International Journal of Plant & Soil Science
4(1): 80-86, 2015; Article no.IJPSS.2015.008
ISSN: 2320-7035

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Physicochemical Properties of Plant Growing Medium Comprising Water Treatment Residuals Amended with Composted Park

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Authors' contributions

This work was carried out in collaboration between all authors. Author YX designed the study, wrote the protocol, collected materials and performed the experiment. Author MM studied the soil microbiological aspects of the medium. Authors YX and KK wrote the first draft of the manuscript and managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2015/11764
Editor(s):
(1) Kefeng Zhang, Ningbo Institute of Technology, Zhejiang University, Zhejiang, China.
(2) Bin Gao, Dept. of Agricultural & Biological Engineering, University of Florida, USA.
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Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=651&id=24&aid=6098

Short Research Article

Received 2nd June 2014
Accepted 26th August 2014
Published 13th September 2014

ABSTRACT

The physicochemical properties were measured for medium comprising water treatment residuals (WTR) amended with composted bark (two different volume ratios of WTR to composted bark) one month after creation, in order to determine its suitability for plant growing purposes. Compared to the WTR alone, the WTR + bark medium exhibited similar neutral pH and a redox potential (Eh) indicating aerobic conditions, higher electrical conductivity (EC), cation exchange capacity (CEC), and total carbon (C) and nitrogen (N) concentrations, and lower phosphate (P) absorption coefficients and available manganese (Mn) concentrations. Comparing to the theoretical baseline medium immediately after creation, the WTR + bark medium, after a one-month incubation, exhibited a decline in available Mn, total C, and total N concentrations and an increase in CEC and P-absorption coefficients. These changes may be attributable not only to the introduction of

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composted bark but, also, to the increase in aerobic microbial activity or some factor by incubation. The pH, Eh, EC and C/N ratio for the WTR + bark medium indicated that it is suitable for growing plants. The reduction in available Mn concentration by nearly half relative to WTR alone suggests a lower occurrence of Mn toxicity syndrome for plants. Furthermore, despite the potential for the high P-absorption coefficient of WTR + bark medium to cause P deficiencies in plants, this deficit can be compensated by the application of P fertilizer. Thus, the WTR + bark medium is concluded to be suitable as a plant growing medium.

Keywords: Available manganese; microbial activity; phosphate absorption; water treatment sludge.

1. INTRODUCTION

Water treatment residuals (WTR), otherwise known as “water treatment sludge” or “water purification sludge,” are the industrial waste discharged from water purification plants. Since large amounts of WTR are discharged continuously, its efficient disposal or use is a challenge. WTR have soil like qualities, therefore WTR have a potential to be used as a soil substitute medium (or plant growing medium) [1]. For using WTR as a plant growing medium, its physicochemical properties are important. On the properties of WTR, cation exchange capacity (CEC) and organic carbon content are suitable [2], but phosphorus (P) is too readily adsorbed [3] and manganese (Mn) levels are excessive [4], which are unsuitable for plant growing purposes.

According to Tamaue [5], plant growth is severely limited when WTR alone is used as a growing medium. As such, soil [6,7] and composted bark and soil [8] are added to WTR. This medium is referred to as the combined growing medium in the following.

According to Roppongi [9], the exchangeable Mn concentration of a combined growing medium decreases with time. The decrease is perhaps due to the change in the chemical form of Mn in the medium, and Kenneth [10] indicated that the change in chemical form of Mn was caused by the microbial activity in the soil medium. For the combined growing medium, the physicochemical properties and its changes with time have not been studied, except the Mn concentration.

Therefore, various physicochemical properties are measured on WTR and the combined growing medium. For the latter medium, the properties are measured after a period of time, while its initial (baseline) properties are derived from estimation. After then, it is clarified that how the properties of the combined growing medium change from those of WTR and from baseline properties of the combined growing medium, what is the cause of the changes if they are found, and if the combined growing medium can be used for plant growing purposes.

2. MATERIALS AND METHODS

A plant growing medium was prepared by using WTR and composted bark (as a soil conditioner) and its physicochemical properties were measured, with particular emphasis on the chemical properties. Measurements were performed not only on the combined growing medium (hereinafter “WTR+ medium”), one month after set-up, but also on the WTR and composted bark. Based on the measurements for the WTR and bark alone, baseline properties were estimated for the WTR+ medium immediately after set-up (hereinafter “baseline medium”). WTR was collected from the Tatara Water Purification Plant in Fukuoka City, Japan and air-dried, crushed, and passed through a 2-mm mesh sieve. The composted bark was a commercially available product. Composted bark is a soil amendment to help drainage and aeration and increase nutrient retention [11]. The composted bark were grounded and air-dried and then combined with the WTR. Two kinds of WTR + plant growing media were created by combining WTR with composted bark at a volume ratio of 4:1 (WTR: bark), referred to as WTR+A, and at a ratio of 3:2, referred to as WTR+B. The respective media were placed in plastic bags and a volume of water was added to saturate the media. Next, the bags were sealed to prevent evaporation of water and stored in the open air for a period of one month. The mean temperature and humidity of the open air during the experiment were 25.6℃ and 77% by referring to the nearest weather station data [12]. After one month, the media were removed from the bags and air-dried prior to the performance of measurements. The media were stored for one month prior to measurement as there was a possibility that the physicochemical properties would change, if only slightly, with time. The quantity of WTR obtained was so small that the measurements of properties described below cannot be repeated for different WTR samples, and thus the statistical analysis on the differences of the properties cannot be performed.

The physicochemical properties were measured for the two types of WTR + media, the WTR, and composted bark. The parameters measured and methods used are as follows. pH and ORP (Oxidation-Reduction Potential) were measured using a pH/ORP meter (Horiba D51 and D52). Since a comparative electrode was used for the ORP meter, the recorded ORPs were converted to values corresponding to a standard hydrogen electrode (equivalent to the redox condition of Eh). Electrical conductivity (EC) was measured using an EC meter (Horiba ES51). Water-soluble and exchangeable Mn concentrations were determined based on the procedure by Gambrell [13]. Plants only absorb divalent Mn species. The P-absorption coefficient was determined by the ammonium phosphate method [14]. The coefficient shows the strength of phosphorus fixation. The higher the value, the stronger the fixation and P fertilizer is less effective [15].

Total–C and total–N concentrations, from which the C/N ratio was calculated, were determined using a CN corder (MT–5/MT-6 CHN corder). Release of N by soil microbes from decomposition of organic matter depends on the C/N ratio, and when the C/N ratio is less than 20, soil microbes mineralize the nitrogen into plant-available inorganic form [16]. CEC was calculated as the sum of exchangeable cations (Ca, K, Mg and Na) as determined by the leaching method [14].

3. RESULTS AND DISCUSSION

3.1 Differences in Physicochemical Properties of the WTR+ and Baseline Media and the Effect of Composted Bark

Table 1 shows the measured physicochemical properties of the media and media components. The quantitative properties of the baseline medium were estimated based on the measured values for WTR and composted bark and the WTR: bark ratio.

Result from Table 1 showed that the pH of WTR and composted bark (6.6-6.9) did not differ substantially. In contrast, the pH of both the WTR + A and WTR+B media was near neutral (7.1 and 7.2, respectively). Given that Eh of the WTR+ medium (405-412 mV) fell within the Eh range for aerobic conditions [17], we assumed that the medium was under aerobic conditions.

Eh for the WTR+ medium was lower than that of the WTR alone (431 mV), and the Eh or WTR+B was lower than that of the WTR+A. Since it has been shown that composted bark enhances microbial respiration [18], we speculate that this result was due to increased oxygen consumption by microbes in WTR+B compared to WTR+A, which, in turn, was the result of the higher relative volume of composted bark in WTR+B. Considering the Eh results, we assume the increased microbial respiration was aerobic.

EC was found to be higher in WTR+B (0.37) than WTR+A (0.33). According to WRAP [19], EC increases with increasing total ion concentration of soil. Ion concentrations may have been higher in WTR+ B than WTR+A, again due to higher proportion of composted bark in the former, resulting in the higher EC for WTR+B. Both water-soluble and exchangeable Mn concentrations were higher in WTR than in composted bark. In the WTR+ medium, water-soluble Mn was undetectable, and the exchangeable Mn concentration (27.7-30.5mg/kg) was almost half that in the WTR alone (55.1 mg/kg). For the baseline medium, we assumed that water-soluble and exchangeable Mn concentrations would be higher in WTR+A than in WTR+B, based on the former's higher proportion of WTR, which had higher water-soluble and exchangeable Mn concentrations than the composted bark.

The P-absorption coefficient was lower in the composted bark than the WTR by more than 1,500 (mg/100g). In the baseline medium, we estimated that the P-absorption coefficient of WTR+A would be greater than that of WTR+B, reflecting the impact of the low P-absorption coefficient of the composted bark.

Total C and N concentrations and CEC were much higher in composted bark than in WTR. In the baseline medium, we estimated these properties to be greater in WTR+A than WTR+B again reflecting the effect of composted bark. This assumed ranking was maintained in the actual WTR+ medium.

Further, properties of WTR similar to our results were observed on Mn, total C and total N concentrations, P-absorption coefficient and/or CEC [1,20-22], indicating that the properties mentioned above are the usual ones for WTR.

3.2 Changes in Physicochemical Properties of WTR+ Medium over One Month

Here, the measured properties of the WTR+ medium were measured with the estimated properties of the baseline medium. From Table 1, it is apparent that the exchangeable Mn concentration declines substantially in the WTR+ medium relative to the baseline medium for both WTR+A and B. This may be attributed to the activity of Mn-oxidizing bacteria, as suggested by Kakuta et al. [8], which convert soluble Mn^{2+} to insoluble MnO [23]. Considering the higher Eh of WTR+A relative to WTR+B, which indicates the former's higher oxidative state, the greater decline in exchangeable Mn concentration in WTR+ A relative to WTR + B may indicate higher bacterial activity in the former. However, the difference in Eh between WTR + A and WTR+B was not so large, indicating that the effect of Eh on the Mn concentration may not be different between the media. It leads to the conclusion that other factors may be involved and suggests that further study is necessary.

In Table 1, the P-absorption coefficient was slighter higher in the WTR+ medium than in the baseline medium for both WTR + A and WTR+B. The coefficient indicates the strength of P-fixation. Its value for WTR is high from the beginning, because WTR contain a lot of aluminum (Al) -based flocculants used in the production process, which comprise high quantities of positive Al ions, combine negative P ions. Since the quantity of Al (total-Al) is not different between the baseline and the WTR+ media, some qualitative change may have occurred in Al by incubation, affecting to make the coefficient higher in the WTR+ medium than in the baseline medium.

Both C and N concentrations were lower in the WTR+ medium than in baseline medium for both WTR + A and WTR+B. In other words, C and N concentrations decreased over the one-month incubation period. The decrease (%) was greater for WTR+B (C=9.0, N=0.8) than WTR+A (C=4.6, N=0.4), perhaps reflecting the former's higher proportion of composted bark. According to Rohde [24], soil microbes utilize C for growth and N for protein synthesis. Thus, it is likely that the level of soil microorganism activity influences the degree of decline in the C and N concentrations.

Meanwhile, CEC was higher in the WTR+ medium than in the baseline medium for both WTR + A and WTR+B, indicating that CEC increased over the one-month incubation period. According to Sato [25], during the bark composting process, organic matter is oxidized by bacteria. Thus, the increased CEC may reflect the liberation of ions resulting from bacterial activity.

3.3 Evaluation of WTR+ Medium as a Plant Growing Medium

In the WTR+ medium, exchangeable Mn was equivalent to available Mn in concentration, because the amount of water-soluble Mn was negligible. Charlet et al. [26] showed that available Mn concentrations in the range of 0.1-10mg/kg were normal and too low to cause Mn toxicity syndrome (due to excess Mn) in plants. The available Mn concentration of the WTR+ medium (27.7 to 30.5mg/kg, Table 1) still exceeded normal levels, but was nearly half that of WTR alone (51.2 to 56.2mg/kg), which showed a trend toward a lower occurrence of Mn toxicity syndrome.

Given that plants absorb nutrients well in the range of pH 5.5 to 7.5 [27], the pH of the WTR+ medium (7.1 to 7.2) is not problematic for plants. Similarly, the EC of the WTR+ medium (0.3-0.4 dS/m) is also not problematic, because most plants are only adversely affected by EC greater than 4dS/m [28]. The C/N ratio of the WTR+ medium is less than 20:1, which indicates that plant-available N may be generated according to ARC [16], thus the medium is suitable as a plant growing medium.

The optimum Eh range for plant growth is +400 to +450mV [29]. Thus, the EH of the WTR+ medium, which falls within in this range, will not be problematic for plants. According to Price [30], sandy soils, which usually have a low CEC of less than 10cmolc/kg, retain smaller quantities of cations, which has important implications for fertilization. While the CEC of WTR alone (11.6 cmolc/kg) was similar to that of sandy soils, the CEC of the WTR+ medium (31.7 to 42.1cmolc/kg) was much higher than that of sandy soils. As such, the CEC of WTR+ will most likely not be problematic for plants.

Table 1. Measurement results of pH, Eh, EC, P-absorption coefficient, water-soluble and exchangeable Mn and total C and N concentrations and CEC for water treatment residuals, composted bark and plant growing media

Material			Qualitative properties			Quantitative properties					
			pH	Eh	EC	P-absorption coef.	Water-soluble Mn conc.	Exchange-able Mn conc.	C conc.	N conc.	CEC
				(mV)	(dS/m)	(mg/100g)	(mg/kg)	(mg/kg)	(%)	(%)	(cmol/kg)
Water treatment residuals (WTR)			6.6	431	0.24	2,224	6.3	55.1	7.17	0.68	11.6
Composted bark			6.9	434	6.69	719	4.1	31.5	37.59	2.9	50.5
Plant growing medium	Immediately after creation (baseline medium) (assumed values)	A				1,923	5.9	50.3	13.25	1.12	19.4
		B				1,622	5.6	45.6	19.34	1.57	27.1
	One month after creation (WTR+ medium)	A	7.2	412	0.33	2,000	ND	27.7	8.64	0.71	31.7
		B	7.1	405	0.37	1,912	ND	30.5	10.29	0.81	42.1

ND: not detectable
A: Volumetric ratio of WTR: bark is 4:1
B: Volumetric ratio of WTR: bark is 3:2

The P fixation capacity is categorized as high when the P-absorption coefficient is ≥1500 [15]. If the P fixation capacity of a medium is high, P will be readily adsorbed to the medium will be difficult for plants to access. In media whose P-absorption coefficients fall in the range from 1,900 to 2,000 mg/100g, plants can suffer from P deficiency. However, a phosphorus deficiency can be compensated by the application of phosphate fertilizer. As such, the WTR+ medium may still be suitable for plant growing purposes.

4. CONCLUSIONS

Based on the result above, the following conclusions were drawn.

(1) The WTR+ medium exhibited similar pH and Eh, higher EC, CEC, total C and N concentrations, and lower available Mn concentration and P-absorption coefficient. After a one-month incubation, WTR+ medium showed a decrease in available Mn, total C and N concentrations and an increase CEC and P-absorption coefficients relative to the theoretical baseline medium.

(2) Decrease in available Mn, total C, and N concentrations and increase in CEC and P-absorption coefficient by one-month incubation may be attributable not only to the introduction of composted bark but, also, the resulting increase in aerobic microbial activity, or some others due to incubation.

(3) All chemical parameters, with the exception of available Mn concentration and P-absorption coefficient, indicated that WTR+ would be suitable as a plant growing medium. The available Mn concentration of the WTR+ medium was nearly half that of WTR alone, which we suspect would result in lower occurrence of Mn toxicity syndrome. The P-absorption coefficient of the WTR+ medium was still high, but P deficiencies caused by the high adsorption can be compensated for by application of P fertilizer. Thus, the WTR+ medium may still be considered suitable for planting purposes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=651&id=24&aid=6098