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ECONOMIC BENEFITS FROM IRRIGATION OF MAIZE WITH TREATED EFFLUENT OF WASTE STABILIZATION PONDS

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Abstract

Shortage of fresh water is worldwide, particularly in the tropics. Treated wastewater can be utilized in arid regions not only as irrigation water but also as a liquid fertilizer. This investigation examines the applicability of waste stabilization pond (WSP) technology to obtain safe irrigation water and also determines the influence of treated wastewater on the growth parameters of maize. Irrigation with wastewater that contained sufficient quantities of N (21.02 mg/l), P (3.49 mg/l) and K (6.66 mg/l) significantly increased plant height, fresh and dry weight of leaves, leaf area as well as crop yield. The advantages of the use of treated wastewater as irrigation water and liquid fertilizer are presented and discussed.

Introduction

Fresh water scarcity is becoming an increasingly acute problem primarily in arid and semi arid regions of the world. Treated wastewater is being used in many countries throughout the world as a reliable source of water which can fulfill the gap between supply and demand in water sector (Oron *et al*., 2007). Advancements in the effectiveness and reliability of wastewater treatment technologies have improved the capacity to produce recycled water that can serve as an alternative water source in addition in meeting water quality protection and abatement requirements (Papadopoulos & Savvides, 2003; Lazarova, 2000; Camargo *et al*., 2007).

The benefits from the use of treated wastewater are manifold especially to the countries that are facing chronic shortage of water supply and where the economy is mostly agri-based. However, at the same time the health and environmental risk pertaining to the reuse of treated wastewater specially in agriculture cannot be ignored. Therefore, reuses of treated wastewater requires effective treatment and to protect public health and the environment at an affordable cost. (Sipala *et al.,* 2003; Anderson *et al.,* 2001; Asano & Levine, 1996; Marcos do Monte *et al.,* 1996).

Waste Stabilization Ponds (WSP) technology is one of the most appropriate technologies for wastewater treatment especially for the countries located in tropical and subtropical regions and that cannot afford the luxury of mechanical wastewater treatment systems. The simplicity of the technology with effective removal of organisms of public health importance have made WSP technology as a treatment of choice in may parts of the world (Alcalde *et al*., 2003; Mara & Pearson, 1998; Khan & Ahmed, 1992). Pakistan is one of the countries that is facing chronic shortage of water supply. The increasing demand of water mostly in agriculture has rendered the country to explore alternative water resources whilst at the same time wastewater treatment is being done only at a limited scale. Green revolution in the 20th century had minimal impact on crop production in Pakistan and the average yields of crops are still low as compared to other countries. The main factor which is responsible for low crop yield is the lesser availability of irrigation water (Abbas *et al.,* 1998).

In Pakistan maize is the third important crop after wheat and rice while it is the third most grown crop in the world with an annual production of about 750 million metric tones. In Pakistan maize is being grown on an area of about one million hectares with annual grain production of 1.76 million tones (Anon., 2003). According to Economic Survey of Pakistan (Anon., 2006-2007) the maize production in the country was 2968 million tones with the total area of cultivation 1026 hectares. The trend from 2005 to 2007 showed negative growth (-4.5) rates in terms of maize cultivation (Anon., 2006-2007). Approximately 65% of the maize in Pakistan has access to irrigation whereas remainder is grown as rain-fed crop. Eighty-four % of the maize production in Pakistan is concentrated in the districts in North West Frontier Province /Northern Punjab and 9 districts in the central Punjab. Maize in Pakistan is cultivated as a multipurpose food and forage crop, therefore the economic potential of this important crop is overwhelming.

Keeping in view the importance of this crop viz., a viz., the potential of treated effluent in Pakistan as a liquid fertilizer, the present investigation was undertaken at a pilot plant level at Karachi University Campus (KUC).

Materials and Methods

Technical details of ponds: The technical details and general layout of the four waste stabilization ponds (WSP) at the KUC are shown in Table 1 and Fig. 1. These ponds are trapezoidal in shape, of equal dimension and are lined with thin layer of concrete and cement at the bottom as well as on the sides in order to avoid seepage problem and mosquito breeding. Two ponds in one set are in series interlinked and outlet provided in such a way that they could be operated in series at a depth of 0.9, 1.20 and 1.50m. They are designated as P-1 and P-2. In another set two ponds are likewise interlinked and can be operated at a depth of 1.0, 1.3 and 1.5 m. They are designated as P-3 and P-4. P-1 and P-2 are equipped with baffles. These ponds are connected with influent distribution channel that is connected with the service tank. The service tank in turn receives water from the influent sump. The raw domestic wastewater is received in the influent sump through a network of underground sewerage line laid down for the purpose.

Sample collection: Samples of influent were collected at the time of pumping of wastewater from the influent sump into the service tank. Samples from the individual ponds were collected from approximately 12 mm depth at the outlet of each pond in plastic containers. Sampling was performed every month from August to October and the collected samples were immediately transported to the laboratory for processing.

Processing of samples: After collection, the samples were analyzed for the NPK values of the effluent of WSP.

i. TKN was determined by Kjeldahl method as reported in Standard Methods for the Examination of Water and Wastewater (Anon., 1998) .
ii. Phosphate phosphorus was determined by ascorbic acid method as per method described in the Standard Methods for the Examination of Water and Wastewater (Anon., 1998).
iii. The total dissolved potassium was determined by atomic absorption spectrophotometer (Pye Unicam).
iv. Total organic matter content in the treated wastewater was determined by Standard Methods for the Examination of Water and Wastewater (Anon., 1998).

Table 1. Technical data of waste stabilization pond system at the Karachi University Campus.

S. No	Parameters	Characteristics
1.	Pond area (bottom)	98 m^2
2.	Pond area (WSP)	184 m^2
3.	Pond area (average)	130 m^2
4.	Outlet for effluent	1.0, 1.3, 1.5 m
5.	Influent sump capacity	13630 L
6.	Effluent sump capacity	5455 L
7.	Service tank capacity	3068 L
8.	Pond volume at 1.5m depth	198,625 L
9.	Average retention time in P-3	7.5 days
10.	Average retention time in P-4	7.5 days
11.	Average total retention time	15 days
12.	Total average hydraulic load	27000L
13.	Total average BOD_5 load	500 Kg/ha.d

(Based on average BOD_5 load of 225-250 mg/L)

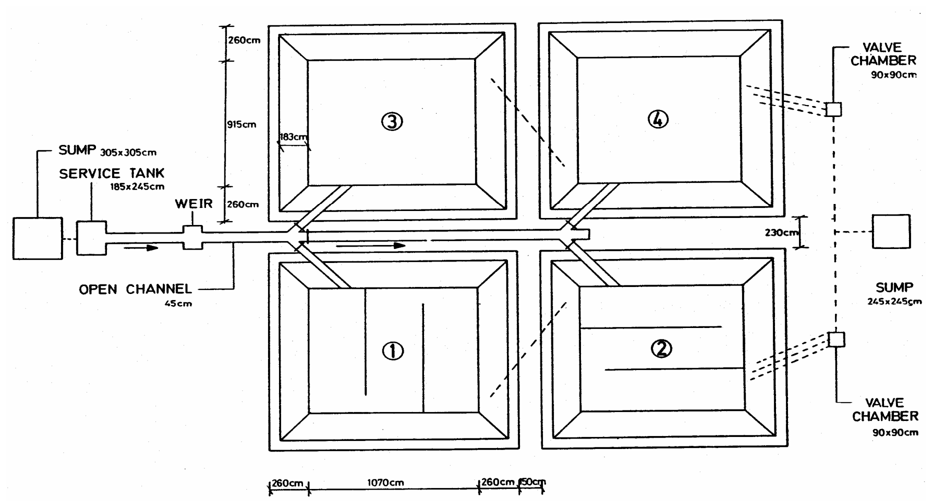

Fig. 1. General layout of waste stabilization ponds at the Karachi University campus

Selection of soil: During treatment of wastewater through WSP a minimum of 45000 L was received every day. Before it was used for irrigation of maize field, the liquid effluent was subjected to NPK analysis. The soil in which maize was cultivated was loamy.

Development of experimental plots: In all nine plots were developed each measuring 256m^2. In order to avoid edge effect due to solid movement or cross-penetration of roots plots are divided from each other by the insertion of polythene sheet up to a minimum depth of 30 cm. Various treatments were used such as fresh water (A) which represents the control, fresh water with basal fertilizer (0.010 gm/l K_2SO_4; 0.08 gm/l $CaHPO_4$ H_2O; 0.010gm/l g Urea) (B) WSP effluent (C). The three treatments were randomized within each of the three blocks in a randomized complete block design.

Table 2. NPK values and organic matter concentration of effluent collected on different dates for the feeding of maize crop.

Sample No.	Dates	Total nitrogen (mg/l)	Phosphate-phosphorus (mg/l)	Potassium (mg/l)	Organic matter mg/l
1.	25-08- 2000	34.39	2.77	6.00	582
2.	31-08- 2000	16.32	3.65	5.80	574
3.	06-09- 2000	14.92	3.30	6.30	565
4.	12-09- 2000	15.19	3.85	7.10	542
5.	18-09- 2000	14.58	3.20	6.00	645
6.	24-09- 2000	20.41	3.65	6.50	537
7.	30-09- 2000	15.74	3.00	6.80	672
8.	06-10-2000	16.32	1.50	7.30	656
9.	12-10-2000	38.49	3.42	6.60	688
10.	18-10-2000	24.44	3.65	7.70	591
11.	25-10-2000	20.42	6.40	7.20	564
Average		21.02	3.49	6.66	601
Min-Max		14.92-38.49	1.50-6.40	5.80-7.70	537-688

Sowing of maize seeds: Seeds of maize variety Akbar kindly provided by the Agriculture Research Station, Sindh Tandojam, were sown in 6 rows with a distance of 2.5 feet between the rows and two feet between the seeds on August 2, 2000.

Irrigation of plots: The plots were irrigated every week with 100 gallons of water per plot. Plots A and B were irrigated with fresh water while plot C was irrigated with WSP effluent. The plots were irrigated 11 times during the growing season. This amounts to 0.048 acre-inch.

Use of insecticide: The crop was sprayed only once with malathion for the control of borers and stem borers.

Growth studies: The vegetative growth was recorded by following the increase in plant height, fresh and dry weight of leaves, water and chlorophyll contents and leaf area. All these parameters were measured at vegetative stage, flowering stage and fruiting stage.

Estimation of chlorophyll: Chlorophyll was extracted from fully expanded leaves. Three replicates were made in each treatment. Extraction was done in 80 % acetone. The extract was filtered and optical densities were recorded at 663 and 645 nm. Chlorophylls a and b were estimated in accordance with the procedure of Arnon (1949).

Statistical analysis: Data of individual variables were subjected to two-way analysis of variance ANOVA (Zar, 1999). As a follow up of ANOVA, Duncan's multiple range test was performed.

Results and Discussion

The WSP effluent designated as liquid fertilizer was used as a source of irrigation water and fertilizer for the cultivation of maize. The NPK analysis of the liquid fertilizer fed to the maize plants is shown in Table 2. The available nitrogen in the liquid fertilizer was 21.02 ppm, phosphorus 3.49 ppm and potassium 6.66 ppm. The total NPK applied through wastewater in each plot were 0.10 kg, 0.017 kg and 0.032 kg respectively. Based on these values the total nitrogen, phosphorus and potassium applied through irrigation of maize with liquid fertilizer turned out to be 66, 11 and 21kg per hectare respectively. Maize usually gives a profitable response to application of 65-130 kg N/ha, 5-25 kg P/ha and 4-24 kg K/ha. The NPK quantities applied through liquid fertilizer are well within the recommended quantities (Hinkle & Garrot, 1965).

A critical evaluation of the results presented in Fig. 2 and Table 3 clearly demonstrated that irrigation of maize plants with liquid fertilizer (treated effluent) considerably increased plant growth and yield as measured by various parameters mentioned in Fig. 2. The increase in plant growth in the treatment C over treatment B can be attributed to the presence of high organic matter content in the liquid fertilizer that improves the soil structure and availability of nutrients (Brady & Weil, 2008). The comparison of the two treatments B and C, that is, plants that received fresh water and basal fertilizer (B) and plants which received liquid fertilizer (C) reveals that during vegetative phase, the plants of treatment C alone showed considerable increase in all parameters except moisture content than those with treatment B. Moreover, in flowering and fruiting stages also the plants irrigated with the liquid fertilizer registered significant (p at the most 0.05) increase in height, fresh and dry weight of leaves, moisture contents and leaf area over the controls. On the other hand the application of liquid fertilizer did not show any significant effect on the chlorophyll – a and b contents of leaves during both flowering and fruiting stages. Table 3 represents the data on yield parameters of the maize crop during the fruiting phases In the fruiting stage, the response of plants to basal fertilizer (B) and liquid fertilizer (treated wastewater) (C) seems to be similar in respect of cob length but number of cob and grain yield per plant were significantly elevated in plants irrigated with liquid fertilizer ($p<0.05$ and $p<0.01$ respectively). These results corroborate the findings of Tsadilas (1999) and Tsadilas & Vakalis (2003) who found increased yield of maize irrigated with treated wastewater.

Generally, it is suggested that the increase in maize yield resulted from the following items: (i) increase of treated wastewater application rate causing higher nutrient inputs (Overman, 1981); (ii) higher uptake and accumulation of nutrients, mainly of N and P (Vazquez-Montiel *et al.*, 1996); and (iii) occurrence of macro and micronutrients in the effluent which can neutralize the undesirable effect of high Na concentrations in treated wastewater (Al-Jaloud *et al*., 1995). Moreover, the often described antagonistic effect between Na and K was more pronounced under low K concentrations in soil (Fonseca *et al.*, 2005).

The effluent reuse criterion for WSP refers vaguely to irrigation and disposal technology and ignores the advantages of drip irrigation and subsurface drip-irrigation methods. The reaction of corn cultivated during late summer and irrigated by wastewater gave a positive response to the applied effluent quality. The wastewater quality was acceptable for unrestricted irrigation for the cultivation of maize as reported by Oron *et al.*, (1999). In the present study, prior to the irrigation of plots the wastewater was tested for coliforms and heavy metals. The coliforms were found to be well within the guidelines of WHO (Anon., 1989) without any advanced wastewater treatment. Most heavy metals including As, Co, Cr, Cd, Hg, Pb, and Ni were completely absent while concentrations of Zn and Mn were less than 0.05 mg/l that are within the permissible limits of health and safety standards (personnel observations, data not presented).

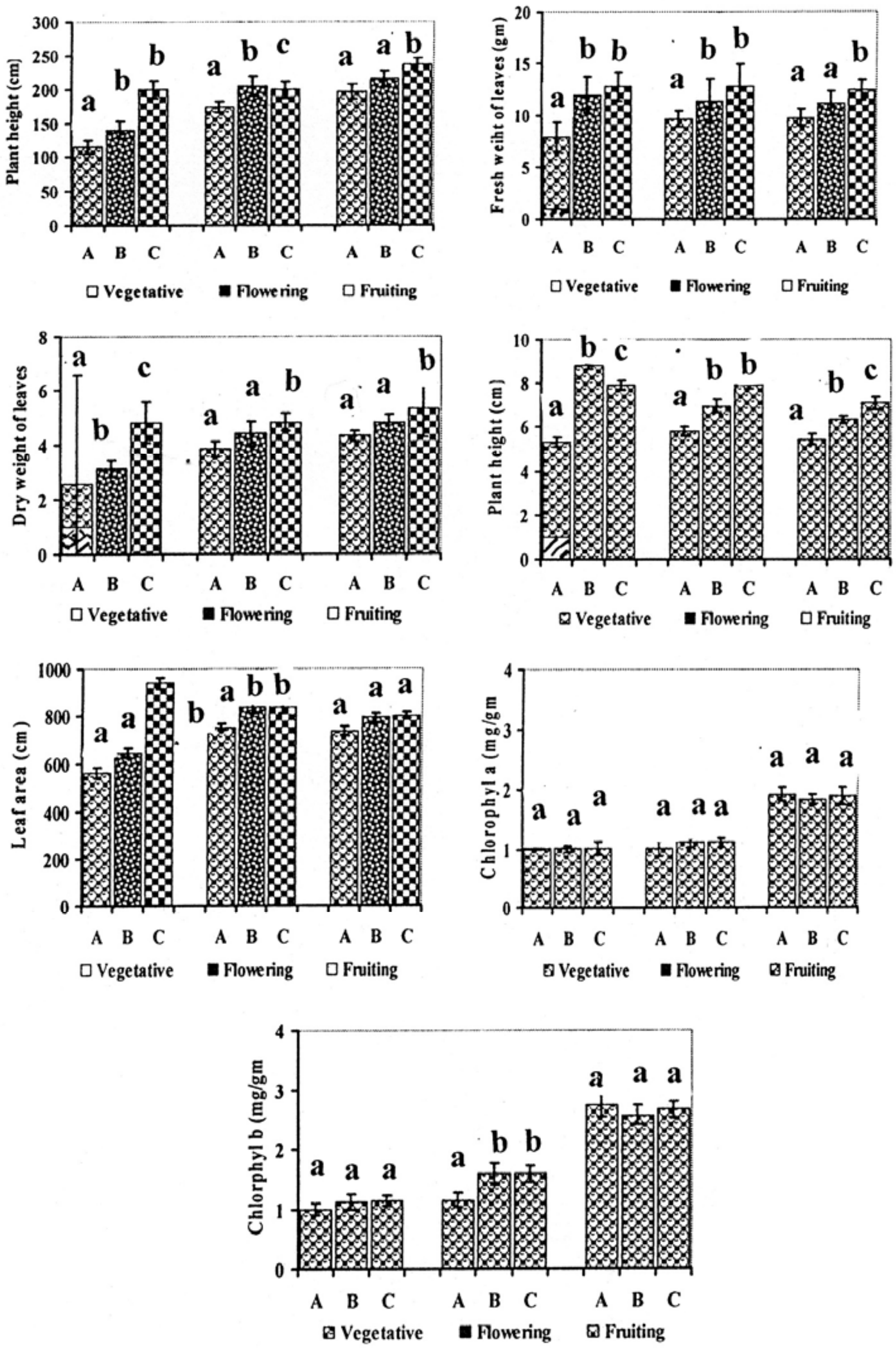

Fig. 2. Effect of WSP effluent on the growth (vegetative, flowering and fruiting stages) of maize plant; A= fresh water; B= freshwater plus basal fertilizer urea, $CaHPO_4$, K_2SO_4; C=liquid fertilizer).

Table 3. Yield parameters of maize using WSP effluent as a liquid fertilizer.

Reproductive phase				
Parameters	**Sample size**	**Treatment**		
		A	**B**	**C**
Length of cob (cm)	n= 200	15.9 ± 2.4^a	23.3 ± 2.7^b	22.06 ± 2.2^b
No. of cobs/plant	n= 100	1.7 ± 0.3^a	2.6 ± 0.5^b	3.0 ± 0.4^b
No. of grain/cob	n= 50	341 ± 23^a	408 ± 25^b	403 ± 27^b
Grain yield/plant*	n= 50	423 ± 28^a	534 ± 32^b	887 ± 30^c
Weight of 100 grains (g)	n= 10	26.51 ± 3.2^a	26.40 ± 3.5^a	26.46 ± 3.3^a

A = Fresh water, B = Fresh water plus inorganic fertilizer (urea, $CaHP_4$, K_2SO_4)
C = Effluent (liquid fertilizer), * = Total number of grains per plant
Different letters in the same row indicated significant difference ($p<0.05$) as given by Duncan's multiple range test.

Conclusions

The treated wastewater generated through the WSP was shown to be as effective as the inorganic fertilizer and provides good yield of maize crop. Since the treated wastewater is sufficiently rich in NPK nutrients, the cost of inorganic fertilizer can be saved. The most important advantage in the use of treated wastewater is that it can avoid environmental problems of discarding it into adjacent water bodies. Thus considerable quantities of fresh water can be saved for human consumption. Besides, the WSP technology can be used for sustainable production of maize and other crops.

References

Abbas, K., H.I. Javed and S.R. Chugtai. 1998. Maize in the rain fed areas of Pakistan: An analysis for production sustainability. *Pak. Devlop. Rev*., 37: 237-243.

Alcalde, L., G. Oron, L. Gillerman, M. Salgot and Y. Manor. 2003. Removal of faecal coliforms somatic coliphages and F- specific bacteriophages in a stabilization pond and reservoir system in arid regions. *Water. Sci. Technol.,* 3: 177-184.

Al-Jaloud, A.A., G. Hussian, A.J. Al-Saati and S. Karimulla. 1995. Effects of wastewater irrigation on mineral composition of corn and sorghum plants in a pot experiment. *J. Plant. Nutr*., 18: 1677-1692.

Anderson, I., A. Adin, J. Crook, C. Davis, R. Holtquist, B. Jimenez-Cisneros, W. Kennedy, B. Sheikh and B. Vander Merwe. 2001. Climbing the ladder: a step-by-step approach to international guidelines for water recycling. *Water. Sci. Technol.,* 43: 1-8.

Anonymous. 1989. *WHO guidelines for the use of treated wastewater in agriculture*. WHO, Geneva.

Anonymous. 1998. *Standard methods for the examination of water and wastewater*. 19th edition. American Public Health Association. Washington DC., USA.

Anonymous. 2003. *Agricultural Statistics of Pakistan*. Ministry of Food, Agriculture and Live Stock Government of Pakistan, Islamabad.

Anonymous. 2006-2007. *Economic Survey of Pakistan*. Government of Pakistan. Islamabad.

Arnon, D.I. 1949. Copper enzyme in isolated chloroplast I Polyphenol oxidase in *Beta vulgaris. Plant Physiol.,* 24: 1-16.

Asano, T. and A.D. Levine. 1996. Wastewater reclamation, recycling: past, present and future. *Water. Sci. Technol.,* 33: 1-14.

Brady, N. and R. Weil. 2008. *The nature and properties of soils*. 14th ed. Prentice-Hall, N.J.

Camargo, M.A., V.M. Johnson, T. Mather and D.D. Mara. 2007. Enhanced phosphorus removal in a stabilization pond system with blast furnace slag filters. *11 International Conf. Small Wat07, 11-15 November 2007, Seville, Spain*.

Fonseca, A.F., A.J. Melfi and C.R. Montes. 2005. Maize growth and changes in soil fertility after irrigation with treated sewage effluent II. Soil acidity, exchangeable cations and sulfur, boron and heavy metal availability. *Comm. Soil Sci. and Pl. Analys*., 36: 1983-2003.

Hinkle, D.A and J. Garrot. 1965. Corn fertilizer and spacing experiments. *Ark. Agr. Exp. Sta. Bull*., 635.

Khan, M.A. and S.I. Ahmed. 1992. Performance evaluation of pilot waste stabilization ponds in subtropical region. *Wat. Sci. Technol.,* 26: 1717-1718.

Lazarova, V. 2000. Wastewater disinfection. Assessment of available technologies for water reclamation water conservation. Vol. 3. *Water Management Purification and Conservation in Arid Climates.* (Eds.): M.F.A. Goosen and W.H. Shayya. Technomic Publishing Co. Inc. 171 -198.

Mara, D.D. and H. Pearson. 1998. *Design Manual for Waste Stabilization Ponds in Mediterranean Countries*. European Investment Bank. Mediterranean Environmental Technical Assistance Programme. Lagoon Technology International Leeds, UK.

Marcos do Monte, M.H., A.N. Angelakis and T. Asano. 1996. Necessity and basis for establishment European guidelines for reclaimed wastewater in the Mediterranean region. *Wat. Sci. Technol.,* 33: 303-316.

Oron, G., C. Campos, L. Gillerman and M. Salgot. 1999. Wastewater treatment, renovation and reuse for agricultural irrigation in small communities. *Agric. Water Manag*., 38: 223-234.

Oron, G., L. Gillerman, A. Bick, Y. Mnaor, N. Buriakovsky and J. Hagin. 2007. Advanced low quality waters treatment for unrestricted use purposes: Imminent challenges. *Desalination,* 213: 189-198.

Overman, A.R. 1981. Irrigation of corn with municipal effluent. *Trans. Amer. Soc. Agric. Engrs*., 24: 74-80.

Papadopoulos, I. and S. Savvides. 2003. Optimization of the use of nitrogen in the treated wastewater reuse for irrigation. *Wat. Sci. Tech*., 3: 217-221.

Sipala, S., G. Mancini and F.G.A. Vagliasindi. 2003. Development of web-based tool for the calculation of costs of different wastewater treatment and reuse scenarios. *Wat. Sci. Tech*., 3: 89-96.

Tsadilas, D.C. 1999. Recycling of municipal wastes in agriculture II. Irrigation of corn with treated municipal wastewater. *Proceedings of R 99 4th World Congress, Geneva*, 2-5 February: 263-268.

Tsadilas, D.C. and P.S. Vakalis. 2003. Economic benefit from irrigation of cotton and corn with treated wastewater. *Water Sci. Technol*., 3: 223-229.

Vazquez-Montiel, O., N.J. Horan and D.D. Mara. 1996. Mangement of domestic wastewater for reuse in irrigation. *Water. Sci. Technol*., 33: 355-362.

Zar, J.H. 1999. *Biostatisical Analysis*. Prentice-Hall, Englewood Cliffs, New Jersey.

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