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EFFECT OF ADDING DRINKING WATER TREATMENT RESIDUALS AND SEWAGE SLUDGE ON P FRACTIONS IN SANDY SOIL

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Accelerating the drive to re-use waste remnants due to growing stress and directives to recycle and re-use waste in addition to directives to soil improvement, resulting in water treatment residuals (WTRs) reuse that recently assorted as non-hazardous waste sludge, commonly using Alum [A12 (SO4)314H20] as coagulating and flocculating agents to precipitate undesired constituents. Disquiets over application WTRs to land are due to its supposed decreasing P availability and increasing AI toxicity with rising WTRs levels. Co-applying WTRs-sewage sludge can be beneficial for land application, especially sewage sludge high inherently in P and may act as a source of phytoavailable P, overcoming WTRs adsorptive capacity, by adjusting WTRs rate might prevent its negative effects and improve the quality of sandy soils. In pot experiment, the effect of co-applying WTRs-SS on the content of different forms of P in soil was investigated their effect as well on P & AI concentrations in radish plant and their uptake. The highest content of P in our soil was in Ca-bound P fraction while the lowest in soluble fraction, co-application of WTRs-SS increased total-P, moderately available and non-available P contents. Applying 5 gkg-1 of WTRs with P source (sewage sludge) to soil resulted in lower significant negative effects on available-P content and was effective in increasing hard-P content were increased by 84.18%. There is a negative linear relationship with increasing WTRs level and root, shoot P and shoot AI content ($p < 0.05$) and no symptoms for P deficiency or AI toxicity in radish plant with WTRs application.

Keywords: Drinking water treatment residuals, P fractions, radish and sewage sludge

INTRODUCTION

In recent years, the propel for reapplying waste materials greatly increased to meet directives recycle and re-use waste remnants in addition to directives soil improvement (Hazbavi and Sadeghi, 2016 and Krause et al., 2016), Water treatment residuals (WTRs) are byproducts of the flocculation and coagulation phase of the drinking water purification process that globally is utilized in the most water treatment plants. output of WTRs is susceptible to increase as pure drinking water gets a standard watering-place. Water purification processes generate significant amounts of WTRs sludges (several million tons every year) (Turner et al., 2019 and Kleemann et al., 2020), WTRs routinely disposed of through landfill, and can be assorted as a non-hazardous waste sludge from water purification' (European Waste Code 190902, within 11. Common Sludges) (Heather et al., 2022). Several low-cost coagulating and flocculating agents such as $FeCl_3$, alum [$Al_2(SO_4)_3.14H_2O$], or $Fe_2(SO_4)_3$ are used for precipitation of undesired dissolved and particulate constituents from water supplies (Lombi et al., 2010 and Keely et al., 2014). Alum [$A1_2$ $(SO_4)_3 14H_2 0$] is ordinarily used, so Alum sludge **(**Al-WTRs**)** is massive byproducts of treatment process (Dassanayake et al., 2015).

WTRs are mainly consisted of around 97% water, chemical substances used in treatment process, and unsettled solids, mainly soil particles-clay, silt, and sand as well as organic matter, bacteria, algae, and viruses (Boscov et al., 2021). Typically, WTRs contains predominately Al or Fe salts/oxyhydroxides, constituting around 60% that have a strong affinity for anionic species (Ippolito et al. 2011). WTRs also carry the elemental and mineral signature of water source. The organic carbon content of WTRs is inconstant where ranged from 0.85 to 6.5%, similar to soil organic carbon which is constant and has resistance to degradation and contributes to water holding capacity and good aggregation in soils treated with WTRs **(**Elliott et al., 1991). Al and Fe oxides in WTRs also have a cementing effect, which share in aggregation of soil (Elliott et al., 1991). In reclaiming sandy soils, this sludge supplies a main source of inorganic and organic matter since both of them present in WTRs.

In the previous days, the potency benefits of applying WTRs to the soil had been limited (Ippolito et al., 1999). The agricultural purpose of addition this sludge is depended on the premise they essentially contain organic matter, silt and clay-size minerals and nutrients (Petterle et al., 2018). However there is a growing group of research that confirms that residue has possibility for beneficial applications in the environment. Reusing WTRs in agricultural soil is one option demonstrating great promise (Howells et al., 2018), when used as an amendment, conditioner to soil, growth of plant and nutrient uptake increased (with regard to at least Al or Fe), but anionic species should be closely monitored. The application in agricultural soils has been recommended as a sustainable alternative (Dassanayake et al., 2015). The final appropriate destination of this residue has been a worldwide challenge (Dassanayake et al., 2015; Zhao et al., 2018 and Wang et al., 2021).

WTRs have potentially ability to enhance cultivated sandy soils quality which are approximately 199,600,000 ha around the world that commonly have, low cation exchangeable capacity, poor water holding capacity and low aggregation stability (Ibrahim et al., 2015; Huang and Hartemink, 2020 and Mahmoud et al., 2020). So, applying WTRs to sandy soils may stop negative effects (i.e. erosion and groundwater contamination) and enhance soil quality (i.e. nutrient cycling and aggregation). Negative impacts are usually regarding deficiency of P while positive responses are mostly related to good soil quality due to enhanced cation exchangeable capacity, aeration of soil and availability of water, however, affect crop yield have not been shown (Shaheen et al., 2017 and Zhao et al., 2018). Aplenty of Al in WTRs is one of the main disquiets about their applying in agriculture. The soluble form of Al^{3+} is toxic to plants and the aluminum hydroxide ($Al(OH)_3$) may decrease availability of P in soil (Brennan et al., 2019; Penn and Camberato, 2019 and Kleemann et al., 2020).

Co-addition of WTRs with biosolids may be beneficial in P availability where biosolids are high inherently in P content (Ippolito et al., 1999), and should benefit ecosystems (Bayley et al., 2008) sewage sludge has nutrients and organic matter which make it an excellent fertilizer to increase fertility of soil. However, heavy metals present in sludge is a great concern for applying in agricultural soils; the high potentiality of WTRs as a adsorbing agent for chemical- and bio-contaminants in water and as amendment for soil has been explained by specific properties for WTRs such as its amorphous phases. good porosity and Fe and Al (hydr) oxides present (Wołowiec et al., 2019; Xu et al., 2019 and 2020). Nevertheless, Al-WTRs addition decreased availability of heavy metals in soil (Mahdy et al., 2012 and Shaheen et al., 2017). WTRs is applied as an additive for treatment of sewage sludge in Portugal, and USEPA determined directives for reusing of WTRs in 2011 (Boscov et al., 2021).

Phosphorus is a macronutrient, essential for living things growth, the content of bioavailable fractions of P can be investigated with fractionation analyses, that involve methods that enable both quantitative and qualitative identification of P forms (Cabeza et al., 2019). Soil possesses both organic-P and inorganic-P forms. Most P in soil present in weakly soluble fractions, poorly available or unavailable to plants (Murphy and Sims, 2012). The organic-P fractions are positively correlated with the organic matter percent while correlated negatively with Al and Fe oxides (Wierzbowska et al., 2020). Organic-P compounds get labile to plants only after mineralizing of organic matter, leading to increase inorganic-P forms that become labile and return to circulation of P in soil (Noack et al., 2012 and Wang et al., 2012).

There are evidences of enhanced plant growth and P uptake when WTRs are co-added with a source of P (e.g. fertilizer, compost or sewage sludge). Heil and Barbarick (1989) reported that 5 g kg^{-1} of Al and Fe WTRs raise sorghum yield by 29% this referred to their Fe relieving and increasing of pH, while yields decreased with WTRs rate more than 15 g kg^{-1} as a result of adsorption of P by WTRs. Peters and Basta (1996) observed no deficiencies in nutrients in wheat (*Triticum* sp.) planted in alum-treated soils and in their soils, levels of available P are above the requirement P for wheat growth. Bayley et al. (2008) noted that 5 mg WTRs ha^{-1} with 10 mg biosolids ha^{-1} was comparable with a 10 mg biosolids ha^{-1} application rate and the P fractionation data from co-applied plots were more than a control. Zohar et al. (2020) found that co-applying Al- and Fe-WTR with wastewater will form moderately available P pools, improving the potential to reuse these waste residues as P fertilizers. co-addition of WTR and sewage sludge to the soil has not been extensively studied so the objectives of this current study were to investigate the effect of co-application WTRs-Sewage sludge on the content of different forms of P in sandy soil and its availability to radish plant (*Raphanus sativus* L.) as well as their effects on P and AI concentrations in radish root, shoot and their uptake,

MATERIALS AND METHODS

The upper layer of 25 cm of sandy loam soil was taken from west Suez area. Water treatment residuals (WTRs) was collected from water treatment stations, where alum is used as coagulating agent, El-Marg water station, Cairo, Egypt and sewage sludge (SS) was obtained from municipal wastewater treatment plant (WWTP) located in Al-Jabal Al-Asfar, Cairo, Egypt. The samples of soil, water treatment residuals (WTRs) and sewage sludge (SS) were air- dried (30°C, 1 month) before being crushed to pass through a 2 mm sieve and subjected to analyses. Some physical and chemical properties of composite soil sample, WTRs and SS are shown in (Table 1a and b).

1. Pot Experiment

A pot experiment was set up during winter growing season of 2021/2022 at greenhouse of Desert Research Center (DRC), Egypt, to assess the impact of WTRs- Sewage sludge (WTR-SS) co-addition on the content of different forms of P in sandy loam soil and its availability to radish plant (*Raphanus sativus* L.) as well as their effects on P and Al concentrations in radish root and shoot and their uptake. Using 20-cm height plastic pots having 2.5 kg of soil with various application rates of sewage sludge (0, 7.5, 15 and 22.5 gkg^{-1} soil (w/w) with 0, 5, 10 and 15 g WTRs kg^{-1} soil. All treatments were manually mixed into the soil and incubated for two weeks. After incubation period, six radish seeds (*Raphanus sativus* L.) per pot were planted then foliated to 2 plants per pot. The experiment was set in a randomized completely block design with four replicates. Each pot was irrigated two to three times per week maintaining field water capacity. Radish plant samples were collected at preflowering time, i.e., after 40-45 days and the roots were separated from the aerial parts. The radish samples (roots and aerial parts) were thoroughly washed and dried at 70ºC, fresh and dry weights were recorded, and plant samples were wet- digested by H_2O_2 and H_2SO_4, Nicholson (1984) then P was measured spectro-photometrically, according to Jackson (1973) and Al content in plant subjected to analyses using inductively coupled plasma-atomic emission spectroscopy ICP-AES. P and A1 plant uptake were determined by multiplying P and A1 concentration in the aerial parts and roots by the dry weights (DW) yield. After harvesting, soil samples from the pots were sieved (2 mm) to remove roots and air-dried, crushed, passed through a 2 mm sieve and stored for the following analyses; EC in soil paste extract and pH were determined using a 1:2.5 suspension according to Jackson (1973). Organic matter was determined according to Walkley-Black method (Nelson and Sommers, 1982), Total calcium carbonate equivalent content was determined using Collin's calcimeter (Black, 1965). Cation-exchange capacity according to Rhoades (1982) method. Chemically-extractable Al and micronutrients (Zn, Fe, Mn, and Cu) in soil, WTR and SS were determined by Amm. bicarbonate-DTPA (Barbarick and Workman, 1987), extractable element analyzed by ICP–AES. Labile P was extracted according to Olsen et al. *(*1965) and was measured spectro-photometrically, according to Jackson (1973). Also, Total elemental composition of soil, WTR and SS are digested by a $HC1O_4$-HNO_3-H_2SO_4 mixture (Table 1) (Hesse, 1972) and analyzed by (ICP-AES). Total N was measured following digestion by concentrated $HC1O_4$ and H_2SO_4, 4:1, respectively (Bremner and Mulvaney, 1982), and NH_4-N and NO $_3$-N following extraction by 2 M KC1 (Keeney and Nelson, 1982).

2. P Sequential Chemical Extraction

Phosphorus sequential chemical extraction of soil samples was carried out according to Chen, et al. (2000) by modifying the procedures described by Hedley et al. (1982). 1.0 g of 1 mm sieved soil sample was mixed and shaken with 0.5 M NH_4Cl (30 mL) for 30 min. then centrifugated for 10 min at 4000 rpm to extract water soluble-P, then shaking the residue for 16 h continuously with 30 mL of 0.5 M $NaHCO_3$, adjusting its pH to 8.5 to extract exchangeable-P, to extract P bound to organic matter and Al & Fe hydroxide minerals shaking the remaining soil with 0.1 M NaOH for 16 h and centrifugated for 30 min at 4000 rpm after that the Ca-bound P was extracted by shaking the soil residues for 16 h with 1 M HCl continuously (HCl_D-P). After gaining the pervious extracts, the residual soil was heated at 80C in a water bath with 10 mL of concentrated HCl for 10 min, then add 5 mL 12 M HCl, and reach the volume of the solution to 50 mL with distilled water to extract hardly soluble P; Fe- and Al–P (HCl_C-P) Finally, Residual P was obtained as Subtraction sum of P fractions from total P (Frossard et al., 1989). We could determine organic and inorganic fractions of P by using the 0.5 M NaHCO3, 0.1 M NaOH, and 12 M HCl extracts individually. Where The P in these filtrates were digested by potassium persulfate to determine its total P content (Pi+Po), Organic P fractions were calculated by the subtract the inorganic P from total P as described by Bowman (1989). Phosphorus in all extracts was estimated Spectro-photometrically, according to Jackson (1973).

Table (1a). Some physical properties of the experimental soil.

Location	C. sand %	F. sand %	Silt %	Clay %	Texture class	Field capacity %	Wilting point %	Available water %
West Suez	20.29	50.82	15.38	13.51	Sandy loam	17.38	7.55	9.83

Table (1b). Some chemical properties of the experimental soil, water treatment residuals (WTRs), and sewage sludge (SS).

Parameter	Unit	Suez soil	WTRs	SS
pH		7.56	7.33	6.40
EC	dSm^{-1}	1.89	0.93	4.45
Organic matter	gkg^{-1}	2.90	49.11	٢95.40
$CaCO_3$	gkg^{-1}	136.62	١8.90	٣1.73
CEC	$cmolkg^{-1}$	7.52	39.91	56.82
Ca		68.25	6.25	39.03
Mg		3.43	2.85	10.45
Na		0.57	0.28	0.85
K		2.51	3.75	5.62
P		0.31	1.06	19.92
Al	gkg^{-1}	6.87	38.93	17.63
Fe		8.36	60.45	27.19
Mn		0.27	5.44	33,74
N		4.01	4.22	48.05
NH_4-N		0.17	0.135	21.61
NO_3-N		0.11	0.17	7.91
Cu		62.63	11.92	462.30
Zn		1.60	84.5	1064
Ni		87.9	90.2	168.9
Mo		174.2	196	71.12
Cd		0.07	ND	0.08
Co		97.9	0.003	30.90
Cr	$mgkg^{-1}$	78.7	161.30	689.30
Sr		151.8	63.4	390.42
B		21.5	56.2	165.2
Ba		49.9	28.2	12.95
Pb		135.3	2.89	373.4
Si		43.1	581.73	473.4
V		38.4	21.13	119.1

WTRs = water treatment residuals and SS = sewage sludge ND not detected

3. Statistical Analysis

Analysis of variance was used to measure significant differences at p <0.05 then the least significant differences test (LSD) was applied. Correlation was used to determine the relationships between various P fractions due to WTRs-SS co-application rate using SPSS 20.0.s. As well as analysis of regression was conducted to illustrate the effects of WTRs-SS co-application rates on plant P and Al concentration and their uptake

RESULTS AND DISCUSSION

1. Effect of WTRs-SS Co-application on Main Soil Chemical Properties

1.1. Soil pH and soil electrical conductivity (EC)

In Table (2) data show that the interaction treatments of sewage sludge and WTRs has great effect on soil pH where soil pH values generally decreased by applying WTRs and SS either separately or in combine. This might be referred to the production of organic acids (humic, glycine, amino and cysteine acids) during mineralization of organic matter (Consuegra et al., 2015) or biodegradation of organic carbon, which is rich in sewage sludge and water treatment residuals (Singh and Agrawal 2010 and Consuegra et al., 2015). Soil pH was decreased especially at high application rate, where the pH values decreased from 7.56 to 7.14. The highest decrease was observed in treatment of 22.5 gkg^{-1} SS with 15 gkg^{-1} WTRs (5.56%). This decreasing in pH of treated soil causes increases in nutrients availability. These findings were in agreement with that found by Ahmed et al. (2010).

Data in Table (2) also show that the soil EC (dSm^{-1}) values have significant increments as increase the rates of sewage sludge. Where increased from 2.39 to 2.57, 2.75 and 2.85 dSm^{-1} with treatment 7.5,15 and 22.5 gkg^{-1} of SS respectively These results agree with those of Roig et al. (2012) and Lloret et al. (2016), who found that the application of sludge caused an increase in the soil EC (dSm^{-1}) without cause salinization, this increment in EC might be due to the stabilization of sludge by salts or might be due to organic carbon mineralization and subsequent produce OH^- ion by ligand exchange mechanism and to release the basic cations (Na^+, K^+, Ca^{2+},Mg^{2+}) from the sludge (Curci et al., 2020), while applications of WTRs alone or in combination with sewage sludge significantly reduced EC (dSm^{-1}) values this may be due to that WTRs reduced of Cl^- and Na^+. soil content (meq/l) These decrements may be clearer in the individual additions of WTRs. The addition of 15g WTR kg^{-1} soil alone gave the highest reduction in EC values (2.08 dSm^{-1}) directed by the treatment of 15g WTR kg^{-1} soil with 7.5g sewage sludge kg^{-1} soil (2.10 dSm^{-1}).

1.2. Soil organic matter (SOM) and $CaCO_3$ content

Organic matter in soil is relatively low. In Table (2), data show that, the soil organic matter percentage was significantly increased (p <0.05) in soil treated with SS and WTRs compared with control. These results agree with that found by Mattana et al. (2014) and Consuegra et al. (2015) who announced that application of sewage sludge to soil increase soil organic matter. Burducea et al. (2019) stated that Sewage sludge (SS) or biosolids is a resource of organic matter and nutrient renewal for the eroded soils reclamation. The higher the rate of treatments was the higher the content of organic matter was.

The greatest increments of organic matter (%) were observed with combine of 22.5g SS kg^{-1} soil with 5, 10 and 15 g WTRs kg^{-1} soil where increased up to 2.96, 3.16 and 3.51% respectively. The total $CaCO_3$ content of the soil took the same trend of organic matter as affected by all treatments and this may be due to presence of $CaCO_3$ in both WTRs and SS.

Table (2). Effect of WTRs-SS co-application on main chemical properties of studied soil.

Treatments (gkg^{-1})		pH	EC (dS/m)	O.C (%)	O.M (%)	$CaCO_3$ (%)	CEC ($cmolkg^{-1}$)
SS	WTRs	1:2.5 soil:water suspension	Soil paste extract				
Control		7.56^{a}	2.39^{de}	0.19^{h}	0.29^{i}	13.66^{e}	7.52^{g}
0	5	7.53^{ab}	2.18^{g}	0.22^{g}	0.37^{h}	13.89^{d}	7.80^{f}
	10	7.49^{b}	2.16^{g}	$0,26^{g}$	0.45^{h}	13.94^{cd}	7.85^{f}
	15	7.43^{c}	2.08^{h}	0.30^{g}	0.52^{h}	13.98^{c}	7.90^{e}
7.5	0	7.31^{d}	2.57^{c}	1.05^{f}	1.81^{g}	13.93^{cd}	7.84^{f}
	5	7.33^{d}	2.55^{c}	1.09^{f}	1.88^{fg}	13.97^{c}	7.91^{e}
	10	7.30^{de}	2.42^{d}	1.14^{e}	1.96^{f}	14.00^{c}	8.03^{e}
	15	7.29^{de}	2.11^{h}	1.18^{e}	2.03^{f}	14.05^{b}	8.25^{cd}
15	0	7.25^{e}	2.75^{b}	1.35^{d}	2.32^{e}	13.99^{c}	7.97^{e}
	5	7.22^{ef}	2.44^{d}	1.39^{c}	2.39^{e}	14.04^{b}	8.13^{d}
	10	7.17^{f}	2.23^{fg}	1.43^{c}	2.46^{d}	14.08^{b}	8.35^{c}
	15	7.16^{f}	2.36^{e}	1.47^{c}	2.53^{d}	14.12^{ab}	8.55^{b}
22.5	0	7.22^{g}	2.85^{a}	1.64^{b}	2.82^{c}	14.07^{b}	8.23^{c}
	5	7.21^{g}	2.26^{f}	1.65^{b}	2.94^{c}	14.11^{ab}	8.54^{b}
	10	7.16^{h}	2.24^{f}	1.72^{a}	3.16^{b}	14.16^{a}	8.65^{b}
	15	7.14^{h}	2.26^{f}	1.76^{a}	3.51^{a}	14.19^{a}	8.88^{a}
LSD		0.56	0.122	0.055	0.23	1.05	0.33

SS = sewage sludge, WTRs = water treatment residuals. O.C = organic carbon percentage, O.M = organic matter

1.3. Cation exchange capacity (CEC)

Data in Table (2) show that, the CEC values were significantly increased (p <0.05) with SS or /and WTRs increasing applying rates compared to control. The present data indicated that the addition of WTRs alone at 5, 10 and 15 g /kg soil, increased the CEC by 3.72, 4.39 and 5.05% respectively, compared to the control. The high CEC presented with WTRs referred that this sludge can provide cationic. The increases of CEC upon the addition of 7.5, 15, and 22.5g kg^{-1} sewage sludge were 4.26, 5.98 and 9.44 %, respectively, compared to the control. These results announced that rising the levels of SS resulted in more CEC values than that of WTRs, this is due to the organic amendments (SS), enhance CEC through increasing concentrations of humic acid and nutrients, as Ca and Mg due to decomposition of organic matter, these results were in agreement with Jenkinson (1990). The greatest increasing of CEC values were observed with combine of 22.5g /kg soil SS with each 5, 10 and 15 g WTRs /kg soil by 13.56, 15.03 and 18.09 % respectively. Finally cation exchange capacity of the soil took the same trend of organic matter as affected by all treatments and this might be related to that soil organic matter increases cation exchange capacity (CEC), also encourages granulation, and adsorbing power of the soils (El-Maaz et al., 2014).

1.4. Macronutrient contents in the soil

Phosphorus is one of the most essential nutrients for plant. Available-P significantly (p < 0.05) increases as sewage sludge application rate increases, this increment of available-P with sewage sludge may be related to humic acid releasing during organic matter decomposition, results in a turn's unlabeled soil phosphate into labile forms. In addition, sewage sludge is high in P content (Table 3). Hernandez et al. (1991) performed a study to investigate the effect of sewage sludge addition to a Calciorthid soil on the macronutrients availability and found that total N, extractable N and P contents raised in the soil amended with sludge while the extractable K was unaltered. Bonini et al. (2015) observed that 30 mg ha^{-1} of SS increases the P contents in the soils and given 560 kg ha of P to the crops soils This confirms that, SS fertilization may lead to accumulation of available P in the soil (Bittencourt et al., 2012). On the contrary available P content decreased with WTRs application compared to sewage sludge alone. WTRs ability to bind P was well documented (e.g. Heil and Barbarick, 1989; Cox et al., 1997 and Ippolito et al., 2003). It is worth to find that WTRs had 38.932 g Al^{+3}, 6.246g Ca^{+2} and 2.85 g Mg^{+2} kg^{-1}. This referee that there are inorganic components, which may bind and precipitate PO_4^{-3} as aluminum, calcium and magnesium phosphates, respectively. During the water purification process, in coagulation phase alum is turned to aluminum hydroxides that are the same to aluminum hydroxides that present naturally in soils. These hydroxides can raise buffering capacity of soil and can raise the specific anions precipitation and adsorption high such as orthophosphorus (Basta et al., 2001). Dempsey et al. (1989) stated that alum sludge had high P sportive capacity that decreased bioavailability of P and reduced plant growth. Data in Table (3) show that sewage sludge application alone at rate of 7.5, 15 and 22.5gkg^{-1} soil significantly increased the available-P (mgkg^{-1}) values by 11, 15 and 17-fold over the control, respectively. The available-P significantly differed (p < 0.05) as affected by the WTRs-SS co-application. Where the application of WTRs reduced available P. Soil amended with 15 gkg^{-1} WTRs had less available-P than other treatments. Where reduced available-P by 46.19, 54.10 and 49.78% when co-applied with 7.5, 15 and 22.5 gSSkg^{-1} soil respectively.

Concerning nitrogen and potassium availability, data in Table (3) indicate that sewage sludge or / and WTRs treatments were effective at giving Nitrogen and Potassium to calcareous soil. Also, results showed that there are significantly increments in available N and K as increasing the rate WTRs-SS co-application and these combinations were superior in rising Nitrogen and Potassium availability compared to other treatment solely. This is due to reduction of pH values and increment in the soluble ions and total soluble salts (Consuegra et al., 2015). Decreasing soil pH oversees nutrients availability in soils. Malakouti (1993) found that decreasing pH leads to increase solubility of most nutrients and enhance Potassium status in soil. The highest available N and K contents were found in soils amended with 22.5 g kg^{-1} sewage sludge, whereas the lowest contents presented in unamended sample.

1.5. Micronutrients content in the soil

Limited micronutrients availability (Fe, Mn, Zn, and Cu) is due to high $CaCO_3$ content in the soil (Marschner, 1995). Influence of soil pH and percentage of carbonate contents in soil are related to availability decrease of these elements (Loeppert et al., 1984). The WTRs-SS co-application treatments provide micronutrients to the calcareous soil. Data in Table (3) show that there were increments in soil content of extractable micronutrients (Fe, Mn, Zn and Cu) because of the used treatments. This may be due to adding of organic matter (OM) because of increasing applying rates of SS or / and WTRs. where available Fe, Mn, Zn and Cu contents in soil significantly increased from7.76 to 59.96, 2.61 to 8.08,2.94 to 10.40 and 0.28 to 6.72 $mgkg^{-1}$, respectively. These results are in a great agreement with those stated by Hernandez et al. (1991), who found that when sewage sludge was applied to the soil availability of Fe, Cu, Mn, Zn, and Pb increased, as compared to untreated soil. Organic compounds mineralization leads to release low molecular weight organic acids which reduce pH values in soil and increase micronutrient availability in soil (Ramachandran and D'Souza, 1998). These results are in agreed with the results reported by Bhanooduth (2006) who stated that micronutrients availability (Mn, Zn, Fe, and Cu) increased by applying of compost and organic wastes.

2. Phosphorus Fractions

According to Niederberger et al. (2015), fractions of P were divided into three groups, Available P (soluble P (NH_4Cl-P) and Exchangeable P ($NaHCO_3$-Pi and $NaHCO_3$-Po)), Moderately available P (NaOH-P (Pi and Po) and HCl_D-Pi and Non-available or Stable was HClc (Pi and Po) and residual P. Fig. (1) demonstrates the content of bound P in the featured fractions that decreased in the following order: Soluble P < Exchangeable P < organic-mineral bound P < Residual P < Hardly soluble Fe- and Al-bound P < Ca-bound P.

Table (3). Mean available values of macro & micronutrients and chemically extractable Al of sandy soil as affecting by the experimental treatments.

Treatments		Macronutrients			Micronutrients				Available Al
SS	WTRs	N	P	K	Fe	Mn	Zn	Cu	
(g kg^{-1})					(mg kg^{-1})				
Control		4.08	4.65	96.55	7.76	2.61	2.94	0.28	0.289
0	5	4.78^{fg}	4.05	96.67	8.66	2.52	1.98	0.39	0.438
	10	5.67^{f}	3.31	96.96	9.64	1.52	1.71	0.44	0.642
	15	7.78^{f}	2.94	97.22	10.84	3.70	3.78	0.67	0.727
7.5	0	102.45^{e}	49.53	118.55	27.18	4.04	3.07	2.22	0.314
	5	112.56^{d}	42.97	139.21	29.62	2.94	3.63	2.72	0.452
	10	118.67^{d}	35.58	139.83	30.88	2.64	3.15	2.34	0.668
	15	132.56^{cd}	26.65	140.45	31.08	3.44	3.12	2.31	0.927
15	0	145.75c	69.39	143.56	39.46	4.98	4.43	2.93	0.606
	5	155.05^{c}	58.28	144.75	32.64	5.95	5.82	3.27	1.358
	10	167.52^{b}	39.84^{b}	145.02	39.94	8.85	6.24	3.96	1.414
	15	177.75^{b}	31.85^{c}	155.85	36.82	9.72	5.94	4.24	1.998
22.5	0	198.25^{ab}	78.55^{a}	197.20	71.04	7.58	11.88	6.24	0.738
	5	203.55^{a}	69.95^{a}	198.24	75.40	8.37	11.64	7.16	1.573
	10	212.54^{a}	43.83^{b}	208.40	67.12	8.94	10.18	6.62	2.114
	15	225.15^{a}	39.45^{b}	210.82	59.96	8.08	10.40	6.72	2.304
LSD		1.55	0.05	1.023	0.02	0.23	0.25	0.02	0.53

The similar letters in each column means that no any significant difference presents at 0.05 level.

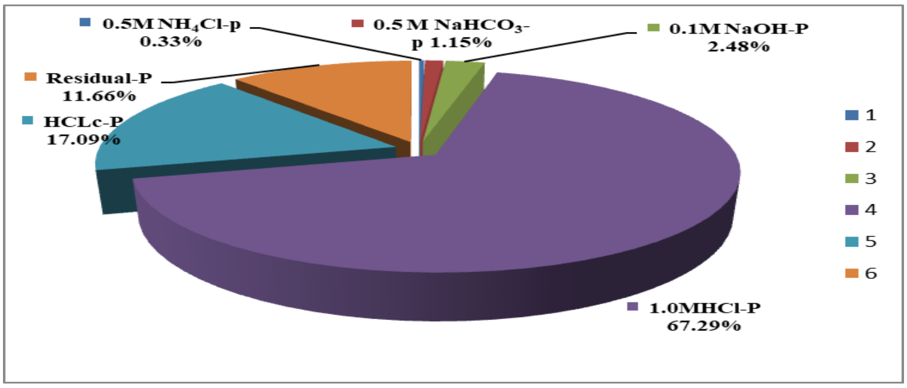

Fig. (1). The percentages of bound P content in the featured fractions in the studied soil.

2.1. Available fraction

P in this fraction is the most bio-available form of P and directly exchanges with soil solution and rapid turnover. P is geochemically non-occluded and adsorbed on colloids and crystalline compounds surface in the soil. Data in Table (4) show that available-P was less abundant P fractions in soil under study which constituting 1.48% of the total P and addition of sewage sludge cause a significant increase of available P at p <0.05 compared to control. The highest content was observed at 22.5g SS kg^{-1} soil which constituted about 16.62% of total P.

2.2. Water soluble P

Data of Water soluble fraction (the ionic form of P as $H_2PO_4^-$ and HPO_4^{2-}) in Table (4) show that the content of soluble P constitute 0.33% of total P in control sample, sewage sludge increased the proportion of this fraction up to 6.65, 7.52 and 9.30% of total P at rate 7.5, 15 and 22, 5g kg^{-1} sewage sludge respectively, while the WTRs effect was reversed, where WTRs treatment led to decrease the proportion of soluble P by 19.80, 27.73 and 42.57% at rate 5,10 and 15g kg^{-1} WTRs respectively., the combination, of 15 g kg^{-1} WRTs with each 7.5, 15 and 22.5 g kg^{-1} sewage sludge led to the highest decrease in soluble P where decreased by 53.27%, 46.34% and 56.73%, respectively. These results refereed to that increasing WTRs rates resulted in lower soluble P content, while combination of 5 g WRTs kg^{-1} soil with each 7.5, 15 and 22.5 g kg^{-1} sewage sludge lead to the lowest negative effect on content of soluble P where decreased by 9.76, 8.91 and 11.20%, respectively. These results indicate that 5 g kg^{-1} of WTRs to soils with P source (sewage sludge) resulted in lower negative effect on content of water-soluble P. These results were in agreement with that found by Cox et al. (1997) and Jonasson (1996), who found that the applying WTRs to soil cause decreasing in available P content and increasing in less-soluble chemisorbed Al- and Fe-bound P content and high addition rates of WTRs (>10%) result in P deficiency in crops. water soluble P content in soil was most strongly positive correlated with organic matter content, total-Po, available-P, and exchangeable-P (r = 0.816*, 0.928*,0.962*and 0.965, respectively) and positively correlated with total-P (0.668*) these in agreement with that found by Jakubus (2015), who state that organic matter content and total P and available P have a strong effect on water-soluble P content. while water soluble P content was negatively correlated with soil pH (r = − 0.409*). This result was in agreement with Jokubauskaitė et al. (2015), who reported water soluble P content and phytoavailable P increased when the soil's pH was neutral.

Table (4). Mean of P concentration (mgkg^{-1}) in the different forms of P as affected by applying WTRs and SS in the sandy soil.

Treatment		Available-P		Moderately available-P		Non- available-P		Total P
SS	WTRs (g kg^{-1})	0.5M NH_4Cl-P	0.5M - Na-HCO_3P	0.1M NaOH-P	1.0M HCl-P	HClc-P	Residual P	
Control		1.01^{h}	3.58^{i}	7.65^{e}	207.28^{h}	52.64^{h}	36.81^{f}	308.06^{i}
0	5	0.81^{h}	3.26^{i}	8.09^{e}	217.82^{g}	55.12^{h}	39.03^{e}	322.69^{h}
	10	0.73^{h}	2.78^{i}	8.14^{e}	220.86^{f}	55.67^{h}	39.74^{d}	327.82^{gh}
	15	0.58^{h}	2.34^{i}	8. 28^{e}	224.61^{e}	55.44^{h}	40.94^{c}	333.29^{g}
7.5	0	20.50^{d}	26.63^{e}	18.42^{ce}	229.94^{cd}	65.50^{g}	38.56^{e}	399.55^{fg}
	5	18.50^{e}	24.17^{ef}	21.38^{c}	232. 28^{c}	69.31^{f}	41.43^{cd}	405.07f
	10	14.54^{f}	18.04^{g}	29.83^{b}	238.12^{b}	73.64^{ef}	42.54^{c}	416.71^{e}
	15	10.58^{g}	13.04^{h}	26.67^{bc}	238.33^{b}	75.80^{e}	43.89^{c}	414.31^{e}
15	0	26.16^{b}	36.13^{c}	19.67^{c}	227.03^{d}	78.53^{d}	39.66^{d}	425.18^{d}
	5	23.83^{c}	32.75^{d}	26.04^{bc}	232.53^{c}	88.31^{c}	40.95^{c}	436.41^{c}
	10	14.04^{f}	23.46^{ef}	28.37^{b}	239.65^{b}	89.81^{bc}	42.57^{c}	438.90^{bc}
	15	13.50^{f}	22.42^{f}	29.79^{b}	241.73^{b}	90.22^{bc}	45.89^{b}	440.55^{bc}
22.5	0	28.66^{a}	45.79^{a}	25.25^{b}	242.86^{a}	84.04^{c}	39.23^{d}	447.83^{b}
	5	25.45^{b}	42.50^{b}	29.21^{b}	243.90^{a}	92.17^{b}	42.34^{c}	447.57^{b}
	10	13.54^{f}	28.29^{e}	32.62^{ab}	242.86^{a}	95.78^{a}	44.55^{b}	455.64^{a}
	15	12.41f^{g}	24.54^{ef}	37.24^{a}	243.64^{a}	96.95^{a}	46.24^{a}	458.02^{a}
LSD		1.45	2.04	0.76	3.66	2.001	0.055	12.05

The similar letters in each column means that no any significant difference presents at 0.05 level.

2.3. Exchangeable P

Phosphorus exchangeable bind, nonspecifically adsorbed to solid phase of the soil, results in Table (4) reveal that the content of exchangeable P constitute 1.15% of total P in control sample. It was the second-lowest P content of all P fractions in studied soil. Data also showed that the concentration of $NaHCO_3$-P gradually increased at (*p* <0.05) with increasing SS rates alone, where at rates of 7.5, 15 and 22.5 g kg^{-1} sewage sludge significantly raise $NaHCO_3$-P content (mg kg^{-1}) by 7, 10 and 13-fold more than in the control soil respectively. $NaHCO_3$-P content differed significantly ($p < 0.05$) as affected by the interaction treatments of WTRs-SS co-application where the application of WTRs led to decrease the proportion of $NaHCO_3$-P by 8.93%, 22.34% and 34.64% at rate of 5,10 and 15 g WTRs/kg soil respectively, while combine, of 5 g kg^{-1} WRTs with each 7.5, 15 and 22.5 g kg^{-1} sewage sludge had the lowest impact on decreasing the content of exchangeable P where decreased by 9.24, 9.36 and 7.20%, respectively. The exchangeable P content was most strong positively correlated with available-P, and total-Po (r = 0.988*and 0.968*, respectively) and positively correlated with total-P (0.693*). Generally, an increase in total-P is chaperoned with more available fractions bulk, while the soil exchangeable P content was negatively correlated with soil pH (r = - 0.610*).

2.4. Moderately available fractions

Moderately available P represents potentially bioavailable form of P and includes Organic-mineral fraction and Ca-bound P, mineral bound P (NaOH-Pi). Geochemically non-occluded and chemically adsorbed to Al and Fe oxides and NaOH-Po was predominantly associated with organic matter, namely humic and fulvic acids (Cassagne et al., 2000; Schroeder and Kovar, 2006 and Tiessen and Moir, 2008). lesser plant available with slow turnover while P adsorbed or receipted with Ca (HCl_D-P), is a more stable form than available and Organic -mineral bound P forms (Diez et al., 2006), P in those two fractions likely are P inputs recently from fertilization (Wright, 2009).

2.5. Organic-mineral bound P

Data presented in Table (4) show that NaOH-P was the third-lowest P content of all P fractions in studied soil which constitute 2.48% of total; this was likely due to high concentration of Ca ions in the soil, that determine the speciation of ion in soil solution (Bohn et al., 2001). The result in table 4 revealed that the co-application of WTRs-SS to soil led to increase NaOH-P. Data also showed that sewage sludge led to increase content of NaOH-P were increased by 2, 3 and 7-fold more than the control soil at rate 7.5, 15 and 22, 5 g sewage sludge kg^{-1} soil respectively, and also WTRs treatment increased NaOH-P as the application rate increase. The highest NaOH-P increments in soil was obtained with 15 g WTRs kg^{-1} soil where NaOH-P increased by 50.22%, 51.45% and 47.49% at 7.5, 15 and 22, 5 g sewage sludge kg^{-1} soil respectively. This is because WTRs can adsorb large amounts of P due to the amorphous nature of Al $(OH)_3$ (Ippolito et al., (2003). Organic-mineral bound P content was most strong positively correlated with organic matter content, CEC and total-P (r = 0.826*, 0.924* and 0.863*respectively) positively correlated with total-Po and exchangeable P (r=0.529* and 0.623*). .

2.6. Ca-bound P

Ca-bound P was the most plentiful P fraction in the soils, constituting 67.29% of the total P in control sample. The results in Table (4) show that Ca-bound P significantly increased as co-application of WTRs and SS rate increases where ranged from 207.28 to 243.64 mg kg^{-1} this is due to the high free $CaCO_3$ content in the soil, P in sewage sludge forms Ca-correlating P forms that are of poor solubility and low availability for plant (Alharbi et al. 2018). The least Ca-bound P content was in the control soil (207.28 mg Pkg^{-1}). Sewage sludge and WTRs significantly raised this P fraction content in soil. these results in agree with that found by Wierzbowska et al. (2020) whom found that most P in the Ca-P bound fraction was noted in soil treated with sewage sludge alone or with WTRs-SS co-application. The highest increment was observed in soil treated with 22.5 gkg^{-1} of SS with 15 g/kg WTRs (over 18.02% than in the control soil, while the least increase in its content (about 9.47%) was noted in the soil treated with 15g kg^{-1} WTRs. these finding was in agreed with that found by Wierzbowska et al. (2020) who stated that most P of Ca-bound P was determined in the soil fertilized with dried and granulated sewage sludge (DGSS) (over 45% more than in control) or NPK alone. Ca-bound P content was most strongly correlated with total P content and $CaCO_3$ % (r=0.888* and 0.832*, respectively) but showed a weaker correlation with available-P and the organic matter content (r = 0.586*; r = 0.472*, respectively)

2.7. Stable fractions

Non available or stable P represents the recalcitrant P fraction that is highly stable and non-available to plants (HCl_C-P and residual P). Hardly soluble Fe- and Al-bound P (HClc-P), non-occluded while residual P is P occluded within primary and second minerals (Aulakh et al., 2003 and Zicker et al., 2018).

2.8. Hardly soluble Fe- and Al-bound P

Stable organic-mineral and mineral bonds, the results obtained in Table 4 showed a higher significant increase in HCl_C-P fraction with studied treatments as compared to untreated soil.Where increased from 52.64 to 96.95 mg kg^{-1} (84.18%), Combine of WTRs and sewage sludge was effective treatments in increase the HCl_C-P content compared to other solely treatments where the lowest concentration of HCl_C-P fraction was observed in control soil and tend to increase by increasing WTRs applied rate. The greatest increments were observed in the combination, of 15 g WTRs kg^{-1} with each of 7.5, 15 and 22.5 g sewage sludge kg^{-1}soil where P content in HCl_C-P fraction increased by 15.73%, 14.89% and 15.36%, respectively. These results refereed that increasing WTRs rates resulted in more unavailable P content, these increases in HCl_C-P content are due to adsorption of P to WTRs. Where the soil pH was not suitable for Al^{3+} to be soluble, even pH of soil likely promoted Al $(OH)_2^+$ formation and subsequent binding of P to WTRs via ligand exchange mechanism (Ippolito et al., 2009). These results are according to those obtained by Mahdy et al. (2017) who found addition of nWTRs to El-Bostan soil that amended with biosolids increased hardly soluble Al-P fraction from 27.30 to 88.90, 92.20, and 94.93% at 0.10, 0.20, and 0.30% application rate, respectively. Also, Wierzbowska et al. (2020) stated that adding municipal waste to soil, favored P binding into stable organic and mineral bonds. Hardly soluble

Fe- and Al-bound P content was highly significant positively correlated with organic matter content, total-P content and total-Po (r = 0.979*, r = 0.961* and r = 0.868* respectively) and significant positively correlated with available-P, (r = 0.549*), while being negatively correlated with soil pH (r = − 0.665*).

2.9. Residual P

Data in Table (4) show that residual P had significantly increase trend which ranged from 36.81 to 46.24 mg kg^{-1} (11.95 to 15.01% of total P), the results obtained in Table 4 showed that there was a significantly increase in residual P content with WTRs-SS co-application treatments as compared to control, where combine 15 g kg^{-1} WTRs with each of 7.5, 15 and 22.5 g kg^{-1} sewage sludge was the most effective treatment compared to other treatments where the concentration of residual P fraction tended to increase by 13.82, 15.71 and 17.86%, respectively. Wierzbowska et al. (2020) found that addition of sewage sludge to the soil either dried or granulated or composted, raised the proportion of this P fraction in soil by about 25%. The P content in the residual form strongly related to total P content in soil (r = 0.875*) and slightly strong related to organic matter content, total-Pi and total-Po (r = 0.684*, 0.596* and 0.649* respectively) while negatively correlated with soil pH (r = − 0.697*).

2.10. Total P content

Total soil phosphorous content in all treatments is shown in Table (4). The results demonstrated that there were statistically significant increments in total P contents at SS application rates with/without WTRs applied, due to P addition in sludge compared to control, where increased from 308.06 to 458.02 $mgkg^{-1}$. Data also showed total P concentrations of treatments of SS with WTRs application were higher than those without WTRs application. The obtained data showed that slightly significant increase in total P content with WTRs treatments alone as compared to control where addition WTRs at rates 5, 10 and 15 gkg^{-1} soil increased the total phosphate content by 4.75, 5.77 and 7.54%, respectively. The increments of the total phosphate content upon the addition of 7.5, 1.5 and 22.5 g/kg sewage sludge were 29.70, 38.02 and, 45.37 %, respectively, compared to the control. Meanwhile, the highest total phosphate content was found in combination, of 22.5 g sewage sludge kg^{-1} soil with each of 5, 10 and 15 g kg^{-1} soil of WTRs where increase total P by 45.29, 47.91 and 48.68%, respectively. These results are in greatly agreement with that found by Wierzbowska et al. (2020), who reported that the highest total P content in soil was detected in the dry granulated sewage sludge treatments (DGSS) where increased from 524.2 to 686.3$mgkg^{-1}$ and also Kalembasa and Kuziemska (2007) stated that sewage sludge introduced to soil increased total P content in soil and the highest percentage of extracted P was in P bound to Al-and Fe-oxides while the lowest was in occluded phosphates. Generally, the increments in total-P contents are chaperoned by greater accumulation of available P contents.

2.11. Organic P (Po) fractions

Organic P constitutes a small portion of the total soil P (1.11%) while the remaining 98.89% was contributed by the inorganic P. The differences in Po fractions restraint to co-application treatments is found in Table (5). The increasing trend of Po followed the order of HCl_C-Po > $NaHCO_3$-Po > NaOH-Po compared to control. The high increases in Po in all organic fractions are related to increase SS rates, where Po increased from 4.38 to 7.85 mg kg^{-1}, 2.52 to 3.01 mg kg^{-1}, and 11.79 to 15.13 mg kg^{-1} for $NaHCO_3$-Po, NaOH-Po, and HCl_C-Po, as SS rate increase from 7.5 to 22.5 gkg^{-1} respectively. While The organic P decrease as co-application WTRs-SS rate increase, The highest decreasing of Po in soil was obtained with combine 15 gkg^{-1} WTRs with 7.5,15 and 22.5 gkg^{-1}. This is due to P mineralization which occurs via organic anions releasing and siderophores & acid phosphatase production by microbes/plant roots (Yadaf and Tarafdar, 2001) or alkaline phosphatase (Tarafdar and Claasen, 1988) these enzymes cause hydrolysis of soil organic P or splitting of P from organic compounds. Organic P residues become available to plants only after mineralizing of organic matter leading to an increase in the soil inorganic P contents, that gets available to plant and returns to soil P circulation (Noack et al. 2012 and Wang et al. 2012). In inorganic form, P most often adsorbed to aluminum or iron oxides. According to Tiecher et al. (2017), the increment in organic P content is related to increase of organic carbon amount in soil.

2.12. Inorganic P (Pi) fractions

The co-application WTRs and SS had great significant effects on the proportion's inorganic P in soil where significantly enhanced their proportions in the soil, data in Table (5) shows that among all Pi fractions, HCl_D-P is the highest in concentration (207.28-243.64 $mgkg^{-1}$). The increasing pattern in Pi fractions in response to co-application WTRs-SS rate treatments showed changing trend compared to control that take the order of HCl_D-Pi > HCl_C-Pi > NaOH-Pi > $NaHCO_3$-P > NH_4Cl-P. Available fractions of inorganic P had a greater effect than other instable bonds of P on its availability to plants. Galvăo and Salcedo (2009) stated that long-term application of natural fertilizers influenced P in soil and led to its accumulation in mineral forms, predominant over the organic forms.

2.13. P concentration in radish parts and its uptake

Concerning dry matter of root and shoot of radish yield. Data in Table (6) show that contents of shoot and root dry weight had significantly increments ($p < 0.05$) as increasing the applied rate of WTRs, SS individually or in combination as compared to untreated treatment. Co-application WTRs and SS treatment had scored higher contents of dry weight of Shoot and root in radish yield as compared to those given by individually of WTRs or SS treatments. The highest root and shoot dry weight were obtained by combine of 15 gkg^{-1} WTRs with each of 7.5, 15 and 22.5 gkg^{-1}sewage sludge, where the increasing rates were 56.25, 62.79 & 81.61 and 46.53, 53.04 & 66.67% of dry

Table (5). Mean values for organic and inorganic P fractions (mgkg^{-1}) as affected by co-application of WTRs-SS in the studied soil.

Treatment (gkg^{-1})		Organic fraction (mgkg^{-1})			∑ Po	Inorganic fraction (mg/kg)					∑ Pi
SS	WTRs	$NaHCO_3$-Po	NaOH-Po	HClc- Po		NH_4Cl-P	$NaHCO_3$-Pi	NaOH-Pi	HCl_D-P	HClc- P	
Control		0.23^{g}	0.95^{e}	2.23^{f}	3.41^{f}	1.01^{f}	3.35^{g}	6.70^{f}	207.28^{h}	50.41^{h}	304.65^{j}
0	5	0.22^{g}	0.87^{e}	2.22^{f}	3.31^{f}	0.81^{f}	3.04^{g}	7.22^{f}	217.82^{g}	52.90^{gh}	319.38^{i}
	10	0.22^{g}	0.85^{e}	2.20^{f}	3.27^{f}	0.73^{f}	2.56^{g}	7.29^{f}	220.86^{f}	53.47^{g}	324.55^{h}
	15	0.21^{g}	0.91^{e}	2.21^{f}	3.33^{f}	0.58^{f}	2.13^{g}	7.37^{f}	224.61^{e}	53.21^{g}	329.96^{h}
7.5	0	4.38^{de}	2.52^{dc}	11.79^{c}	18.19^{cd}	20.50^{c}	22.25^{cd}	15.90	229.94^{d}	54.71^{g}	381.36^{g}
	5	3.71^{e}	2.43^{d}	10.23^{d}	16.37^{d}	18.50^{cd}	20.46^{d}	18.95^{e}	232. 28^{c}	59.80^{f}	388.70^{g}
	10	2.63^{f}	2.23^{d}	8.85^{e}	13.71^{e}	14.54^{d}	15.41	27.60^{b}	238.12^{b}	64.79^{e}	403.00^{e}
	15	2.53^{f}	2.16^{d}	8.35^{e}	13.04^{e}	10.58^{e}	10.51^{f}	24.51^{c}	238.33^{b}	67.45^{d}	401.27^{e}
15	0	6.56^{b}	2.75^{c}	14.45^{b}	23.76^{ab}	26.16^{b}	29.57^{c}	16.92^{ef}	227.03^{d}	64.08^{e}	401.42^{e}
	5	5.55^{c}	2.71^{c}	12.22^{cd}	20.48^{b}	23.83^{bc}	27.20^{c}	23.33^{c}	232.53^{c}	76.09^{cd}	415.93^{d}
	10	5.06^{d}	2.73^{c}	11.65^{c}	19.44^{c}	14.04^{d}	18.40^{e}	25.64^{bc}	239.65^{b}	78.16^{c}	419.46^{c}
	15	4.82^{d}	2.69^{c}	10.02^{d}	17.53^{cd}	13.50^{d}	17.60^{e}	27.10^{b}	241.73^{b}	80.20^{bc}	440.55^{a}
22.5	0	7.83^{a}	3.01^{a}	15.13^{a}	25.97^{a}	28.66^{a}	37.96^{a}	22.24^{d}	242.86^{a}	68.91^{d}	397.06^{f}
	5	7.23^{a}	3.00^{a}	13.85^{b}	24.08^{a}	25.45^{b}	35.27^{b}	26.21^{b}	243.90^{a}	78.32^{c}	423.49^{c}
	10	7.01^{b}	2.89^{b}	11.35^{c}	21.25^{b}	13.54^{d}	21.28^{d}	29.73^{a}	242.86^{a}	84.43^{b}	434.39^{b}
	15	6.68^{b}	2.91^{ab}	10.55^{d}	20.14^{b}	12.41^{de}	17.86^{e}	30.33^{a}	243.64^{a}	86.40^{a}	437.88^{b}
LSD $_{(0.05)}$		0.045	0.33	0.02-	0.21	1.45	0.025	0.55	3.66	1.011	0.33

The similar letters in each column means that no any significant difference presents at 0.05 level.

Table (6). Effects of co-application water treatment residuals (WTR) and sewage sludge (SS) on root and shoot dry weight (g/pot), P and Al Conc. (mgkg^{-1}) and uptake of root and shoot of radish grown on experimental soil.

Treatments SS	Treatments WTRs	Dry weight of root	Dry weight of shoot	Root P (mgkg^{-1})	Shoot P (mgkg^{-1})	P uptake of root (mgpot^{-1})	P uptake of shoot (mgpot^{-1})	Root Al (mgkg^{-1})	Shoot Al (mgkg^{-1})	Al uptake of root (µgpot^{-1})	Al uptake of shoot (µgpot^{-1})
(gkg^{-1})											
Control		0.16^{e}	0.54^{h}	1245^{g}	1875	0.199^{f}	1.013^{h}	27.85^{a}	18.89^{a}	4.46^{f}	14.20^{de}
0	5	0.16^{e}	0.56^{h}	1240^{g}	1865	0.198^{f}	1.044^{h}	27.56^{a}	17.35^{b}	4.41^{f}	9.72^{e}
	10	0.17^{e}	0.64^{h}	1124^{g}	1554	0.191^{f}	0.995^{h}	27.23^{a}	14.52^{d}	4.63^{f}	9.29^{e}
	15	0.18^{e}	0.66^{h}	1079^{g}	1355	0.194^{f}	0.894^{h}	26.45^{b}	14.37^{d}	4.76^{f}	9.48^{e}
7.5	0	0.25^{d}	0.92^{g}	2354^{e}	3652	0.589^{e}	3.360^{f}	26.75^{b}	17.59^{b}	6.69 ^{e}	16.18^{c}
	5	0.24^{d}	0.93^{g}	2218^{e}	3575	0.532^{e}	3.325^{f}	25.32^{b}	15.55^{d}	6.08^{e}	14.46
	10	0.27^{d}	0.99^{f}	2015^{ef}	3085	0.544^{e}	3.054^{f}	25.05^{b}	14.23^{d}	6.76 ^{e}	14.09^{de}
	15	0.28^{d}	1.01^{f}	1985^{f}	2575	0.555^{e}	2.600^{g}	24.76^{c}	12.57^{e}	6.93^{e}	12.70^{d}
15	0	0.41^{c}	1.12^{e}	2887^{cd}	4215	1.184^{c}	4.720^{e}	25.75^{b}	16.21^{c}	10.56^{c}	18.16^{c}
	5	0.40^{c}	1.14^{d}	2765^{d}	4355	1.106^{c}	4.965^{e}	23.55^{d}	15.52^{d}	9.42 ^{d}	17.69^{c}
	10	0.42^{c}	1.11^{e}	2395^{e}	3912	1.006^{d}	4.342^{e}	23.04^{d}	12.58^{e}	9.68^{d}	13.96^{d}
	15	0.43^{c}	1.15^{d}	2155^{ef}	3657	0.927^{d}	4.206^{e}	22.75^{f}	11.22^{e}	9.78^{d}	12.90^{d}
22.5	0	0.73^{b}	1.52^{c}	3657^{a}	5326	2.670^{a}	8.095^{b}	25.55^{b}	15.05^{d}	18.56^{b}	22.88^{b}
	5	0.72^{b}	1.57^{c}	3357^{b}	5225	2.417^{b}	8.203^{a}	25.23^{b}	18.17^{a}	20.69^{a}	28.53^{a}
	10	0.82^{a}	1.62^{b}	3075^{c}	4875	2.522^{a}	7.898^{c}	23.67^{d}	12.85^{e}	19.41^{b}	20.82^{bc}
	15	0.83^{a}	1.70^{a}	2875^{cd}	3995	2.386^{b}	6.793^{d}	22.75^{e}	11.75^{e}	18.88^{b}	19.98^{bc}
LSD $_{(0.05)}$		0.01	-	1.02	2.45	0.12	0.33	1.56	0.12	1.88	0.85

The similar letters in each column means that no any significant difference presents at 0.05 level.

weight of root and shoot respectively, compared to control. these results meant that WTRs did not have negative effects on dry matter and yield of radish plant but rather WTRs enhanced the growth and yield. While increasing applied WTRs rate significantly ($p < 0.05$) reduced P and Al contents in root and shoot (Table 6 and Fig. 2). These decreasing in P contents may be due to binding of mineral P to Al $(OH)_3$ but symptoms of P-deficiency were not noted with rising WTRs levels or A1 toxicity either, It has been supposed that resistance of plants to AI precipitates $AlPO_4$ at the surface of root and makes as a barrier to decrease Al transportation into the root, and subsequent to the shoot (Millard et al., 1990). Many researchers (Fageria et al., 1988 and Taylor, 1991) confirmed that as well as Al immobilization, chelation and precipitation mechanisms in non-sensitive cell sites, other insularity mechanisms as a plant resistance to Al, while McLaughlino et al. (1981) could supposed that decreasing in plant A1 concentrations would be due to possible formation of crystalline $Al(OH)_3$

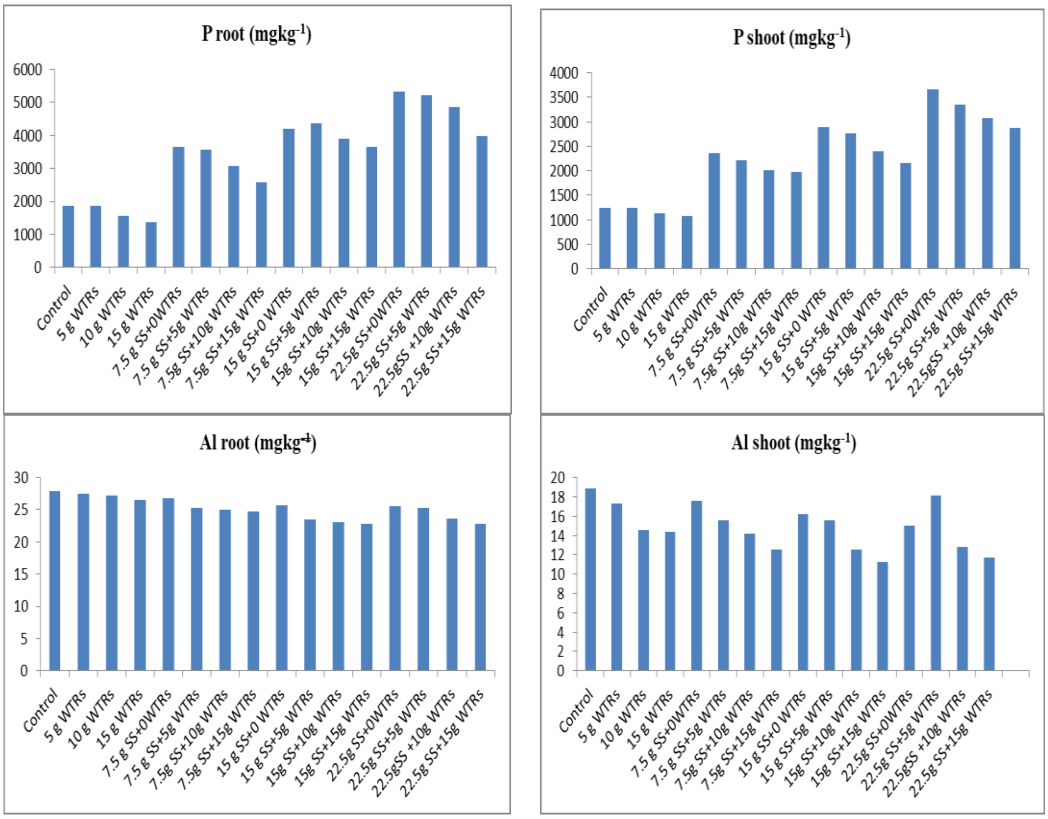

Fig. (2). Concentration of P and Al ($mgkg^{-1}$) in root and shoot of radish plant as affected by co-application of WTRs-SS.

These results agree with the those found by Ippolito et al. (1999 and 2009) whom reported that there were a positive linearly relationship between increasing WTRs rate and dry matter values of blue grama and a negatively relationship with raising of WTRs rate and concentration of P and AI in shoot ($p < 0.10$).The same obtained results recorded by Heil and Barbarick (1989) stated that with increasing WTRs application rate, the increment in dry matter and the decrement in P concentration were observed in the plants. They also, reported that the higher adsorptive capacity of WTRs, can limit P availability even in present of other source of P (i.e., biosolids). Cornell et al. (1995) noted that an increase in natural pasture plants compared with lower co-application rates 3 years after co-application of 5 tons biosolids acre $^{-1}$ with 10 tons WTRs acre $^{-1}$. Sewage sludge may act as a source of phytoavailable P, overcoming the P adsorptive capacity of WTRs, as well as WTRs improves water holding capacity and aeration. McLaughlino et al. (1981) could hypothesized that plant A1 concentrations would decrease due to possible crystalline $Al(OH)_3$ formation. Ribeiro et al. (2022) reported that WTRs levels did not have negative effects on the agrarian variables of ryegrass or maize plants. Thus, they recommended application rates of WTRs up to 30 mg ha^{-1}.

CONCLUSION

The highest P content in the Suez soil was in Ca-bound P fraction and the lowest in water soluble fraction, Co-application of WTRs with sewage sludge may be beneficial land application, and may benefit in P availability especially sewage sludge inherently high in P concentrations. Sewage sludge may act as a source of phytoavailable P, overcoming the P adsorptive capacity of WTRs, as well as by adjusting the WTRs application rate might prevent its negative effects and improve the quality of sandy soils. Co-application of WTRs with sewage sludge increased the total-P content and P content in moderately available and non-available fractions especially hard soluble Al-Fe bound P. 5 g kg^{-1} of WTRs applied to soils with P source (sewage sludge) resulted in lower negative effects on water soluble P and exchangeable-P contents and was effective in increasing the hard-P content compared to other solely treatments where increased by 84.18%.The acquired results that good evidence that WTR-SS co-application promotes plant growth and productivity, WTRs-SS co-application has a positive impacts on radish growth and yield. There was a growing interest in the beneficial use of WTRs as soil amendment, where the addition of WTRs improves the soil phyiso-chemical characteristics.

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تأثير إضافة مخلفات تنقية مياه الشرب وحمأة الصرف الصحي على صور الفسفور في تربة رملية

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إن تسريع السياق بشكل كبير لإعادة استخدام المخلفات بسبب الضغط المتزايد والاتجاهات لإعادة استخدام النفايات وإعادة تدويرها بالإضافة إلى التوجيهات لتحسين التربة أدى إلى إعادة الاستخدام المفيد لمخلفات تنقية مياه الشرب (WTRs) التي تم تصنيفها مؤخرًا على أنها مخلفات غير خطرة. ناتجة عن محطات المعالجة، والتي تستخدم عادة الشبة $[A1_2(SO_4)_3 14H_2 0]$ كعوامل تخثر وتلبد لترسيب المكونات غير المرغوب فيها من إمدادات المياه وترجع المخاوف بشأن إضافة WTRs للأراضي إلى الانخفاض المفترض في تيسر الفسفور وسمية الألومنيوم المحتملة مع زيادة معدلات إضافتها قد تكون الإضافة المشتركة لـ WTRs مع حمأة الصرف الصحي تطبيق مفيدًا في الأراضي. خاصة أن حمأة الصرف الصحي تحتوي بطبيعتها على تركيزات عالية من الفسفور ومن خلال ضبط معدل إضافة WTRs قد يمنع آثاره السلبية ويحسن جودة التربة الرملية. في تجربة أصص، قمنا بدراسة فعالية الإضافة المشتركة لمخلفات تنقية مياه الشرب وحمأة الصرف الصحي على محتوى الصور المختلفة من الفسفور في التربة وعلى تركيزات P&AI في الجزء الخضري والجذري لنبات الفجل وامتصاصهم. أشارت النتائج إلى أن أعلى كمية من الفسفور في التربة المدروسة كانت في الصورة المرتبطة بالكربونات (Ca-bound P) وأقل تركيز للفسفور كان في الصورة الذائبة في الماء. كما أدت الإضافة المشتركة لـ WTRs-SS إلى زيادة محتوى الفسفور الكلي وP المرتبط في الصور المعتدلة التيسر وغير الميسرة. وأظهرت النتائج أن إضافة WTRs بمعدل ٥ جم/كجم تربة كمصدر للفسفور (حمأة الصرف الصحي) أدت إلى انخفاض التأثيرات السلبية بشكل معنوي على محتوى الفسفور في الصورة الذائبة والمتبادلة، وكانت فعالة معنويًا في زيادة محتوى الفسفور في الصورة الثابتة لأكاسيد الألومنيوم والحديد، مقارنة بالمعالجات الأخرى حيث زادت بنسبة ٨٤.١٨٪. أظهرت النتائج أيضًا وجود علاقة خطية سلبية مع زيادة معدل WTRs وتركيز الفسفور في الجزء الخضري والجذري لنبات الفجل وتركيزات AI في الجزء الخضري للفجل وعدم وجود أعراض لنقص P أو سمية AI في نبات الفجل المرتبطة بإضافة WTRs.