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Effect of Oil Crops Irrigation with Treated Wastewater and Different Irrigation Systems on Seed Yield, Quality and Water Productivity in Sandy and Clay Soils

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Abstract: Field trials were conducted in winter and summer seasons in two sites located about 20 km north east of Cairo; Clay soil (El Gabal El Asfar site) and virgin soil (El Berka site). The trials aimed to evaluate the impact of different irrigation methods of some oil crops with secondary treated wastewater on yield, quality and heavy metal content. The results clearly showed that treated wastewater supplied N with 50, 40 and 35% and P with 61, 39 and 43% and K at 223, 158 and 156% of the recommended requirements of N, P and K for soybean, sunflower and rapeseed, respectively in the clay soil while the corresponding values were 54, 61 and 79% for N; 88, 72 and 96 for P and 174, 99 and 191% for K in the virgin soil for soya bean, sunflower and rapeseed, respectively. Water requirements varied according to irrigation systems used and the mean wastewater irrigation quantities recorded were 6034 m^3 ha^{-1} and 7638 m^3 ha^{-1} for surface irrigation in in soybean and rapeseed while it was 6792 m^3 ha^{-1} for sprinkler irrigation in rapeseed and 6856 m^3 ha^{-1} for drip irrigation in sunflower. There were significant increases in seed yield, straw and biological yields due to NPK application for all oil crops used. Oil yields of rapeseed were and t ha^{-1} on virgin and fertile soils, respectively. Seed analysis indicated that the ranges of heavy metals were within the normal ranges expected and were far below levels that would be of concern due to the high pH of both sites. There were highly significant effects of fertilizers on all of the water productivity parameters of sunflower and rapeseed, with substantial increases in water productivity for seed and oil compared with those achieved with only treated wastewater. It could be concluded from this study that the yields achieved where fertilizer was applied were larger than from wastewater alone and were proportionately increased more on the infertile soil at sandy soil where nutrient demand would be greatest, indicating the importance of applying supplementary fertilizer at appropriate levels for the oil crops. Drip and sprinkler irrigation systems decreased water requirements used for oil crops and drip irrigation for sunflower and sprinkler for soybean surpassed the surface irrigation in water productivity per water unit(m^3).

Key words: Rapeseed · Soybean · Sunflower · Wastewater · Irrigation systems yields · Oil content · Heavy metals

INTRODUCTION

The secondary treated wastewater generated from Greater Cairo is about 1.85 million m^3 day^{-1} and it is estimated that the generated treated wastewater will eventually reach up to 3.5 million m^3 day^{-1} by the year 2020. From environmental point of view such quantities should be disposed off safely. Under limited water resources and drought conditions wastewater has been used to support the agricultural production in many countries such as USA, Germany, India, Kuwait, Saudi Arabia, Oman, Jordan and Tunisia [1]. Several investigators indicated the beneficial role of wastewater in increasing crop yields without or with minimal risks to the plant, soil, groundwater and health [2-7]. One of the most recognized benefits of wastewater use in agriculture is the associated decrease in pressure on freshwater sources. Thus, wastewater serves as an alternative irrigation source [8], especially for agriculture, the greatest global water user, which consumes 70% of available water TWW provides a promising, unconventional water source for irrigation in Egypt [9]. Furthermore, wastewater reuse

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increases agricultural production in regions experiencing water shortages, thus contributing to food safety [10]. Depending on the nutrients, wastewater may be a potential source of macro- (N, P and K) and micronutrients (Ca, Mg, B, Mg, Fe, Mn or Zn) [11-12]. Indeed, wastewater reuse has been proven to improve crop yield [12-13] and result in the reduced use of fertilizers in agriculture [14]. However, under Egyptian conditions many restrictions have been adopted on wastewater reuse and it is only permitted for wooden trees production. Since oil crops production is considered very important to Egypt and it needs processing before consumption, they may fit irrigation with secondary treated wastewater and benefit from the nutrient additions of wastewater. Therefore, the aim of this work is to evaluate the effect of oil crops irrigation methods with secondary treated wastewater on yield, quality, water productivity and heavy metal content. Under two types of Egyptian soils. Localised irrigation systems which include on-line drippers, micro-jets and bubblers are the most suitable for the use of treated treated wastewater for irrigation. These methods of irrigation are suitable for fruit trees and for wide spaced row crops but for field crops such as wheat and berseem, it is not practicable or economic to irrigate by these methods and the only options are to use either surface (flood) or sprinkler systems. All systems of irrigation require training and education of field staff to avoid potential health hazards involved in handling the treated treated wastewater. On sandy soils, sprinkler and drip irrigation are preferred to surface irrigation since such methods make more efficient use of water and on uneven ground, land levelling is not normally necessary. With heavier textured soils on level ground, surface irrigation is normal practice in Egypt. All all these irrigation systems are included in the trials to demonstrate and compare their respective effects on water use efficiency, crop production and the potential health and environmental hazards. Sub-surface irrigation was not included as it is not suitable for field crop production and when treated wastewater is used.

MATERIALS AND METHODS

Two field trials were carried out in winter and summer seasons of 2017 and winter 2017/18 seasons in two sites located about 20 km north east of Cairo; Gabal El Asfar farm (fertile soil) and El Berka site (sandy soil). The trials aimed to evaluate the impact of oil crops irrigation methods with secondary treated wastewater on yield, quality, water productivity and heavy metal content. The area of each trial the was 2.5 feddans (1.1 hectars) close to the new Gabal El- Asfar wastewater treatment plant and the soil could be classified as loomy sand soil. The same area was chosen in the second site and located inside El-Berka wastewater treatment plant, the soil is gravelly sand and could be classified as virgin soil (Table 1). The physical and chemical analysis of each soils presented in Table (1).

This work was carried out in two sites using all the facilities installed by the project "Cairo East Bank Wastewater Re-use Study", the client is the Cairo Wastewater Organuzation (CWO) and the study is partially funded by the Kuwait Fund for Arab Economic Development (KFAED). After completing the study the facilities (irrigation networks, equipment) were used in this study. Both experimental sites were cultivated using fixed tine-harrow, then leveling was carried out. The experiment was arranged as factorial where the the first factor (A) was irrigation systems and factor (B) was oil crops and factor (C) was fertilizer application unites according to the crop and the irrigation method. The design of each trial implemented where half of the experimental units received treated wastewater only and the other half received wastewater plus supplementary fertilizer to be adjusted for each crop according to the normal recommended and for each site conditions. In clay soil site, surface irrigation were used to irrgate soybean and canola while in virgin soil site sprinkler irrigation was used for canola seed and soybean while drip irrigation was employeed for sunflower in clay and sandy soils.

Sprinkler irrigation was carried out using a metal impact sprinkler 3/4" male with a discharge of 1.170 $m^3 h^{-1}$, wetted radius of 13.5m, working pressure of 300 KPa and irrigation intensity of 8.10 mmh^{-1}. The irrigation system’s control unit had a two sand filters 3" inlet/outlet diameterand screen filter 200 mesh, a flow-meter and a pressure regulated valve were installed at the head of the irrigation system to measure the applied water and to control the system pressure. After the filtration system the solid set sprinkler irrigation system had 27 laterals 60m long installed in the allocated area for sprinkler irrigation. The drip irrigation network included (1) Control head: It is located at the water source supply. It consists of centrifugal pump 4`` /4``, driven by diesel engine (pump QRM charge of 100 $m^3 h^{-1}$ and 50 m lift), sand media filter 48`` (two tanks), screen filter 2`` (120 mesh) back flow prevention device, pressure regulator, pressure gauges, flow-meter, control (2) Main line: PVC pipes of 125 mm in diameter (OD) to convey the water from the source to the main control points in the field.

Table 1: Physical characteristics of soil at clay and sandy soil sites (Means to 30 cm depth)

Value	Gravel (%)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture class	WHC (%)	Particle density (g/cm^3)	SBD (g cm^{-3})
Clay soil									
Mean	0	58.9	22.5	7.9	10.6	Loamy Sand	40.6	2.38	1.37
Min.	0	34.1	12.3	1.9	4.0		28.6	1.81	1.25
Max.	0	75.1	33.7	14.6	18.2		56.9	2.70	1.52
CV%	-	18.4	33.3	47.2	34.9		17.7	10.70	5.80
Sandy soil									
Mean	28.9	67.2	23.2	5.6	4.0	Gravelly Sand	28.5	2.56	1.56
Min.	1.7	46.9	7.0	2.0	2.0		20.8	2.36	1.41
Max.	58.3	83.1	34.4	17.3	8.1		35.8	2.65	1.67
CV%	-	15.5	39.5	67.8	46.0		14.8	2.90	4.90

Table 1 (Continued): General chemical quality of soil at clay and sandy soil sites (Means to 30 cm depth)

Value	PH	EC (dS/m)	HCO_3 (meq/l)	OM (%)	CEC (meq/ 100g)	NO_3 (mg/kg)	N (mg/kg)	P (mg/kg)	K (mg/kg)
Clay soil									
Mean	6.87	0.27	0.74	4.29	34.5	106	2826	1737	1996
Min.	6.34	0.17	0.40	0.47	12.8	52	1120	812	1200
Max.	7.26	0.38	1.25	7.54	64.9	290	4480	2602	3080
CV%	3.70	22.5	39.6	46.30	47.0	59	40	30	26
Sandy soil									
Mean	8.16	0.79	0.98	0.79	13.4	24	901	229	1506
Min.	7.69	0.21	0.65	0.19	5.5	5	140	92	900
Max.	8.69	2.40	1.35	1.13	25.8	125	2100	343	2350
CV%	3.10	81.10	20.3	37.9	42.8	124	60	33	29

(3) Sub-main lines: PVC pipes of 75 mm diameter (OD) were connected to with the main line through a control unit consists of a 2`` ball valve and pressure gauges. (4) Manifold lines: PVC pipes of 40 mm in diameter (OD) were connected to the sub main line through control valves 1.5``. (5) Emitters: These emitters Built in (GR) dripper from Polyethylene (PE) tubes 16 mm in diameter (OD) and 50 m in long (emitter QRM charge of 4 lph at 1.0 bar operating pressure, 0.3 m spacing between emitters, 1.0 m spacing between lateral lines.

Rapeseed seeds (Pactol variety) were grown soybean (Giza 82) variety was planted under surface and drip irrigation in sandy and clay soils, respectively while and sunflower (Giza) was grown under drip irrigation. The irrigation water was measured by water meter for each plot. Fertilizers were applied according to the normal recommended rates in Egypt. Nitrogen, phosphorus and potassium were applied as ammonium nitrate (33.5% N), calcium super phosphate (15.5% P_2O_5) and potassium sulphate (48% K_2O), respectively. Samples of treated wastewater from clay soil and sandy soil were taken during crop cycle and analysed for a range of agronomic parameters. Nutrient and heavy metal loading rates to field trials were calculated according to the irrigation quantities applied to each crop. Treated wastewaters were analyzed according to [15]. Crop yields were determined, seed, nutrient and heavy metal content were determined by [16-17].

Oil Yield: Oil yield (kg fed^{-1}) was calculated by seed yield (kg fed^{-1}) × seed oil content (%). Seed oil %: was determined by Soxhlet apparatus using petroleum ether (40°C - 60°C b.p) according to [16].

Water Productivity of Oil Crops Seed: $Wp_{sunflower}$ seed, $WP_{rapeseed}$ seed and $WP_{soybean}$ seed are indicators of effectiveness use of irrigation treated waste water for crop production. Water productivity seed was calculated according to [18] as follows: $WP_{sunflower,\ rapeseed\ ,\ soybean}$ seed = Ey/Ir

where: WP sunflower seed is the water productivity of crop seed (kg seed m^{-3} irrigation water), Ey is the economical yield (kg sunflower seed fed^{-1}) and Ir is the amount of applied irrigation water (m^{-3} irrigation water fed^{-1} season^{-1}).

Statistical Analysis: The data were subjected to statistical analysis of variance of split plot design was carried out using MSTAT-C Computer Software [19].

Since the trend was similar in both seasons the homogeneity test Bartlet's equation was applied and the combined analysis of the two seasons was done. Means were compared by using least significant difference (LSD) at 5%.

RESULTS

It is worthy to mention that including the sprinkler irrigation was done according to the guidelines by WHO and all the precautions for preventing exposing of the workers to the irrigation practice were done. Also, since all of the treated wastewaters used for the field trials pass through sand filters prior to irrigation, there is unlikely to be any hazard to the field workers. The aim of including sprinkler irrigation was to compare all irrigation systems and to give an idea about its effect when the advanced treatment (tertiary treatment is applied. Data presented in Table (2) present wastewater qualities applied to oil crops in both sites, all of these parameters are well within the maximum limit values set by the Egyptian Decree 44/2000 for wastewater reuse (Table 2). The amounts of wastewater irrigated to each crop and fertilizer treatment at both sites were recorded accurately (Tables A1, A2, B1 and B2, Appendices). Mean wastewater irrigation quantities 6034 m^3 ha^{-1} and 7638 m^3 ha^{-1} for surface irrigation in in soybean and rapeseed while it was 6792 m^3 ha^{-1} for sprinkler irrigation in rapeseed and 6856 m^3 ha^{-1} for drip irrigation in sunflower (Table 3). The quantities of wastewater applied were broadly in line with normal farmer practice in the district. Calculating the major nutrients (NPK) supplied by wastewater as percentage of the fertilizer recommended rates indicated that treated wastewater supplied N at 50, 40 and 35 % and P 61, 39 and 43% and K 223, 158 and 156 % of the recommended requirements of N, P and K for soybean, sunflower and rapeseed, respectively in the clay soil (Gabal El Asfar site) while the corresponding values were 54, 61 and 79% for N, 88, 72 and 96 for P and 174, 99 and 191% for K in the virgin soil (El Berka site) for soybean, sunflower and rapeseed, respectively (Table 4).

Table 2: Chemical analyses of wastewater irrigated in the experimental sites

		mg l^{-1}													
Parameters	pH	Tot. N	Tot. P	K	B	Fe	Mn	Cr	Ni	Zn	Cu	Cd	Pb	Co	Mo
Clay soil	7.83	9.7	2.6	19.0	0.34	0.362	0.113	0.021	0.025	0.162	0.043	<0.005	0.069	<0.01	0.01
Sandy soil	7.78	12.8	3.4	13.6	0.4	0.577	0.115	0.027	0.039	0.094	0.049	<0.005	0.079	<0.01	<0.005

Table 3: Quantities of wastewater irrigated according to crop type and treatment.

		Fertilizer ha^{-1} (m^3)		
Crop	Irrigation method	None	Applied	Mean
Soybean	Surface	5273	6794	6034
Sunflower	Drip	6790	6922	6856
Rapeseed	Surface	8143	7133	7638
Rapeseed	Sprinkler	7322	6262	6792

Table 4: Proportion of nutrients supplied by wastewaters to oil crops compared with generally recommended rates of fertilizer

	Fertilizer recommended (kg/ha)			Addition in wastewater (kg/ha)			Nutrients supplied by wastewater as % of fertilizer		
Crop	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Fertile soil (Clay soil)									
Soybean	108	54.0	57.6	54.2	33.1	128.2	50	61	223
Sunflower	108	74.4	57.6	43.4	26.6	102.7	40	36	178
Rapeseed	108	54.0	57.6	38.2	23.3	90.0	35	43	156
Desert soil (Sandy soil)									
Soybean	144	54.0	57.6	77.5	47.3	100.3	54	88	174
Sunflower	144	74.4	115.2	88.1	53.8	114.0	61	72	99
Rapeseed	108	54.0	57.6	85.0	51.8	109.9	79	96	191

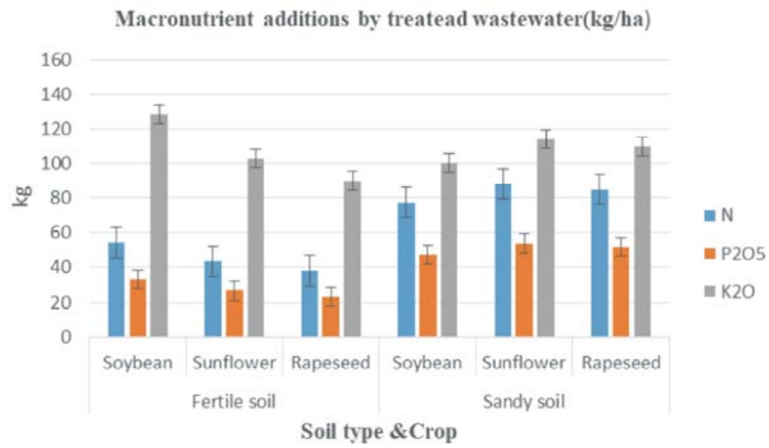

Fig. 1: Nutrients supplied by treated wastewater to oil crops in fertile and sandy soils

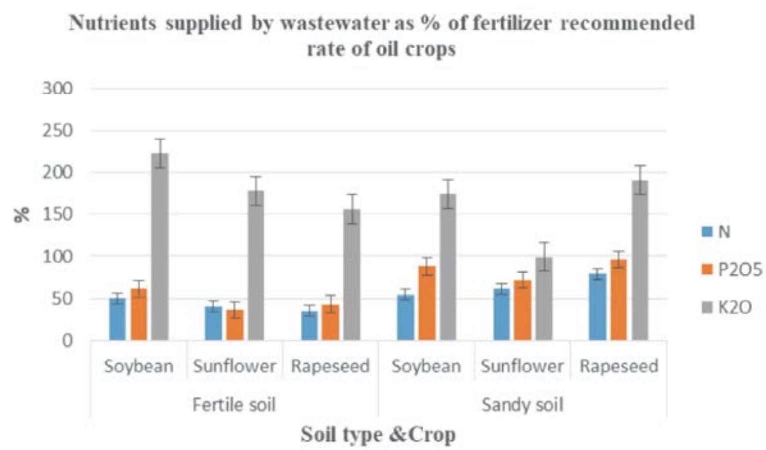

Fig. 2: Nutrients supplied by treated wastewater to oil crops in fertile and sandy soils as % fertilizer recommended rate

Highly significant increases in all of yield parameters of soybean characters were achieved by the addition of fertilizer over those achieved by the treated wastewater on its own (Table 5). Clearly, the treated wastewater alone provided insufficient nutrients since fertilizer increased the measured parameters by about 150%. Seed yield increased from 4.14 t ha^{-1} to 6.63 t ha^{-1} and both yields were favourably higher than the national average yield of 2.64 t ha^{-1}, considering the poor quality of this soil. Straw yield also increased substantially with the addition of fertilizer but the seed, straw ratio was slightly smaller, indicating that optimum yield had not been reached. The oil content was significantly greater with fertilizer addition under clay or sandy soil conditions and the increase under sandy soil was more pronounced.

Data presented in Table (5) indicate that there were highly significant effects of fertilizers on all of the yield parameters of sunflower, with substantial increases in seed and straw yields, compared with those achieved with only treated wastewater. The addition of fertilizer increased seed yield by 29% for both seeds and oil under clay soil conditions and the corresponding values under sandy soil was were 67%, this may be attributed in part to the nutrient supply from Sandy soil wastewater which closely met with recommended amounts of fertilizer for this crop. The oil contents were 1.72 and 2.22 under clay soil while it reached 1.81 and 3.03 t ha^{-1} without and with fertilizer addition, respectively.

Data presented in Table (5) indicate that fertilizer increased rapeseed yields (seeds, straw and biological) significantly only at clay soil. The data also show that rapeseed production under surface irrigation was greater than sprinkler irrigation. The oil content of rapeseed seed at sandy soil was slightly larger (39.5%) than at clay soil (38.2%), giving an oil production of 0.750 t ha^{-1} compared with 5.30 t ha^{-1} surface irrigation in Sandy and clay soils, respectively.

Table 5: Yields components of oil crops (t ha^{-1}) irrigated with secondary treated wastewater

	Crop					
	Soybean		Sunflower		Rapeseed	
	Clay soil					
	Surface		Drip		Surface	
Yield component	No F	With F	No F	With F	No F	With F
Seed	4.14 b	6.62 a	5.13 b	6.62 a	11.75 b	13.82 a
Straw	18.55 b	24.31 a	18.89 a	17.35 b	45.73 b	50.40 a
Biological	22.69 b	31.30 a	24.02 a	23.98 a	57.49 b	64.22 a
Oil	0.82 b	1.30 a	1.72 b	2.22 a	4.49 b	5.53 a

	Sandy soil							
	Sprinkler		Drip		Surface		Sprinkler	
Yield component	No F	With F	No F	With F	No F	With F	No F	With F
Seed	0.84 b	2.11 a	5.41 b	9.04 a	1.38 a	1.90 a	1.04 a	1.21 a
Straw	3.60 b	8.42 a	26.83 b	64.72 a	15.61 a	15.21 a	8.64 b	14.52 a
Biological	4.42 b	10.54 a	32.25 b	73.76 a	16.99 a	17.11 a	9.68 b	15.73 a
Oil	0.40 b	0.99 a	1.81 b	3.03 a	0.55 a	0.75 a	0.41 a	0.48 a

Note: Numbers in each column followed by different letters are significantly different at P<0.05 between pairs of fertilizer treatments (No F and With F) within each irrigation treatment, crop and site

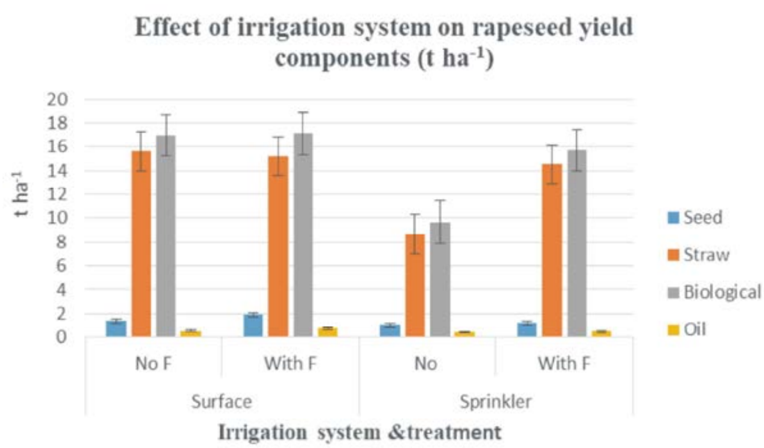

Fig. 3: Effect of irrigation system and fertilizer treatment on rapeseed yield components (t ha^{-1})

Highly significant increases in all of water productivity of soybean were achieved by the addition of fertilizer over those achieved by the treated wastewater alone (Table 6). In clay soil, the treated wastewater alone provided insufficient nutrients since fertilizer increased the measured water productivity by about 24 and 22% for WP_{seeds} and WP_{oil}, respectively. Under sandy soil conditions water productivity increased from 193 and 194 % for WP_{seeds} and WP_{oil}, respectively achieving 0.337 and 0.159 kg m^{-3} for WP_{seeds} and WP_{oil}, respectively considering the poor quality of this soil. Straw water productivity also increased substantially with the addition of fertilizer but the seed, straw water productivity ratio was slightly smaller, indicating that optimum water productivity had not been reached.

Data presented in Tables (6a, b) indicate that there were highly significant effects of fertilizers on all of the water productivity parameters of sunflower, with substantial increases in water productivity for seed and oil compared with those achieved with only treated wastewater. The addition of fertilizer increased water productivity of seeds and oil (WP_{seeds} and Wp_{oil})

Table 6a: Water productivity kg m^{-3} in clay soil

	Crop					
	Soybean		Sunflower		Rapeseed	
	Surface		Drip		Surface	
Yield component	No F	With F	No F	With F	No F	With F
Seed	0.785	0.975 (124)*	0.755	0.957 (127)	1.443	1.938
Straw	3.517	3.578 (101)	2.782	2.507 (-9)	5.616	7.066
Biological	4.302	4.606 (109)	3.538	3.464 (-3)	7.059	9.004
Oil	0.156	0.191 (122)	0.253	0.321 (127)	0.551	0.775

Table 6b: Water productivity kg m^{-3} in sandy soil

	Crop							
	Soybean		Sunflower		Rapeseed			
	Sprinkler		Drip		Surface		Sprinkler	
Yield component	No F	With F	No F	With F	No F	With F	No F	With F
Seed	0.115	0.337 (293)	0.797	1.332 (167)	0.170	0.267 (157)	0.142	0.193 (136)
Straw	0.492	1.345 (273)	3.952	9.532 (241)	1.917	2.132 (111)	1.180	2.318 (196)
Biological	0.603	1.683 (279)	4.750	10.864 (229)	2.087	2.398 (15)	1.322	2.511 (190)
Oil	0.054	0.159 (294)	0.267	0.446 (167)	0.067	0.105 (172)	0.056	0.076 (136)

*values between brackets refer to % of the non-fertilized treatment

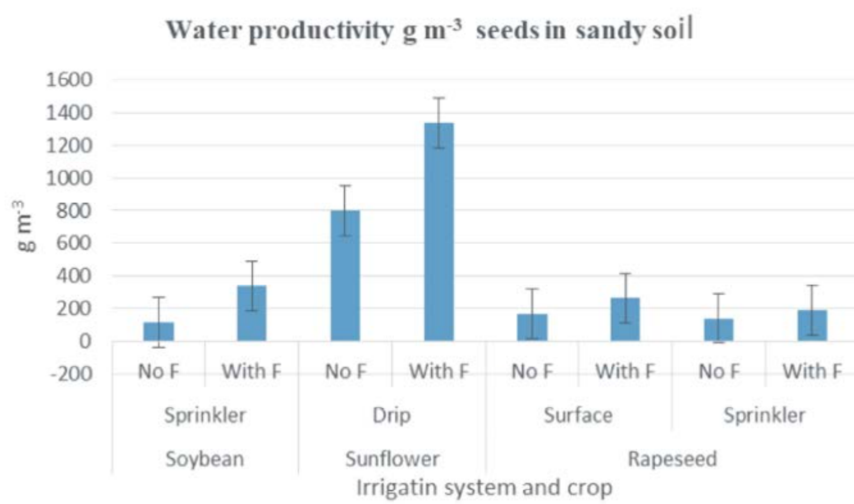

Fig. 4: Effect of irrigation system and oil crop on water productivity of seeds (g m^{-3}) in fertile soil

by 27% and 67% under both clay and sandy soils, respectively, but decreased straw water productivity by 9%. This may be attributed in part to the nutrient supply from Sandy soil wastewater which closely met with recommended amounts of fertilizer for this crop.

Data presented in Table (6a) indicate that fertilizer increased rapeseed water productivity of (seeds, straw and biological) significantly only at clay soil. The data also show that rapeseed water productivity for seeds under surface irrigation was greater than sprinkler irrigation. The oil content of rapeseed seed at Sandy soil was slightly larger (39.5%) than at Clay soil (38.2%), giving an oil water production of kg m^{-3} compared with kg m^{-3} at each site under surface irrigation in El Berka soil and El Gabal Al Asfar, respectively.

As demonstrated above, treated wastewater supplies only a proportion of the nitrogen and phosphorus requirements of the crop, but generally adequate levels of potassium. The crop yield responses showed conclusively that additional fertilizer is necessary to achieve reasonable crop growth response and economic yields. Chemical analysis of the economic components of

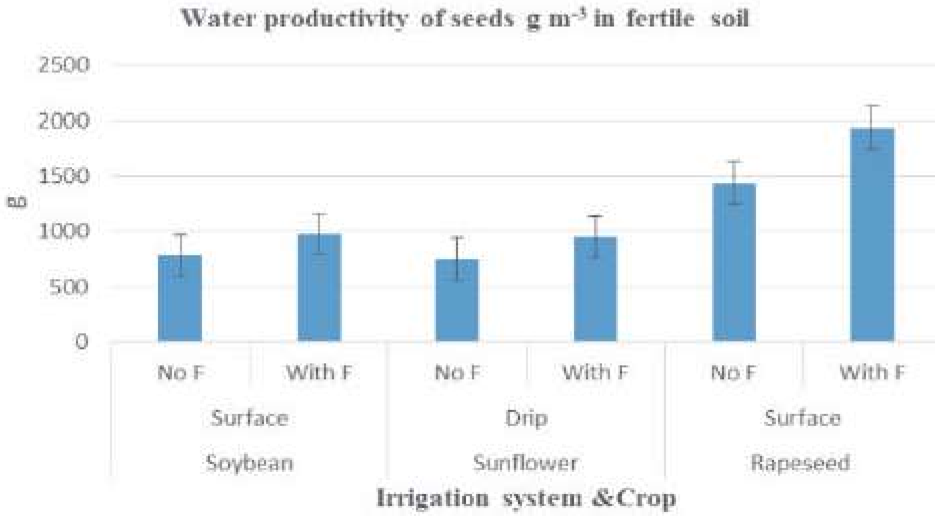

Fig. 5: Effect of irrigation system and oil crop on water productivity of seeds (g m^{-3}) in fertile soil

Table 7: Nutrient concentrations in oil crops under treated wastewater irrigation, with and without added fertilizer, at clay soil and sandy soil (% DM)

Crop	Site	Fertilizer	N	P	K
Soybean seed	Clay soil	- F	4.02	0.52	2.02
		+ F	4.08	0.52	2.29
	Sandy soil	- F	4.83	0.40	1.68
		+ F	4.73	0.38	1.88
Sunflower seed	Clay soil	- F	2.35	0.30	1.23
		+ F	2.20	0.28	1.13
	Sandy soil	- F	2.72	0.21	1.60
		+ F	2.35	0.18	1.08
Rapeseed seed	Clay soil	- F	4.31	0.53	0.94
		+ F	3.83	0.6	0.96
	Sandy soil	- F	4.01	0.31	0.81
		+ F	4.22	0.47	0.82

Table 8: Mean concentrations of heavy metals (ppm) in summer and winter crops at clay soil and sandy soil

Crop	Soil type	Zn	Cu	Cr	Cd	Pb	Ni
Soybean	Clay soil	61.4	5.40	1.04	0.07	0.22	1.26
	Sandy soil	64.7	13.74	1.82	0.24	0.14	0.11
Sunflower	Clay soil	53.6	6.69	0.44	0.06	0.36	0.74
	Sandy soil	36.6	8.22	0.94	0.07	0.20	0.17
Rapeseed	Clay soil	32.5	3.71	0.23	0.03	0.74	0.16
	Sandy soil	45.3	4.24	0.18	0.02	2.29	0.22

Note: Figures in bold for each element indicates the greater of pairs of mean concentrations for each crop

the crops demonstrated that nutrient content did not necessarily increase with fertilizer addition and in many instances decreased (see summaries in Table (7), although few effects achieved statistical significance. However, this is explained by the fact that crop growth and yields were increased by the addition of fertilizer compared with wastewater alone, often substantially depending on the crop and site and this in effect diluted tissue concentrations.

The economic components of the crops grown during the field trials were analysed for heavy metal content. There were only a few occasions where there statistically significant differences in concentrations in crops irrigated by treated wastewater alone and those that had received additional fertilizer, but in general the trend was for smaller concentrations in the fertilised crops due to the dilution effect of greater growth with the additional nutrients. Crop off-take of heavy metals would be much greater from these treatments despite the smaller crop concentration. There were no consistent effects on crop quality resulting from the differing soil concentrations of heavy metals on the two sites. This is demonstrated by Table (7) where the mean concentrations of the principal heavy metals in the crops grown at Clay soil are compared with those from sandy soil and where the greater of the comparable pairs of concentrations occurred at similar frequencies between the two sites. Table (8) provides an even more condensed summary showing that there are only very small differences in overall crop quality between the sites.

DISCUSSION

The obtained results show that crop irrigation with wastewater provides a useful contribution to crop nutrient needs, these are applied uniformly throughout the growing period of the crop, whereas fertilizer (specifically nitrogen) is applied deliberately in targeted split applications according to the changing crop requirements during the growing cycle.

Irrigation with wastewater alone, particularly low fertility soils, results in poor early crop growth due to nutrient deficiency and normal levels of fertilizer should be applied during the early growth stages crops. Therefore, the yields achieved where fertilizer was applied were larger than from wastewater alone and were proportionately increased more on the infertile soil at sandy soil where nutrient demand would be greatest, although yields overall were generally much smaller than at clay soil. Soybean seed and straw yields were approximately 50% greater at clay soil overall, but as this crop responded well to the addition of fertilizer at Sandy soil, the yield advantage under this treatment was much reduced compared with the responses to treated wastewater on its own.

Sunflower yields were larger on sandy soil compared with clay soil. With treated wastewater alone, seed yield at clay soil was similar to sandy soil, but the addition of fertilizer resulted in a greater response at sandy soil. Consequently, the combination of sandy soil and wastewater would apparently suit sunflower growth more than at clay soil.

These results show that treated wastewater alone cannot provide adequate quantities of nutrients to achieve optimum crop yields. This is most pronounced on the infertile soil of Sandy soil where additional fertilizer is essential to achieve reasonable yields. On the fertile soil of clay soil, this is less crucial although the addition of fertilizer still provided useful yield increases.

The addition of fertilizer consistently increased the yields of all crops (Table 5) at both sites compared with those from treated wastewater alone. At clay soil, fertilizer increased total crop yields by 44% on average, whereas at sandy soil, the increase due to fertilizer was on average 81 %. This reflects the relative fertility of the two sites: a larger response to fertilizer would be expected from the poor soil at Sandy soil compared with the relatively fertile conditions at clay soil. Also, recommended rates of fertilizer were applied at sandy soil, whereas rates were adjusted at clay soil to account for the assumed greater soil fertility. Comparisons of crop yields between the sites show some interesting effects. Surprisingly, when fertilizer was applied, the overall mean seed yield of all crops at Sandy soil was slightly larger than at clay soil, although straw yields were larger at clay soil. Without fertilizer, there was no overall difference between the sites for seed yield but straw yield was much greater on clay soil. These results indicate that whilst clay soil is more fertile than sandy soil, near normal rates of fertilizer would be advised to achieve satisfactory yields.

Chemical analysis of crops provides an indication of the quality of the crop in terms of its agronomic nutritional status and its dietary quality for human and animal consumption. Crop growth and quality is controlled principally by soil quality (physical and chemical) and nutrient supply, in addition to an adequate amount of water. The interactions between these factors are complex and this is illustrated by the comparison of the crop qualities from these trials conducted under contrasting soil conditions. As demonstrated above, treated treated wastewater supplies only a proportion of the nitrogen and phosphorus requirements of the crop, but generally adequate levels of potassium. The crop yield responses showed conclusively that additional fertilizer is necessary to achieve reasonable crop growth response and economic yields. Chemical analysis of the economic components of the crops demonstrated that nutrient content did not necessarily increase with fertilizer addition and in many instances decreased (see summaries in Table 7), although few effects achieved statistical significance. However, this is explained by the fact that crop growth and yields were increased by the addition of fertilizer compared with wastewater alone, often substantially depending on the crop and site and this in effect diluted tissue concentrations. These results demonstrate the importance of applying supplementary fertilizer at appropriate levels for the crop and soil and emphasize that the nutrients naturally present in wastewater which allow savings on fertilizer expenses to be realized [20, 21, 8, 13]. The advantage of field crop irrigation with treated wastewater is evident from agronomic and economic scene. Several investigators assured that the nutrients naturally present in wastewater allow savings on fertilizer expenses to be realized [20, 8].

Also, Liu and Haynes [22] and Barreto *et al*., [8] indicated that depending on the nutrients, wastewater may be a potential source of macro- (N, P and K) and micronutrients (Ca, Mg, B, Mg, Fe, Mn or Zn).

The key conclusion from these data is that plant tissue concentrations of nutrients and heavy metals are within the normally expected ranges for these crops. For all heavy metals (Table 8), plant tissue concentrations were very small compared with toxic thresholds and consequently there are no environmental, health or crop quality implications. For some essential trace elements, particularly copper, concentrations were close to the deficiency thresholds at both sites.

The small concentrations of heavy metals in the seeds were expected and attributed to the high pH of the Egyptian soil which make the heavy metals are not readily bioavailable for crop uptake and do not represent a threat to the quality of the crops grown on this for human or animal consumption [23]. These results clearly reflect minimum pollution in the short and long terms and indicate the suitability of Cairo wastewater for reuse on the agricultural land. Similar results were obtained by Mahmoud *et al*. [24] in Jordan and WRc [23], Ministry of Water Resources and Irrigation [25] in Egypt. Rapeseed is a relatively new crop in Egypt and so its yield characteristics are not yet fully evaluated under local conditions, but these results show clearly that rapeseed is unsuited to infertile soil but can respond well to wastewater when grown on fertile soil [21, 13]. Finally, wastewater reuse has been proven to improve crop yield Jimenez [12] and Moscoso [13] and result in the reduced use of fertilizers in agriculture [14].

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Appendicises:

Table A1: Quantity of treated wastewater irrigated to soya bean at clay soil.

Block B1 (2200 m^2)			Block B2 (2800 m^2)			Block B3 (2800 m^2)			Block B4 (2200 m^2)		
Surface irrigation, not fertilized			Drip irrigation, not fertilized			Surface irrigation, fertilized			Surface irrigation, fertilized		
Date	Duration (h.)	Quantity (m^3)	Date	Duration (h.)	Quantity (m^3)	Date	Duration (h.)	Quantity (m^3)	Date	Duration (h.)	Quantity (m^3)
3/6	2.55	53.1	6/6	7.10	221.8	5/6	5.35	198.1	3/6	1.50	71.2
7/6	1.10	23.2	7/6	2.45	37.1	15/6	5.45	172.0	4/6	1.00	20.1
17/6	5.25	227.8	13/6	2.05	90.3	2/7	3.30	39.8	14/6	3.00	153.3
27/6	2.50	54.7	18/6	4.35	119.2	5/7	3.10	92.0	18/6	1.05	97.5
4/7	1.55	28.0	27/6	1.00	36.2	10/7	2.45	175.5	1/7	3.40	143.7
13/7	2.00	64.3	4/7	2.45	73.7	14/7	2.00	76.2	5/7	2.30	47.0
17/7	3.00	110.8	6/7	2.00	145.0	19/7	2.00	78.2	13/7	2.00	64.3
22/7	3.00	126.2	14/7	2.00	76.1	22/7	3.00	126.6	19/7	2.30	97.8
24/7	2.00	36.2	19/7	2.30	97.8	26/7	2.30	124.4	24/7	3.00	107.1
29/7	2.30	140.0	23/7	2.00	38.2	1/8	3.00	96.2	29/7	1.30	60.3
3/8	4.00	87.4	26/7	3.00	103.2	7/8	2.00	84.1	3/8	1.30	67.2
10/8	2.00	84.9	1/8	2.30	97.0	10/8	2.00	84.3	10/8	2.00	87.0
13/8	2.00	81.0	7/8	2.00	87.6	13/8	3.00	82.6	21/8	2.00	56.2
21/8	2.00	56.7	10/8	2.00	85.6	22/8	2.00	71.0	3/9	2.00	71.0
28/8	2.00	71.0	21/8	2.00	89.0	3/9	2.00	71.0			
12/9	3.00	106.5	28/8	2.30	89.0						
			10/9	2.00	71.0						

Table A2: Quantity of treated wastewater irrigated to sunflower at clay soil

Block B1(2800 m^2)			Block B2 (2200 m^2)			Block B3 (2800 m^2)			Block B4 (2200 m^2)		
Surface irrigation, not fertilized			Drip irrigation, not fertilized			Drip irrigation, fertilized			Drip irrigation, fertilized		
Date	Duration (h.)	Quantity (m^3)	Date	Duration (h.)	Quantity (m^3)	Date	Duration (h.)	Quantity (m^3)	Date	Duration (h.)	Quantity (m^3)
11/7	1.30	83.0	26/6	1.55	36.5	11/7	1.30	82.5	10/7	2.00	63.1
18/7	1.00	27.1	5/7	4.50	99.5	18/7	1.50	42.1	11/7	3.15	109.3
31/7	1.00	35.5	8/7	1.30	71.5	25/7	1.00	35.0	18/7	1.00	27.1
8/8	1.00	35.5	9/7	2.00	46.8	31/7	4.00	142.0	31/7	2.00	67.0
12/8	1.00	35.5	16/7	1.50	73.7	6/8	1.00	35.5	5/8	3.10	112.1

17/8	1.30	52.8	25/7	2.00	71.0	8/8	1.00	35.5	9/8	1.30	53.3
24/8	1.10	49.7	6/8	1.00	71.0	14/8	3.00	105.0	14/8	1.00	35.5
30/8	1.30	52.8	8/8	1.05	42.6	20/8	2.00	71.0	19/8	2.00	71.3
2/9	2.00	71.5	12/8	1.30	35.5	24/8	2.00	71.0	23/8	1.00	35.5
4/9	1.00	35.5	17/8	1.30	52.8	26/8	1.30	52.8	27/8	2.00	71.0
7/9	2.00	71.5	24/8	2.00	71.0	27/8	2.00	71.0	30/8	1.30	52.8
9/9	1.30	52.8	26/8	2.00	71.0	30/ 8	1.30	52.8	2/9	2.00	41.0
11/9	2.00	71.0	27/8	2.00	71.0	2/9	1.00	35.5	4/9	1.00	35.5
13/9	2.00	71.0	2/9	1.00	35.5	4/9	1.00	35.5	7/9	2.00	71.0
16/9	2.00	71.0				7/9	2.00	71.0	9/9	2.00	71.0
18/9	2.00	71.0				11/9	12.00	71.0	12/9	2.00	71.0
20/9	1.00	71.0				13/9	2.30	71.0	16/9	1.00	35.5
23/9	1.15	44.5				16/9	1.00	35.5	18/9	1.30	88.3
26/9	1.30	52.8				18/9	1.30	52.8	23/9	3.00	71.0
						23/9	2.00	71.0	26/9	1.30	52.8
						26/9	1.30	52.8			

Table B1: Quantity of treated wastewater irrigated to Soya Bean at Sandy soil.

Blocks B1 + B2				Blocks B3 + B4			
Sprinkler irrigation, not fertilized				Sprinkler irrigation, fertilized			
Block	Date	Duration (h.)	Quantity (m^3)	Block	Date	Duration (h.)	Quantity (m^3)
B2	8/6	0.30	13.9	B4	6/6	1.50	60.4
B1	12/6	1.20	40.9	B4	7/6	1.25	42.7
B2	13/6	0.55	65.2	B3	7/6	1.00	33.5
B2	17/6	0.10	10.8	B3	10/6	4.35	36.4
B2	18/6	1.00	30.3	B4	11/6	2.50	65.0
B1	19/6	1.10	49.7	B3	12/6	1.55	53.6
B2	21/6	1.56	59.5	B4	14/6	1.00	42.7
B1	22/6	2.22	100.0	B3	17/6	0.20	12.7
B1	26/6	0.33	32.6	B4	20/6	2.00	81.1
B2	26/6	1.42	55.2	B3	20/6	1.05	47.0
B2	29/6	0.42	29.2	B4	24/6	1.51	76.0
B1	1/7	1.20	58.0	B4	2/7	1.30	62.0
B1+B2	4/7	1.00	46.0	B3	3/7	2.12	70.0
B1+B2	7/7	1.28	64.4	B3+B4	5/7	2.36	93.4
B1+B2	15/7	1.05	43.2	B3+B4	8/7	2.05	75.0
B1+B2	17/7	1.20	61.2	B3+B4	12/7	2.40	127.2
B1+B2	23/7	1.30	61.4	B3+B4	16/7	1.51	76.7
B1+B2	26/7	3.02	100.6	B3	25/7	2.20	66.8
B1+B2	1/8	1.52	27.9	B4	18/7	0.12	8.0
B1	8/8	0.45	14.4	B3+B4	19/7	2.15	99.3
B1+B2	20/8	2.00	91.0	B3+B4	23/7	0.50	39.2
B1+B2	24/8	3.00	91.1	B3+B4	25/7	3.45	117.4
B1+B2	10/8	0.43	54.0	B3+B4	30/7	2.39	117.6
B1+B2	27/8	2.00	62.4	B3+B4	3/7	1.45	40.3
B1+B2	17/8	1.03	32.2	B3+B4	6/8	1.20	55.6
B1+B2	30/8	2.00	74.9	B3+B4	9/8	0.23	9.2
B1+B2	3/9	2.15	89.6	B3+B4		1.15	57.8
B1+B2	18/9	1.55	56.9	B3+B4		0.05	4.2
B1+B2	6/9	1.50	76.5	B3+B4	21/8	2.35	109.0
B1+B2	23/9	1.0	40.1	B4	26/8	0.30	26.0
B1+B2	10/9	3.40	90.8	B3	10/8	0.30	18.2
B1+B2	14/9	1.16	45.5	B3+B4	27/8	1.50	59.2

Table B1: Quantity of treated wastewater irrigated to Soya Bean at Sandy soil (continued)

Blocks B3 + B4			
Sprinkler irrigation, fertilized			
Block	Date	Duration (hours)	Quantity (m^3)
B3+B4	12/8	1.20	53.0
B3+B4	13/8	4.06	91.2
B3	19/8	0.51	42.2
B3+B4	17/8	1.15	36.7
B3+B4	29/8	2.05	65.4
B3+B4	2/9	2.20	71.6
B3+B4	5/9	2.35	74.0
B3+B4	21/9	1.00	28.9
B3+B4	9/9	3.30	81.7
B3+B4	11/9	2.05	72.0
B3+B4	14/9	1.16	45.5
B3+B4	16/9	1.55	62.4
B3+B4	19/9	2.05	62.2
B3+B4	26/9	2.10	58.4
B3			1322.4
B4			1405.9

Table B2: Quantity of treated wastewater irrigated to Sunflower at Sandy soil.

Blocks B2 + B8				Blocks B9 + B16			
Drip irrigation, not fertilized				Drip irrigation, fertilized			
Block	Date	Duration (hours)	Quantity (m^3)	Block	Date	Duration (hours)	Quantity (m^3)
B8	29/6	0.23	14.6	B9+B16	21/6	7.30	181.4
B2+B8	3/7	1.00	34.0	B16	25/6/200	1.10	33.4
B2+B8	4/7	1.40	80.8	B9+B16	26/6	1.04	28.5
B2	5/7	1.18	46.7	B9+B16	28/6	1.18	56.2
B2+B8	7/7	2.04	94.4	B9+B16	1/7	1.00	41.2
B2+B8	9/7	1.49	78.8	B9	4/7	0.50	40.4
B2+B8	12/7	1.40	93.7	B9+B16	5/7	1.18	46.7
B2+B8	16/7	2.05	91.6	B9+B16	6/7	0.45	35.0
B2+B8	19/7	1.30	80.3	B9+B16	8/7	0.30	24.8
B2+B8	22/7	2.04	43.8	B9+B16	8/7	0.35	30.7
B2+B8	24/7	1.27	53.3	B9+B16	10/7	2.15	94.8
B2+B8	26/7	0.48	20.3	B9+B16	12/7	1.10	60.4
B2+B8	26/7	2.30	83.3	B9+B16	15/7	0.45	32.8
B2+B8	30/7	1.23	57.2	B9+B16	17/7	3.00	114.3
B2+B8	1/8	2.55	129.4	B9+B16	19/7	1.00	46.0
B2+B8	3/8	0.48	25.4	B9+B16	20/7	0.27	20.6
B2+B8	6/8	1.23	55.0	B9+B16	22/7	2.53	82.3
B2+B8	7/8	0.33	17.7	B9+B16	23/7	1.00	38.5
B2+B8	24/8	0.30	18.4	B9+B16	25/7	3.19	121.2
B2+B8	24/8	1.00	24.0	B9+B16	29/7	2.44	128.9
B2+B8	9/8	0.40	18.9	B9+B16	31/7	2.22	94.0
B2	20/8	0.40	27.7	B9	2/8	0.52	33.0
B2+B8	20/8	0.30	20.3	B16	3/8	1.19	36.0
B2+B8	10/8	1.00	25.5	B16	6/8	0.58	27.2
B2+B8	27/8	2.00	60.0	B9+B16	7/8	1.35	56.4
B2+B8	13/8	0.24	13.6	B9	8/8	2.37	89.1
B2+B8	13/8	0.40	37.2	B9+B16	12/8	2.05	84.5
B2+B8	19/8	0.15	6.2	B9+B16	15/8	0.25	11.7
B2+B8	30/8	0.30	17.0	B9+B16	19/8	0.40	29.4
B8	30/8	2.08	66.4	B9	19/8	0.25	21.1
B2+B8	3/9	1.03	36.4	B9+B16	21/8	1.10	42.8
B2+B8	3/9	1.10	44.8	B9+B16	26/8	3.04	95.3
B2+B8	5/9	2.20	82.0	B9+B16	27/8	0.20	10.0

Table B2: Quantity of treated wastewater irrigated to Sunflower at Sandy soil (continued).

Blocks B2 + B8				Blocks B9 + B16			
Drip irrigation, not fertilized				Drip irrigation, fertilized			
Block	Date	Duration (hours)	Quantity (m^3)	Block	Date	Duration (hours)	Quantity (m^3)
B2+B8	18/9	2.15	78.7	B9+B16	23/8	2.50	54.8
B2	6/9	1.20	47.5	B9+B16	29/8	2.00	65.4
B2+B8	23/9	2.25	92.9	B9+B16	31/8	2.50	99.7
B2+B8	10/9	3.20	114.5	B9+B16	2/9	1.45	70.6
B2+B8	14/9	1.16	45.5	B16	4/9	0.18	13.0
B2+B8	16/9	3.00	96.1	B9+B16	5/9	2.10	69.0
B2+B8	16/9	1.40	56.6	B16	7/9	0.30	27.0
B2+B8	26/9	0.38	19.8	B9+B16	8/9	3.00	78.4
B2+B8	26/9	.00	22.2	B9+B16	8/9	4.00	104.6
B2+B8	28/9	1.45	80.8	B9+B16	11/9	3.50	121.7
B2+B8	30/9	0.45	24.5	B9+B16	13/9	1.20	40.2
				B16	14/9	0.38	23.0
				B9+B16	16/9	1.40	56.5
				B9+B16	19/9	1.10	31.6