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The Disposal of Biosolids and Water Treatment Residuals on Soils of Arid Regions: A Glasshouse Investigation

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Abbreviation List: DW: Dry Weight; WTR: Water Treatment Residuals

ABSTRACT

Land co-application of biosolids and WTR is a new concept. Therefore, information on the effect of co-application of biosolids and WTR on plant growth and elements uptake are very limited especially in alkaline soils. A glasshouse experiments was established to evaluate the effects of co-application of WTR and biosolids on agronomic performance of wheat crop grown in alkaline soils as well as P plant concentration and uptake, and to improve management of industrial and toxic wastes and provides environmentally sound guidelines for their disposal. The results indicated that increases of 47, 359 and 55 % in total dry matter yield were achieved as a result of applying 40 gkg^{-1} WTR and 10 gkg^{-1} biosolids to clay, sandy and calcareous soils respectively. In all studied soils treated with a constant biosolid rate 10 gkg^{-1}, application of 20 gkg^{-1} WTR significantly increased plant P concentration in the plant materials. Combined analyses of all soils ,all treatments of biosolid and WTR rates studied indicated clearly significant relationships between ABDTPA P concentration and P uptake ($r = 0.81$, $p < 0.001$).

Keywords: - biosolids, water treatment residuals, phosphorus, aluminum, availability

INTRODUCTION

Alum [$Al_2 (SO_4)_3 . 14 H_2O$] is commonly used in the municipal water treatment process to destabilize colloids for subsequent flocculation and water clarification. Water treatment residuals (WTR) are by-products of water purification systems in which undesirable attributes of the raw water such as turbidity, color and dissolved solids are removed by a variety of physical and chemical processes. WTR have commonly either been returned to the source waterway downstream of the treatment plant intake or has been released to a municipal sanitary sewer. Both methods of disposal of water treatment residuals (WTR) have become unattractive for a variety of reasons. As the alternatives to disposal of WTR have decreased in recent years, more attention has focused on beneficial reuse of the material. One such beneficial reuse is land application. However, the potential benefits of applying WTR to the soil have been limited due to its postulated reduction of plant available P and potential plant Al toxicity with increasing WTR rates. Co-application of WTR with biosolids inherently high in P could offer a good opportunity to reconcile these problems. Land co-application of biosolids and WTR is a new concept. Therefore, information on the effect of co-application of biosolids and WTR on plant growth and elements uptake are very limited especially in alkaline soils. Co-application of WTR with biosolids may be advantageous in terms of a cost saving and potential reduction of bioavailable P in high P containing sludge (Ippolito,1999).The objectives of this study were: to evaluate the effects of co-application of WTR and biosolids on agronomic performance of wheat crop grown in alkaline soils as well as P plant concentration and uptake and to improve management of industrial and toxic wastes and provides environmentally sound guidelines for their disposal.

MATERIALS and METHODS

Soil, WTR and Biosolids Characterization

Three soils with different properties (clay, sandy and calcareous) were selected for the study and sampled (0-15 cm) from three different locations. Sub-samples of the air-dried soils were ground to pass a 2-mm sieve prior to the following chemical analysis: Soil pH and EC were measured in the soil-paste extracts (Richards, 1954). The organic matter content was determined by dichromate oxidation (Nelson and Sommers,1982), cation exchange capacity was determined by IM NaOAc (Rhoades , 1982). Particle size analysis was determined by the hydrometer (Day, 1965). Calcium carbonate content was determined using a calcimeter (Nelson, 1982). Total nitrogen was determined by the Kjeldahl/digestion method (Bremner and Mulvaney ,1982). Available P was extracted by AB-DTPA test (Soltanpour and Schwab, 1977). The selected properties of the three soils are summarized in Table 1.

The chemical properties of WTR and biosolids and metal content were determined (Table 1). The pH was determined in 1: 2 sludge /deionized water. Salinity was measured in 1: 2 sludge/deionized water extract. Cation exchange capacity of WTR and biosolids was determined by sodium saturation (Rhoades, 1982). Organic carbon content of WTR and biosolids was determined by dichromate oxidation (Nelson and Sommers, 1982). Total Al was determined using the acid ammonium oxalate method (Ross and Wang, 1993). Extractable Aluminum was extracted by 1M KCl (Barnhisel and Bertsch, 1982) and determined colorimetrically by 8-hdroxyquinoline butyle acetate method (Bloom et al., 1978).

Incubation and Greenhouse Experiments

To ensure amendment–soils equilibria, incubation experiment was conducted. Four biosolids rates (0, 10, 20 and 30 g kg^{-1} on an oven dry basis) and/or five WTR rates (0, 10, 20, 30 and 40g kg^{-1}) and/or co-application rates of WTR and rates of biosolids were applied to each soil (calcareous, sandy and clay soils) thoroughly mixed and placed in Jars (2 kg). Following amendments applications, the soil water content was brought to field capacity. Jars were covered with perforated plastic cover and incubated at 25^{o}C for 60 days. After the incubation period, corresponding soil samples were air-dried, crushed to pass a 2 mm sieve and stored for analysis.

Seeds of wheat (*Triticum aestivum*) were sown in pots containing 2 kg of soil (s) with co-application rates of WTR and biosolids .The seedlings were thinned to 4 seedlings per pot and distilled water was added to bring the soil moisture to 70% of field capacity. The experiment was arranged in split-split plot design with four replicates. Plants were harvested after 13 weeks. Plant shoots, panicles and roots were harvested separately, oven dried at 65°C for 48 h to determine dry matter yield. Plant tissues were ground in a stainless steel mill. Subsamples of ground plant material were ashed in muffle furnace at 450°C for 6h, and analyzed colorimetricaly for P (Jones, 2001).

AB-DTPA Extraction

The ammonium bicarbonate-DTPA extractant solution was used to extract available phosphorus from soils treated with and without WTR and biosolids after cultivation (Soltanpour and Schwab, 1977).

Data Analysis

Statistical and mathematical analyses were performed using Statistical Analysis System (SAS, 1994). Analysis of Variance (ANOVA) techniques was used to determine treatment effects and check for interaction. The least significant difference method was used to separate treatment means. Regression analysis was employed to determine the relationships between available P concentration in soils and P concentration in plants.

RESULTS and DISCUSSION

Soils, (WTR) and Biosolids Characteristics

Selected properties of the soils,WTR and biosolids used in the study are given in Table (1).

Table 1. Some physical and chemical characteristics of studied soils.

Characteristics	Units	Clay	Sandy	Calcareous	WTR	Biosolids
EC*	dSm^{-1}	2.66	3.84	2.92	1.67	11.25
PH*		8.13	7.69	8.08	7.45	6.69
$CaCO_3$	%	5.79	0.24	35.68	-	-
Sand	%	59.64	86.82	74.00	-	-
Silt	%	14.13	2.51	10.15	-	-
Clay	%	26.23	10.67	15.85	-	-
Texture		S.C.L	L.S	S.L	-	-
O.M	%	0.85	0.10	0.46	5.70	45.00
T-N	%	0.22	0.03	0.09	0.42	3.20
T-P	%	0.09	0.03	0.05	0.19	0.46
T-Al	$g\ kg^{-1}$				38.01	3.14
CEC	$Cmol(+)\ kg^{-1}$	39.13	8.70	26.00	34.78	73.57
AB-DTPA-P	$mg\ kg^{-1}$	8.13	3.12	5.15	8.32	24.00
Extractable Al	$mg\ kg^{-1}$	1.03	0.13	0.08	28.18	4.22
Soil solution-P	$mg\ kg^{-1}$	1.98	0.89	1.22	0.73	2.13
Soil solution-Al	$mg\ kg^{-1}$	0.03	0.01	0.02	1.80	0.18
W.H.C	$g\ kg^{-1}$	259.30	93.80	166.70	470.00	250.00

SCl:Sandy Clay Loam; LS:Loamy Sand; SL:Sandy Loam

The soils differ dramatically in their textures, $CaCO_3$ and organic matter contents. The sandy soil samples represent soil with coarse texture, low contents of $CaCO_3$ and organic matter (O.M). It is classified as (*Typic Torripsamments*). In contrast, the clay soil is (*Typic Torrifluvents*), containing approximately 3 to 10 times as much as clay and organic matter contents. The $CaCO_3$ content and the CEC are much higher than the sandy soil. The pH of the clay soil is 0.5 unit higher than the sandy soil. The calcareous soil is classified as (*Typic Calciorthids*). The calcium carbonate content in the calcareous soil samples is 6 times higher than that in the clay soil samples. The three studied soils had concentrations of ABDTPA-P ranging from low (sandy soil) to high (clay soil). The clay soil contains approximately 2.5 and 1.5 times ABDTPA-P concentration more that of the sandy and calcareous soils, respectively.

The WTR was slightly alkaline (7.45) within the adequate typical range for plant growth (5-8) (Bohn et al., 1985).The EC of WTR is well below the 4 dSm^{-1} associated with the high exchange capacity of the WTR indicates its ability to supply cationic nutrients for plant growth. The organic matter content of the WTR is considerably greater than typical levels in soils of arid ecosystems. The small amount water soluble P (< 0.04 % of the total P) extracted from WTR implied strong P binding by the WTR. Dayton et al.,(2003) reported that low P extractability of WTR was due to the abundance of Al. However, the ABDTPA-P concentration in WTR was very similar. The water holding capacity of WTR is high (470 gkg^{-1}). Therefore, the WTR could be considered a good ameliorating agent to soil properties (Skene et al., (1995).

Biosolid is slightly acidic with high content of organic matter . Biosolids could be regarded as a low analysis P source (0.46 %) but the AB-DTPA extractability suggests that total P may not completely assess P solubility. The total nitrogen and phosphorus was higher than WTR The water holding capacity of biosolid (250 gkg^{-1}) was lower than its value in WTR. Therefore, the coapplication of WTR and biosolids could be considered good ameliorating agents to soil properties.

Dry Matter Yield of Wheat

The effect of WTR rates, co-applied with different biosolids rates on total dry matter of wheat grown on the three studied soils is shown in Table (2).

Table 2. Total dry matter yield of wheat plants grown in the three soils as influenced by co-application of biosolids and WTR rates.

Biosolids rate, gkg^{-1}	WTR rate, gkg^{-1}	Total dry matter yield, g pot^{-1}		
		Clay	Sand	Calcareous
10	0	2.71	2.54	2.83
10	10	2.91	2.80	2.87
10	20	3.24	3.00	3.10
10	30	3.34	3.14	3.22
10	40	3.71	3.49	3.49
	$LSD_{0.05}$	**0.42**	**0.41**	**0.45**
20	0	3.11	2.83	3.03
20	10	3.31	2.74	2.92
20	20	3.56	3.15	3.29
20	30	3.85	3.37	3.55
20	40	3.37	3.23	3.28
	$LSD_{0.05}$	**0.30**	**0.28**	**0.64**
30	0	3.40	3.08	3.22
30	10	3.49	3.26	3.38
30	20	3.70	3.53	3.59
30	30	3.92	3.82	3.88
30	40	3.43	3.21	3.37
	$LSD_{0.05}$	**0.64**	**0.39**	**0.30**
Analysis of variance		F-test		
Soil (S)		*		
Treatment (T)		***		
Rate (R)		***		
T X S		NS		
R X S		NS		
R X T		***		
R X T X S		NS		

* ,*** significant at the 0.05 and 0.001 probability levels respectively.

NS: Not Significant.

In the all studied soils treated with WTR rates co-applied with 10 gkg^{-1} biosolids rate, the total dry matter yield was not significantly different between the control treatment and the 10 gkg^{-1} WTR treatment. However, a significant increase in total dry matter was found between the control treatment and 20 or 30 or 40 gkg^{-1} treatments. Increases of 47, 359 and 55 % in total dry matter yield were achieved as a result of applying 40 gkg^{-1} WTR and 10 gkg^{-1} biosolids to clay, sandy and calcareous soils respectively. However, increases of 52, 343, and 58 % in total dry matter yield were achieved as a result of applying 30 gkg^{-1} WTR and 20 gkg^{-1} biosolids to clay, sandy, and calcareous respectively. Increases of 55, 403 and 72 % in total dry matter yield were achieved as a result of applying 30 gkg^{-1} WTR and 30 gkg^{-1} biosolids to clay, sandy and calcareous soils respectively. In the soils treated with WTR rates co-applied with 20 gkg^{-1} biosolid rate, the total dry matter yield was significantly different between the control treatment and the 20,30 or 40 gkg^{-1} treatments.These results coincide with the results of Harris-Pierce et al.,(1993,1994). Heil and Barbarick (1989) also observed an increase in dry matter with WTR application at high rates. In sandy and calcareous soils treated with WTR coapplied with a constant biosolid rate of 30 gkg^{-1}, there was no significant different between the control treatment and that the 10 gkg^{-1} treatment. However, there was a significant different between the control treatment and 20 or 30 gkg^{-1} treatments. Soil, biosolid treatments and WTR rates main effects were significant for total dry yield ($p < 0.001$) (Table 2). According to the previous results,it can be concluded that the application of WTR to high P soils may be a very good opportunity for farmers and water municipalities to reconcile several problems. Many farmers are being pressured to reduce the pollution impact of their traditional fertilization practices are less threatened. Additionally, farmers would receive a very good conditioner material to improve the physical and chemical characteristics of soils and, consequently high production of yield. Water utilities could have a more economic and labor conservative disposal method than the more common methods of WTR disposal, such as land filling, sewage disposal and coagulant recovery. Finally, the co-application of WTR and biosolids, resulted in total dry matter yield more than WTR or biosolids when it is applied individually (Ippolito, 1999).

Phosphorus Concentration and Uptake

In general, phosphorus concentration in plants tends to be accumulated in the order panicles > shoots > roots (Table 3). Significant soil type, biosolid treatments, WTR rates and their interactions effects were found for phosphorus concentration in panicles, shoots and roots of wheat plants grown in all the soils studied (Table 3).

In all studied soils treated with a constant biosolid rate 10 gkg^{-1}, application of 20 gkg^{-1} WTR significantly increased plant P concentration in the plant materials (Table 3). The P concentration significantly increased in plant materials (e.g.panicles) from 3000 to 3504, from 2910 to 3180 and from 2902 to 3030 $mgkg^{-1}$ in clay, sandy and calcareous soils treated with 20 gkg^{-1} biosolid and WTR rates (Table 3). The increase in extractable P in the amended soil with increasing the application rate of WTRs might be due to the high content of available P in the WTRs used in this study. Therefore the addition of cations from the WTR-application (10-30 $g.kg^{-1}$) was not able to effectively reduce the extractable P in the soils, which might be attributed partially to the inaccessibility to P held on intraparticle sites (Makris et al., 2004) and also more reaction time might be required to reach the equilibrium between the cation of WTRs and extractable P of biosolids within the treated soils (Makris et al., 2004) .However, further increase in WTR application rate has resulted in negative significant impact on plant P concentration . The application of the highest sludge rate (30 gkg^{-1}) produced higher P concentration in plant materials than the other two lower treatments. These results coincide with the results of Heil and Barbarick (1989) who indicated that WTR have a high capacity to fix P and that plant P deficiencies develop when plants are grown in WTR-soil mixtures or coapplied with a constant rate of biosolids.

Table 3. Phosphorus concentrations and uptake of wheat plants grown in the three soils as affected by co-application of biosolids and WTR rates

Biosolids rate	*WTR rate*	*Clay*				*Sandy*				*Calcareous*			
gkg^{-1}		**PP**	**SP**	**RP**	***PU***	**PP**	**SP**	**RP**	**PU**	**PP**	**SP**	**RP**	**PU**
			$mg.kg^{-1}$		$mg.pot^{-1}$		$mg.kg^{-1}$		$mg.pot^{-1}$		$mg.kg^{-1}$		$mg.pot^{-1}$
10	**0**	2889.00	2003.00	1713.00	6.82	2801.00	1998.00	1415.00	6.27	2714.00	2101.00	1571.00	6.86
10	**10**	3020.00	1801.00	1780.00	7.26	2810.00	2000.00	1530.00	6.85	2736.00	2200.00	1600.00	7.10
10	**20**	3309.00	1906.00	1830.00	8.83	2990.00	2100.00	1770.00	7.77	2813.00	2391.00	1690.00	8.00
10	**30**	2811.00	1330.00	1260.00	7.02	2920.00	1550.00	1410.00	7.16	2501.00	2010.00	1201.00	7.12
10	**40**	2213.00	960.00	910.00	6.06	2660.00	630.00	510.00	5.99	2101.00	1830.00	410.00	6.67
	$LSD_{0.05}$	14.37	9.46	15.43	1.22	15.37	22.64	18.98	0.90	18.83	23.76	13.59	1.03
20	**0**	3000.00	2643.00	2180.00	8.81	2910.00	2315.00	2214.00	7.55	2902.00	2440.00	1857.00	8.09
20	**10**	3109.00	2020.00	1801.00	8.79	3020.00	2081.00	1606.00	7.03	2881.00	1880.00	1670.00	7.09
20	**20**	3504.00	2504.00	1880.00	11.03	3180.00	2220.00	1690.00	8.38	3030.00	1990.00	1717.00	8.27
20	**30**	2603.00	1440.00	1202.00	8.01	2690.00	1370.00	930.00	6.72	2201.00	1101.00	810.00	5.87
20	**40**	2091.00	710.00	580.00	5.14	2310.00	580.00	440.00	4.61	1681.00	630.00	507.00	3.89
	$LSD_{0.05}$	31.61	15.53	17.64	0.76	31.38	24.90	16.65	0.60	19.07	27.88	22.99	1.54
30	**0**	4786.00	2990.00	2500.00	13.53	3501.00	2612.00	2402.00	9.60	3334.00	2701.00	2423.00	9.83
30	**10**	4880.00	2201.00	1890.00	12.94	3440.00	2103.00	1630.00	9.16	2902.00	1803.00	1499.00	8.12
30	**20**	5010.00	2403.00	1901.00	14.25	3630.00	2221.00	1690.00	10.51	3011.00	1880.00	1560.00	8.95
30	**30**	2710.00	1101.00	710.00	7.63	2803.00	990.00	801.00	7.52	1801.00	621.00	570.00	4.89
30	**40**	1991.00	603.00	499.00	4.64	2002.23	510.00	460.00	4.33	1590.00	460.00	420.00	3.63
	$LSD_{0.05}$	33.19	24.36	81.36	3.05	52.78	26.66	24.09	0.80	35.79	21.65	21.81	0.53
Analysis of variance			**PP**			**SP**		**RP**			**PU**		
Soil (S)			***			***		***			***		
Treatment (T)			***			***		***			***		
Rate (R)			***			***		***			***		
T X S			***			***		***			***		
R X S			***			***		***			***		
R X T			***			***		***			***		
R X T X S			***			***		***			*		

*,*** significant at the 0.05 and 0.001probability levels respectively.

PP: panicles phosphorus SP: shoots phosphorus

RP: root phosphorus PU: phosphorus uptake

Similar to wheat phosphorus content data, P uptake increased at the low WTR rates coapplied with 10 or 20 or30 gkg^{-1} biosolid treatments (Table 3). Soil type, biosolid treatment, WTR rates and their interactions significantly affected P uptake. The P uptake was higher in clay soils than in sandy and calcareous soils at all biosolids treatments coapplied with WTR rates, but the 20 gkg^{-1} WTR coapplied with 30 gkg^{-1} biosolid treatment was the best co-application rate (2:3 ratio). Such data indicated that co-mixing of WTR and biosolids at ratios of 4:1 will adsorb all soluble biosolids P ,and beyond this ratio the WTR could adsorb all biosolids available P and possibly some soil-borne P (Ippolito,1999).

Phosphorus Extractability after Wheat Harvest

Soil type, biosolid treatments, WTR rates and their interactions significantly affected AB-DTPA extractable P (Table 4). Application of WTR at rates of 10, 20 and 30 g kg^{-1} to clay and sandy soils treated with 10 gkg^{-1} biosolid, significantly increased AB-DTPA extractable P. In calcareous soil the extractable P increased with increasing WTR up to 20 gkg^{-1}and decreased with increasing WTR application rate. In all the soils studied treated with WTR co-applied with 20 or 30 gkg^{-1} biosolid, the extractable P significantly increased at rates 10 and 20 gkg^{-1} WTR, then the extractable P dramatically decreased to about 35% compared with the control treatment (Table 4).

Table 4. AB-DTPA extractable phosphorus concentrations for three soils influenced by co-application of biosolid and WTR rates.

Biosolids rate	WTR rate	AB-DTPA extractable P , mg.kg^{-1}		
gkg^{-1}		**Clay**	**Sandy**	**Calcareous**
10	**0**	6.87	8.13	8.27
10	**10**	10.13	8.88	9.23
10	**20**	12.19	9.12	11.77
10	**30**	13.99	11.14	7.13
10	**40**	7.66	6.12	4.22
	LSD0.05	**0.82**	**0.82**	**1.18**
20	**0**	12.66	12.42	13.01
20	**10**	14.28	12.93	13.86
20	**20**	19.09	15.87	15.08
20	**30**	12.22	8.18	9.01
20	**40**	5.88	4.43	5.82
	LSD0.05	**1.03**	**0.88**	**0.43**
30	**0**	17.99	13.99	15.83
30	**10**	22.18	18.82	19.39
30	**20**	26.27	21.23	23.13
30	**30**	15.55	11.98	12.91
30	**40**	6.22	5.82	6.02
	LSD0.05	**0.53**	**0.70**	**0.53**

Analysis of variance	**F-test** AB-DTPA extractable P
Soil (S)	***
Treatment (T)	***
Rate (R)	***
T X S	***
R X S	***
R X T	***
R X T X S	***

*** Significant at the 0.001 probability level.

The use of WTR as a soil or poultry litter amendment have been reported to significantly lower extractable P concentrations (Moore et al., 1995). Codling et al.,(2000), Elliott et al.,(2002), and other researchers noted similar declines in soil P concentration after the addition of WTRs to manure-treated soils. Combined analyses of all soils, all treatments of biosolid and WTR rates studied revealed clearly significant relationships between AB-DTPA extractable P concentration and P uptake ($r = 0.81$, $p < 0.001$, fig.1) .These results agree with the studies of Harris-Pierce et al.,(1993) and Shreve et al.,(1995).

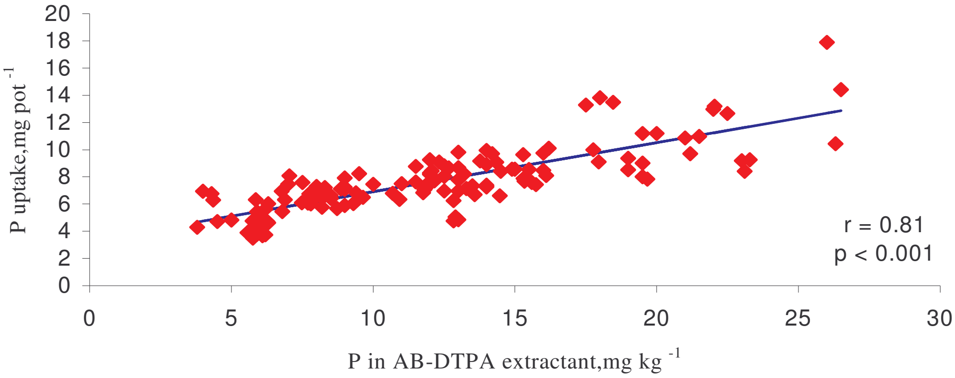

Fig.(1).Relationship between AB-DTPA P and P uptake of wheat plants grown in biosolids- WTR-treated soils .

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