Yield improvement with compost amendment and *Trichoderma* microbial inoculant (TMI) in rice paddies inundated by copper-rich mine tailings

Virginia C. Cuevas*[1], Cirilo A. Lagman, Jr.[2,3], Xavier Anupo[2], Joey I. Orajay[2,4], and Frances G.E. Malamnao[5]

[1]Institute of Biological Sciences, College of Arts and Sciences, University of the Philippines Los Baños
[2]University of the Philippines Los Baños Foundation, Inc.
[3]Department of Soil Science, College of Agriculture, Benguet State University, La Trinidad, Benguet
[4]Del Monte Philippines, Bukidnon
[5]University of the Philippines Los Baños Graduate School

This research evaluated the improvements in the rice yield of paddies contaminated with copper-rich (Cu-rich) mine tailings that had been applied with rice straw compost and *Trichoderma* microbial inoculum (TMI). A field trial with three replicates was conducted in two sites to evaluate the effect of varying rates of compost application on rice yield. Treatments were: 0, 1, 2, 4 kg m^{-2} compost application. Dry weight of grains and number of productive tillers were monitored. Another study was conducted that served also as a field demonstration trial on using TMI alone and in combination with rice straw compost to improve yield in these Cu-contaminated rice paddies on the same sites for four seasons involving three pairs of paddy fields in each site. Two paddies compared were: TD0 (Technique Demonstrated) - TMI, 0 compost; TD1 – TMI + compost at 2 kg m^{-2}. Yield, changes on soil organic matter, soil Cu, and soil pH were monitored. Results of the field trial showed that 2 kg m^{-2} application significantly improved yield and number of productive tillers, and this rate was found to be optimum for rehabilitation of Cu-contaminated paddies in the area. Field demonstration on other techniques that can increase yield in Cu-rich rice paddies showed that yield in paddy fields with TMI alone was higher when compared to no amendment shown in the first trial. Yield with TMI + compost was consistently higher compared to paddies with TMI alone.

KEYWORDS

mine tailings, Cu, rice, compost, *Trichoderma*, remediation

*Corresponding author
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INTRODUCTION

Heavy metal (HM) contamination of terrestrial and aquatic habitats is a serious environmental concern. HMs are nonbiodegradable and can be transferred to the various trophic levels of the food chain via bioaccumulation. They persist mostly unchanged for a long time in the environment, and their toxicity levels in the soil adversely affect soil quality, agricultural production, human health, and the environment (Ahmad et al. 2015).

Most often, HM contamination results from human activities. Mining activities that produce large quantities of mine tailings are major sources of the contamination (Abdul-Wahab et al. 2015), especially in developing countries not strongly compliant with environmental laws (Fashola et al. 2016).

The Philippines is a highly mineralized country. Its mining industry produces precious metals, such as gold, silver, iron, and other ferrous alloy metals (PSA 2011). However, despite having strong environmental laws, the government does not strictly implement them. Thus the country has a long record of accidental breaches of mine tailings storage facilities or tailing ponds (Doyle et al. 2007). Agricultural lands contaminated by mine tailings in the country usually have toxic levels of HMs such as copper (Cu).

Soil contamination happens when the dam of tailing reservoirs breaches, thereby releasing materials with high levels of HMs to nearby areas. Most often, the reservoirs are located in river valleys. Thus, when dams breach, mine tailings are released to the river waters, consequently inundating the agricultural lands located along the riverbank. Gold mine tailings have particles that are like river sand and silt; they are characterized by poor physical properties such as poor aggregation, high hydraulic conductivity, fine texture, and very limited cohesion ability (Fashola et al. 2016). The lack of cohesion is responsible for the varied moisture content and temperature of gold mine tailings. Thus, these properties make tailings different from soil.

The agricultural fields used in this study were inundated by mine tailings during the 1986 dam failure of a large gold mining company, which has been in the area for almost seven decades. These affected fields have high levels of soil Cu (Cuevas et al. 2014). The results of the 2014 study showed that these affected fields had soil Cu level of 281 mg kg^{-1} and yielded only about 246 g m^{-2} or 2.46 tha^{-1} of *palay* (paddy rice). This amounts to only about half of the national average *palay* yield (i.e., 4.31 tha^{-1}) for irrigated fields (PSA 2016).

Cu is a micronutrient essential in many different plant processes. It exists in multiple oxidation-reduction state and participates in photosynthetic electron transport, mitochondrial respiration, oxidative stresses, and hormonal signaling (Yruela 2005). It is also a structural element in regulatory proteins and an important cofactor in many enzyme systems involved in plant metabolism. Its unavailability to plants causes deficiency symptoms. However, high concentration of the element in the plant environment causes toxicity. The redox properties that make the element essential to plant metabolism also cause Cu's inherent toxicity, which consequently damages DNA, lipids, and protein molecules. Likewise, high levels of Cu in plants can cause stunting and root growth inhibition. High levels of Cu adversely affected cereals as the toxic levels inhibit seed germination of the crop (Mahmood et al. 2007).

Cu toxicity in rice can decrease root mass (Lidon and Henriques 1993). With soil Cu at 100–200 mg kg^{-1}, rice yield decreases due to the reduced number of spikelets per panicle (Xu Jia-kuan et al. 2005). At levels more than 400 mg kg^{-1} soil Cu, considerable yield loss was recorded due to the decrease in the number of panicles caused by Cu stresses. This also caused low recovery from transplanting, delayed tillering, and reduced tiller numbers.
One of the strategies used to rehabilitate HM-contaminated soil is through the use of compost or organic matter (OM) amendment. OM improves the soil's biochemical and physicochemical properties that are often impaired in areas contaminated with mine tailings (Cooke and Johnson 2002). Applying 16 kg m^{-2} rice straw compost in rice fields covered with mine tailings can increase yield by 30% (Cuevas et al. 2014). It also significantly increases soil pH. Soil Cu originally at 281 mg kg^{-1} decreased to <30 mg kg^{-1} showing the diluting effect of organic straw.

Bioremediation technique or the use of biological materials (e.g., microorganisms) to mitigate the harmful effects of HMs in contaminated areas has gained much attention among researchers worldwide. Microorganisms degrade or detoxify hazardous substances through the reactions that take place in the metabolic processes. Such strategy of using living organisms in the environmental cleanup process offers a viable, safer, more efficient, and less expensive measure (Siddiquee et al. 2015).

Accordingly, one fungus that is often cited as a potential bioremediation agent is *Trichoderma.* The genus is genetically diverse and is the anamorph of the ascomycete *Hypocrea. Trichoderma* is cosmopolitan, and the species of the genus are isolated in diverse ecosystems all over the world. The wide range of the geographic distribution of its species is attributed to their metabolic diversity, high reproductive rate, and competitive ability (Kredics et al. 2014). Different species of the genus are used as commercial sources of cellulases and other enzymes, as biocontrol agents of various plant diseases, as growth promoters of crops, and in giving crops immunity to diseases (Gupta et al. 2014). *Trichoderma* microbial inoculant (TMI) enhanced rice yield in noncontaminated irrigated paddy systems (Cuevas 2006).

Different species of the genus have also been cited as tolerant to several pollutants, including HMs, pesticides, and polycyclic aromatic hydrocarbons (Siddiquee et al. 2015; Tripathi et al. 2012). The bioremediation strategies of various *Trichoderma* species on HMs can be through biosorption, bioaccumulation, biovolatilization, and phytobial remediation (Tripathi et al. 2012). *T. reesei* FS-10C had a high tolerance to cadmium (Cd) and enhanced the phytoremediation efficiency of *Sedum plumbizincicola* in Cd-contaminated soil (Teng et al. 2015). In Chile *Trichoderma* spp. increased the growth and yield of potato in a degraded soil, which was located in an area contaminated by waste from Cu and gold mining (E&GA 2010). *Trichoderma autroviride, T. harzianum, T. virens,* and *Aspergillus niger* were used to clean up HM-polluted areas due to the ability of the organisms to remove the concentrated HM ions from liquid substrates (Siddiquee et al. 2015). Filamentous fungal biomasses had high percentage of cell wall materials with HM-binding properties and thus take considerable quantities of heavy metals even with the absence of physiological activity (Siddiquee et al. 2015).

The present study is a continuation of the 2014 study (Cuevas et al. 2014) which showed that rice straw compost applied at 16 kg m^{-2} could be a promising remediation technique. However, this rate of compost application was not feasible at the field level of large areas. Thus the present study tested the lowest rate of compost application that would significantly improve crop yield. A field demonstration was done to convince farmers that rice yield could improve with the use of TMI combined with 2 kg m^{-2} rice straw compost or through using TMI alone. This field demo was conducted for four cropping seasons, involving three pairs of paddies in each site where the first trial had been conducted.

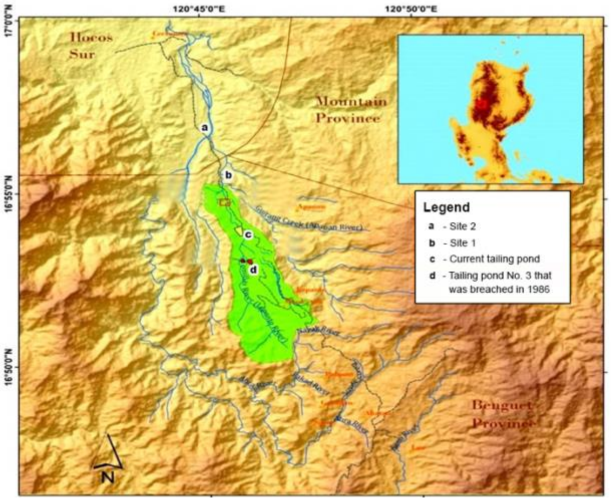

Figure 1: Topographic map of the Comillas (Lepanto) river system

Note: The map shows the relative locations of the two sites where the field trials were conducted. The rice paddies were inundated by mine tailings from tailing pond 3 when the dam breached in 1986.

MATERIALS AND METHODS

This study was conducted in Colalo, Mankayan, Benguet; and Pilipil, Cervantes, Ilocos Sur (Northern Luzon provinces) from 2013 to 2015 (fig. 1). The rice paddies along Comillas river banks (Lepanto or Mankayan River to local people) were inundated with mine tailings when the dam of reservoir pond No. 3 - owned by a gold mining company in Mankayan, Benguet—breached in 1986. These affected rice paddies had not been studied until 2012, and the problem of decreased rice productivity of these contaminated lands was not addressed until very recently. The rice fields contain soil Cu much higher than 30 mg g^{-1} (the normal level of Cu in uncontaminated soil) (Kabata-Pendias and Pendias 2001).

The first field trial tested for the rate of rice straw compost application that would significantly improve rice yield. The test was done in two sites located downstream of the breached tailing pond (site 1: Colalo, Mankayan, Benguet; site 2: Pilipil, Cervantes, Ilocos Sur) (fig. 1). Four treatments were made. These treatments were replicated three times by using a randomized complete block design and with the following treatments: T0 (control), T1 (compost applied at 1 kg m^{-2}), T2 (2 kg m^{-2}), and T3 (4 kg m^{-2}).

Each plot treatment measured 12 m^2 (4 m × 3 m), and a 3 m × 2 m quadrat was placed in the middle of each plot treatment. Compost, equivalent to the designated amount prescribed for each treatment, was applied to each plot. The dry weights of grains and the number of productive tillers in each replicated treatment were monitored at harvest.

Rice straws were composted in situ by using a modified windrow type of composting; *Trichoderma harzianum* was used as an activator (Cuevas 1988). Rice straws from previous cropping were mixed with animal manure, leaves of *Leucaena leucocephala*, and *Glericidia sepium* as nitrogen (N) sources; the ratio applied was 3-parts rice straw and 1-part N materials. Mineral fertilizers nitrogen, phosphorus and potassium (i.e., Complete 14N-14P-14K and Urea 46-0-0) were applied in accordance with the results of the soil chemical analysis of soil fertility. The yield and number of productive tillers were compared among treatments by using ANOVA (analysis of variance). Treatment means were compared through Tukey's test ($P \leq 0.05$) using SAS (statistical analysis system) version 9.1.3. Regression analysis between the rate of compost application and yield was also done.

Concurrent with the first trial on effective rate of compost application, a field demonstration that showed other techniques of improving the yield of contaminated paddies was conducted. The techniques/interventions done were: (1) use of TMI alone – technique demonstrated (TD0) and (2) TMI + compost (TD1). This field demonstration was done continuously for four cropping seasons on the contiguous paddies of the first trial sites in Colalo and Pilipil during the period 2013–2015. Three farmers per site, using a pair of paddy fields per farmer, were involved. The rate of compost application was roughly equivalent to 2 kg m^{-2}.

One farmer in Colalo planted RC 18, whereas the other two farmers planted RC 160. Likewise, the three farmers in Pilipil planted RC 160. All the farmers planted the same varieties during the four cropping seasons monitored. The rice varieties used are those recommended by the Philippine Seed Board for irrigated paddies (PhilRice, n.d.). The farmers might have selected these varieties based on their experience that these varieties are tolerant to the pollutant, and accordingly gave them modest harvest.

Soil Cu analyses were initially conducted at different soil depths: (1) two depths at 15-centimeter interval in Site 1 (Colalo, Mankayan) (0–30 cm) and (2) three depths at 0–45-centimeter interval in Site 2 (Pilipil, Cervantes). Although this was a field demonstration, yield and some soil parameters (e.g., pH, % OM, and Cu) were also monitored at the start of each cropping season, and the data were given to the farmers. Since the paddy size was variable, crop yield was measured in terms of dry weight of grains. All monitored data on soil parameters were collected from the middle of the rice paddy of a 1 m^{-2} subplot.

In this farmer-led demonstration the interventions done by the researchers were only about the techniques to improve yield and data gathering. The amount of mineral fertilizer applied, the rice variety used, and other cultural management practices were based on the farmers' decision. This strategy was done to convince farmers that rehabilitating their damaged rice fields would entail only minimal changes in their farming practices. Such approach would lead to easy adoption of the rehabilitation techniques.

All the rice straws gathered from one paddy from the previous cropping were composted in situ as described above. The rice straws were applied on the same paddy at a rate that is roughly equivalent to 2 kg m^{-2}. This process of in situ composting was more acceptable to the farmers since this was easy to follow and entailed less labor. TMI was applied as seed coating at the rate of 250 g inoculant per 40 kg of *palay*, which is equivalent to 10^6 spores per gram of seeds (Banaay et al. 2012).

All soil Cu analyses were conducted as extractable Cu through the Flame Atomic Absorption Spectrophotometry method. The analyses were done at the Natural Science Research Unit of St. Louis University, Baguio City. Likewise, soil fertility analyses were conducted on the basis of *Methods of Soil, Plant, Water and Fertilizer Analysis for Research* (Recel and Labre 1988); the samples were analyzed at the Soil Analytical Chemistry Laboratory, Institute of Agricultural Systems Cluster, College of Agriculture and Food Science, University of the Philippines Los Baños. Soil pH was monitored by using a pH meter, specifically the Multi-Parameter Terstr 35 Series ay Eutech Instruments (made in Singapore). The soil samples analyzed were composite of four subsamples collected from depths 0–15 cm at various spots of the paddy fields.

Table 1: Mean dry weights of rice grains and number of productive tillers in plots with and without compost amendments in the field experiment (Field trial 1)

Trt: Rate of Compost Application + Mineral Fertilizer	Mean Grain Weight (tha^{-1})*		Mean Number of Productive Tillers*	
	Colalo	Pilipil	Colalo	Pilipil
Control	2.8 b	3.8 b	12.85 b	14.54 b
T1 - 1 kg m^{-2}	3.7 ab	4.7 a	13.88 ab	16.02 a
T2 - 2 kg m^{-2}	4.4 a	4.9 a	15.46 a	16.69 a
T3 - 4 kg m^{-2}	4.3 a	4.9 a	15.10 a	16.33 a

Note: (1) * = means three replicates (2) In a column, means followed by the same letters are not significantly different at 5% level by Tukey's HSD test.

RESULTS AND DISCUSSION

Study 1: Rate of compost application and yield improvement

The results of the first field trial on the rate of effective compost application for improving crop yield are shown in table 1.

In both sites, T0—control (0 compost) had the lowest yield and the lowest number of productive tillers, with only 2.8 tha^{-1} in Colalo (site 1) and 3.8 tha^{-1} in Pilipil (site 2). The yield difference in these two sites may be due to the higher % soil OM in Pilipil (2.43%) than that of Colalo (1.63%) (table 2). The difference in the soil fertility of the two sites may also be responsible for the crops' responses to 1 kg m^{-2} compost application (T1).

Table 2: Baseline information on soil fertility level of paddies in Colalo (site 1) and Pilapil (site 2) on field trial 1

Sites	% soil OM*	P (ppm)*	K me 100 g soil*	Soil pH*	Soil Cu mg kg^{-1}
Colalo	1.63	14	0.34	6.4	162.0
Pilipil	2.43	18	0.20	6.2	164.7

Note: (1) Filed trial 1 had the rate of compost application that significantly improved rice yield. (2) * mean of three replicates

In Colalo yield from T1 at 3.7 tha^{-1} was not significantly different from that of T0; in Pilipil yield from T1 at 4.7 tha^{-2} was significantly different from that of T0. With the original 2.43% soil OM of paddies in Pilipil, possibly the additional 1 kg m^2 compost was sufficient to elicit a positive response in the growth of *palay*. In Colalo paddies that had original 1.63% soil OM had to be added with 2 kg m^{-2} of compost (T2) to give a positive response; yield at 4.4 tha^{-1} was significantly different from that of T0—control. However, the yield from T2 was no longer significantly different from that of T3 at 4.3 kg m^{-2}. In Pilipil, by contrast, T2 and T3 both yielded 4.9 tha^{-1}. Although they were not significantly different from each other, T2 was significantly higher than that of T0. This implies that compost application higher than 1 kg m^{-2} that had been used in T2 and T3 did not give additional benefit.

The trend observed in grain yield was also observed in the number of productive tillers in both sites. Number of productive tillers is an important trait in grain production; it is also an important contributor to the increase in grain yield (Mirza et al. 2010). This implies that an increase in productive tiller results in a significant increase in grain yield.

The yield in both sites significantly increased with the 1–2 kg m^{-2} compost application as compared to T0—control. The increase in yield was about 57% in Colalo and 24% in Pilipil. Moreover, the regression correlation analysis showed that the mean grain dry weight in both sites was significantly correlated to the rate of compost application. In Colalo R^2 = 0.6948 (P = 0.01), whereas R^2 = 0.6168 (P = 0.01) in Pilipil. Thus the results of field test 1 showed that the 1–2 kg m^{-2} compost application rate (depending on the initial soil % OM) was sufficient to improve yield under the prevailing high-Cu-concentration condition of the soil.

Study 2: Field demonstration

Table 3 presents the soil Cu collected from the two sites at different soil depths. The registered data of soil Cu level in site 1 (Colalo) was not very high at 47–60 mg kg^{-1}; however, the data from tables 2 and 4 show that the paddies in site 1 (Colalo) also had high Cu content (>100 mg kg^{-1}). The differences in the level of soil Cu at different sampling dates may be due to the heterogeneity of samples, coupled with spatial variability of Cu concentration (called hot spots) that might have been taken during data collection. Contamination was quite deep in Pilipil, in which Cu level was still at 216 mg kg^{-1} at 45 cm depth; at the surface Cu level was at 132 mg kg^{-1}. It can be surmised that Cu was dispersed in the soil matrix that constituted the root environment. Such soil environment is critical to the growth of rice crop since any land tillage done would mean that the Cu ions from below may tend to be placed on the surface and vice versa.

Table 3: Soil Cu concentration taken from varying depths of paddies used in the field demonstration conducted in Colalo (site 1) and Pilipil (site 2)

Soil Depth (cm)	Soil Cu Concentration (mg kg^{-1})*	
	Colalo	Pilipil
0–15	47	132
16–30	60	117
31–45	**No data	216

Note: * mean of two replicates
** Cu level at 16-30 cm was not too high compared to average level at 30 mg kg^{-1} and did not exceed the upper limit of the range reported for soils at 100 mg kg^{-1} (McLean and Bledsoe, 1992), thus no data was collected from soil depth of 31-45 cm.

Tables 4, 5, and 6 present the initial soil fertility levels of the different paddies used in the field demonstrations, chemical analysis of the compost applied in the demonstrations, and the amount of inorganic fertilizer applied during the four-season cropping.

Soil pH ranged from 5.35–7.1 in all sites (table 4). Soil OM was quite low, ranging from 0.06% to 2.93%. Available P and exchangeable K were moderately adequate at 14–33 ppm and at 0.12–0.38 me/100 g soil, respectively. The most influential factor affecting soil productivity was the toxic level of soil Cu, which ranged from 47–117 mg kg^{-1} in Colalo to 71–358 mg kg^{-1} in Pilipil. The paddy field of Farmer 3 in Pilipil (P3) had very high Cu content (358 mg kg^{-1}), although the soil pH was neutral. As can be seen from results given below, this high soil Cu level greatly affected grain yield (tables 5 and 7).

The farmers continued to plant rice in these paddies for a few years after the 1986 accident. The soil properties that were determined in the present study had most probably been very different from the first time the farmers cultivated the field after the 1986 accident. We can speculate that these soil properties must have improved through time. Continuous cropping year after year with mineral fertilizer application has contributed to the soil fertility and to the soil OM content of the field, as roots of weeds and crops and other crop residues decay. In this demonstration trial the applied compost, which was made from

Table 4: Initial soil fertility level of farmers' paddy fields involved in field demonstration

Farmer Field	Initial Soil Fertility Level of Paddy Fields in Field Demonstration Trials			Initial soil pH and Cu Levels	
	% OM	P (ppm) Olsen	K me / 100g soil	Soil pH	Sil Cu Content ($mg\ kg^{-1}$)
C1	1.58	14.0	0.06	5.90	47.00
C2	0.66	45.0	0.22	5.35	117.00
C3	1.59	33.0	0.09	6.93	116.00
Mean	1.27	30.6	0.12	6.06	93.30
P1	1.33	36.0	0.08	6.62	156.00
P2	2.93	30.0	0.38	7.10	70.60
P3	2.52	33.0	0.11	7.01	358.00
Mean	2.26	33.0	0.19	6.91	194.86

Table 5: Chemical analysis of compost applied in the field demonstrations

Parameters	Compost
% OM	41.2
P $mg\ kg^{-1}$	% P_2O_5–0.35
K me 100 g soil	% K_2O–0.18
% total N	0.96
Soil pH	7.7

Table 6: Amount of inorganic fertilizer applied during the four-season cropping

Mineral Element	Amount of Inorganic Fertilizer Applied ($g\ m^{-2}$)							
	C1	C2	C3	Mean	P1	P2	P3	Mean
Wet Season (Jun–Oct 2013; Jun–Oct 2014)								
N	7.2	8.4	4.5	6.7	5.0	4.3	4.3	4.53
P	2.6	2.8	4.5	3.3	5.0	4.3	4.3	4.53
K	2.6	2.8	4.5	3.3	5.0	4.3	4.3	4.53
Dry season (Dec 2013–Apr 2014; Dec 2014–Apr 2015)								
N	10.9	18.8	18.4	16.03	20.7	17.5	15.7	18.0
P	10.9	4.5	7.8	7.73	6.0	6.0	6.0	6.0
K	10.9	4.5	7.8	7.73	6.0	6.0	6.0	6.0

rice straw with additional plant materials from legume trees, had 41.2% OM content and pH of 7.7. The N, P, and K contents of the compost were low (table 5), and therefore fertilizer value may be minimal. The high OM content was favorable for remediation process as OM amendment improves the physical, chemical, and biological properties of the soil (Sabir et al. 2014). Mineral fertilizers were also applied in the fields. No yellowing of rice leaves was observed during the cropping.

Table 6 presents the amount of mineral elements N, P, K that the farmers applied in the two sites during the field demonstration. The rate of inorganic fertilizer application must be based on the soil type and the desired yield (IRRI 2015). In general, the assumption is that 1 ton of grain will remove 15 $kg\ ha^{-1}$ of N, 2–3 $kg\ ha^{-1}$ of P, and 15–20 $kg\ ha^{-1}$ of K. In the two sites the average yield was about 3 tha^{-1}. Therefore the N, P, and K needed were about 45 $kg\ ha^{-1}$ N, 15 $kg\ ha^{-1}$ P, and 54 $kg\ ha^{-1}$ K, which are equivalent to 4.5 $g\ m^{-2}$ N, 1.5 $g\ m^{-2}$ P, and 5.4 $g\ m^{-2}$ K. As shown in table 6, the farmers applied more fertilizers during the dry season than during the wet season at almost four times the amount of fertilizers N and P needed (i.e., 16 $g\ m^{-2}$ N and 7.7 $g\ m^{-2}$ P in Colalo, 18 $g\ m^{-2}$ N and 6 $g\ m^{-2}$ P in Pilipil). The fertilizer K applied was equal to the required amount. During the wet season the farmers applied a little over the required amount. The farmers explained that they applied more fertilizers due to the pollution caused by the mine tailings. They believed that by applying more fertilizers they would yield the amount that would be commensurate to their efforts.

Table 7 presents the rice grain yield in the field demonstration paddies for the four-season cropping. The yield in TD1 (TMI + compost) was consistently higher than that in TD0 (TMI alone) in all seasons and in all the six farmers' fields. In Colalo paddies with TMI alone (TD0) in all seasons had resulting yields (4.8–5.2 tha^{-1} = 0.48–0.52 $g\ m^{-2}$) that were much higher than that with the no amendment (2.8 tha^{-1}) shown in the first trial. In Pilipil farmers 1 and 2 (P1, P2) also had a much higher yield (TD0 = 4.7–5.5 tha^{-1} = 0.47–0.55 $g\ m^{-2}$) than the no amendment at 3.8 tha^{-1} = 0.38 $g\ m^{-2}$. Farmer 3 (P3) had a much lower yield at less than 1 tha^{-1} due to the very high Cu content of the rice paddies (195–358 $mg\ kg^{-1}$). Using TMI alone can therefore improve yield; such improvement is almost similar to using 2 $kg\ m^{-2}$ of compost alone as shown in the first trial. The combined use of compost and TMI (TD1) yielded more by 18%–27% than the yield using TMI alone (TD0).

This study therefore showed that *Trichoderma* is a potential microbial remediation agent for agricultural soil that is contaminated with HMs such as Cu. This has been similarly discussed by other researchers (Siddiquee et al. 2015; Tripathi et al. 2012). This remediation ability may be due to the high tolerance of the fungus to HMs and may be due to its profuse growth in the soil. The fungus has the ability to remove the concentrated heavy metal ions from the soil solution since its biomass has a high percentage of cell wall materials with a high-metal-binding property. Such property enables the microorganism to take considerable quantities of HMs even with the absence of physiological activity.

In the field demonstration the soil pH in TD1 paddies registered a higher pH than that in TD0 paddies (table 8). Thus, the results showed that compost was responsible for the pH improvement.

The ability of compost to increase soil pH is due to the large, complex, and diverse compounds present in the organic matter, which accordingly provides negatively charged attachment

Table 7: Rice grain yield (gm^{-2}) for four seasons of the field demonstration trial

Farmer Field	Wet Season (June–Oct 2013)		Dry Season (Dec 2013–Apr 2014)		June–Oct 2014		Dec 2014–Apr 2015	
	TD0	TD1	TD0	TD1	TD0	TD1	TD0	TD1
C1	0.484	0.586	0.51	0.659	0.51	0.63	0.52	0.67
C2	0.496	0.570	0.50	0.630	0.52	0.64	0.52	0.65
C3	0.500	0.580	0.49	0.600	0.51	0. 64	0.50	0.64
Mean	0.490	0.580	0.50	0.630	0.51	0.64	0.51	0.65
P1	0.540	0.630	0.59	0.680	0.55	0.64	0.58	0.69
P2	0.490	0.560	0.50	0.600	0.47	0.57	0.55	0.61
P3	0.067	0.170	0.09	0.170	0.05	0.08	0.12	0.21
Mean	0.360	0.450	0.39	0.480	0.36	0.43	0.38	0.54

Table 8: Soil pH measured after each cropping

Farmer Field	Initial Wet Season (Jun–Oct 2013)		Dry Season (Dec 2013–Apr 2014)		June–Oct 2014		Dec 2014–Apr 2015	
	TD0	TD1	TD0	TD1	TD0	TD1	TD0	TD1
C1	5.90	5.90	4.47	5.60	4.30	5.70	4.20	5.70
C2	5.35	5.35	5.07	6.52	5.03	6.52	5.13	6.64
C3	6.93	6.93	4.55	5.52	4.53	5.70	4.66	5.87
Mean	6.06	6.06	4.69	5.88	4.62	5.97	4.66	6.07
P1	6.62	6.62	4.56	5.53	4.43	5.70	4.37	5.60
P2	6.60	6.60	5.05	5.87	5.03	5.90	5.13	6.07
P3	7.10	7.10	4.86	5.07	4.90	5.17	4.95	5.21
Mean	6.77	6.77	4.82	5.49	4.78	5.59	4.81	5.62

Table 9: % soil OM after each cropping

Farmer Field	Initial Wet Season (Jun–Oct 2013)		Dry Season (Dec 2013–Apr 2014)		June–Oct 2014		Dec 2014–Apr 2015	
	TD0	TD1	TD0	TD1	TD0	TD1	TD0	TD1
C1	1.58	1.58	1.60	2.26	2.12	5.19	1.87	3.86
C2	0.66	0.66	0.88	1.01	0.58	6.68	1.71	2.08
C3	1.59	1.59	3.01	3.62	1.56	3.6	1.60	1.96
Mean	1.27	1.27	1.83	2.29	1.42	5.15	1.72	2.63
P1	1.93	1.93	2.81	4.63	3.75	4.31	3.98	3.80
P2	2.52	2.52	1.95	1.63	1.89	4.62	1.60	1.94
P3	2.33	2.33	3.39	3.28	1.72	6.81	3.10	4.00
Mean	2.26	2.26	2.71	3.18	2.45	5.24	2.89	3.24

Table 10: Soil Cu ($mg\ kg^{-1}$) after each cropping

Farmer Field	Initial Wet Season (Jun–Oct 2013)		Dry Season (Dec 2013–Apr 2014)		June–Oct 2014		Dec 2014–Apr 2015	
	TD0	TD1	TD0	TD1	TD0	TD1	TD0	TD1
C1	47.00	47.00	61.50	51.10	58.70	53.10	62.40	62.3
C2	117.00	117.00	110.70	107.0	112.50	123.60	115.40	194.6
C3	116.00	116.00	72.70	63.90	143.70	118.90	60.60	57.5
Mean	93.33	93.33	81.63	74.00	104.96	98.53	79.46	104.8
P1	156.00	156.00	101.00	97.40	103.00	75.00	101.00	100.0
P2	70.60	70.60	90.00	70.00	127.00	57.00	62.80	62.3
P3	358.00	358.00	241.00	227.00	342.00	174.00	195.00	165.0
Mean	194.86	184.86	144.00	131.46	190.66	102.00	119.60	109.1

points to cations such as hydrogen ions (H^+). In acidic soils the free H^+ in the soil solution are attached to the negatively charged sites, consequently increasing soil pH level, especially when sufficient H^+ are removed from the solution (Planet Natural Research Center 2017). As soil pH improves, more essential plant nutrients become more available for absorption by the crop. Such phenomenon may be a factor that is responsible for the significantly higher yield in TD1 paddies than that in TD0. Similar increases in soil pH and yield with rice straw compost application were reported (Cuevas et al. 2014). Green waste compost also reduced soil acidity and increased soil OM, N, and P, which facilitated the establishment and growth of perennial ryegrass (Karami et al. 2011). Using municipal waste and biosolid composts in soil contaminated with heavy metals in Southern Spain also increased the pH and available nutrients in the soil (Perez de Mora et al. 2006). Similarly applying compost to soil increased pH, allowing *Brassica juncea* to germinate and grow in Cu-contaminated soil (Novo and Gonzalez 2014).

Table 9 presents the % soil OM content of the rice paddies used in the demonstration trial. As expected, paddies in TD1 (TMI + compost) had much higher soil OM than that in TD0 (TMI alone). Improving soil OM content improved soil physical and chemical properties (already discussed earlier), that are reflected in the continuous increase in yield in every cropping season (table 8).

The improved yield from the trial with compost application (TD0 vs. TD1) observed in this field demonstration may be attributed to the improved physicochemical and biological conditions of the soil, thereby improving plant growth (Bolana et al. 2014). OM from compost improves soil structure, reduces erosion, increases infiltration, and serves as microbial inoculum

(Mendez and Maeir 2008). Soil OM can also increase the water-holding capacity and cation exchange capacity of mine tailings. When compost is incorporated into the soil, it becomes part of the soil OM (Craswell and Lefroy 2001). It then remains as the driving force for biological activity and as the primary source of energy and nutrients for many soil organisms such as bacteria and fungi. Likewise, the compost from municipal wastes and biosolid composts increased OM, total organic carbon, and microbial biomass, which stimulated the plant growth in HM-contaminated soil in Spain (Beesly et al. 2014). As mentioned earlier, increasing soil OM increases yield due to the positive effects of soil OM in the biophysical and chemical properties.

In the field demonstration conducted in this study for four cropping seasons, compost application seemed to have no effect on soil Cu level (table 10). There was no decrease in the Cu levels of TD1 paddies. This may be due to the complex interaction of Cu with OM. Over time, soil microbes could easily decompose OM, which would then produce low molecular organic molecules acting as chelators (Lee at al. 2014). This could accordingly increase the mobility and availability of trace elements, especially Cu, since it has a higher affinity for organic carbon or matter that increased Cu bioavailability. Some researchers have also reported that soil OM increases the opportunity for forming stable OM complexes through chelation and reduces solubility of HM in the soil (Karami et al. 2011).

CONCLUSION

This study showed that applying 1–2 kg m^{-2} rice straw compost to Cu-rich paddies contaminated by mine tailings is optimal to increase yield. Doubling this application rate to 4 kg m^{-2} did not significantly increase yield. The 1 kg m^{-2} application rate did not give significant yield improvement over the control (0 kg m^{-2}) application in paddies with low soil OM. The 2 kg m^{-2} rate of application can be achieved by simply converting all straws into compost and then applying the compost to the paddy where the straws were gathered.

In the field demonstration conducted, combining compost with TMI considerably improved yield as compared to the yield from using TMI alone. Compost also gave beneficial effects (i.e., improved soil pH and soil OM); however, it did not reduce soil Cu levels. Compost treatment was not effective in decreasing the level of soil Cu, which may be due to the mixing of soil Cu from below to the surface or due to the complex interaction of soil OM with Cu. This study did not explore the reason for this observed result. This can be studied in subsequent research projects.

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