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(Original Article)

Impact of Surface Drip Irrigation System and Fertigation Management on Yield and Water Use Efficiency of Potato

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Abstract

Potassium (K) is an essential element vital for plant growth, as it actively regulates water balance within their cells. This research focused on studying the effects of alternative forms of potassium on growth and yield of potato plants. Rosetta potato variety was cultivated under surface drip irrigation systems at the experimental farm of the Soils and Water Department, Faculty of Agriculture, Assiut University, Egypt, during the winter seasons of 2020/2021 and 2021/2022. Three different sources of potassium, i.e. K-humate, K-sulfate, and Vinasse (Vinasse is organic by-product of the sugarcane industry) were used. The three fertilizers were tested under four water levels of surface drip irrigation (I_1 =100, I_2 = 88, I_3 = 74, and I_4 = 61% of evapotranspiration (ETc). Split-plot design was used in the experiment.

The Results showed that the highest mean values of potato tubers yield, were recorded from the first irrigation treatment (I_1) compared to the other water levels treatments (I_2, I_3, I_4). Fertilization with organic materials such as vinasse and K-humate gave a higher yield rate than potassium sulphate. However, fertilization with vinasse gave the highest yield and quality parameters including tuber size, number of tubers, dry weight, amount of starch, and amount of potassium in tubers. Also soil fertility was better with vinasse application than potassium sulfate.

***Keywords**: Drip irrigation, Fertigation, Potassium Use Efficiency, Potato, Vinasse, Water Use Efficiency.*

Introduction

Egypt occupies the sixth position in the world among potatoes exporting countries, with an export value of $206 million, representing 5.9% of the average value of global exports with production amounts of about 572 thousand tons (Allam *et al.*,2022).

Drip irrigation often enables high water application efficiencies due to reduced surface evaporation, decreased surface runoff, and minimal deep percolation (Jiusheng *et al*. 2003). Moreover, drip irrigation systems offer a convenient method for fertigation, allowing precise fulfillment of crop nutrient needs. The level of fertigation management required to achieve optimal yields and crop quality often

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surpasses what is achievable with other irrigation methods. Additionally, there are numerous other benefits associated with fertigation through drip irrigation systems, as elaborated by Burt *et al*. (1998).

Potassium plays a crucial role as an essential nutrient for plant growth, impacting various aspects such as carbohydrate synthesis, tuber quality, processing characteristics, and plant resilience to stresses and diseases (Ebert, 2009). Despite typically high reserves of potassium in the soil, a significant portion is bound within the crystal lattice structure of clay minerals, rendering it inaccessible to plants. Consequently, supplementary sources of potassium are required to maintain optimal plant growth performance and yield components (Zorb *et al*., 2014).

Potassium humate, an organic fertilizer, is considered a safer potassium source for food production compared to potassium sulfate, a mineral fertilizer. This organic material not only enhances product quality but also boosts plant resilience against diseases, pests, and various environmental stresses such as heat, cold, and drought (Ajalli *et al*., 2013). Additionally, it has the potential to augment the nutrient content of both soil and growing plants, thereby enhancing fertilizer use efficiency (Mosa, 2012).

Vinasse is the liquid residue resulting from the distillation process used to separate alcohol or solvents from fermenters during the fermentation of sugar cane or beets's molasses. According to Camargo *et al*. (2009), the initial research on vinasse application to soil in Brazil began in the 1950s and was carried out by the Luiz de Queiroz College of Agriculture (ESALQ). The practice of using vinasse as fertilizer in fertigation became widespread in sugarcane refineries starting in the 1980s (Corazza, 1996). Fertigation involves the direct application of raw vinasse to the soil through irrigation of sugarcane crops (Camargo *et al*., 2009). When applied directly to the soil, sugarcane vinasse serves as both irrigation and fertilizer for the crop, reducing the need for chemical fertilizers and lowering associated costs (Laime *et al*., 2011).

Utilizing vinasse as fertilizer represents an alternative approach that emphasizes the sustainable utilization of by product natural resources and using it as substitute to K_2SO_4 the expensive and inorganic fertilizer. This practice helps prevent the discharge of vinasse into rivers, while simultaneously fertilizing agricultural land (Gianchini and Ferraz, 2009).

Therefore, this study aimed to study the effects of using vinasse and K-Humate as organic sources of potassium versus inorganic chemical potassium sulfate, Also, these treatments are to be tested under four drip irrigation water levels.

Material and Methods

Rosetta potato variety was grown under surface drip irrigation systems at the experimental farm of the soils and water dept., Faculty of Agric., Assiut University, Egypt during the winter seasons of 5/10/2020 – 9/10/2021 to study in a split-plot design experiment, the effects of three different sources of potassium (K) (K-humate, K-sulfate, and vinasse) , in interaction with four irrigation water (I_1 =100 , I_2 = 88 , I_3 = 74 and I_4 = 61 % of ETc) were tested on potato.

The physical and chemical analyses were performed on the soil of the experimental site at a depth of 0-30 cm. The results are shown in Table (1).

Table 1. Some physical and chemical properties of the soil used in the experiments during winter seasons 2020/2021 and 2021/2022.

property		value
Mechanical analyses	Sand, %	21.21
silt, %		29.55
Clay, %		49.24
Soil Texture class		clay
Bulk density, gm/cm^3		1.21
Field capacity, (F.C) %		40.27
Wilting Point, (W.P) %		21.00
Infiltration rate (cm/h)		0.13
$CaCO_3$ (%)		3.50
pH $_{(1:2.5)}$		8.01
$EC_{1:1}$ dSm^{-1}		1.07
Soluble Cations, meq 100 gm^{-1} soil		
Ca^{2+}		0.95
Mg^{2+}		0.30
Na^{+}		0.61
K^{+}		0.10
Soluble Anions, meq 100 gm^{-1} soil		
Cl^{-}		0.40
$HCO_3 + CO_3^{2-}$		0.70
SO_4^{2-}		1.31
Total nitrogen %		0.08
Available phosphorus ppm		11.17
Available potassium ppm		300

Experimental work

Irrigation system

The experiment included four irrigation levels interacted with four fertilization treatments and four replications. Each plot contained two black (GR-drip lines) polyethylene drip lines with 16 mm diameter and 10 meters in length. The distance between each line was 0.7 meters with built in dripper 30 cm apart, which discharges 4 liters average per hour.

Seed planting

Potato tuber (red Rosetta var.) of medium size were planted at rate of two seeds beside each dripper with total number of 33 seeds / line (66 seeds $plot^{-1}$).

Irrigation levels

The irrigation treatments were I_1 (1160 m^3/fed =100% ETc), I_2 (1017 m^3/fed =88% ETc), I_3 (860 m^3/fed =74% ETc) and I_4 (710 m^3/fed =61% ETc). General irrigation for all experiments started just after planting the seeds on 5/10/2020 in the first season and 9/10/2021 in the second season. However, the treatment started after

80 % complete seedlings emergence. FAO Cropwat 8.0 computer program for windows was used for calculating the crop water requirements (FAO, 1992). Total irrigation water for each treatment is shown in Table (2).

Table 2. Total applied water and ETc calculated by Cropwat 8.0 using 80% soil surface cover.

Irrigation treatment	I_1	I_2	I_3	I_4
Total applied water m^3	1160	1017	860	710
% of ETc	100	88	74	61

Fertilization

In order to test the effect of vinasse as a substitute of the inorganic potassium sulfate K_2SO_4 fertilizer, the experiment included vinasse, K-humate, potassium sulfate, and control treatment in interaction with the four irrigation levels.

One level of potassium of 132 Kg of potassium sulfate (K_2SO_4) per feddan (1 feddan = 4200m^2) (317 Kg ha^{-1}) was applied. Also, one level of potassium humate (13.3 Kg fed^{-1}) and dry vinasse (22.2 Kg fed^{-1}) were used. The amount of each fertilizer was divided into 20 doses to be distributed throughout the growth season. Each dose was dissolved in water and sprayed evenly on the soil surface beside the growing plants.

Sampling and Harvesting

After 100 days of planting and complete growth of the experimental plots 6 plants from each plot were harvested for the laboratory physical and chemical measurements. The tubers of each plant were collected and cleaned manually from the soil then graded to small and large tuber size (> 5 cm diameter), counted and weighed. The total plant weight and the shoot weight also were measured and recorded. Sub samples of leaves were taken for chemical analysis. At the end of the experiment 9/2/2021 in the 1st season and 13/2/2022 in the 2nd season, the whole plot was harvested and weighted and recorded.

Soil Sampling and Analysis

Representative soil samples after harvesting in the second season were collected from the plant root zone (0-30 cm) of each plot for chemical analysis. Soil chemical analyses were performed as the following:

1- Electrical conductivity was measured by the electrical conductivity meter in filtrates of 1:1 (soil:water) suspension according to Jackson (1973), and Bashour and Sayegh (2007). The ECe was calculated using the soil saturation water percentage.

2- Soil pH: Soil pH was measured by pH meter in 1: 2.5 (soil: water) suspension using a glass electrode at 25C° (Jackson, 1973).

3- Soluble potassium: Soluble potassium (K^+) cations was extracted by 1:1 (soil: water) suspension then K^+ measured in the filtrate using the flame photometry method (Jackson, 1973).

4- Available soil potassium: was extracted using ammonium acetate (1:20) as a saturating solution. The extracted (K^+) was determined with a flam photometer. (Jackson, 1973).

Plant Analysis

1-Dry matter in the tubers %

Representative tuber from each plot was cleaned with dry cloth and cut into slice after being weighed then dried in oven at 70 C° tell reach constant weight and the dry matter were calculated as the following

$$\text{Dry matter \%} = \frac{\text{dry weight}}{\text{fresh weight}} \times 100$$

2-Starch content in the tuber

The starch percentage in the tuber was calculated using the dry matter content according to the equation proposed by Cataldo *et al.* (1975).

Starch % =17.55+0.891(dry matter % - 24.182) as sited from (A.O.A.C, 1980),

3-Potassium content in the tubers

Twenty grams of fresh tuber were grounded with 200ml of distilled water for 5 minutes then filtered to measure soluble potassium using flam photometer according to Parkinson and Allen (1975).

4-Potassium content in plant leaves

Dry grounded leaves samples were digested using H_2SO_4 +H_2O_2 mixture as described by Parkinson and Allen (1975), then potassium was determined by Flam photometer.

5-Potassium use efficiency (KUE)

It was calculated by multiplying potassium concentration in potato tuber by the total tubers yield (FAO,1982).

6-Water use Efficiency (WUE)

It was calculated by dividing the tubers yield by the amount of irrigation water used, m^3/fed to produce Kg of tuber/m^3 of irrigation water (FAO,1982).

Statistical Analysis

Data obtained in each season were statistically analyzed. Statistical computer program MSTAT-C, Crop & Soil Sciences Dept. Michigan State University was used. To compare treatment means, a New Least Significant Difference (NLSD) was used according to Duncan MSTAT (1989) micro -computer program.

Results and Discussion

The results are divided into six sections to show the effects of fertilization by vinasse as a source of potassium nutrient and comparing it with the expensive inorganic chemical fertilizer namely potassium sulfate and with the potassium humate all that were tested under four levels of surface drip irrigation. These sections are.

1-Soil EC, pH, soluble and available potassium

2-Potato tuber analysis: potassium, starch, and dry matter contents.

3-Potato growth and yield parameter.

4-Potato potassium use efficiency KUE and water use efficiency WUE.

5-Multi correlations between all studied factors.

1-Soil EC, pH, soluble and available potassium

A-Soil Salinity ECe

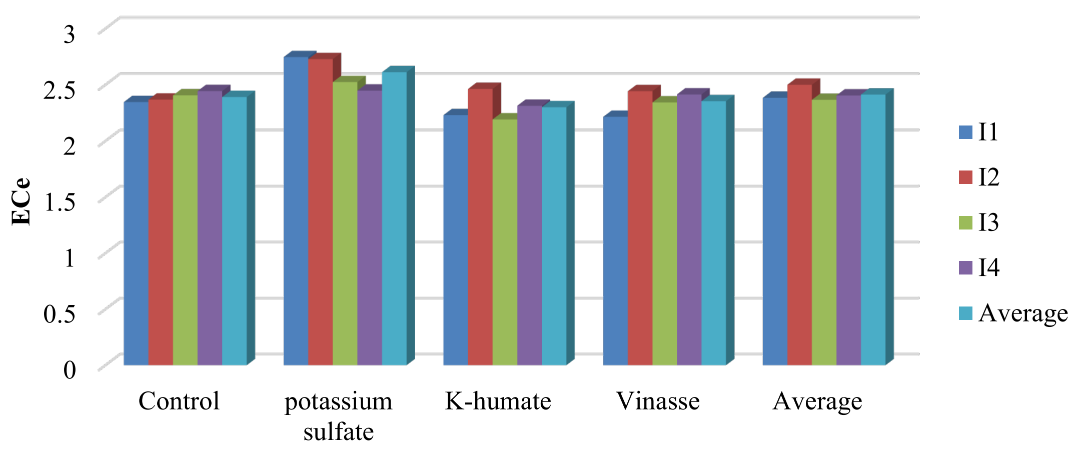
The soil ECe (Table 3 and Figure 1A and B) showed no significant differences among all treatments. Only K-sulfate treatment increased the soil salinity slightly (9%) over the control and K-humate and vinasse treatments. Also, irrigation levels did not show noticeable changes in the ECe.

Table 3. The changes in the soil salinity ECe as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels in Assiut.

Items	Control	K_2SO_4	K-humate	Vinasse	Average
			ds/m		
I_1	2.346	2.746	2.230	2.215	2.384
I_2	2.368	2.728	2.463	2.443	2.500
I_3	2.406	2.524	2.192	2.343	2.366
I_4	2.444	2.448	2.313	2.414	2.405
Average	**2.391**	**2.612**	**2.300**	**2.354**	**2.413**
LSD	**Irrig. = ns**	**Fert. = ns**	**Inter.=ns**		

I_1 =100, I_2 = 88, I_3 = 74, and I_4 = 61% of evapotranspiration. ns= not significant

A-Effect of fertilizer



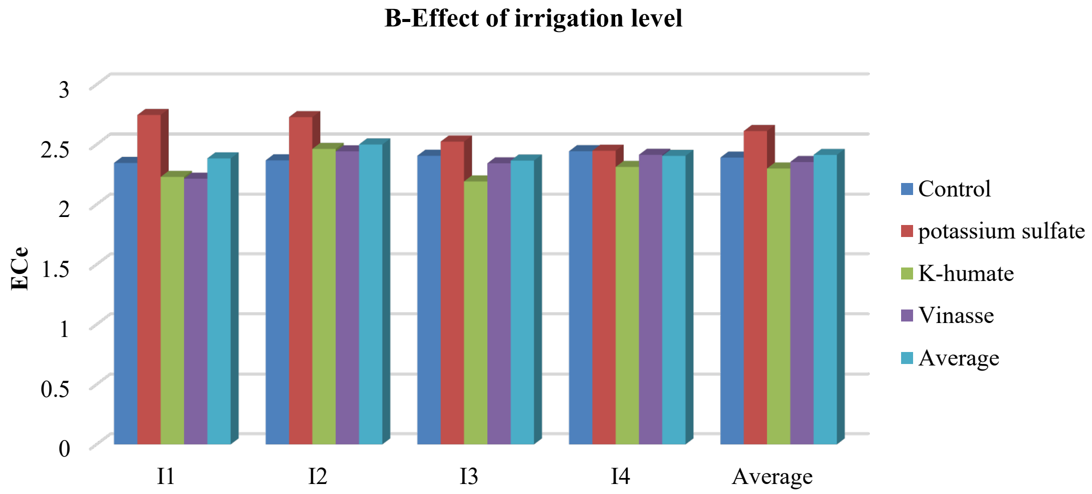


Figure 1. The changes in the soil salinity EC_e as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels (I1 =100, I2 = 88, I3 = 74, and I4 = 61% of evapotranspiration) in Assiut.

B-Soil pH

Data in Table 4 and Figure 2 showed a significant decrease in the soil pH values as affected by either irrigation or fertilization. The averages pH values of irrigation treatments I1, I2, I3, and I4 were 8.24, 8.05, 8.06 and 8.03 respectively. This means, less water causes more acidity and more active hydrogen ions. Does that mean less water allows the soil organisms to work better and reduce the acidity? Only I1 showed significantly higher soil pH values than I2, I3, and I4.

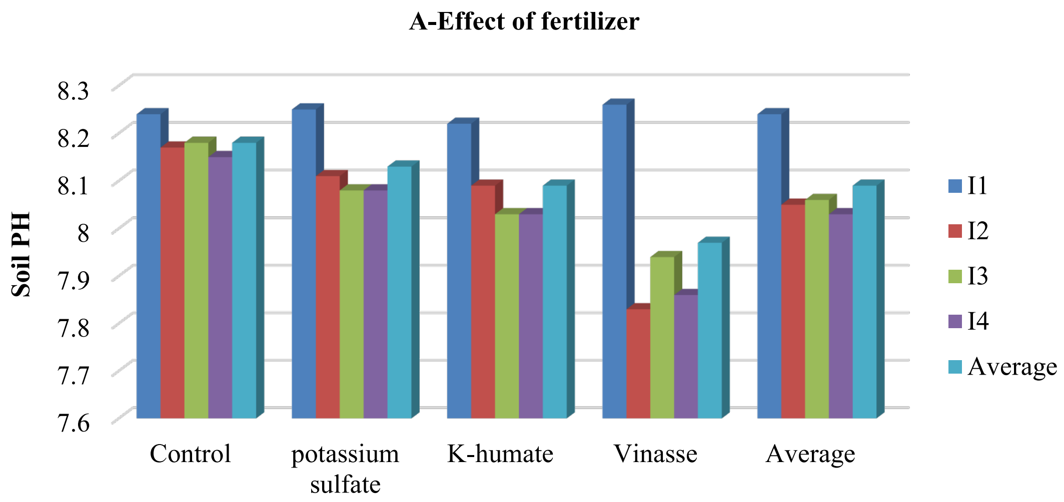
Fertilization with vinasse reduced the soil pH values significantly than the control, k-sulfate, K-humate. The soil pH values were reduced from 8.18 for the control to 8.13, 8.09, and 7.97 pH when fertilized with K-Sulfate, K-Humate, and vinasse, respectively. This result matched the acidity of the applied materials. The original pH of vinasse 4.43. The soil pH changes may solubilize more nutrients and produce more biomass and yield.

The interactions between fertilization and irrigation showed significant changes in the soil pH at $P < 0.05$ and LSD 0.19. The lowest pH values were associated with lower water and fertilization.

Table 4. The changes in the soil pH as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels

Items	Control	K_2SO_4	K-humate	Vinasse	Average
I_1	8.24	8.25	8.22	8.26	8.24 a
I_2	8.17	8.11	8.09	7.83	8.05 b
I_3	8.18	8.08	8.03	7.94	8.06 b
I_4	8.15	8.08	8.03	7.86	8.03 b
Average	8.18 a	8.13 a	8.09 a	7.97 b	8.09
LSD	**Irrig. = 0.17**	**fert. = 0.15**	**Inter. = 0.19**		

I_1 =100, I_2 = 88, I_3 = 74, and I_4 = 61% of evapotranspiration



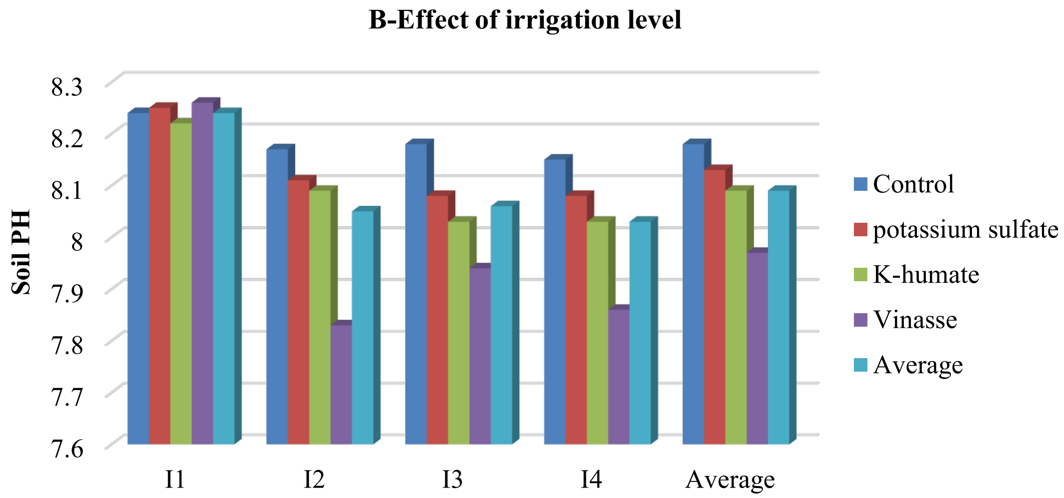


Figure 2. The changes in the soil pH as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels (I1 =100, I2 = 88, I3 = 74, and I4 = 61% of evapotranspiration).

C-Soil soluble potassium

The data in Table 5 and Figure 3 show that irrigation treatments did not reflect trend in soluble K with the four levels. However, the lowest irrigation treatment showed an increase of 9% in soluble potassium as compared with the highest water level I4 (114 mg k/kg soil). lower water use may cause reduced potassium leaching.

The K-fertilization treatments showed significant increases in soluble K by 37, 14, and 116% for K_2SO_4, K-humate and vinasse, respectively, as compared with the control which has only 81 mg/kg K soluble in soil.

Vinasse application more than doubled the soluble potassium. This may be considered in the recommendation that the applied amount of vinasse was too match. The interaction between water level and fertilizer was significant. The control has no significant effects due to water level, while reducing water level increased the soluble soil potassium. When K was applied as K-sulfate, K-humate and vinasse. That may be due to lower leaching of potassium matched reducing apply water.

The level of soluble K in the control soil averaged 81 mg k/kg soil or 2 meq K/Kg soil which is around the sufficient level as recommended by Ryan and Mater (1990).

Table 5. The changes in the soil soluble and available potassium (mg/Kg soil) as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels in Assiut.

Items	Control	K_2SO_4	K-humate	Vinasse	Average	Decrease%	Diff.	Diff
Soil Soluble Potassium mg/kg								
I_1	96	113	81	165	114	0		0
I_2	66	106	91	182	111	2		3
I_3	79	106	101	155	110	3		4
I_4	83	120	95	198	124	-9		-10
Average	81	111	92	175	115	0		0
Increase%	0	37	14	116	42	0		0
Dif.		30	11	94	34	0		0
LSD	**Irrig. = ns**	**Fert. = 25**	**Inter.=81**					
Available potassium mg/kg								
I_1	243	307	236	400	297	0		0
I_2	248	296	246	496	322	-8		-25
I_3	243	298	256	448	311	-5		-14
I_4	246	349	284	518	349	-18		-52
Average	245	313	256	465	320	-8		-23
Increase%	0	28	4	df	30	0		0
Dif.		68	11	220	0			
LSD	**Irrig. = ns**	**Fert. =65**	**inter.=91**					

I_1 =100, I_2 = 88, I_3 = 74, and I_4 = 61% of evapotranspiration. ns= not significant

D-Available K in soil

Irrigation level showed significant increase in the available potassium in the soil with reducing water level which may be due to less water saved the applied potassium unwashed. The increases were 8, 5, and 18% of available K with irrigation I2, I3, and by I4 respectively as compared with the I1, the highest water which has average of 297 ppm available K.

According to potassium application (Table 5) the available K was increased from average of 245 mg K/Kg soil to 313, 256, and 465 for the K sulfate, K-humate, and vinasse, respectively. The values mean increases percentages of 28, 4, and 89% for the three fertilizers as compared with the control. This implies that the amounts of added vinasse were too match.

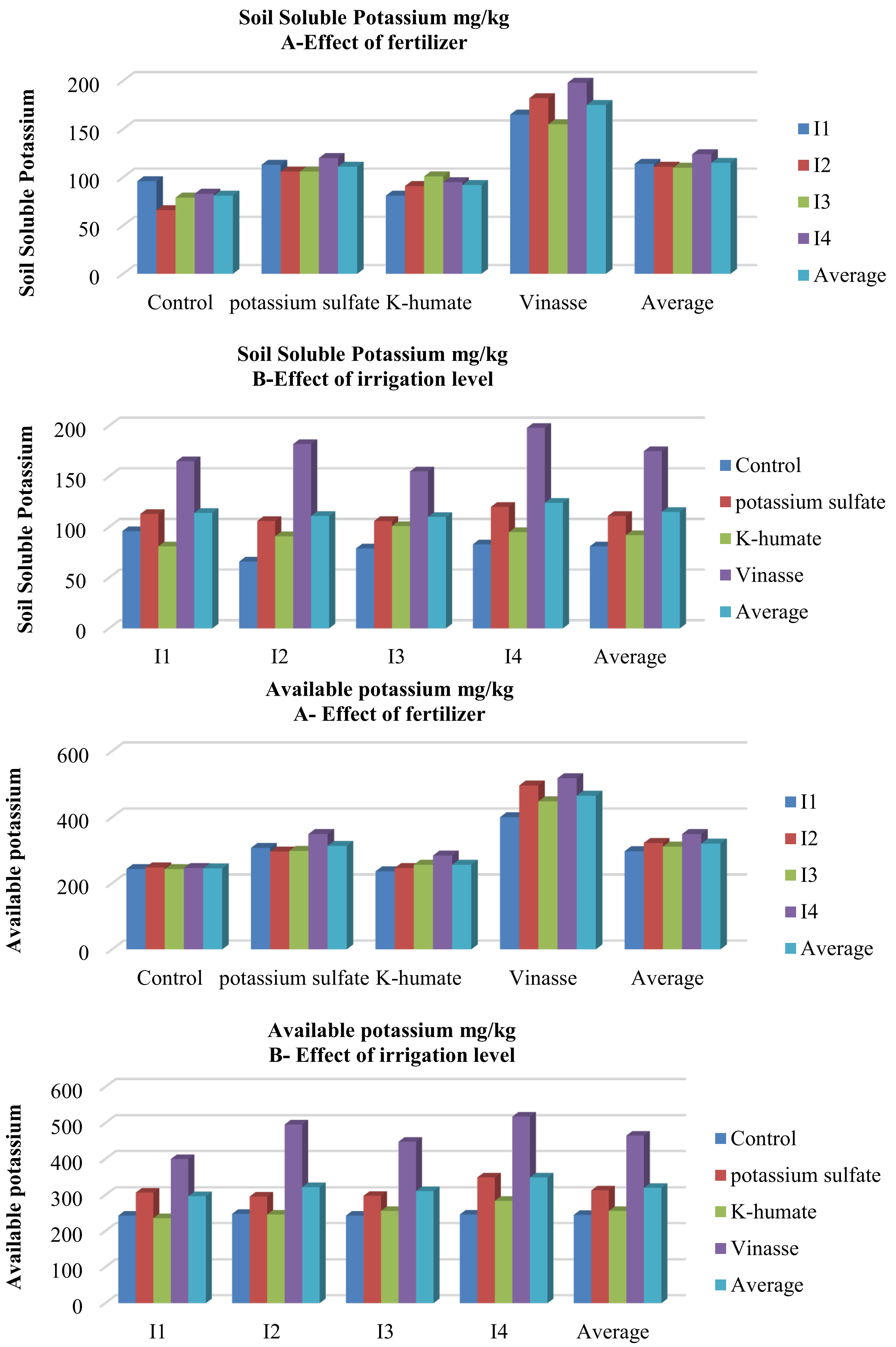


Figure 3. The changes in the soil soluble and available potassium (mg/Kg) as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels (I1 =100, I2 = 88, I3 = 74, and I4 = 61% of evapotranspiration) in Assiut.

2-Potato tuber analysis: potassium, starch, and dry matter contents

A-Potassium contents in the tubers

Potassium content in the Rosetta potato tuber (Table 6 and Figure 4) did not show steady trend with irrigation or fertilization. However, the data shows a slight increase in potassium content in tuber (9.1, 11.4, and 4.9%) with reducing irrigation water from I1 to I2, I3, and I4. That may be a misleading trend as it may be caused by less water and less K-leaching. Also, application of K-sulfate and K-humate decreased K-content, while vinasse gave 6.4% increase over the control. The application of potassium might increase the volume of tubers and caused dilution which is accounted for decrease in the K-content. Calculating uptake by total tuber yield may reflect differences.

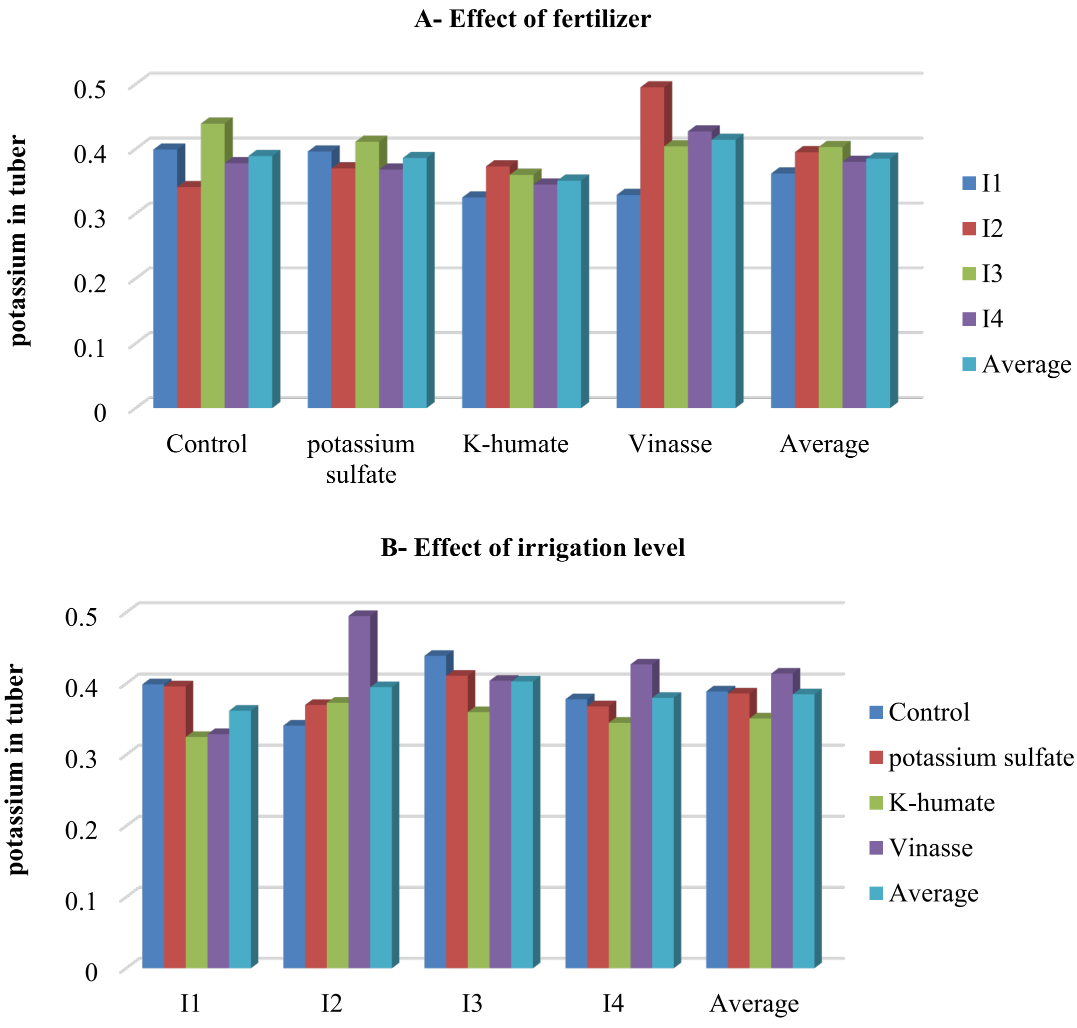


Figure 4. The changes in the potassium content in potato tubers % (Rosetta Var.) as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels (I1 =100, I2 = 88, I3 = 74, and I4 = 61% of evapotranspiration), grown in 2020 and 2021 winter seasons in Assiut governorate, Egypt.

Table 6. The changes in the potassium content in potato tubers % (Rosetta Var.) as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels, grown in 2020 and 2021 winter seasons in Assiut governorate, Egypt.

Items	Control	K_2SO_4	K-humate	Vinasse	Average	Diff. %
			%			
I_1	0.399	0.396	0.325	0.329	0.362	-
I_2	0.341	0.370	0.373	0.495	0.395	+9.144
I_3	0.439	0.411	0.360	0.404	0.403	+11.444
I_4	0.378	0.368	0.345	0.427	0.380	+4.850
Average	0.389	0.386	0.351	0.414	0.385	--
Changes%	--	-0.676	-9.836	+6.447	-	--
LSD	**Irrig. = ns**	**Fert. = ns**	**Inter.= ns**			

I_1 =100, I_2 = 88, I_3 = 74, and I_4 = 61% of evapotranspiration. ns= not significant

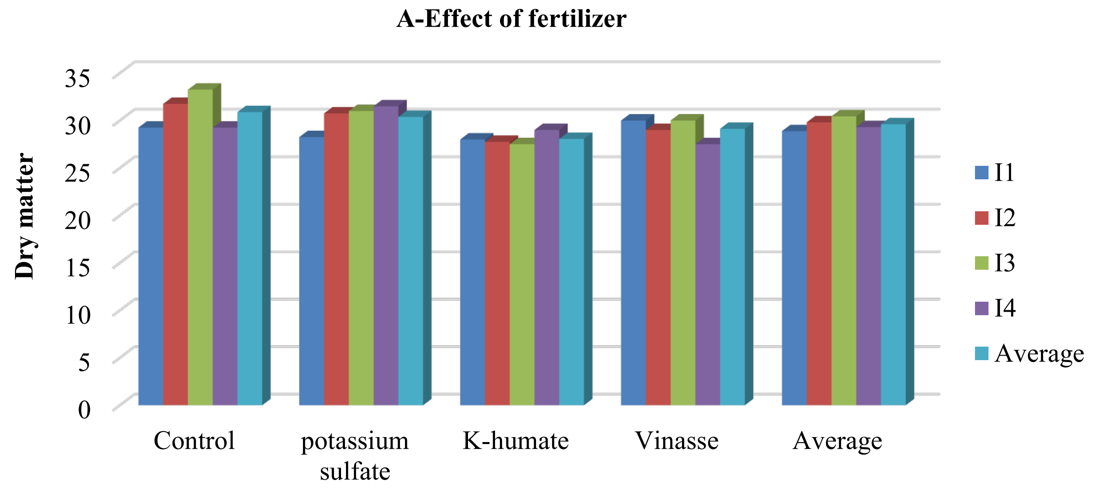
B-Dry matter of the tuber

The dry matter content in the potato tubers (Table 7 and Figure 5) did not change significantly by reducing irrigation water, since it was 28.8, 29.81, 30.44, and 29.31, which reflect slight increase in dry matter percentage by 3.25, 5.41, and 1.52 % for I2, I3, and I4 as compared to I1. That may be logical as less water will increase the dry matter. Also, application of the three forms of potassium reduced the dry matter by 1,62, 9.11, and 5.67% for K-Sulfate, K-humate, and vinasse, respectively as compared with the value of the control of 30.88% dry matter. Same explanation may be introduced as potassium increased tuber volume growth and reduced the dry matter.

Table 7. The changes in the dry matter content of the potato tubers % (Rosetta Var.) as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels, grown in 2020 and 2021 winter seasons.

Items	Control	K_2SO_4	K-humate	Vinasse	Average	Diff.%
				%		
I_1	29.25	28.25	28.00	30.00	28.88	0.00
I_2	31.75	30.75	27.75	29.00	29.81	+3.25
I_3	33.25	31.00	27.50	30.00	30.44	+5.41
I_4	29.25	31.50	29.00	27.50	29.31	+1.52
Average	30.88	30.38	28.06	29.13	29.61	-
Increase%	0.00	-1.62	-9.11	-5.67	-	-
LSD	**irrig= ns**	**Fert. =ns**	**inter.= ns**			

I_1 =100, I_2 = 88, I_3 = 74, and I_4 = 61% of evapotranspiration. ns= not significant



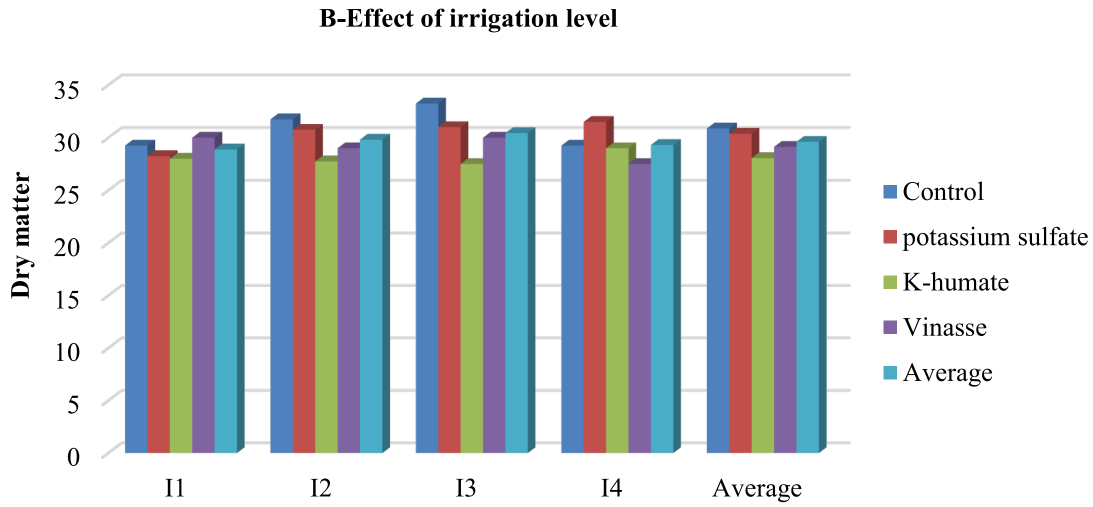
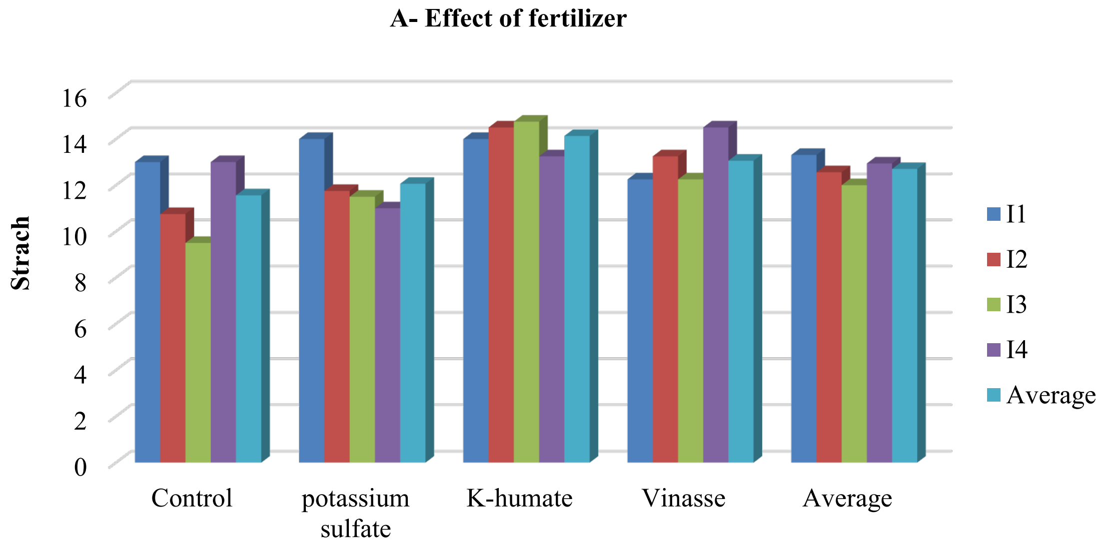


Figure 5. The changes in the dry matter content of the potato tubers % (Rosetta Var.) as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels (I1 =100, I2 = 88, I3 = 74, and I4 = 61% of evapotranspiration), grown in 2020 and 2021 winter seasons.

C-Starch in tubers

Starch in potato tuber (Table 8 and Figure 6) decreased slightly by reducing irrigation water level by 5.63, 9,86, and 2.82% for I2, I3, and I4, respectively as compared by the control I1, with value of 13.31% starch. This trend may be explained as less water applied led to less biological activity and less photosynthetic rates. However, fertilization with K-sulfate, K-humate and vinasse increased starch % by 4.35, 22.19, and 13.00 for the above fertilizers in the same order as compared with the control value of 11.50% average. The increment caused by K-humate was the highest followed by vinasse which contain many promoting organic chemicals plus K. The interactions of irrigation and fertilizer were not significant.



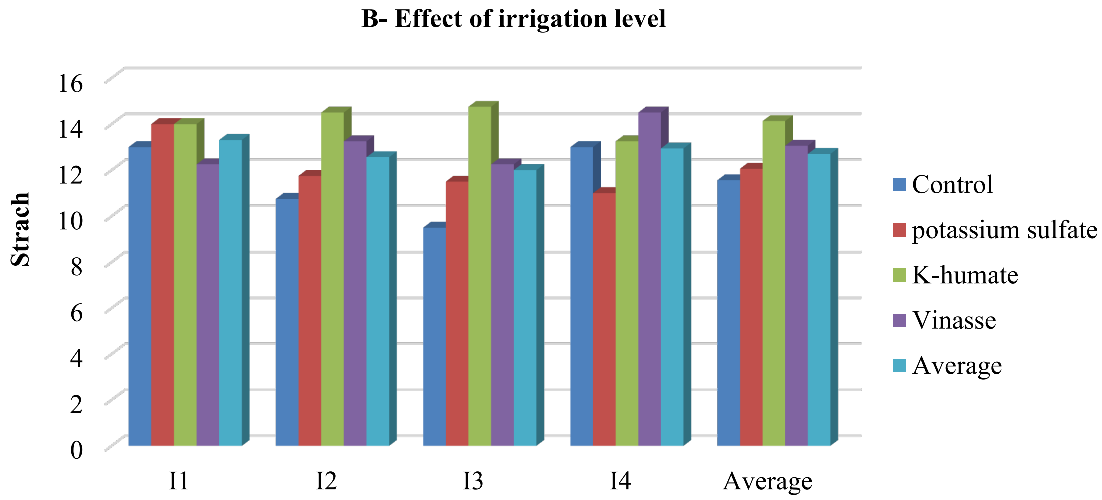


Figure 6. The changes in the Starch in the potato tubers % (Rosetta Var.) as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels (I1 =100, I2 = 88, I3 = 74, and I4 = 61% of evapotranspiration), grown in 2020 and 2021 winter seasons.

Table 8. The changes in the Starch in the potato tubers % (Rosetta Var.) as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels, grown in 2020 and 2021 winter seasons.

Items	Control	K_2SO_4	K-humate	Vinasse	Average	Decrease %
I_1	13.00	14.00	14.00	12.25	13.31	-
I_2	10.75	11.75	14.50	13.25	12.56	-5.63
I_3	9.50	11.50	14.75	12.25	12.00	-9.86
I_4	13.00	11.00	13.25	14.50	12.94	-2.82
Average	11.56	12.06	14.13	13.06	12.70	-
Changes%	-	+4.35	+22.19	+13.00	-	-
LSD	**Irrig. = ns**	**Fert. =1.4**	**inter.= ns**			

I_1 =100, I_2 = 88, I_3 = 74, and I_4 = 61% of evapotranspiration. ns= not significant

3-Effects of fertilization and drip irrigation on yield of Rosetta Potato

The data in Table 9 and Figure 7 show that the yield of potato tubers in the 1st season was reduced by reducing the irrigation from 10.163 tons from I_1 to 9.522, 8.958, and 8.050 from I_2, I_3 and I_4 a respectively that equal 6, 12, and 21% yield reduction. These differences were significant for I_3 and I_4, which means that we can reduce the irrigation water to I_2 without significant yield reduction. The effects of fertilization with potassium increased the yield by 0.153, 1.080 and 3.061 tons per feddan as compared by the control of 8.100 tons. The percentages of this increment are 2, 13, and 38%. Due to fertilization with K_2SO_4, K-humate, and vinasse respectively. The increase by K_2SO_4 was not significant while K-humate and vinasse were significant.

That could mean that the level of potassium in the soil was sufficient in the control, while, the high increases were obtained by K-humate, and vinasse are due to the organic amino acids in both.

In the second season the same trends as reducing irrigation water from I_1 to I_2, I_3 and I_4 reduced the potato tubers yield from 10.745 tons to 10.063, 8.507 and 7.803 for the I_2, I_3, and I_4, respectively. These reductions are 6.6, 20.8, and 27.4% as compared to I_1. The decreases in I_3 and I_4 were significant.

Also, the three K-fertilizations, K_2SO_4, K-humate, and vinasse increased the yield significantly by 10, 19, and 29% respectively as compared to the control which produced 8.115 tons of potato tubers. Also, the interactions between irrigation and fertilizations were significant.

The average yield of the two seasons

Same trends. The irrigation levels at I_1 and I_2 have 6.3% reduction between them which was not significant. However, I_3 and I_4 showed a reduction of 16.5 and 24.2% yield reduction as compared to I_1.

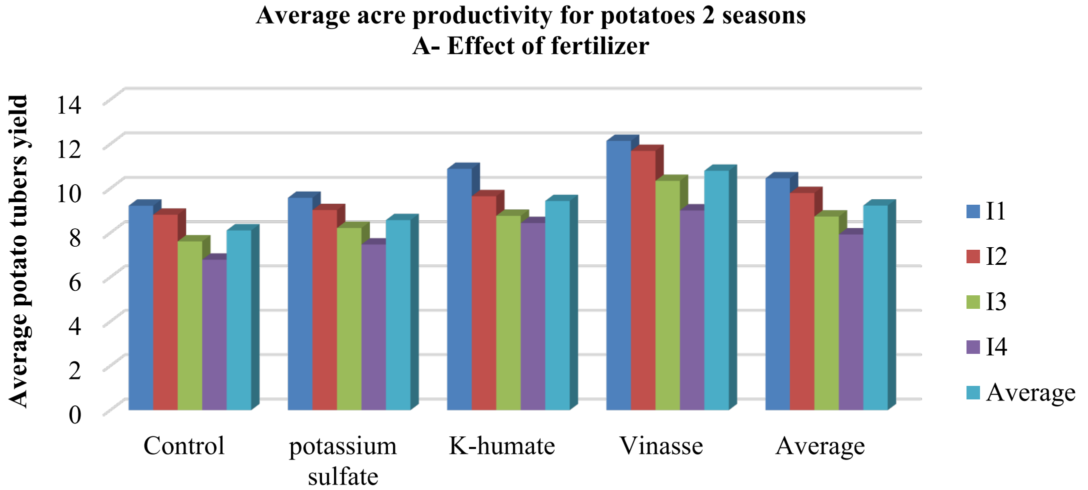
Fertilization with K_2SO_4, K-Humate, and Vinasse increased the tuber Yield From 8.108 Tons of the control to 8.572, 9.432 and 10.794 Tons by the three Fertilizer as in the above order. These increases percentage are 5.7, 16.3, and 33.1% respectively. As mentioned before, the high significant increases obtained by K-humate and Vinasse may be due to the organic amino acids in both, while K_2SO_4, is Just inorganic compound.

The interactions between irrigation and fertilization were significant either between or within each fertilization of irrigation level. Vinasse showed domination in all values. The amounts of K in K_2SO_4 or vinasse was equal, however the high significant differences might be due to the nutrient either macro or micro plus the amino and organic acids in vinasse which caused those increases.

Table 9. Potato tubers yield (ton/fed) as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels, grown in 2020 and 2021 winter seasons.

Items	Control	K_2SO_4	K-humate	Vinasse	Average	Decrease
			First season 2020/2021			
I_1	8.704	9.060	10.684	12.206	10.163 a	**0**
I_2	8.648	8.483	9.461	11.498	9.522 ab	**- 6**
I_3	8.291	8.153	8.385	11.003	8.958 b	**- 12**
I_4	6.758	7.316	8.190	9.938	8.050 c	**- 21**
Average	8.100 c	8.253 c	9.180 b	11.161a	9.173	
Increase%		2	13	38		
LSD	**Irrig. = 901**	**Fert. =920**	**inter.= 970**			
			Second season 2021/2022			
I_1	9.737	10.092	11.076	12.077	10.745 a	
I_2	8.978	9.563	9.833	11.880	10.063 b	**6.60%**
I_3	6.930	8.280	9.141	9.675	8.507 c	**20.80%**
I_4	6.818	7.633.5	8.685	8.078	7.803 d	**27.40%**
Average	8.115 d	8.892 c	9.684 b	10.427 a	9.280	
Increase%		10%	19%	29%		
LSD	**Irrig. = 701**	**Fert. =730**	**inter.= 721**			
			Average two seasons 2020-2022			
I_1	9.220	9.576	10.880	12.141	10.454 a	
I_2	8.813	9.023	9.647	11.689	9.793 a	**6.30%**
I_3	7.611	8.216	8.763	10.339	8.732 b	**16.50%**
I_4	6.788	7.475	8.438	9.008	7.927 c	**24.2**
Average	8.108 c	8.572 c	9.432 b	10.794 a	9.227	
Increase%		5.70%	16.30%	33.10%		
LSD	**Irrig. = 791**	**Fert. =830**	**inter.= 820**			

I_1 =100, I_2 = 88, I_3 = 74, and I_4 = 61% of evapotranspiration.



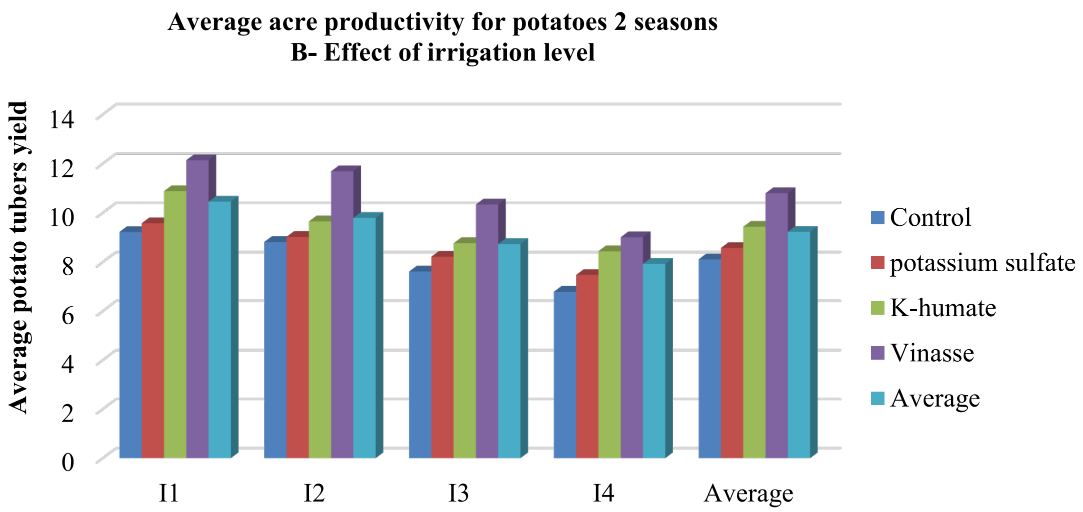


Figure 7. Potato tubers yield (ton/fed) as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels (I1 =100, I2 = 88, I3 = 74, and I4 = 61% of evapotranspiration), grown in 2020 and 2021 winter seasons.

4-Potato potassium use efficiency (KUE) and water use efficiency (WUE)

A-Potassium Use Efficiency

The data in Table 10 and Figure 8 showed that, in the first season of 2020/2021, the amount of potassium removed from the soil by potato tubers were 36.4, 38.30, 36.18, and 30,8 Kg K/Feddan with the irrigation levels I_1, I_2, I_3, and I_4 respectively. There were no significant differences among I_1, I_2 and I_3, While I_4 was reduced significantly by 15.4% That as compared by I_1.

Fertilization with vinasse removed 46.0 Kg K/ Feddan, while the control, K-sulfate and K-humate treatments extracted amount of 31.5, 31.9, and 32.1 Kg-K which were significantly lower than vinasse. The increments percentage of potassium removed by vinasse treatments were 45.92%, 44.11, and 44.67 % as compared by the control, K- sulfate, and K- humate treatments. This increase is due to the higher potato yield as it is well known that potassium increases the carbohydrate allocation.

Vinasse includes many other plant nutrients compared with the other three treatments. The interactions values also were significant. The highest KUE were from vinasse under I_2 irrigation Level with value of 56.99 Kg K / Fadden and the lowest was obtained with the control treatment under I4 irrigation with a value of 25.52 Kg K.

In the second growth season of 2021/2022 the same trends were obtained. The obtained values of KUE of I_1, I_2, I_3, and I_4 were 38.64, 40.40, 34.11, and 29.58 Kg k/Fadden. The treatments irrigation level I_1, and I_2 produced significantly higher values than I_3 and I_4 with reduction value percentages of 11.74 and 23.45% as compared by the control also I_4 was significantly lower than I_3.

Table 10. Potassium use efficiency by potato tubers (K Kg /fed) as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels, grown in 2020 and 2021 winter seasons.

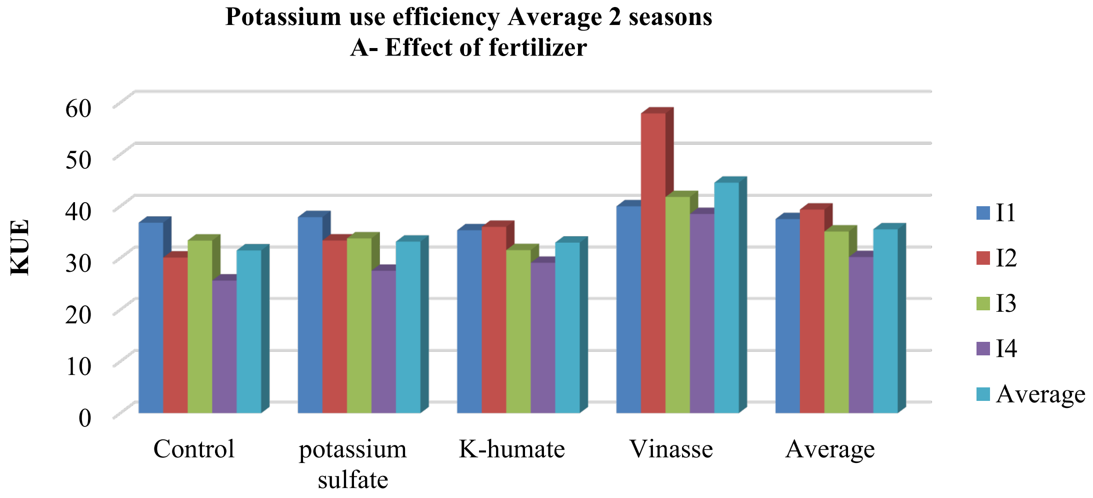
Items	Control	K_2SO_4	K-humate	Vinasse	Average	Decrease%
First season 2020/2021						
I_1	34.75	35.85	34.72	40.19	36.38 a	
I_2	29.52	31.39	35.32	56.95	38.30 a	5.28
I_3	36.36	33.53	30.17	44.46	36.13 a	-0.69
I_4	25.52	26.96	28.22	42.47	30.79 b	-15.35
Average	31.54 b	31.93 b	32.11 b	46.02 a	35.40	
Increase%		1.25	1.81	45.91		
LSD	**Irrig. = 4.3**	**Fert. =5.21**	**inter.= 4.91**			
Second season 2021/2022						
I_1	38.87	39.93	35.99	39.77	38.64 a	
I_2	30.65	35.39	36.71	58.85	40.40 a	4.55
I_3	30.39	34.05	32.89	39.1	34.11 b	-11.74
I_4	25.75	28.13	29.93	34.52	29.58 c	-23.45
Average	31.42 b	34.38 b	33.88 b	43.06 a	35.68	
Increase%		9.43	7.84	37.06		
LSD	**Irrig. = 4.11**	**Fert. =5.42**	**inter.= 5.35**			
Average 2 seasons						
I_1	36.82	37.89	35.36	39.98	37.51 a	
I_2	30.09	33.39	36.02	57.91	39.35 a	4.90
I_3	33.37	33.79	31.53	41.78	35.12 a	-6.38
I_4	25.64	27.54	29.07	38.5	30.19 b	-19.52
Average	31.47 b	33.16 b	32.97 b	44.54 a	35.54	
Increase%		5.33	4.82	41.50		
LSD	**Irrig. = 4.49**	**Fert. =5.54**	**inter.= 5.91**			

I_1 =100, I_2 = 88, I_3 = 74, and I_4 = 61% of evapotranspiration.

Fertilizing with K-Sulfate, K-humate and vinasse increased the KUE by 9.43, 7.85, and 37.06 0% as compared by the control treatment (Table:5). The results of K-sulfate and K-humate were significantly higher than the control while vinasse was significantly higher than both. Also, the interactions of fertilization and irrigation were significant with the lowest value of 25.75 Kg-KUE for the control treatment under I_4 and the highest value of 58. 86 Kg-KUE was obtained by vinasse under I_4.

The two-years average of KUE showed the same trends. Reducing irrigation water from I_1, to I_2, I_3, and I_4 caused significant reduction by 19.2% by I_4 only while the changes among I_1, I_2, and I_3 were not significant as compared with I_1.

Fertilization with K-sulfate and K-humate and vinasse increased the KUE by from 31.48 Kg k/ Fadden to 33.16, 33.00, and 44.54 respectively. Only vinasse caused significantly higher values than the control, the K- sulfite, and K-humate.



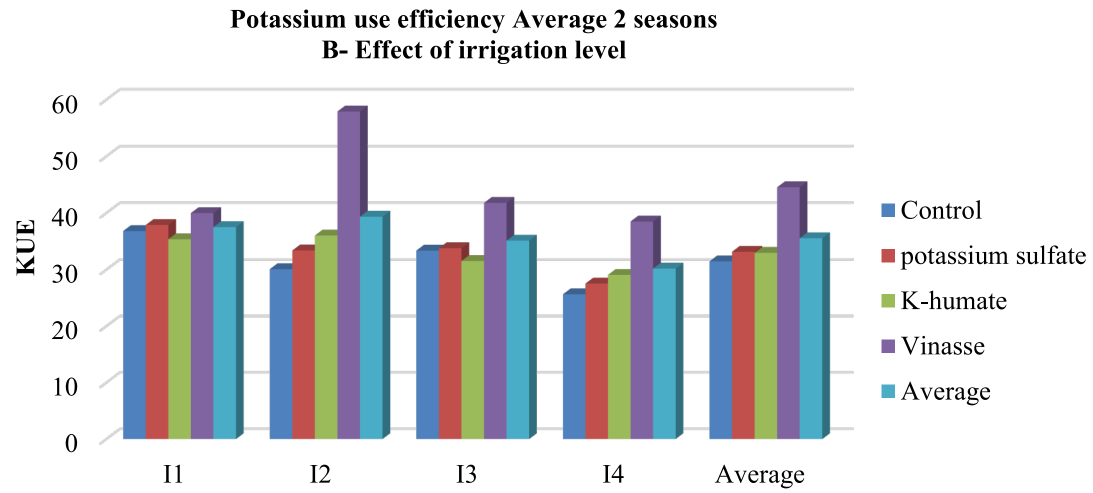


Figure 8. Potassium use efficiency season's average as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels (I1 =100, I2 = 88, I3 = 74, and I4 = 61% of evapotranspiration), grown in 2020 and 2021 winter seasons.

B-Potato water use efficiency (WUE)

The effects of the first season 2020-2021 shown in Table11 and Figure 9 showed significant increase in WUE values which were 8.76, 9.16, 10.42, and 11.34 kg/m^3 for I_1, I_2, I_3 and I_4 respectively. That means that reducing irrigation water increases WUE but reduces total yield. This needs economical study to calculate which is better. The increase in WUE values percentage were 6.86, 18.88, and 29.11 for I_2, I_3, and I_4. Fertilization with K-sulfate, K-humate, and vinasse increased the WUE from 8.77 kg tubers/m^3 of the control to 8.98, 9.74 and 12.15 when fertilized with K-sulfate, K-humate, and vinasse, respectively. These values amounted to 2.19, 13.18, and 38.26% increase. The results of K-humate were significantly higher than the control and the K-sulfate, while vinasse was significantly higher than K-humate values. The organic biochemical component in humate and vinasse showed significant effects.

Table 11. Water use efficiency (WUE) of potato tuber (Kg/m^3) as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels, grown in 2020 and 2021 winter seasons.

Items	Control	K_2SO_4	K-humate	Vinasse	Average	Decrease%
			First season 2020/2021			
I_1	7.50	7.81	9.21	10.52	8.76 c	
I_2	8.50	8.34	9.30	11.31	9.36 c	6.86
I_3	9.64	9.48	9.75	12.79	10.41 b	18.88
I_4	9.52	10.30	11.54	13.99	11.34 a	29.41
Average	8.79 c	8.98 c	9.95 b	12.15 a	9.97	
Increase%		2.19	13.18	38.25		
LSD	**Irrig. = 0.91**	**Fert. =1.12**	**inter.= 1.31**			
			Second season 2021/2022			
I_1	8.39	8.7	9.55	10.41	9.26 c	
I_2	8.83	9.40	9.67	11.68	9.89 b	6.82
I_3	8.06	9.63	10.63	11.25	9.89 b	6.78
I_4	9.60	10.75	12.23	11.38	10.99 a	18.65
Average	8.72 d	9.62 c	10.52 b	11.18 a	10.01	
Increase%		10.32	20.63	28.20		
LSD	**Irrig. = 0.61**	**Fert. =0.59**	**inter.= 0.81**			
			Average 2 seasons			
I_1	7.95	8.26	9.38	10.46	9.01 c	
I_2	8.67	8.87	9.49	11.49	9.63 bc	6.84
I_3	8.85	9.55	10.19	12.02	10.15 b	12.66
I_4	9.56	10.53	11.88	12.68	11.16 a	23.88
Average	8.76 c	9.30 c	10.23 b	11.66 a	9.98	
Increase%		6.24	16.89	33.25		
LSD	**Irrig. = 0.99**	**Fert. =0.91**	**inter.= 1.10**			

I_1 =100, I_2 = 88, I_3 = 74, and I_4 = 61% of evapotranspiration.

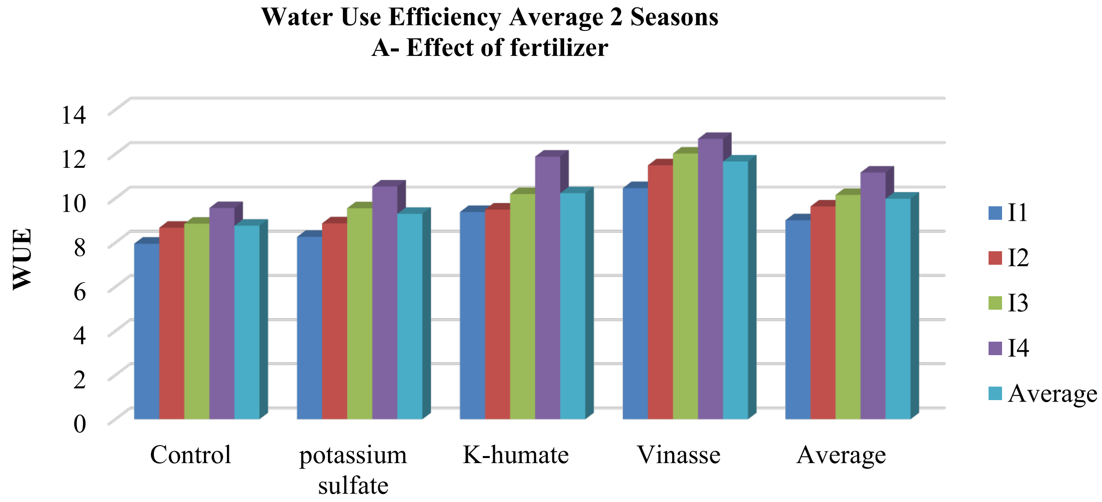
The interactions of irrigation levels with fertilizer types were significant under every irrigation level. The results of WUE in the second season were 9.263, 9.895, 9.891, and 10.991 Kg/m^3 for irrigation levels of I_1, I_2, I_3, and I_4. Increasing percentages of 6.82, 6.78, and 18.65% were obtained for I_2, I_3, and I_4 as compared with I_1.

The values of WUE increased by fertilization from 8.722 of the control to 9.620, 10.502, and 11.183 Kg/m^3 the fertilizer with K-sulfate, K-humate, and vinasse with increment percentage of 10.32, 20.63, and 28.2% in the same respect. Those increases were significant at $P <.05$.

The interactions of the two factors were significant, where the lowest values were obtained with the control of fertilization and of the highest applied irrigation (I_1). The average of WUE of the 2 years showed steady increase by reducing the applied irrigation from 9,012 of I_1, to 9.693, 10.154, and 11.165 Kg tuber/m^3 for I_2, I_3, and I_4 or steady increase of 6.843, 12.66, and 23.88%. Only I_3 and I_4 were significantly higher than I_1, and I_2.

The Average of fertilization effects of the two seasons were 8.768, 9.304, 10.233, and 11.667 kg potato tuber/m3 of water for the control, K-sulfate, K-humate, and vinasse, respectively, which means an increase of 6.242, 16.897, and 33.259 % as compared by the control. Humate and vinasse caused significant increase in WUE.

According to the interactions, the highest WUE of values were obtained with vinasse while the lowest values were obtained with the control. All values increased as irrigation water decreased. In this respect it would be recommend by using vinasse as cheap and environmentally save K-sources.



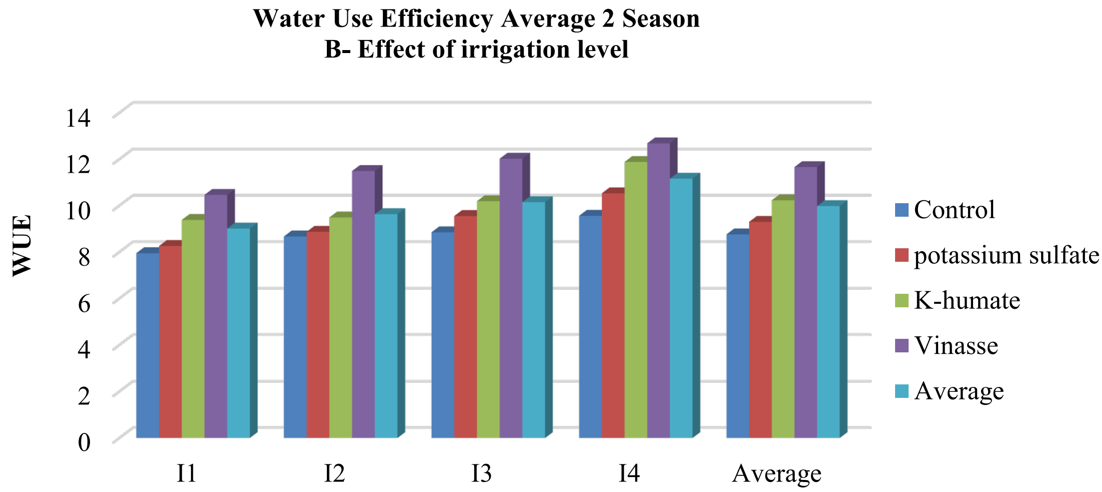


Figure 9. Water use efficiency (WUE) of potato tuber (Kg/m²) as affected by fertilization with potassium sulfate, K-humate and vinasse under four drip irrigation levels (I1 =100, I2 = 88, I3 = 74, and I4 = 61% of evapotranspiration), grown in 2020 and 2021 winter seasons.

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تأثير أنظمة الري بالتنقيط السطحي وإدارة التسميد على إنتاجية البطاطس وكفاءة استخدام المياه.

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الملخص

يعد البوتاسيوم عنصرًا أساسيًا وحيويًا لنمو النباتات، حيث إنه ينظم بشكل فعال توازن الماء داخل خلاياها. ركز هذا البحث على دراسة تأثير الأشكال البديلة للبوتاسيوم على نمو وإنتاجية نباتات البطاطس. تمت زراعة صنف البطاطس روزيتا تحت أنظمة الري السطحي بالتنقيط في المزرعة التجريبية لصرف التربة والمياه. كلية الزراعة جامعة أسيوط بمصر خلال الموسم الشتوي 2021/2020 و2022/2021 لتأثير التسميد بثلاثة مصادر مختلفة للبوتاسيوم. تم استخدام الفيناس وهو منتج عضوي ثانوي لصناعة السكر ومقارنته مع الأسمدة الكيماوية غير العضوية الباهظة الثمن مثل كبريتات البوتاسيوم وهيومات البوتاسيوم والتي تم اختبارها تحت أربعة مستويات من الماء للري السطحي بالتنقيط. تم استخدام تصميم القطع المنشقة في التجربة. تم اختبار الأسمدة الثلاثة تحت أربعة مستويات مياه للري بالتنقيط السطحي، وهي I_1 = 100% و I_2 =88 % و I_3 = 74% و I_4 = 61% من الاستهلاك المائي للمحصول.

أظهرت النتائج أن أعلى القيم المتوسطة لمحصول درنات البطاطس سجلت من أول معاملة للري(I_1) بالمقارنة مع معاملات مستويات الري الاقل الأخرى (I_2، I_3، I_4). أعطى التسميد بالمواد العضوية مثل الفيناس vinasse ويلية هيومات البوتاسيوم K-humate معدل إنتاج أعلى من كبريتات البوتاسيوم. حيث اعطي التسميد بالفيناس vinasse أعلى معدل درنات واعلي جودة مثل حجم الدرنات وعدد الدرنات والوزن الجاف وكمية النشا وكمية البوتاسيوم في الدرنات.

كما زادت خصوبة التربة مع تطبيق الفيناس مقارنة بباقي الاسمدة.

الكلمات المفتاحية: *البطاطس، التسميد بالري الموضعي، الري بالتنقيط، كفاءة استخدام البوتاسيوم، الفيناس*