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Physicochemical Properties of Water Treatment Residuals Generated from Different Water Purification Plants and the Growth of Vegetables Using these Residuals as a Plant Growing Medium

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In order to clarify whether the water treatment residual (WTR), i.e. an industrial waste, can be used as a plant growing medium or not, physicochemical properties of WTRs generated from two different water purification plants in Kitakyushu City in Japan were measured, and the growth of vegetables was experimented by using the WTRs to show the possible use of it as a plant growing medium. Komatsuna (*Brassica rapa var. perviridis*) was used as the vegetable. Bark compost (a soil conditioner) and/or phosphate (P) fertilizer were mixed to WTRs for improving its physicochemical properties. These mixture mediums were called cultivation soils. As a result, pH, and P absorption coefficient were not different between the WTRs and the cultivation soils. The pH, electric conductivity and effective cation exchange capacity of the cultivation soils were favorable, but the P absorption coefficient of the soils was too high for plant growth. Water–soluble and exchangeable manganese (Mn) concentrations of WTRs and cultivation soils differed largely between the two water purification plants. These Mn concentrations of the cultivation soils were high enough to cause Mn toxicity in plants. In the bark compost mixture soils, the water–soluble and exchangeable Mn concentrations were lower than those in the WTRs; the same characteristic of the Mn concentrations was also observed in the P fertilizer mixture soils. Concerning the vegetable growth experiment, almost no vegetables grew by using only the WTRs, and a positive effect of bark compost and P fertilizer mixtures on the vegetable growth was recognized. Mixtures of bark compost and/or P fertilizer to WTRs are, therefore, required for use WTRs as the plant growing medium.

Key words: bark compost, foliage weight, Japanese mustard spinach, phosphate fertilizer, use of industrial waste

INTRODUCTION

Water treatment residual (WTR), which is an industrial waste generated from water purification plants, has the potential to be used as a plant growing medium. There are some examples of research on the possibility of the use of WTR for growing plants, including the plants of bottle gourds (Kakuta *et al*., 2003), strawberries (Ohta *et al*., 2011), tomatoes (Dayton and Basta, 2001) etc. In these researches, plants exhibited a certain growth, indicating the availability of WTR for plant growing purposes.

However, since WTR contains a lot of manganese (Mn), the cultivated plants may suffer from Mn toxicity (or Mn excess) (Novak *et al*., 2007; Titshall and Hughes 2005; Trollip *et al*., 2013). In addition, WTR has a high phosphorous (P) absorption coefficient, thus, the plants may suffer from P deficiency (Xie *et al*., 2015; O'Connor *et al*., 2002; Razali *et al*., 2007; Ippolito *et al*., 2011). In addition, pH and cation exchange capacity are thought to greatly affect plant growth.

In the present study, some important physicochemical properties of the WTR, including the above mentioned ones, were measured, and then a plant growth experiment was performed using the WTR. Without experimenting plant growth, it is not easy to determine whether the physicochemical properties of the WTR are appropriate or not.

Usually, compost (a soil conditioner) and/or phosphate (P) fertilizer are mixed into WTR for plant growing purposes (Kakuta *et al*., 2003; Basta *et al*., 2000; Mahmoud and Elbaroudy, 2009; Hyde and Morris, 2004). Here, bark compost and P fertilizer were mixed in several levels, by which the physicochemical properties of the WTR may change respectively. These mixed mediums are hereafter called cultivation soils.

In the present study, WTRs, generated from two different water purification plants located in a municipality, were targeted, because there is a possibility that the properties of WTR may change with the water purification plants, and accordingly the utility value of the WTR may change, even in the neighboring locations.

Komatsuna (*Brassica rapa var. perviridis*) (Japanese mustard spinach), which is one of the common vegetables in Japan, was used in the plant growth experiment. Komatsuna has a good adaptability to various soil environments.

Based on the above, the followings were examined: 1. what were the characteristics of the physicochemical properties of WTRs and the cultivation soils, and what were the differences between them; 2. how did the vegetable growth relate to the physicochemical properties of the cultivation soils. In addition, the variation of the properties of the WTR in the different water purification plants was examined, but the examination was minimal, because the number of water purification plant targeted was only two.

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MATERIALS AND METHODS

WTRs were collected from the two different water purification plants of Anou and Ideura in Kitakyushu City, Fukuoka Prefecture, Japan. Bark compost and P fertilizer were mixed with WTRs to use for cultivating purposes. The cultivation soils, in which WTRs generated from the Anou plant are called "Anou soils", and those from the Ideura plant are called "Ideura soils" hereafter.

Bark compost was mixed into WTRs at three levels of 0, 15, and 40 percent volume of WTRs. Namely, WTR concentration in the cultivation soil was 100, 85 and 60% in the respective cases. These are hereafter denoted as WTR–100, WTR–85 and WTR–60, respectively.

P fertilizer was mixed at three levels of 0, 0.5 and 1.5 g per one litre of the cultivation soils. The mixture was done just before the growth experiment. These are hereafter denoted as P–0, P–0.5 and P–1.5, respectively. The P fertilizer used was manufactured by Seiwa Fertilizer Ind. Co., Ltd. in Japan, which contained 17.5% weight of P. In the following, the mixtures of 0 percent bark compost and 0 g P fertilizer to WTR, which is composed of WTR alone, is also included into the cultivation soils as long as it is used for plant growing purposes.

For the physicochemical properties of the cultivation soils, pH, electric conductivity (EC), effective cation exchange capacity (ECEC), P absorption coefficient, and concentrations of water–soluble and exchangeable manganese (Mn) were measured. All these properties could have a possibility to contribute to plant growth. The measurement was repeated three times for the respective samples under each level of bark compost and P fertilizer mixture. The measurement methods used were the common methods to determine soil properties, and these methods were already used in our previous research (Xie *et al.*, 2015), and the details were introduced in this research.

The Komatsuna growth experiment was done with four pots for the Anou soil, and five pots for the Ideura soil in terms of replication. The difference in the number of pots between the Anou and Ideura soils was owing to the collected amount of WTRs from the respective plants. In each pot, five seeds of Komatsuna were sown. Among them, three well–grown plants were left and the other two were thinned out seven days after sowing. These three plants were grown for 47 days in Anou soil and 28 days in Ideura soil after sowing. Komatsuna seeds were the commercially available ones purchased from Sakata Seed Corporation, Japan.

The vegetable growth experiment was performed in a phytotron facility in *Kyushu University*, where the air temperature was maintained at 20°C and the relative air humidity was maintained at 70%. During the experiment, water in an amount corresponding to the field capacity was supplied to the plants once in two days. Just after the 47 and 28 days of growth, foliage weight of the plants (above ground biomass weight; raw weight), was measured as a representative plant growth.

In order to clarify the effect of bark compost and/or P fertilizer mixtures on the physicochemical properties and foliage weight, the analysis of variance (ANOVA) was applied by using the Excel Software.

RESULTS AND DISCUSSION

Physicochemical properties of the WTRs and cultivation soils

The measured physicochemical properties on the

Table 1. Physicochemical properties of the WTRs (i.e. WTR–100) and cultivation soils, and the foliage weight of Komatsuna vegetables in the growth experiment (Average values)

Physicochemical properties/ foliage weight	Cultiv. soils	WTR–100 (Bark compost 0%)			WTR–85 (Bark compost 15%)			WTR–60 (Bark compost 40%)		
		P–0	P–0.5	P–1.5	P–0	P–0.5	P–1.5	P–0	P–0.5	P–1.5
pH	Anou	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.8	6.8
	Ideura	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
EC (ms/cm)	Anou	0.36	0.40	0.43	0.38	0.37	0.43	0.39	0.40	0.45
	Ideura	0.29	0.30	0.31	0.28	0.24	0.30	0.26	0.27	0.35
ECEC (cmol/kg)	Anou	14.8	14.5	16.7	17.5	17.8	19.8	21.2	22.2	24.6
	Ideura	11.9	12.5	14.3	14.9	15.1	17.2	19.7	21.4	23.4
P absorption coefficient	Anou	2231	2219	2257	2157	2204	2234	2244	2281	2348
	Ideura	2183	2181	2238	2292	2293	2347	2331	2349	2326
Water–soluble Mn conc. (mg/kg)	Anou	30	27	25	20	19	18	12	13	14
	Ideura	142	141	136	116	88	90	64	53	54
Exchangeable Mn conc. (mg/kg)	Anou	81	82	82	81	81	81	81	80	80
	Ideura	1480	1465	1429	1437	1420	1406	1311	1306	1253
Foliage weight of Komatsuna (g/plant)	Anou	0.01	0.87	2.62	1.55	2.31	2.17	0.55	0.36	0.56
	Ideura	0.00	0.00	0.00	0.04	0.04	0.08	0.40	0.54	0.58

P–0, P–0.5, P–1.5: Level of P–fertilizer mixture; WTR: Water treatment residual.

Table 2. Results of ANOVA for the effect of mixtures of bark compost and/or P fertilizer on the physicochemical properties and the foliage weight of the Komatsuna vegetables in the respective experiments

Physicochem. properties/ foliage wt.	Cultiv. soils	Effects	Mixture of bark compost		Mixture of P fertilizer		Interaction and the simple main effect test
EC	Anou	*	WTR–100,WTR–85 < WTR–60	**	P–0, P–0.5 < P–1.5		–
	Ideura	*	WTR–100 >WTR–85	**	P–0, P–0.5 < P–1.5		–
ECEC	Anou	**	WTR–100 < WTR–85 < WTR60	**	P–0, P–0.5 < P–1.5		–
	Ideura	**	WTR–100 < WTR–85 < WTR–60	**	P–0 < P–0.5 < P–1.5		–
P absorption coefficient	Anou	**	WTR–100, WTR–85 < WTR–60	*	P–0, P–0.5 < P–1.5		–
	Ideura	**	WTR–100 < WTR–85, WTR–60	*	P–0, P–0.5 < P–1.5		–
Water– soluble Mn conc.	Anou					**	WTR–100: P–0 > P–0.5, P–1.5; P–0, P–0.5, P–1.5: WTR–100 > WTR–85 > WTR–60
	Ideura					**	WTR–85,WTR–60: P–0 > P–0.5, P–1.5; P–0, P–0.5, P–1.5: WTR–100 > WTR–85 > WTR–60
Exchangeable Mn conc. (mg/kg)	Anou					**	WTR–100: P–0 < P–0.5 , P–1.5; WTR–60: P–0 > P–0.5 , P–1.5; P–0.5,P–1.5: WTR–100 > WTR–85> WTR–60
	Ideura	**	WTR–100 > WTR–85 > WTR–60	**	P–0 > P–0.5 > P–1.5		–
Foliage wt. of Komatsuna (g/plant)	Anou					**	WTR–100: P–0, P–0.5 < P–1.5; P–0, P–0.5: WTR–85 >WTR–100,WTR–60; P–1.5: WTR–100,WTR–85 >WTR–60
	Ideura	**	WTR100, WTR85 < WTR–60	*	P–0 < P–1.5		–

**and *: Significant at 1% and 5% levels; –: No significant difference was observed.

respective WTRs and cultivation soils are shown in Table 1, together with the Komatsuna's growth (foliage weight). Here, only average values are shown. The ANOVA results are shown in Table 2.

In Table 2, the cases of significant difference were only shown. The cases of no significant difference were not shown, though these cases were presented and discussed in the text.

According to Table 1, pH ranged from 6.7– 6.8 in Anou, and ranged at 7.1 in Ideura soils, showing the neutrality of the soils. Most of the pH values are favorable for plant growth based on Liu and Hanlon (2012).

EC (ms/cm) were 0.36–0.45 in Anou, and 0.26–0.35 in Ideura soils. These values are also favorable for plant growth based on Rayment and Lyons (2011). According to Table 2, EC was larger in WTR–60 than in WTR–85 and WTR–100 for Anou soils. While for Ideura soils, EC was larger in WTR–100 than in WTR–85, and no difference was observed in the other comparisons of WTRs.

EC was increased in P–1.5 compared to P–0 and P–0.5, and was not increased in P–0.5 compared to P–0 in both Anou and Ideura soils (Table 2).

ECEC (cmol/kg) ranged from 14.5–24.6 for Anou, and 11.9–23.4 for Ideura soils, appearing to be no major difference in ECEC between the two cultivation soils. According to the ANOVA results (Table 2), ECEC increased from WTR–100 to WTR–85 and then to WTR–60 for Anou and Ideura soils on the effect of the mixture of bark compost. While ECEC increased from P–0/P–0.5 to P–1.5 for Anou, and increased from P–0 to P–0.5 and then to P–1.5 for Ideura soils on the effect of the mixture of P fertilizer.

In Table 1, the P absorption coefficient ranged from 2,181–2,349 in both Anou and Ideura soils. Generally, if the coefficient exceeds 2,000, most of the P in the soils can be adsorbed in the soil particles, becoming unavailable for plant growth.

According to Table 2, the coefficient was larger in WTR–60 than in WTR–85 and WTR–100 for Anou, and larger in WTR–60 and WTR85 than in WTR–100 for Ideura soils on the effect of bark compost mixture; and the coefficient was larger in P–1.5 than in P–0 and P–0.5 for both soils on the effect of P fertilizer mixture. Here, the coefficient was likely to be increased by the mixtures. The reason was possibly that the P contained in bark compost and P fertilizer made to increase the amount of P adsorbed in soil particles, which raised the coefficient.

The water–soluble Mn concentration (mg/kg) ranged from 12–30 for Anou, and from 53–142 for Ideura soils. The exchangeable Mn concentration (mg/kg) ranged from 80–82 for Anou, and from 1,253–1,480 for Ideura soils (Table 1). Here, both the water–soluble and exchangeable Mn concentrations, in particular the exchangeable Mn concentration, were larger in Ideura than in Anou soils.

In the ANOVA results (Table 2), the interaction between the effects of the mixtures of bark compost and P fertilizer (the two factors) was observed for the water–soluble and for the exchangeable Mn concentrations in Anou soils. In Ideura soils, the interaction was observed in the water–soluble Mn concentration only.

In the case when the interaction was observed, the simple main effect test was performed to investigate the effect of the respective factors, instead of examining the effects of the respective factors. The results were shown in Table 2.

From Table 2, the water–soluble Mn concentration decreased in P–0.5 and P–1.5, compared to P–0 for WTR–100 in Anou soils. No significant change in the concentration was observed by the P fertilizer mixture for both of WTR–85 and WTR–60 for Anou soils.

In Ideura soils, the water–soluble Mn concentration decreased in P–0.5 and P–1.5 compared to P–0 for WTR–85 and WTR–60. However, no significant change in the concentration was observed by the mixture of P fertilizer for WTR–100.

The water–soluble Mn concentration decreased with the increased mixture of bark compost, i.e. decreased from WTR–100 to WTR–86 and then to WTR–60 for both Anou and Ideura soils at P–0, P–0.5 and P–1.5.

For Anou soils, the exchangeable Mn concentration was larger in P–0.5 and P–1.5 than in P–0 for WTR–100, while the concentration was larger in P–0 than in P–0.5 and P–1.5 for WTR–60. No significant change was observed between P–0, P–0.5 and P–1.5 for WTR–85. Here, the effect of P fertilizer mixture on the concentration varied affected by the amount of bark compost mixture.

The exchangeable Mn concentration decreased with the increased mixture of bark compost at P–0.5 and P–1.5 in Anou soils; however, their decreases were small (Table 1).

In Ideura soils, the exchangeable Mn concentration decreased with the increased mixtures of bark compost and P fertilizer (Table 2).

By the mixture of bark compost, the permeability of the cultivation soils could increase, due to the increase in pore spaces in the soils. According to Gilkes *et al.* (1988), Mn exists as a trivalent or tetravalent oxide in soils under aerobic conditions. By the possible increase in the permeability, the water–soluble and exchangeable Mn, which are divalent Mn, decreased by their conversion to trivalent or tetravalent Mn by oxidation. For the oxidation of divalent Mn, the activity of Mn oxidizing bacteria may have been concerned. It is, therefore, important to verify whether the oxidizing bacteria exist or not in bark compost in a further study.

Moreover, the mixture of P fertilizer is considered to decrease the concentrations of water–soluble and exchangeable Mn in most cases (Table 2). Further examination is necessary to clarify this reason.

Growth of the Komatsuna vegetable

According to Table 1, the foliage weight of Komatsuna was 0.01–2.62 g for Anou and 0.00–0.58 g for Ideura soils. At P–0 of WTR–100 (i.e. in case of WTR alone), the weight of 0.00–0.01 g, which showed almost no growth of vegetable, was observed in both Anou and Ideura Soils.

According to the ANOVA results (Table 2), there was an interaction between the effects of bark compost and P fertilizer mixtures in Anou soils. Based on the simple main effect test (Table 2), the foliage weight was larger in P–1.5 than in P–0 and P–0.5 for WTR–100. For both WTR–85 and WTR–60, no significant change in the weight was observed with the P fertilizer mixture.

While, the weight was higher in WTR–85 than in WTR–100 and WTR–60 when the P fertilizer mixture levels were P–0 and P–0.5. The weight was higher in WTR–100 and WTR–85 than in WTR–60, when the P fertilizer level was p–1.5. From the above, the effects of the mixtures of bark compost and P fertilizer on the weight were recognized when the mixtures were in some levels.

For Ideura soils, there was no interaction between the two factors on Komatsuna growth. According to the ANOVA results (Table 2), the weight was larger in WTR–60 than in WTR–85 and WTR–100 on the effect of bark compost mixture. While the weight was larger in P–1.5 than in P–0 on the effect of P fertilizer mixture, however, no significant difference was observed between P–1.5 and P–0.5 and between P–0.5 and P–0. From the above, the positive effects of the mixtures of bark compost and P fertilizer were recognized, though limitedly.

Difference in the physicochemical properties of the cultivation soils and its background, and the effect of the properties on Komatsuna growth

In generating WTRs from water purification plants, the dewatering method was different between the Ideura and Anou plants. A mechanical dewatering method was adopted in the Anou plant, while, a solar drying method was adopted in the Ideura plant. In the Ideura plant, it took over two months for solar drying, during which the sludge to become WTR was exposed to waterlogged reducing conditions. In the reducing conditions, Mn can be converted into available Mn (Stokes *et al.*, 1988), i.e. water–soluble and/or exchangeable Mn. With these conversions, the concentrations of water–soluble and exchangeable Mn can be heightened in the WTR. When the available Mn concentration in the soils becomes high, the Mn are absorbed by plants and the Mn toxicity for plants occurs.

The critical water–soluble Mn concentration which generates the Mn toxicity for plants is 5 mg/kg (Takahashi *et al.*, 1980). According to Watanebe (2002), Mn toxicity apparently occurs when the exchangeable Mn concentration exceeds 100 mg/kg. According to Table 1, water–soluble Mn concentration greatly exceeded the critical level in both Anou and Ideura soils, and the exchangeable Mn concentration exceeded 100 mg/kg in all of the Ideura soils. In addition, according to Hazelton and Murphy (2007), the critical available Mn concentration, which starts to affect crop yield, is 65 mg/kg (for sensitive species). Available (i.e. water–soluble plus exchangeable) Mn concentration greatly exceeded the critical level in both the Anou and Ideura soils (Table 1). These features might inhibit Komatsuna growth.

According to Table 2, the water–soluble and exchangeable Mn concentrations were mostly decreased with the increased mixture of bark compost, as well as with that of P in both the Anou and Ideura soils. Therefore, mixtures of bark compost and/or P fertilizer to WTRs probably contributed to the decrease in water–soluble and exchangeable Mn concentrations.

CONCLUSIONS

The following conclusions were drawn from this study.

For the physicochemical properties on the WTRs generated from two different water purification plants, pH, EC, ECEC and P absorption coefficient, which were not different between the two plants, showed favorable conditions for plant growth, excepting P absorption coefficient.

The pH, EC, ECEC and P absorption coefficient of the cultivation soils, which were made by the mixtures of bark compost and P fertilizer into WTRs, were not largely different to those of the WTRs.

Concentrations of water–soluble and exchangeable Mn of WTRs were high enough to cause Mn toxicity, and the concentrations showed a large difference between the WTRs of the two plants. The difference was thought to be due to the difference in the dewatering method in the respective plants. In a solar–drying dewatering, the materials to become WTRs were exposed to reducing conditions, making Mn to be water–soluble and/or exchangeable Mn.

In the cultivation soils, the mixtures of bark compost and P fertilizer to WTRs decreased the concentrations of water–soluble and exchangeable Mn to some extent.

In the plant growth experiment using Komatsuna vegetables, the growth increased when some amount of bark compost and/or P fertilizer were mixed with the WTRs. When the WTRs alone were used, almost no growth of the vegetable was observed. Here, a positive effect of the mixtures of bark compost and P fertilizer to WTRs was recognized.

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