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Effect of nitrogen, phosphorus, and potassium fertilization on seed and oil yield of *Jatropha curcas* L. Plants irrigated with sewage effluents

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Jatropha curcas L. is an auspicious biofuel crop with commercial plantations. Seed oils are non-edible and do not compete with food production. However, it is a semi-domesticated species with unknown yield potential and nutritional requirements. Therefore, field trials were conducted at the farm attached to the Waste Water Treatment Plant located at Abu Rawash, Giza Governorate, Egypt. The trial was for two consecutive years (2013-2014 and 2014-2015) in three years old *J. curcas* plantation. Each plant was raised in a 2×3m plot in a sandy soil. The effect of N, P, and K on seed yield, oil content, and oil yield were evaluated. The treatments were three rates of K; 0.0, 30 and 60 g K_2O/plant; four rates of P; 0.0, 50, 100 and 200 g P_2O_5/plant; and four rates of N; 0.0, 25, 50 and 100 g N/plant, using flood irrigation with sewage effluents. The treatment $K_0P_0N_{100}$ produced the highest seed yields at 2.56 T/ha and 4.05 T/ha furthermore, the seed oil yields were 0.79 and 1.19 T/ha in each season. In conclusion, applications of N fertilizer proved to be valuable for *Jatropha curcas* in Egypt.

Keywords: Biofuel; *Jatropha curcas*; NPK fertilization; Global warming; Wastewater.

INTRODUCTION

Jatropha curcas L. (*J. curcas*) is a member of the family Euphorbiaceae. It has several and well-known benefits as a crop for arid regions; such as; preventing soil erosion, reclaiming marginal lands, and providing biofuel ready oils. The plant oil cannot be consumed by either humans or other animals because it contains toxins (Makkar and Becker, 1998).The oil can be made into bio-diesel with simple procedures like trans-esterification (Tiwari et al., 2007). The seed oil content of *J. curcas* ranges from 30 - 35% (Pandey et al., 2012). Consequently, *J. curcas* can yield a higher amount of biofuel per hectare than soybean and corn and it can be cultivated in marginal soils (Fitzgerald, 2007). *J. curcas* is an equatorial shrub that has fruits with seeds inside that are rich in oil. Therefore, *J. curcas* is a strong candidate for the production of biodiesel without stress on cultivated soils with edible crops as well as water resources. *J. curcas* has the ability to grow on fringe soils (Achten et al., 2008). Consequently, it is sturdy and can be planted on poor fringe soils (Jongschaap et al., 2007). In Brazil, Europe, China, and India the predicted percentage of biodiesel used will range from 20-22% by 2020 (Kumar and Sharma, 2011). The genetic improvement of *J. curcas* will enhance its characteristics to be more tolerant of all kinds of environmental stresses, especially water and salt stress. Presently, *J. curcas* reproduces by selfing (Brittaine and Lutaladio, 2010). Currently, Egypt and the Saharan regions of Africa have a shortage of available water resources. This is due to climate change, population growth, food demands and industrial growths. Consequently, the region's governments attempt to develop a balanced water policy including the use of drainage water; the distillation of brackish and seawater; and the use of treated wastewater for irrigation. Particular targets include forests for timber; and biofuels. As nonfood applications, they avoid health hazards from sewage based farming. More than 90% of total Egyptian soil space is fringe desert soil (El-Nahrawy, 2011). As a result of limited water resources, there is a need to reclaim marginal soils. *J. curcas* cultivation in Egypt during global warming is characterized by perennial growth, higher and earlier production (Swanberg, 2009). Treated sewage effluents contain nitrogen. However, for the needs of *J. curcas* the nitrogen isn't adequate for moderate yields. Inversely, the P and K contents are sufficient (Rajaona et al., 2012). EL-Nennah et al. (1982) reported that there was a significant variation of organic matter, available P and total and soluble-N in the soil after irrigation with sewage effluents. They hypothesized this was due to accumulation during irrigation period. Furthermore, El-Khateeb et al., (2012), found increased N, P and K contents at soil depths of 30 and 60 cm because of irrigation with wastewater compared to virgin soils. *J. curcas* needs low amounts of nutrients however soil acidity will not raise more than nine (Tewari, 2007). The effect of combination between mineral fertilization and irrigation with treated wastewater as a source of nutrients on seed and oil productivity of *J. curcas* as a non-edible plant didn't be studied deeply in marginal sandy soils in Egypt. So, the new aim here is to study the impact of fertilization of macronutrients (N, P, and K) and their interactions on seed yield and seed oil content of *J. curcas* trees cultivated in desert-marginal soils of Egypt under irrigation with sewage effluents to determine the optimum fertilization level.

MATERIALS AND METHODS

Study Site:

A field study was initiated at the farm attached to Abu Rawash Waste Water Treatment Plant (Abu Rawash WWTP) located at Abu Rawash, Giza Governorate Egypt at the desert fringes northwest of Greater Cairo (30°02'36.8"N, 31°05'51.1"E); where the raw wastewater from greater Cairo is collected. So, Abu Rawash WWTP provides primary treatments for industrial and domestic waste water and it was designed to treat an average flow 400,000 m^3 day $^{-1}$ and a peak flow 600,000 $m^3 day^{-1}$. The experiment was conducted for two consecutive years (2013-2014 and 2014-2015) applied to three-year-old trees. The experimental design was a split-split plot design, with 3 replicates for each treatment. The net area of each plot was 2×3 m^2. Each contained one tree. Each treatment was replicated twice. Plant density was about 1469 trees/hectare.

Treatments:

The experimental treatments were; N fertilizer was applied as $(NH_4)_2SO_4$ (20% (w/w) N) at four rates N1, N2, N3 and N4; or 0.0, 25, 50 and 100 grams of N/tree respectively, (in other units) 0.0, 36.73, 73.45 and 146.9 kg N ha^{-1}. N fertilizer was added to soil in three equal split doses; the first was applied at the initiation of the experiment during April meanwhile, the second was applied one month after the first, and the third was applied one month after the second. P was applied as single super phosphate (15 % (w/w) P_2O_5) was applied at four rates P1, P2, P3 and P4: 0.0, 50, 100, 200 gram P_2O_5/tree respectively, (in other units) 0.0, 73.45, 146.9 and 293.8 kg P_2O_5 ha^{-1}. Each was applied in one full dose at the same time as nitrogen fertilization during March-April. K was applied as K_2SO_4 (50 % (w/w) K_2O) at three rates K1, K2 and K3; or 0.0, 30 and 60 grams of K_2O per tree; or 0.0, 44.07 and 88.14 kg K_2O ha^{-1}. Also, K was applied in three equal, but split, doses simultaneously with the three equal, but split, doses of N. BA (6-benzyladenine, a synthetic compound with cytokinin activity) was used as a chemical pruner for *J. curcas* plants. It was sprayed on each inflorescence and the surrounding leaves to run-off at 160 mg/L. Trace elements were also sprayed. The necessary management operations were conducted at the appropriate times. Surface irrigation was followed with primary treated sewage effluents. They were applied once a week. The average of added irrigation water for each season was approximately 25384 m^3 ha^{-1}.

Total treatments = 4N × 4P × 3K = 48 Treatments/year

Experimental units = 48 × 3 Replicates = 144 Units/year

Water sampling and analysis:

Samples of sewage effluents were collected immediately, before the starting of irrigation. The monthly means of the concentrations of elements were calculated. Next, the total average of each element was calculated during the growth season. The analysis of the sewage effluents used in irrigations is shown in Table 1. The Kjeldahl method was followed to estimate soluble N (Page et al., 1982). The determination of soluble P was followed by (Watanabe and Olsen, 1965). Atomic Absorption Spectrophotometer was used for analysis of micronutrients. The five days biochemical oxygen demand was expressed by the amount of missing oxygen after five days of incubation at 20° C in the dark (APHA, 1995). The Winkler procedure (azide modification) was applied to measure Dissolved Oxygen (DO) while, the dichromate oxidation method was used to estimate Chemical Oxygen Demand (COD).

Soil sampling and analysis:

At random spacing, the soil samples were brought from the depths (0-30 and 30-60 cm) from the experimental location at the initiation of the experiment (before the application of fertilizers) and from every plot (after the end of the experiment). The soil samples were dried and ground thereafter; an equal weight of each sample was taken then the equal weights of the same sample were thoroughly mixed to become the composite soil sample which passed through a 2 mm sieve then kept, to measure chemical and physical properties (Table 2). Due to Dewis and Freitas (1970), the physical and chemical characteristics of the soil were determined. Using DTPA solution, the heavy metals (Cd, Cu, Fe, Mn, Zn, Ni, and Pb) were extracted and determined by the method of (Lindsay and Norvell, 1978).

Table 1. Average composition of primary sewage effluents used in irrigation of treatments in the experiment in the first and second year.

Parameters	Primary sewage effluents		Limits of wastewater for agric. reuse*
	First year	Second year	
pH	6.99	6.85	6.50-8.40
EC(dS/m)	2.30	2.41	0.7 -3.00
Soluble cations (me/l)			
Ca^{2+}	6.20	6.80	-
Mg^{2+}	7.65	7.89	-
K^+	0.46	0.57	-
Na^+	8.70	8.87	-
Soluble anions (me/l)			
CO_3^{2-}	-	-	-
HCO_3^-	7.37	7.10	1.5-8.5
Cl^-	8.75	9.01	4-10(Surface Irrigation)
Water quality parameters			
SAR	3.31	3.27	3-9 (Surface Irrigation)
BOD_5 (mg/l)	255	270	40-500
COD (mg/l)	374	398	80-600
TDS (mg/l)	810	835	450-2000
Soluble N (ppm)	9.04	12.01	-
Soluble P (ppm)	7.75	8.35	-
The heavy metals (ppm)			
Cd	0.002	0.004	0.01
Cu	0.14	0.11	0.20
Mn	0.09	0.12	0.20
Ni	0.08	0.07	0.20
Pb	1.49	1.33	5.00
Zn	1.39	1.55	2.00
Fe	3.45	2.89	5.00

Data adopted from FAO (1992).

Table 2. Physical and chemical characteristics of the soil

Parameters		First year(Before)		First year(At the end)		Second year(At the end)	
		Depth (cm)		Depth (cm)		Depth (cm)	
		0-30	30-60	0-30	30-60	0-30	30-60
Particle size distribution	Sand %	95.20	97.70	94.90	97.10	94.70	97.30
	Silt %	2.30	0.90	2.40	1.20	2.60	1.30
	Clay %	2.50	1.40	2.70	1.70	2.70	1.40
	Soil texture	Sandy	Sandy	Sandy	Sandy	Sandy	Sandy
	pH	6.90	7.76	6.85	7.62	6.81	7.53
	EC (dS/m)	2.12	2.49	2.23	2.51	2.37	2.65
	$CaCO_3$%	2.07	2.31	2.17	2.40	2.20	2.45
	Organic matter %	0.90	0.81	1.03	0.94	1.09	0.98
Soluble cations (me/l)	Ca^{2+}	5.80	7.01	5.95	7.86	6.01	7.97
	Mg^{2+}	4.55	6.95	4.60	5.16	5.52	6.13
	K^+	1.04	0.98	1.34	1.30	1.50	1.46
	Na^+	9.81	9.94	10.36	10.78	10.71	10.97
Soluble anions (me/l)	CO_3^{2-}	0	0	0	0	0	0
	HCO_3^-	4.80	4.02	3.69	2.62	3.11	2.89
	Cl^-	9.00	10.59	10.24	11.45	11.36	11.74
	SO_4^{2-}	7.40	10.27	8.32	11.03	9.27	11.90
	Available N (ppm)	15.28	12.21				
	Available P (ppm)	28.19	26.08				
	Available K (ppm)	91.50	86.15				
Available heavy metals (ppm)	Cd	0.015	0.006	0.017	0.008	0.019	0.009
	Cu	1.91	1.23	1.76	0.98	1.24	0.81
	Mn	3.53	1.76	3.66	1.71	3.61	1.68
	Ni	0.043	0.021	0.049	0.023	0.053	0.026
	Pb	0.44	0.31	0.47	0.33	0.51	0.35
	Zn	2.73	1.22	2.81	1.38	2.88	1.46
	Fe	4.74	2.45	4.89	2.49	5.07	2.51

Plant sampling and analysis:

Irrigated *J. curcas* exhibits two main flushes of flowering (with a few interference flushes). The 1st flush starts in May and fruiting will overlap with the 2nd flush during July. Therefore, the seed yield will be the sum of the 1st and 2nd flowerings. At harvest, when the fruits became dark yellowish to brown and dry, they were picked manually. They were put in indirect sunlight to dry. The seeds were manually husked from the harvested fruits. The seeds were again dried and winnowed. The seeds dry weight was recorded and computed as kg ha^{-1}. The seeds were stored in muslin cloth bags. The seeds were ground using a 20 mesh. *J. curcas* seed oil content, protein and moisture percentages were estimated using a Near Infrared Reflectance (NIR) instrument, the portable grain analyzer, Zeltex ZX-50 (PGA; 130 Western Maryland, Hagerstown, MD. The percentage of the oil content was determined for each treatment, and the estimating of the oil yield was through this equation; the oil yield = the content of oil (% w/w) × the yield of seed (kg ha^{-1}).

Statistical analysis:

The statistical analysis of the collected data was conducted according to (Gomez and Gomez, 1984) using Least Significance Difference (LSD) to compare the means of treatments.

RESULTS

Effect of potassium, phosphorus and nitrogen fertilization and their interactions on seed yield of

J. curcas:

Potassium effect:

Fig. (1-A) shows the effect of K treatments on mean seed yield of *J. curcas* in both the first and second years. In the first year, mean seed yield decreased by increasing K fertilization. However, this decrease wasn't significant (LSD0.05= 0.18). The same trend was found in the second year (LSD0.05= 0.23). In both the 1st and 2nd years, the control treatment K1 (0 gram K_2O/ tree) gave the highest mean seed yield (1.06, 1.64 T ha^{-1} respectively) compared to K2 and K3 (0.87 and 0.82 T ha^{-1} in the 1st year and 1.41 and 1.38 T ha^{-1} in the 2nd year, respectively).

Phosphorus effect:

Fig. (1-B) shows the effect of P treatments on mean seed yield of *J. curcas* in both the first and second years. In the 1st year, mean seed yield decreased gradually by increasing P fertilization but not significantly (LSD0.05= 0.098). The same trend was observed in the 2nd year (LSD0.05=0.13). The control treatment P1 (0 gram P_2O_5/ tree) gave the highest mean seed yield in both 1st and 2nd years (1.09,1.75 T ha^{-1}respectively). In comparison, P2, P3, and P4 seed yields were lower (1.01, 0.90 and 0.67 T ha^{-1} in the 1st year and 1.67, 1.44 and 1.06 T ha^{-1}in the 2nd year, respectively).

Nitrogen effect:

Fig. (1-C) shows the effect of N treatments on the mean seed yield of *J. curcas* in both first and second years. In the 1st year, mean seed yield increased gradually and significantly due to nitrogen application up to 100 g N/tree at (LSD0.05=0.10). The same trend was observed in the 2nd year (LSD0.05=0.14). The N4 treatment (100 g N/tree) gave the highest mean seed yield in both 1st and 2nd years (1.22, 1.997 T ha^{-1} respectively). In comparison, the N3, N2, and N1 treatments produced less seed (1.06, 0.82 and 0.57 T ha^{-1}in the 1st year and 1.71, 1.30 and 0.91 T ha^{-1}in the 2nd year, respectively).

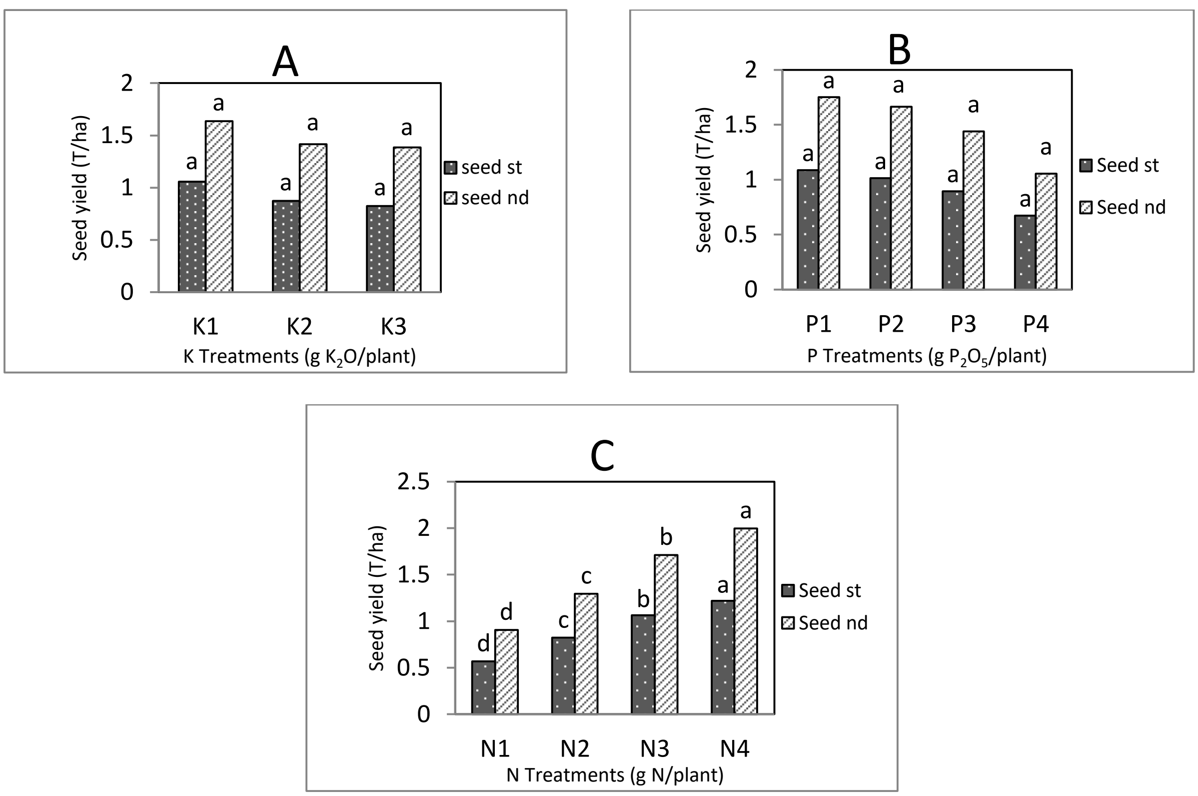

Figure 1. Effect of K treatments (A), P treatments (B) and N treatments (C) on mean seed yield of *J. curcas* in both first and second years.

Potassium and phosphorus interaction effect:

Fig. (2-A) shows the effect of the K×P interaction on the mean seed yield of *J. curcas*. The effect of the K×P interactions was significant (LSD0.05 = 0.18 for the 1st year and LSD0.05 = 0.24 for the 2nd year). In the 1st and the 2nd year, the maximum mean seed yield was obtained with the treatment of control K1P1 while the minimum was in the treatment K3P4.

Potassium and nitrogen interaction effect:

Fig. (2-B) shows the effect of K×N interaction on mean seed yield of *J. curcas* in both the first and second years. The effect of K×N interaction was significant on both of two years (LSD0.05=0.18 for the 1st year and LSD0.05= 0.24 for the 2nd year). In the 1st and the 2nd years, the maximum mean seed yield was obtained with the treatment of K1N4 while the minimum was with the control treatment K1N1.

Phosphorus and nitrogen interaction effect:

Fig. (2-C) shows the effect of P×N interaction on mean seed yield of *J. curcas*. The effect of P×N interaction was significant both years (LSD0.05 = 0.21 for the 1st year and LSD0.05 = 0.28 for the 2nd year). In both the 1st and the 2nd years, the maximum mean seed yield was obtained with the treatment of P1N4, while the minimum was in the control treatment P1N1.

Potassium, phosphorus and nitrogen interaction effect:

Data in Table (3) shows the effect of K×P×N interaction on the mean seed yield of *J. curcas*. In the 1st year, mean seed yield was significantly influenced by K×P×N interactions. The optimum treatment was K1× P1 ×N4. In this treatment, the increase in mean seed yield was about six-fold 2.56 T ha^{-1} compared to the control treatment K_1× P1 ×N1 0.40 T ha^{-1}. In the 2nd-year, the same trend was observed. However, the mean seed yield in the 2nd year was more than the 1st year 4.05 T ha^{-1} but still six-fold greater than the control treatment (K1× P1 ×N1) 0.63 T ha^{-1}.

Effect of potassium, phosphorus and nitrogen fertilization and their interactions on seed oil content (%) of *J. curcas*:

Data in Table (4) shows the effect of K, P and N fertilization and their interaction on seed oil content (%) in the 1st year and the 2nd years. Mean seed oil content increased by increasing K fertilization rates. However, this increase wasn't significant. The treatment K3 (60 gram K_2O/tree) induced the highest value (26.29 %) over both control treatments K1 (24.47 %) and K2 (25.41 %). Further, mean seed oil content increased significantly by increasing P application compared to control treatment P1, the highest value was reached at the second treatment P2 (27.09 %) which was significant with both P1 (24.44 %) and the lowest value at P4 (24.02 %) but it wasn't significant with P3 (26.00 %). Mean seed oil content increased gradually and significantly upon increased N fertilization, the highest value was achieved in the treatment N4 (27.00 %) which was significant with both N1 (23.74 %) and N2 (24.42 %), nonetheless it wasn't with N3 (26.40 %). As for the interaction effect of K×P, they were significant especially between the highest value of mean seed oil content in treatment K3P2 (30.21 %) and control K1P1 (23.47 %) and also, the lowest value in the treatment K3P4 (22.29 %). The interaction effect of K×N was significant particularly, the highest value in treatment K2N4 (31.14 %) and the lowest in K2P1 (21.02 %). Finally, the three-way interaction K×P×N was significant and the highest value was recorded in the treatment K2P4N4 (35.87 %) which wasn't significant with K1P1N4 (30.91%) and both were significant with the lowest value in the control treatment K1P1N1 (15.01%). Data in Table (4) shows the effect of potassium, phosphorous and nitrogen fertilization and their interactions. The same trend was approximately observed in the 2nd year.

Effect of potassium, phosphorus and nitrogen fertilization and their interactions onseed oil yield of *J. curcas*:

Data in Table (5) illustrates the effect of K, P and N fertilization and their interaction on seed oil yield of *J. curcas* in the 1st year and the 2nd years. As shown from these results; mean seed oil yield decreased by increasing K fertilization and this decrease wasn't significant. The control treatment K1 was the highest 0.27 T ha^{-1}. On the other hand, the control treatment P1 significantly gave the highest mean seed oil yield 0.28 T ha^{-1}. Mean seed oil yield increased gradually and significantly due to nitrogen application. The rate of N4 (100 kg N/tree) was the highest (0.34 T ha^{-1}). Two ways interactions were significant, the highest values were in K1P1 (0.39 T ha^{-1}), K1N4 (0.44 T ha^{-1}) and P1N4 (0.47 T ha^{-1}). Finally, the three-way interactions K×P×N were significant and the highest value was recorded in treatment K1P1N4 (0.79 T ha^{-1}).

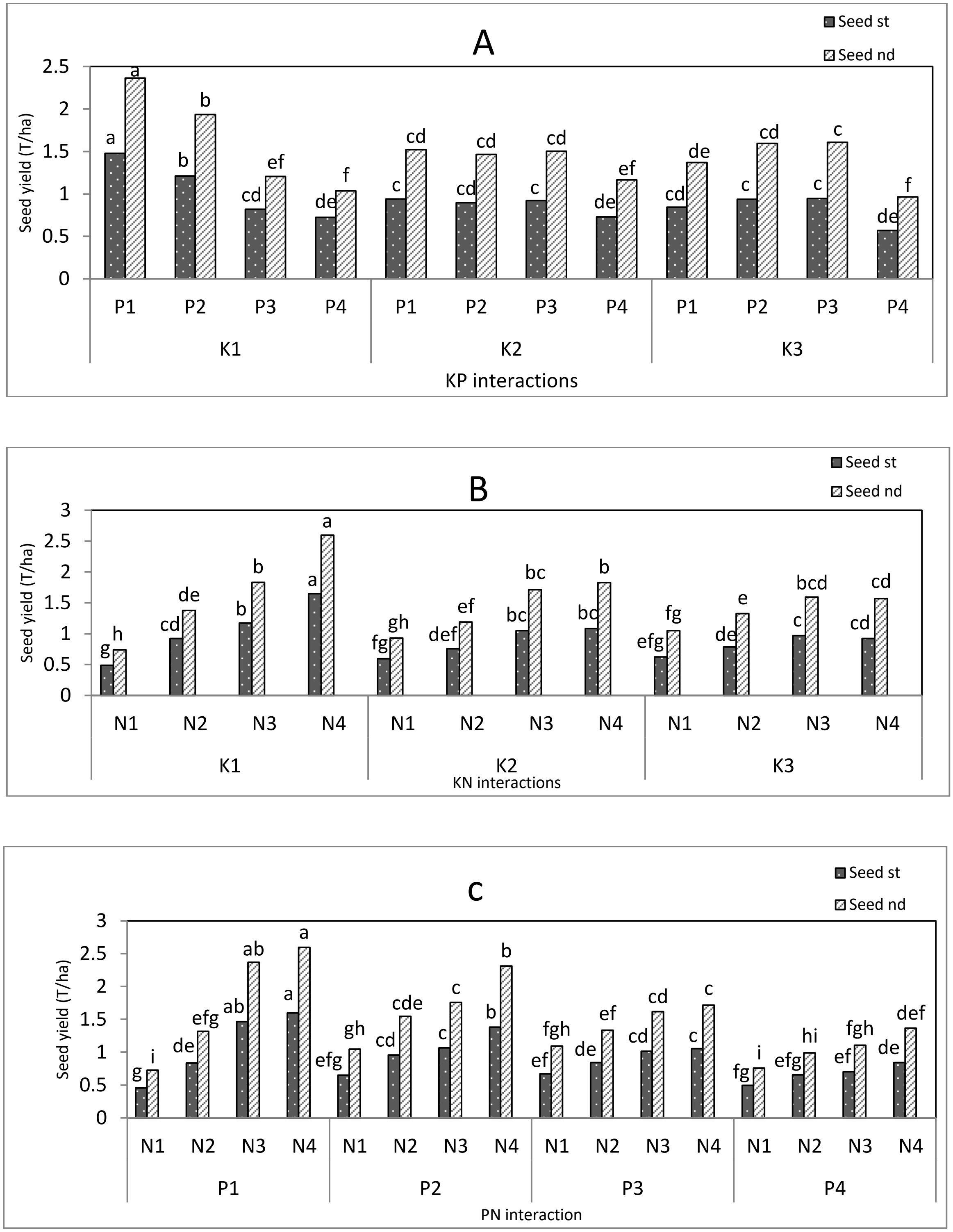

Figure 2. Effect of KP interaction (A), KN interaction (B) and PN interaction (C) on mean seed yield of*J. curcas* in both first and second years.

Table 3: Effect of K×P×N interaction on mean seed yield of *J. curcas* in both first and second years.

K rates	P rates	First year				Second year			
		Mean seed yield T/ha				Mean seed yield T/ha			
		N rates				N rates			
		N1	N2	N3	N4	N1	N2	N3	N4
K1	P1	0.40	1.10	1.85	2.56	0.63	1.77	3.01	4.05
	P2	0.53	1.18	1.19	1.94	0.80	1.85	1.91	3.18
	P3	0.54	0.70	0.86	1.17	0.82	0.95	1.28	1.77
	P4	0.49	0.70	0.79	0.92	0.71	0.93	1.12	1.39
K2	P1	0.46	0.72	1.33	1.25	0.71	1.07	2.20	2.11
	P2	0.66	0.80	1.08	1.04	1.05	1.29	1.77	1.76
	P3	0.68	0.85	1.09	1.06	1.08	1.36	1.79	1.79
	P4	0.58	0.67	0.69	0.98	0.89	1.03	1.09	1.65
K3	P1	0.51	0.68	1.21	0.97	0.84	1.11	1.90	1.63
	P2	0.76	0.89	0.93	1.16	1.30	1.50	1.59	2.00
	P3	0.79	0.98	1.10	0.92	1.38	1.69	1.78	1.58
	P4	0.42	0.59	0.63	0.62	0.68	1.01	1.11	1.06
LSD 0.05		0.36				0.48			

Table 4: Effect of K, P and N fertilization and their interactions on mean seed oil content (%) of*J. curcas* in the first year and second year.

K rates	P rates	First year				Mean of K rates	Second year				Mean of K rates
		Mean seed oil content (%)					Mean seed oil content (%)				
		N rates					N rates				
		N1	N2	N3	N4		N1	N2	N3	N4	
K1	P1	15.01	20.94	27.02	30.91	24.47	14.74	17.04	26.91	29.41	25.23
	P2	20.87	25.20	32.02	27.66		25.91	27.64	30.45	27.05	
	P3	32.54	24.31	19.02	20.07		27.82	25.04	26.34	22.24	
	P4	23.58	23.94	26.02	22.42		28.52	23.81	25.58	25.25	
K2	P1	17.37	29.94	29.00	31.49	25.41	22.25	26.92	28.19	29.97	26.56
	P2	23.21	19.29	25.82	30.17		32.71	26.60	30.12	22.26	
	P3	19.24	25.11	25.79	27.01		25.04	25.93	25.87	25.64	
	P4	24.24	16.87	26.14	35.87		22.09	22.62	24.16	37.56	
K3	P1	21.45	25.98	21.65	22.56	26.29	26.34	27.92	29.21	31.71	28.20
	P2	27.84	32.34	30.20	30.47		26.46	29.42	23.24	28.52	
	P3	33.14	30.59	27.30	27.93		26.74	30.90	31.00	28.01	
	P4	26.36	18.48	26.84	17.46		21.74	29.86	30.87	29.20	
Mean of N rates		23.74	24.42	26.40	27.00		24.78	26.14	27.66	28.07	
Mean of P rates											
P1		24.44					25.88				
P2		27.09					27.53				
P3		26.00					26.46				
P4		24.02					26.77				
LSD 0.05	K	1.94					1.49				
	P	1.98					1.02				
	N	1.92					0.92				
	K×P	3.32					1.60				
	K×N	3.32					1.60				
	P×N	3.84					1.85				
	K×P×N	6.65					3.20				

Table 5: Effect of K, P and N fertilization and their interactions on seed oil yield of *J. curcas* in the first year and second year.

K rates	P rates	First year				Mean of K rates	Second year				Mean of K rates
		Mean seed oil yield T/ha					Mean seed oil yield T/ha				
		N rates					N rates				
		N1	N2	N3	N4		N1	N2	N3	N4	
K1	P1	0.06	0.21	0.50	0.79	0.27	0.09	0.30	0.81	1.19	0.43
	P2	0.11	0.29	0.38	0.54		0.21	0.51	0.58	0.86	
	P3	0.17	0.16	0.17	0.24		0.23	0.24	0.33	0.39	
	P4	0.11	0.16	0.20	0.21		0.20	0.22	0.29	0.35	
K2	P1	0.08	0.21	0.38	0.39	0.23	0.16	0.29	0.62	0.63	0.38
	P2	0.15	0.15	0.28	0.31		0.34	0.34	0.53	0.39	
	P3	0.13	0.23	0.28	0.28		0.24	0.35	0.45	0.45	
	P4	0.14	0.11	0.18	0.35		0.20	0.24	0.26	0.62	
K3	P1	0.11	0.17	0.26	0.22	0.22	0.22	0.31	0.55	0.52	0.39
	P2	0.21	0.28	0.28	0.37		0.34	0.44	0.37	0.55	
	P3	0.26	0.30	0.30	0.26		0.37	0.52	0.55	0.44	
	P4	0.11	0.11	0.16	0.11		0.15	0.30	0.35	0.31	
Mean of N rates		0.14	0.20	0.28	0.34		0.23	0.34	0.47	0.56	
Mean of P rates											
P1		0.28					0.47				
P2		0.28					0.46				
P3		0.23					0.38				
P4		0.16					0.29				
LSD 0.05	K	0.04					0.06				
	P	0.03					0.03				
	N	0.03					0.04				
	K×P	0.05					0.06				
	K×N	0.05					0.06				
	P×N	0.06					0.07				
	K×P×N	0.11					0.13				

Data in Table (5) illustrates the effect of K, P and N fertilization and their interaction on seed oil yield of *J. curcas* in the 2nd year. Obviously, almost the same trend was attained in the 2nd year.

DISCUSSION

Effect of potassium, phosphorus and nitrogen fertilization and their interactions on seed yield and seed oil yield of *J. curcas*:

Potassium effect:

The control treatment K1 (0 gram K_2O/ tree) was superior over (K2, K3) in both seed yield and seed oil yield in the 1st and 2nd years. These results confirm the findings of Montenegro et al., (2014) with irrigation with fresh water. Further, they agree with Rajaona et al., (2012) who concluded that treated sewage effluents contain K. So, K will accumulate in the soil during the season of cultivation of *J. curcas* (El-Khateeb et al., 2012). K can filtrate or be fixed (Janssen et al., 2005). K applications Achten et al., (2008) showed that the seed and oil production will continue to increase to the optimum fertilization and then decrease. K from sewage effluents is over the optimum required K for *J. curcas* (Mandal et al., 2003).

Phosphorus effect:

The control treatment P1 (0 gram P_2O_5/ tree) gave the highest mean seed yield in both 1st and 2nd as compared to P2, P3, and P4. The same trend was followed in seed oil yield. These results are in agreement with Montenegro et al., (2014) with irrigation with fresh water while Sousa et al. (2012) studied the effect ofhigh rates of P fertilization (135 and 200 g P_2O_5 plant^{-1} year^{-1}) on *J. curcas* irrigated with different depths of wastewater and reported that the weight of the fruits was not influenced and consequently the final seed yield. Hence, accumulated P by irrigation with sewage effluents during growth season of *J. curcas* was adequate to get moderate seed yield (El-Khateeb et al., 2012). The surplus quantities will be stored in the vacuole in the plant's leaf if the rate of P is over the required optimum level for the crop (Bielski, 1973). Hence stored P in vacuole will not participate in photosynthesis process so; any excess over optimum level of P will not lead to increasing of seed yield and these results were supported by (Burton et al., 2000). Particularly, the oil crops which required high levels of P under irrigation with fresh water and this in agreement with (Harendra and Yadav, 2007).

Nitrogen effect:

The treatment of N4 (100 g N/tree) was significantly superior over (N1, N2, and N3) in both the1st and 2nd years respectively, for both seed yield and seed oil yield. The findings are also in conformity with the conclusions of (Montenegro et al., 2014). The importance of adding N applications to soil and the significant impact of N on plants (Novoa and Loomis, 1981). Particularly, N is the basic elements of the construction of both fruits and seeds (Jongschaap et al., 2007). Yong et al. (2010) showed that the increase of final total plant oil production due to high nitrogen application through the increasing of the overall number of fruits/seeds resulted per plant. Particularly, the content of available N for plants in sewage effluents is not enough to obtain a moderate yield of *J. curcas* (Rajaona et al., 2012). The type of soil in this study was sandy, which is distinguished by high loss of available N like NO_3^- by leaching with water of irrigation. This might underlie the high requirement of N by *J. curcas*. Consequently, for fertilization of N of *J. curcas* they should be added but in divided dosages (Rao et al., 2008).

Interactions:

For both the mean seed yield and mean seed oil yield, the two ways interactions were significant, the highest values were obtained in K1P1, K1N4 and P1N4 and the three-way interactions were significant and the highest value was recorded in the treatment of K1P1N4 and these outcomes are in agreement with (Rajaona et al., 2012) particularly, under irrigation with sewage effluents and (Montenegro et al., 2014) under irrigation with fresh water.

CONCLUSION

The present study demonstrated that the highest seed yield of *J. curcas* irrigated with sewage effluents in both the1st and 2nd year (2.56 and 4.05.64 T ha^{-1}) respectively, was significantly obtained with fertilizers combination of 100: 0: 0 g N: P_2O_5:K_2O /plant (146.9: 0: 0 kg N: P_2O_5 :K_2O ha^{-1}) which was over all other fertilizers combinations and recorded significantly a high seed oil content (30.91% and 29.41 %) in both the 1st and the 2nd year respectively. From previous results, it can be concluded that the three and four years old*J. curcas* shrubs as a non-edible crop responded only to the high rate of nitrogen fertilization (146.9 kg N ha^{-1}) under irrigation with sewage effluents (low quality water) and under the status of soil fertility in the marginal sandy soil in Abu-Rawash, Giza, Egypt.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

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AUTHOR CONTRIBUTIONS

All authors contributed equally in all parts of this study.

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