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Selection of Parameters for Soil Quality Following Compost Application: A Ranking Method

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Intensive agricultural practices with excessive use of chemical fertiliser have led to the deterioration of soil fertility where soil losses its ability to sustain a consistent crop system with high yield. Compost is a potential substitution to chemical fertiliser. As a biological additive, compost can improve soil quality and crop productivity, controlling plant diseases and reduce nutrient loss and water pollution. However, the effect of compost application to enhance the quality of the soil may be inconsistent due to the slow release nature of the nutrients, compost quality, types of feedstocks and other factors. To evaluate the effects of compost application, it may involve a large number of parameter analyses, which can be costly and time ineffective. There is no indicator to reduce the number of analyses concerning the effect of compost application on soil fertility. In this study, a ranking method is proposed to identify the minimum number of parameters able to track the effect of compost application on soil fertility and the environmental impact. A total of 23 soil parameters were selected through literature review and ranked for their importance to show the effect of compost use. The ranking method was developed based on (1) the reporting frequency of environmental and soil fertility parameters and (2) impact of the selective parameter to the environment. Soil C and N contents were found to be the most frequently reported parameters (85 and 90 %) to affect soil fertility upon compost application. Both contents in the soil also change significantly before and after compost application. Heavy metals and N_2O emissions were found to impact the environment most due to the toxicity of heavy metal to the environment and human health and high global warming potential of N_2O. Based on the ranking method, nine parameters (N, NO_3^--N, P, K, micro-nutrients, heavy metals, C, pH and N_2O emissions) were selected. 60 % of soil analyses were reduced following this ranking method. For the future study, a weightage system could be implemented on each criterion to decide the more essential parameters to be evaluated based on different soil or crop type and under different agricultural practices.

1. Introduction

The use of chemical N fertiliser exerts negative impacts on the environment, including the consumption of virgin materials, release of greenhouse gases (GHG), eutrophication and water pollution. An increment of 30 % use of chemical N fertiliser from 2002 to 2017 has been reported by Food and Agricultural Organisation of the United Nation (2020) to increase the productivity of crops; such application is not sustainable. Compost can be an alternative to chemical N fertiliser. Compost is characterised by its high bonding capacity to water, nutrient and organic matter (OM) due to the presence of humic acids and its structural aggregates, allowing the nutrient and water to be retained and released gradually to the soil.

There are two common practices to assess the effect of compost on the applied soil. One practice is to measure all available parameters. Ashwood et al. (2017) analysed 14 parameters to investigate the effect of gravimetric water content and earthwork activity on tree growth and reclaimed soil nutrient status. Agegnehu

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et al. (2016) analysed 16 parameters to study the effect of compost and biochar-compost on the quality of soil and crop quality. Analyses of a large number of parameters can incur a significant burden in terms of financial and time, especially in developing countries where the resources are limited.

Another practice is to focus only on parameters that are highly related to the scope of the study. Tarrasón et al. (2008) assessed 4 parameters (organic C, N, NH_4^+ and NO_3^-) to measure the effect of dewatered, composted and thermally dried sludge on OM mineralisation in soil. Zhu et al. (2014) focused on the measurement of two parameters (N_2O and CO_2) to investigate the GHG emission from the arable soil following the application of fresh, composted and charred manure. They measured the parameters that are impact-specific and might oversee other parameters that may significantly represent the effect of the compost on soil fertility. Based on both limitations, there is a research gap to formulate an assessing system, capable of identifying the minimum number of most significant parameters, concerning the effect of compost applied in soil.

Fan et al. (2016) proposed an economic assessment system for the selection of parameters on compost quality where the costing is based on agronomic value, technical complexity and analysis cost. Ahmad et al. (2020) proposed a quantitative safety, health and environmental index for the selection of waste-to-energy technology. A logistic function was used to construct the scores for each parameter. The effect of compost in the soil is assessed based on the economic and environmental performance. Song and Lee (2010) studied the environment and economic evaluation of sewage sludge compost on the reclaimed soil in landfill where a saving of 198/t USD from compost was achievable by replacing the commercial fertiliser with sewage sludge compost. Lim et al. (2019) also reported a GHG reduction of 27 – 44 % when food waste is diverted from landfill, and the compost applied on the soil. There are limited studies to identify the significant parameters to evaluate the effect of compost on soil fertility and environmental impact.

This study aims to develop a ranking system, for the selection of parameters related to soil fertility and environmental impact, following compost application. A ranking method was performed based on two criteria: (1) the frequency of the parameters being reported (which also indicating the importance of these parameters to soil fertility), and (2) the impact of the selected parameter to the environment. By selecting only the most significant parameters to achieve the above criteria, one could readily monitor the effect of the compost application in soil with minimum cost and time.

2. Method

2.1 Literature search and data collection

A literature search was conducted through SCOPUS (www.scopus.com) by searching the combination keywords "compost" AND "soil fertility". The search outcomes were limited to "recent 15 y publication" and "document type: Article". Twenty articles were further screened for the reporting of the following data: (1) Compost quality; (2) Clear compost application rate; and (3) Soil quality follow compost application.

A total of 23 parameters were selected after literature reviews, which are: OM, C, N, NH_4^+-N, NO_3^--N, P, K, macro-nutrients (Ca, Mg, S), micro-nutrients (Cl, Fe, B, Mn, Zn, Cu, Mo, Ni), CEC, pH, EC, N-leaching, water holding capacity (WHC), bulk density, porosity, aggregate stability, N_2O emission, CO_2 emission, microbial biomass, microbial biomass N and microbial biomass C.

2.2 Definition of criteria

The assessment and selection of the final soil parameters to analyse soil fertility following compost application were conducted through a ranking analysis. Two criteria, concerning the environmental impact and soil fertility, are defined to support the decision-making for the ranking system. The detail definition of each criterion is shown in Table 1.

Table 1 Definition of decision-making criteria for the ranking system

Criteria	Description
Soil parameter	- Based on the frequency of each parameter being reported in 20 papers (which also indicating as the importance of the selected parameters in previous research and soil fertility). - A high rank is given to the parameter most frequently reported and vice versa.
Environmental impact	- The impact of each parameter on the environment, e.g. GHG (Fan et al, 2019), heavy metals footprints (Charvát et al. 2020). - A high rank is given to the parameter imposing the highest environmental impact and vice versa.

2.3 Ranking of each parameter and score

The range for each criterion was assigned based on the data collected. The ranks were set to be 1 to 5 with "1" representing the "least preferable" while "5" representing the "most preferable" parameter. The total score of each parameter was calculated by adding up the rank assigned.

3. Results and discussion

The first criterion (reporting frequency) was selected to justify the feasibility and importance of each parameter to previous research and soil fertility. Figure 1 presents the frequency and rank of each parameter being reported in the selected 20 papers. Soil C and N contents were found to be the most frequently reported parameter following compost application, i.e. 17 and 18 out of 20 chosen papers (shaded in red, ranked as 5). N leaching (1/20), porosity (3/20), aggregate stability (3/20), N_2O emissions (2/20), CO_2 emissions (4/20), microbial biomass N (1/20) and microbial biomass C (4/20) were found to be least reported in the papers, which were shaded in dark green (ranked as 1). The high reporting frequency of C and N contents are due to two reasons: (1) the significant improvement of C and N contents in soil following compost application; and (2) the importance of C and N contents in the soil systems. The least reporting frequency of parameters mentioned above was due to: (1) the complicated or high cost of the analyses; and (2) the parameter itself when standing alone, is not indicating the soil fertility or environmental issues of the soil.

Reference \ Parameter	OM	C	N	NH_4^+-N	NO_3^--N	P	K	Macro-nutrients	Micro-nutrients	CEC	Heavy metals	pH	EC	N leaching	WHC	Bulk density	Porosity	Aggregate stability	N_2O	CO_2	Microbial biomass	Biomass N	Biomass C
Abujabhah et al. (2016)		√		√	√	√	√	√	√			√	√		√						√		
Gómez-Muñoz et al. (2017)		√	√	√	√										√				√	√			
Ashwood et al. (2017)	√	√	√	√	√	√	√	√	√			√	√		√								
Arthur et al. (2012)		√	√							√		√	√		√	√							
Arif et al. (2018)		√	√			√	√		√		√	√	√								√		
Cellier et al. (2012)	√			√	√	√	√					√	√							√			√
Agegnehu et al. (2016)		√	√	√	√	√	√	√	√	√		√	√		√				√	√			
Weber et al. (2007)		√	√					√	√	√	√				√		√						
Bouzaiane et al. (2007)		√	√						√		√										√	√	√
Liu et al. (2012)		√	√			√	√	√	√	√		√			√								
Evanylo et al. (2008)		√	√											√	√	√	√						
Raza et al. (2017)	√		√			√	√														√	√	√
Wang et al. (2017)		√	√	√	√	√	√					√			√						√		
Chen et al. (2016)	√		√	√	√	√	√					√									√		
Montiel-rozas et al. (2018)		√	√			√	√	√	√		√										√		
Srivastava et al. (2018)		√	√			√	√								√	√		√					
López-Rayo et al. (2016)		√	√			√	√	√	√		√	√											
García-ruiz et al. (2012)	√	√	√			√	√			√		√			√			√					
Hernández et al. (2015)		√	√	√	√	√	√		√		√	√	√		√		√	√		√			√
Doan et al. (2015)		√	√			√	√			√		√			√								
FREQUENCY	5	17	18	8	8	15	15	7	10	6	6	13	7	1	13	5	3	3	2	4	7	2	4
RANK	2	5	5	2	2	4	4	2	3	2	2	4	2	1	4	2	1	1	1	1	2	1	1

Frequency	1-4	5-8	9-12	13-16	17-20
Rank	1	2	3	4	5

Figure 1: The reporting frequency and ranking of parameters (with the last row showing the rank assigned)

According to Gómez-Muñoz et al. (2017), C and N contents in soil were improved by 65 – 169 and 57 – 154 % after 11 y application of 10 – 32 t/(ha·y) municipal solid waste compost. Arif et al. (2018) also reported a 65 % increment in the C pool after 5 y application of sludge compost (1 t/(ha·y)). As reported by Montiel-rozas et al. (2018), 52 – 142 % of N increment was observed when 60 – 120 t/(ha·y) of sewage sludge compost was applied to soil in a 13-y field trial. Improvement of soil carbon levels can compensate for the soil OM loss and improve the physical, chemical and biological properties of the soil (Abujabhah et al., 2016). N is the primary nutrient required by plants and microorganisms; the increase in soil N content improves soil fertility. Soil C and N dynamics are very important to agricultural production. The improvement of soil C and N can increase agricultural productivity by improving soil nutrient cycling.

Figure 2 lists the environmental impact of each parameter and their acceptable range in the soil. The heavy metals concentration and N_2O emissions were found to be the most critical parameter to be analysed upon compost application. Heavy metals are poisonous and neurotoxin. The high concentration of heavy metals in soil can lead to severe pollution, causing the uptake of heavy metals by plants which indirectly affect human health upon consumption. N_2O is a GHG with 298 times higher global warming potential (GWP) than CO_2. The presence of high N_2O in the atmosphere can deplete the ozone layer, which leads to climate change.

Parameter	Range	Impact to environment	Reference	Rank
OM	3 – 6 %	Reduction in plant productivity and increase CO_2 emission if below 3 %	Cantisano (1963)	1
C	NA			1
N	> 100 ppm	N is bound by OM and released by microorganisms activities as NO_3^-	Cantisano (1963)	3
NH_4^+-N	NA			2
NO_3^--N	20 – 60 ppm	Excessive NO_3^-N in water system and drinking water can promote excessive growth of weeds and algae and cause human and animal health problems	Cantisano (1963)	4
P	> 40 ppm	High P and P movement from soil to surface water can lead to excessive vegetation growth and damage aquatic ecosystems	Cantisano (1963)	3
K	150 - 350 ppm	High potential of toxic potassium condition if K concentration is above 350 ppm which can be toxic to soil microbe and plants	Cantisano (1963)	3
Macro-nutrients	S (20 - 500 ppm), Mg (< 300 ppm), Ca (300 – 5,000 ppm)	S: S deficiencies often resemble N deficiencies, the shortage of either will impact the availability of other Mg: High Mg can cause P, K and N deficiencies, decrease soil porosity and prevent water retention Ca: Shortage of Ca can cause poor soil structure and WHC, plant growth, fruit density and microbial activity	CCME (2019)	3
Micro-nutrients	Na (< 100 ppm), Mn (< 1,800 ppm), Ni (< 45 ppm), Cu (< 63 ppm), Zn (2 – 25 ppm), Mo (0.25 – 5 ppm), B (0.5 – 2 ppm) Cl (< 100 ppm)	Na: High Na cause soil sterilisation and plant damage/ death Cu: poisonous at sufficient amount B: Essential plant nutrient but toxic to many agronomic crops when above 5 ppm Mo: toxic to animal when exceeding 10 ppm Zn: toxic to crops when above 100 ppm	Cantisano (1963)	4
Heavy metal	Cd (< 1 ppm), Pb (< 70 ppm), Hg (< 6.6 ppm), Cr (< 64 ppm)	Cr(VI) & Cd: high toxicity and carcinogenic Pb & Hg: poisonous metal; neurotoxin		5
CEC	15 – 40 meq/100g	Soil with CEC below 15 meq/100g have low capacity to "hold" and prevent the leaching of cations	CCME (2019)	1
pH	6 – 8		Cantisano (1963)	2
EC	110 – 570 ms/m			2
N leaching	NA	Referred to NO_3^--N		4
WHC	NA			1
Bulk density	NA			1
Porosity	NA			1
Aggregate stability	NA			1
N_2O	NA	Greenhouse gases with 298 global warming potential in a 100 y horizon		5
CO_2	NA			3
Microbial biomass	NA			1
Biomass N	NA			1
Biomass C	NA			1

Figure 2: The environmental impact and range of each parameter (assigned rank shown in the last column)

Parameter	Reporting frequency	Environmental impact	Total score
OM	2	1	3
C	5	1	6
N	5	3	8
NH_4^+-N	2	2	4
NO_3^--N	2	4	6
P	4	3	7
K	4	3	7
Macro-nutrients	2	3	5
Micro-nutrients	3	4	7
Heavy metal	2	5	7
CEC	2	1	3
pH	4	2	6
EC	2	2	4
N leaching	1	4	5
WHC	4	1	5
Bulk density	2	1	3
Porosity	1	1	2
Aggregate stability	1	1	2
N_2O	1	5	6
CO_2	1	3	4
Microbial biomass	2	1	3
Biomass N	1	1	2
Biomass C	1	1	2

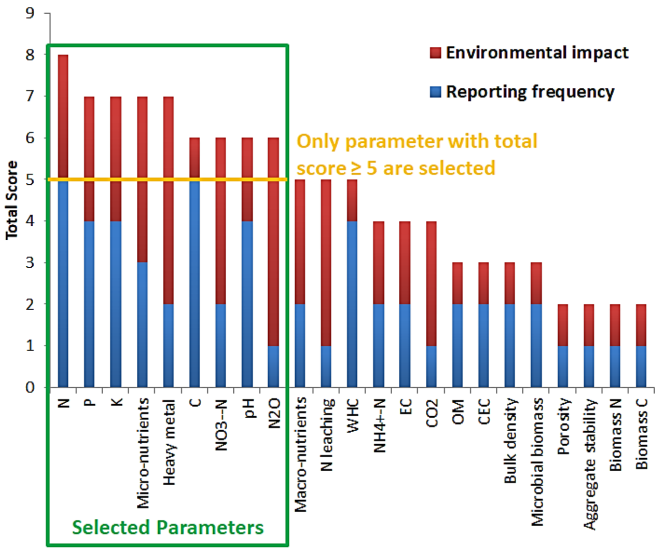

Figure 3: Total score computed based on the soil and environmental parameters following compost application

The ranks of each parameter (Figure 1 and 2) were summed up to give the final score (Figure 3). Only the parameters with a total score > 5 were selected. This ranking system had selected nine parameters, which are N, NO_3^--N, P, K, micro-nutrients, heavy metals, C, pH and N_2O emissions. Within these selected parameters, mineral contents (N, P, K and micro-nutrients) of soil were found to be equally crucial in soil quality and environmental impact. N, P and K are essential nutrients for plant growth. In term of environmental impact, the over-range of these nutrients can cause leaching and pollution of air and water (Lim et al., 2018). High N

(>100 ppm) and P (> 40 ppm) leaching to the surrounding water system can cause algae bloom while high K (> 360 ppm) is toxic to soil microbiome. Even when the plant has a relatively low requirement on micro-nutrients, the lower environmental tolerance leading to its high rank in the second criterion (ranked 4) (Figure 2).
N_2O emission and heavy metals were selected due to the high GWP and poisonous characteristics. Due to the high solubility characteristics of NO_3^--N, where the leaching of NO_3^--N can easily occur especially during excessive rainfall. For C and pH, they are selected due to their buffering effects which are very crucial in maintaining the soil nutrient level.

4. Conclusions

This study developed a novel ranking system to select the minimum number of significant soil parameters following compost application, based on two criteria: the soil parameters and the environmental impact. Nine soil parameters (N, NO_3^--N, P, K, micro-nutrients, heavy metals, C, pH and N_2O emissions) were selected among the 23 parameters extracted from the literature. The ranking system would significantly reduce the intensity of soil analyses following compost application. This ranking method was able to reduce 60 % of the soil analyses. In the future work, more detailed analyses should be considered, such as the feasibility and intensity of the analytical methods, the cost of analysing the sample, the changes (increment/ decrement) of the soil parameters upon compost application, and the effect of compost application on crop yield. Weightage could be assigned to each criterion to improve the accuracy of the ranking systems.

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