM2) tons) on water use efficiency (kg. $ha^{-1}.mm^{-1}$).

Irrigation levels	OM			mean
	OM0	OM1	OM2	
I-30	$37.9^{c} \pm 2.16$	$54.2^{b} \pm 3.35$	$58.1^{ab} \pm 6.18$	$50.0^{b} \pm 3.90$
I-50	$44.7^{c} \pm 1.59$	$61.1^{ab} \pm 3.55$	$64.8^{a} \pm 6.10$	$56.9^{a} \pm 3.75$
I-75	$35.6^{d} \pm 3.49$	$43.3^{c} \pm 6.66$	$51.8^{bc} \pm 8.68$	$43.9^{c} \pm 6.28$
mean	$39.4^{c} \pm 2.42$	$52.9^{b} \pm 4.52$	$58.6^{a} \pm 6.99$	

Note: Values in a column followed by the same letter are not statistically different at $p \leq 0.05$ (Mean± SD)

Conclusion

Potato yield and water use efficiency both rise as a result of bio-organic fertilization. The yield is increased by 0.057 $tons.ha^{-1}$ mm^{-1} water added by reducing the water stress. ($Mg.ha^{-1} .mm^{-1}$).

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Contributions of authors

T.K. M.: Contribute to research project proposal, conducting the practical part of the research, Statistical analysis, Write the manuscript.

A. S. A.; Research project proposal, Read and revise the manuscript.

Q.O.H.: conducting the practical part of the research.

Conflicts of interest

The authors declare that they have no conflict of interest

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تاثير الاجهاد المائي والمادة العضوية الحيوية في كفاءة استعمال المياه وحاصل البطاطا

طارق كمال مسعود والاء صالح عاتي وقصي عبيد حمادي

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المستخلص: اجريت تجربة حقلية في جامعة بغداد–الجادرية في الموسم الربيعي 2021 لمحصول البطاطا تحت تاثير الاسمدة الحيوية العضوية والاجهاد المائي، استخدمت ثلاث مستويات من الاسمدة الحيوية العضوية 0 (OM0) و1(OM1) و 1.5 (OM2) طن.هـ$^{-1}$ وثلاث مستويات من الري 30(30–I) و 50(50–I) و75(75–I) % استنفاد من الماء الجاهز لتقييم دور الاسمدة الحيوية العضوية والاجهاد المائي في دوال الانتاج وكفاءة استعمال الماء. أظهرت معاملة 30–I أعلى أستهلاك مائي تراوح بين468 و486 مم/موسم وأنخفض الى 355 – 436 مم عند معاملات الاجهاد المائي 75–I .أختلفت قيم الاستهلاك المائي حسب مستويات السماد الحيوي العضوي وقد بلغت نسبة الانخفاض في الاستهلاك المائي 1.49 و3.66% عند الاجهاد المنخفض ويصل الى 6.37 % عند الاجهاد العالي (75–I) بالقياس الى OM0. اعطت كلا المعاملتين 30–I و50–I نفس المحصول. أدى التسميد الحيوي العضوي الى زيادة متوسط حاصل الدرنات 32.8 و41.9 % لكل من OM1 وOM2 بالقياس الى OM0. وتشير دوال الانتاج الى ان الحاصل يزداد بمقدار 0.057 طن.هـ$^{-1}$.مم$^{-1}$ ماء مضاف، ويجب ان يزداد عمق الماء عن 64.2 مم للحصول على حاصل يزيد بمقدار 1.96 طن/هـ (حد المعنوية) عن المعاملات في التجربة (1.96=0.057(irr)–1.70). وتزداد مستويات السماد عن 1.9 طن.هـ$^{-1}$ للحصول على انتاج حاصل درنات اعلى بمقدار 26.29 طن.هـ$^{-1}$. وتكون كفاءة استعمال المياه معدومة وفق دالة استعمال المياه عندما يكون الاستهلاك المائي اعلى من 692.7 ملم. انخفض معامل الاستجابة عند اضافة الاسمدة الحيوية العضوية بالقياس الى OM0، وهذا يعني عدم تاثر النباتات بشكل كبير تحت ظروف الاجهاد المائي.

الكلمات المفتاحية: التسميد الحيوي، الري بالتنقيط، حاصل البطاطا، دوال الانتاج، معامل الاستجابة، الاستهلاك المائي.