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Socio-Environmental Effects of Using *Trichoderma* Microbial Inoculant (TMI) and *Trichoderma*-Activated Rice Straw Compost (RSC) In Copper-Contaminated Rice Fields in Selected Barangays in Mogpog, Marinduque, Philippines

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ABSTRACT

In 1993 and 1996, agricultural fields in five barangays in Mogpog, Marinduque, Philippines were inundated with heavy metal (HM)-rich mine tailings when the tailings dam of Marcopper Mining Corporation burst. Additionally, HM-rich tailings from the abandoned mined-out sites of Consolidated Mines Incorporated (CMI) continued to leach into downstream rice fields. This contamination resulted in crop failures and loss of livelihood for the local residents. An earlier study to mitigate these effects utilized a phytobial remediation approach utilizing Trichoderma microbial inoculant (TMI) and Trichoderma-activated rice straw compost (RSC) as soil ameliorants in the contaminated rice fields in the barangays for six cropping seasons (2018-2020). This study assessed the socio-environmental effects of using TMI and RSC in the remediation of rice fields affected by copper contamination in Mogpog, seven years after the start of the remediation project. A total of 100 farmer-respondents were interviewed through semi-structured questions to determine their experiences, perceptions, and observed outcomes related to the remediation efforts. Results showed that 100% of respondents observed improved soil fertility and increased rice yield after the application of RSC and TMI, with 87% reporting increased household income. However, only 3% observed improvements in household health and pest control remained a challenge. Persistent challenges among farmers include poor irrigation, climate variability, and lack of manpower. While remediation using RSC and TMI shows promise, its long-term success requires consistent application, stronger institutional support, and further research, especially on other heavy metals that behave differently from copper. Ultimately, sustainable remediation must integrate environmental and socioeconomic improvements to ensure lasting recovery and resilience in farming communities.

Keywords: remediation, *Trichoderma* microbial inoculant, compost, copper- contamination

Abbreviations: acid mine drainage (AMD); Consolidated Mines Incorporated (CMI); key informant interview (KII); local government unit (LGU); *Trichoderma* microbial inoculant (TMI); *Trichoderma*-activated rice straw compost (RSC)

INTRODUCTION

In 2022 the Philippines ranked fifth in the world for overall mineral deposits (MGB DENR), second in nickel production accounting for an estimated 11% of global production and approximately 3.7% of the world's reserves (Moon 2024) and the fifth-largest producer of cobalt, accounting for 2.0% of global production and an estimated 2.4% of the world's reserves. In addition, the country also produced other mineral commodities, such as cement, chromium, copper, gold, and in iron ore.

The mining industry has significantly contributed to the Philippine economy through the export of minerals and providing livelihood opportunities in the communities in mining sites. According to MGB, there were over 49 metallic mines in the country and reported that employment in the mining sector grew from an estimated 180,000 in 2020 to 208,000 by the end of 2022. Though the contribution of mining to our country's economy cannot be denied, mining operations cause severe environmental degradation. Both Consolidated Mines Inc. (CMI) and MARCOPPER Mining Corp. in Marinduque primarily conducted open-pit mining for minerals gold and copper from 1968 to early 1990s. Ore processing to extract the desired mineral utilizes toxic heavy metals and chemicals and consume large volumes of water. These activities lead to soil erosion, water pollution, and atmospheric pollution, severely impacting the local environmental and the ecological functions of the vegetation (Li et al. 2023). Their operations create volumes of rock wastes consisting of highly acidic ground fine rock which still contain amounts of heavy metals hazardous to the environment and toxic to living organisms (Cooke and Johnson 2002). Mining companies store these rock wastes in tailing ponds.

The first Marcopper mining disaster in 1993 involved the collapse of its Maguila-guila Siltation Dam. This led to the flooding of the town of Mogpog, and total degradation of the Mogpog and Boac River systems. In 1996 a fracture occurred in a drainage tunnel of Marcopper's Tapian pit and released mine tailings to the two river systems (ATM 2011; Dizon 2019; Mining Watch Canada). These disasters released millions of cubic meters of toxic mine tailings, silt, and acidic water in the river systems leading to the disappearance of a large number of river organisms, and inundation of agricultural fields killing crops, poisoning coconut trees, disrupting livelihoods (fishing, farming) with sediments containing heavy metals of copper and manganese. The effects of these disasters are still felt to this day in Barangays Janagdong, Nangka II, and Anapog-Sibucao in Mogpog, Marinduque.

Mine tailings pose a threat to the public as leachates may go into the agricultural areas and bodies of water resulting in the contamination of the local food and water sources of surrounding areas (Aggangan et al. 2019). Currently, the mined-out area of Consolidated Mining & Investments, Ltd. (CMI) in Barangay Capayang continues to contribute to the heavy metal contamination in lowland agricultural areas of Barangays Capayang and Laon. Acid mine drainage (AMD) happens as mine tailings with mineral pyrite are exposed to air and water and get oxidized with other sulfide minerals. This event is coupled with activities of soil oxidizing bacteria, resulting in the production of acids (Prasad 2024). The acidic byproducts get deposited onto the soil surface and rain events produce runoff that flows down into the rice paddies rendering the soil acidic. This phenomenon together with the heavy metals from mine tailings

Transactions NAST PHL Vol. 47 (2025)
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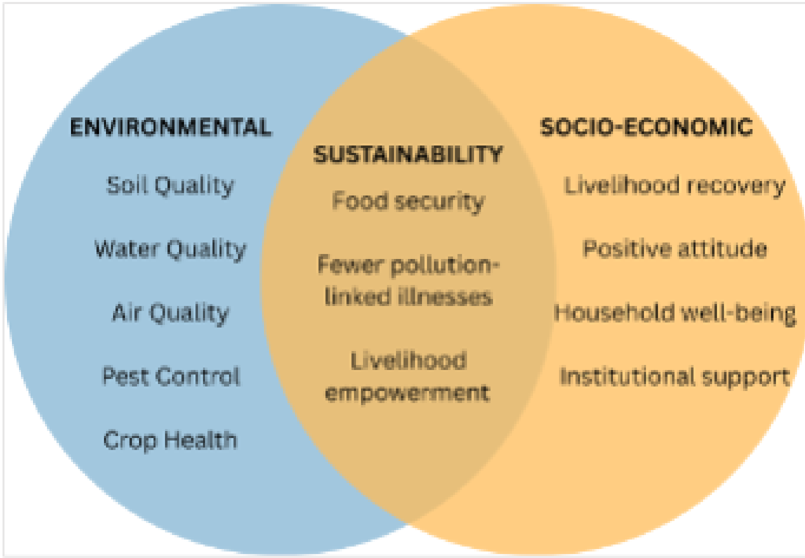

Figure 1. Environmental and socio-economic factors to consider in designing remediation efforts.

negatively affects the growth of rice and other crops.

Bioremediation is one of the technologies that is being used to mitigate the effects of mining on people and communities. It is a process that uses living organisms to neutralize, transform, or remove pollutants from the environment. Phytobial remediation is a highly efficient and eco-friendly remediation technique that utilizes microorganisms and plants to effectively remove heavy metals (Rahman et al. 2023). Cuevas and Banaay (2022a), with funding from the Bureau of Agricultural Research (BAR) of the Department of Agriculture (DA), studied the application of *Trichoderma*-activated rice straw compost (RSC) accomplished through in-situ composting and use of *Trichoderma* Microbial Inoculant (TMI) as seed coating in palay in alleviating the negative effects of heavy metal pollution (Cu) in rice cropping. The results showed increase in yield and reduction of the soil copper contamination levels in the rice paddies of Barangays Capayang, Ino, Anapog-Sibucao, and Janagdong of Mogpog, Marinduque. This process involves a gradual phytobial remediation with an associated increase in rice yield (Banaay et al. 2023). An earlier study showed that RSC reduced mineral fertilizer inputs and the impact of heavy metal contaminants on crops (Cuevas et al. 2014).

This study aimed to assess the environmental, social, and economic effects of using *Trichoderma* technologies in the copper-contaminated rice fields of Mogpog. The specific objectives of the study are as follows: (1) documentation and recording of the experiences and coping strategies of farmers before and after the Marcopper mining disasters and how the remediation project using RSC and TMI affect the environmental conditions of the rice fields and surrounding areas; 2) assessment of the perceptions and attitudes of farmers toward the remediation project before and after it was introduced and understanding of the impacts of the project on the socioeconomic well-being of the farming households; and 3) identification of the current challenges farmers face and the recommendations of the stakeholders for improving similar community-based remediation initiatives.

The data generated from the study attempted to show the relationship between key factors to consider in designing effective remediation efforts for rice fields that contribute to sustainability. Figure 1 illustrates the conceptual framework of this study. The diagram is composed of two interconnected spheres: one representing environmental factors and the other representing socio-economic factors. This highlights the need for integrated approaches that address both ecological restoration and the livelihood concerns of farming communities.

At the intersection of environmental and socio-economic factors are the key indicators that suggest sustainability is being achieved. Food security is significantly strengthened as improved crop health and productivity ensure a more stable and safe food supply for farming households. Reduced pollution-linked illnesses result from a cleaner environment, leading to fewer health issues. Livelihood empowerment emerges as farmers not only to improve their income but also deepen their understanding of sustainable practices, fostering confidence and active participation in environmental stewardship.

MATERIALS AND METHODS

The study consisted of three steps: (1) coordination with the Mogpog Town Mayor, barangay officials, and farmers in the community; (2) conduct of respective surveys for farmers and barangay officials, divided into two components: (a) an environmental survey to gather information regarding the effect of RSC and TMI on soil, water, air quality, as well as crop health and pest occurrence among crops, and (b) a socioeconomic survey to gather information about the farmers' state of livelihood, health, perceptions, and attitudes towards remediation, and assistance received from the government; and (3) analysis and categorization of data. Two methods of data gathering were used: (a) survey-cum-interview of all farmers who participated in the research project using semi-structured questionnaire, (b) Key Informant Interview (KII) of barangay chairpersons who are also farmers and randomly selected farmers.

Coordination with the stakeholders was done via emails, phone calls, and in-person meetings. Courtesy calls were conducted on the first day, prior to the interview proper. Three aides who were then residents of Mogpog assisted in the conduct of interviews by gathering the farmers in their respective barangays. Since they were natives of Mogpog, farmers knew them and good working relationships were easily established.

Interviews were conducted with farmers in five barangays whose rice fields were contaminated with HM-rich tailings. These five barangays were earlier selected based on soil analysis for presence of heavy metals, specifically Cu, in soil samples taken from fields identified by farmers as having serious problems (Banaay and Cuevas 2022). All 100 farmers who participated in the field trials for six cropping seasons from 2018 to 2020 participated in the survey-cum-interview. The discussion focused on the effects of using RSC and TMI on the rice fields, highlighting the local environment and socio-economic status of the farmers. The researchers developed a semi-structured questionnaire to interview the respondents.

Key informants for the KII consisted of randomly selected farmers and the barangay chairpersons of the five affected barangays who are also farmers. A total of 10 respondents were interviewed for the KII. Selection of respondents was done through stratified random probability sampling among residents in each barangay, aged 20 years old and above, to ensure their knowledge of the conditions before and after the rehabilitation effort. A different set of questionnaire was used for the KII.

Study Sites

The study was conducted in the following barangays: Janagdong, Nangka II, Capayang, Anapog-Sibucao, and Laon. Agricultural lands in Barangays Capayang and Laon are affected by the heavy metals from CMI-mined-out area as they derive irrigation from the water in the excavated pit. Barangays Janagdong, Nangka II, and Anapog-Sibucao, on the other hand, were affected by the Marcopper mining accidents, and are located near the Mogpog River (Figure 2).

Figure 3 shows the location and the level of contamination of each of the five barangays with mine tailings-contaminated fields. Categorization of the levels of contamination as moderate or severe was based on the soil analysis of the soil samples from rice fields identified by farmers as having serious rice productivity problems. Barangays in red color exhibit severe soil Cu contamination (Janagdong and Capayang (Banaay and Cuevas 2022), with soil Cu level ranging from 290-386 mg kg^{-1}. The rice fields in yellow color (Anapog-Sibucao, Laon, Nangka II) had moderate levels of HM contamination, with soil Cu level ranging from 110-140 mg kg^{-1} (Banaay and Cuevas 2022).

Ethical Considerations

Permission from the mayor of Mogpog, Marinduque to conduct the study was initially obtained. The rights of the correspondents were explained to them prior to the interview, and consent forms were provided and signed afterwards. The researchers ensured that the farmers had a clear understanding of their participation to help them appreciate the implications of their involvement. In accordance with the Data Privacy Act of 2012, the anonymity of the participants' information was

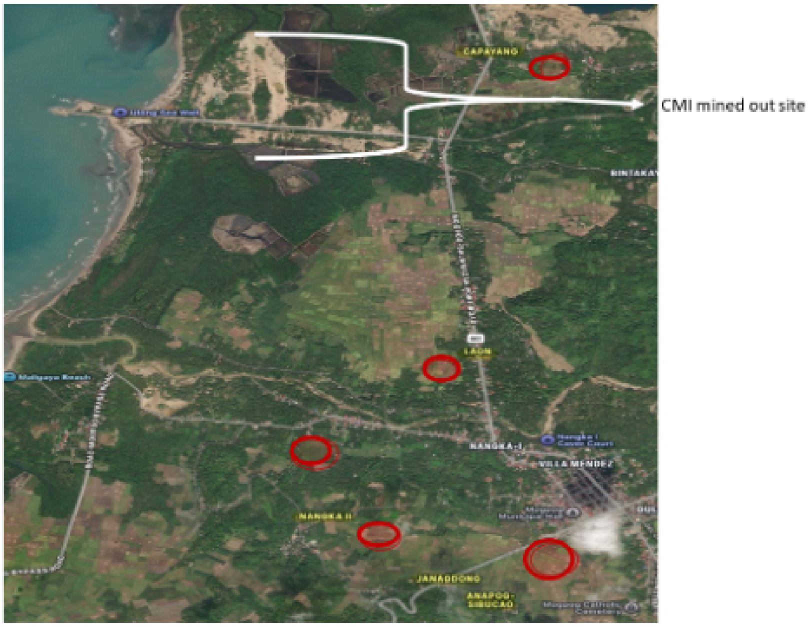

Figure 2. Map showing the location of the 5 barangays where rice paddies are contaminated with HM-rich mine tailings. Red circles indicate the location of the contaminated rice paddies (Apple map- https://maps.apple/r/a53aT3GSmchLbb)

Figure 3. Map showing the location of rice paddies with severe and moderate contamination. Rice fields in red circles (Capayang and Janagdong) had severe contamination with soil Cu level ranging from 290-386 mg kg^{-1}. Rice fields in yellow circles (Laon, Anapog-Sibucao and Nangka II) had moderate level of contamination with soil Cu level ranging from 110-140 mg kg^{-1}. (Apple map - https://maps.apple/r/a53aT3GSmchLbb)

Transactions NAST PHL Vol. 47 (2025)
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respected with utmost confidentiality.

RESULTS AND DISCUSSION

The demographic profile of the respondents in the survey-cum-interview in terms of age, sex, and number of years of residence in Mogpog is shown in Table 1. At the time of the study, out of 100 respondents, 96 had resided in Mogpog since birth, and 4 for less than 20 years.

A. Knowledge provided by key informants

Experiences before and after Marcopper and CMI mining operations

i. Impact on agricultural productivity

An interview with the Barangay Chairperson of Barangay Laon revealed that before the 1993 Marcopper mining accident, residents sourced their water from the Mogpog River for drinking, bathing, and laundry. However, after the 1993 bursting of Marcopper's Maguila-guila Siltation Dam, muddy floodwater covered the rice fields, and all their crops were destroyed.

A farmer in Barangay Capayang shared he learned that after the mining operations accident of CMI, heavy metals, copper and lead were left in their rice fields (Cuevas and Banaay, 2022). As a result, rice yields declined significantly. The crops became stunted, and the soil turned yellow and emitted a foul odor. During periods of heavy rainfall, the fields would get flooded, causing the crops to die. Another farmer from the same barangay stated that before the mining accident, rice yields were occasionally good, although there were times when pests had to be dealt with. However, after the disaster, even with the application of fertilizers, the crops could not survive.

The collapse of Marcopper's Maguila-guila Siltation Dam in 1993 released a flood of metal-enriched silt into the Mogpog River. A kagawad (councilor) from Barangay Anapog-Sibucao shared that the bursting of the dam led to mudwater flooding in their town. Each resident received PhP 1,000.00 from Marcopper as compensation for the damaged properties. An interview with the chairperson of Barangay Nangka II revealed that no one in their community was able to plant crops because the land remained submerged. As a result, farmers lost their livelihood due to the lack of arable land. Fish kills were also observed whenever the river water turned blue. This phenomenon is associated with the presence of copper, a heavy metal known to be toxic to aquatic life, in the Mogpog River. A farmer from Barangay Janagdong shared that growing rice had become difficult because the soil had turned red, resembling rust. The irrigation channels in the rice fields had also become clogged, further hindering crop production.

ii. Impact on health of residents

From 1975 to 1991, Marcopper had discharged mine tailings containing high concentrations of heavy metals into Calancan Bay. Several years have passed but the toxic mine wastes continue to choke the organisms in the waterways. This continuously affects the health of individuals relying on the waterways for their food. There is a grave threat that these discharged heavy metals from the mine tailings may accumulate in the bodies of living organisms. People, like fisherfolks, who are frequently exposed to such bodies of water, would be more exposed to the toxic mine wastes that persist in the environment. However, the informants did not disclose the number of residents who were affected by contaminated waterways. In a study conducted by Marges et al. (2011), the total copper, zinc, and lead concentrations observed in the waters of Calancan Bay were higher than the standards prescribed for Class SB

Table 1. Demographic profile of respondents.

Sex		Age group	
Male	61	30-39	2
Female	39	40-49	12
Total	100	50-59	29
		60-older	57
		Mean age	60

waters or bodies of water that are suitable for shellfish propagation and spawning of fishes (Marges et al. 2011).

B. Information derived from survey cum- interview of all farmers who participated in the remediation project

Before and after using RSC and TMI

The interview results revealed a high level of awareness among respondents regarding the remediation efforts in the rice fields. Approximately 85% of the respondents were aware of the implementation of RSC and TMI technologies (Table 2) and 98% believed that heavy metals were present in the rice fields which affected crop growth as explained by the project researchers (Cuevas and Banaay 2022 a). A majority (98%) also agreed that the presence of heavy metals poses a threat to human health.

With regard to perception and attitude towards the remediation efforts, 97% of the respondents expressed confidence in the effectiveness of the project. The remaining 3% reported a positive change in opinion after observing the results of the implementation.

The community's awareness of the environmental effects of using RSC and TMI is shown in Table 3. All respondents (100%) reported noticeable changes in soil quality, describing the soil as having become more fertile, as shown by better crops' growth and higher yields. In terms of water quality, 80% of the respondents observed improvements as shown by clearer irrigation water and the crops' good growth following the implementation of the remediation project. However, only 5% believed there were changes in air quality. A significant majority (98%) observed improvements in crop quality. Rice farmers from Barangay Janagdong noted that the rice crops were healthier and not stunted, although they remained vulnerable to extreme drought. Moreover, only 58% of respondents indicated a reduction in pest occurrence. Common pests such as *Leptocorisa oratorius* (rice ear bug), *Rattus argentiventer* (rice field

Table 2. Awareness of the respondents on the remediation project in the rice fields.

Questions	Yes	No
Are you aware that UPLB researchers conducted a rehabilitation effort using RSC and TMI in the rice fields?	85	15
Are you aware that there are heavy metals in the rice fields and surrounding areas?	98	2
Do these heavy metals affect the growth of crops in the rice fields?	98	2
Do you think that these heavy metals negatively affect the health of humans	98	2

Table 3. Awareness of the respondents on the environmental changes brought by RSC and TM

Questions	Yes	No
Have you observed changes in rice yield?	100	0
Did you observe changes in the soil quality?	87	13
Have you observed changes in the water quality?	80	20
Have you observed changes in the air quality?	5	95
Have you observed changes in the crop health?	98	2
Have you observed changes in the pest occurrence?	58	42

Transactions NAST PHL Vol. 47 (2025)
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Table 4. Awareness of the respondents on rice productivity and the socio-economic changes brought by RSC and TMI.

Questions	Responses	
	Yes	No
Have you observed changes in rice yield?	100	0
Have you observed any changes in your household's overall income from rice farming?	87	13
Have you observed changes in the health of your household?	3	97

rat), *Pomacea canaliculata* (golden apple snails), and *Lonchura atricapilla* (eurasian tree sparrows) were still present.

Table 4 presents the respondents' awareness on the socio-economic effects brought by RSC and TMI use. Approximately 87% observed changes in their household's overall income from rice farming, noting that their income had relatively increased compared to before the use of TMI. A farmer from Barangay Janagdong shared that yield from eight plots would typically be 50 pails of rice, but with *Trichoderma*, this could reach up to 100 pails.

Regarding health status, only 3% of respondents reported changes in their household's health, stating that no one had fallen ill due to heavy metals since the remediation project. One farmer from Barangay Janagdong reported having white spots on her legs, which were not consulted with a medical professional. This is most likely not related to the heavy metals in rice crops as the rice grains harvested from the remediated-contaminated fields had Cu content which ranged from 0.66-0.98 mg kg^{-1} (Cuevas and Banaay (2022a) which is within the World Health Organization's (WHO) allowable limit of 10 mg kg^{-1} for Cu. The same study reported that soil Cu in the control plots in Brgy Capayang (without soil amendments) with severe Cu contamination of 565.9 mg kg^{-1} significantly decreased to 377.2 mg kg^{-1} after one season treatment with RSC using palay seeds coated with TMI. Similarly, soil Pb at 41.8 mg kg^{-1} in control plots significantly decreased to 36.8 mg kg^{-1} after one season application of the soil amendments. Soil pH of 4.5 of remediated paddies did not significantly improve compared with 4.4 of control paddies.

Ninety percent (90%) of the respondents replied positively when asked if they received support from the government. TMI and *Trichoderma* activator were supplied by the project, free of charge to the farmers from the funds released by DA-BAR. Farmers from all barangays stated that the Municipal Agriculture Office (MAO) provided them with fertilizer and seeds. When other concerns arose in the field, almost all of the farmers in the interview mentioned that they brought these up during farmers' association meetings or whenever they were gathered by the barangay chairperson.

With regard to the effectiveness of using RSC and TMI, 100% of the respondents affirmed that these interventions were effective in improving their farming outcomes. Ninety percent (90%) of the farmers interviewed expressed a desire to receive *Trichoderma* again for future planting seasons. Not only did the project improve rice yield, but it also promoted more sustainable farming practices as all the farmers no longer burn rice straw but instead use it for composting.

Environmental impacts and yield effects of using RSC and TMI

Previous studies on the impacts of using RSC and TMI support the results of the study. The increase in rice yield with application of RSC and TMI in copper-contaminated rice paddies was also observed in Mankayan, Benguet, Northern Luzon where affected farms were contaminated by mine tailings rich in copper from the 1986 dam failure accident of Lepanto Mines Incorporated (Cuevas et al. 2019). In this study, a randomized complete block design with four treatments replicated three times was used as the experimental design. The compost produced using the pile method, applied at the rate of 2 kg m^{-2}, significantly improved yield and the number of productive tillers compared to the control. In addition, Cuevas et al. (2014)

Transactions NAST PHL Vol. 47 (2025)
doi.org/10.57043/transnastphl.2025.5679

showed that compost amendment also significantly improved soil pH and also demonstrated significant correlation between soil Cu concentration and the Cu level present in rice roots. This means that the higher the level of soil Cu, the more Cu was absorbed by the roots. However, minimal amounts of Cu (3 to 5 mg kg^{-1}) were translocated to the straw. On the other hand, in the study in Mogpog, Marinduque, *Trichoderma* technologies demonstrated significantly increased yield compared with control (Cuevas and Banaay 2022b). In moderately contaminated rice fields (110-144 mg kg^{-1} Cu), remediated paddies had an average 34% increase while in severely contaminated fields (290-386 mg kg^{-1} Cu), an average 65% yield increase was registered. These field trials were conducted during the El Niňo years of 2018-2019.

Researchers from other countries also reported similar bioremediation activities of different species of *Trichoderma* (Babu, et al. 2014, Yao et al. 2023, Altaf et al. 2025). Inoculating heavy metal-contaminated mine tailing soil with the *Trichoderma* fungus significantly increased the dry biomass of the roots and shoots of maize (*Zea mays* L.), mustard green (*Brassica juncea*), and mungbean (*Vigna radiata*). Reports include increase in chlorophyll, sugars, starch, and protein contents compared to plants grown in uninoculated soil as well as reduction of residual heavy metal concentrations in the soil.

Remaining Challenges

According to farmers from the five barangays interviewed, the top three major problems they currently face in farming are: poor irrigation systems, pest infestation, and labor shortages. The irrigation systems often dry up during the summer months and overflow during the rainy season. These issues are worsened by climate change, which causes erratic weather patterns, including reduced rainfall, prolonged droughts, and intensified typhoons. While the RSC and TMI project contributed to soil and crop quality improvements, it was not able to effectively address pest problems. Pests such as the rice bug continue to damage crops despite remediation efforts. During the KII, the issue of declining manpower also emerged, as younger generations prefer to pursue education or work elsewhere rather than engage in the laborious and uncertain task of farming in contaminated lands.

Remediation should be approached as a consistent and long-term process, as observable changes in environmental conditions occur gradually over time. Sustained support from the government is essential to ensure its success. In particular, local government units (LGU) must take proactive measures to institutionalize and continuously implement remediation strategies, ensuring that resources, training, and monitoring are made available to affected communities.

Heavy metal removal is a slow and long-term process. Cuevas and Banaay (2022 b) showed that the top 30 cm of contaminated soil can be remediated through the regular application of compost and TMI during each cropping cycle. However, due to land tillage and soil mixing, deeper layers with higher copper concentrations may be brought to the surface, thereby affecting newly planted rice crops. In this way, heavy metals continue to recirculate within the soil system but are gradually reduced over time with continuous compost application. As such, full rehabilitation of the land may take several years or even decades.

Recommendations

The Philippines has experienced several mine tailings dam breakdown disasters similar to the Marinduque MARCOPPER 1993 and 1996 accidents (Bennagen 1998; ATM 2011). Farmers in the affected areas faced the same problems as those of Mogpog farmers. Thus, the recommendations presented here hold true for all such areas.

The problems mentioned earlier mainly revolve around lack of government support to farmers. The LGUs and national agencies, such as the Bureau of Soils and Water Management (BSWM) under the DA, should support the development of climate-resilient irrigation systems that can store excess rainwater and efficiently distribute it to the barangays during dry months. More studies should be conducted on controlling pests in soils affected by heavy metal contamination. This could involve exploring biological controls or pest-resistant rice varieties, or integrated pest management (IPM) strategies suitable for these conditions.

It is important that government agencies demonstrate that engaging in agriculture is financially rewarding to encourage younger individuals to take part in sustainable agriculture and land rehabilitation efforts. This will help address the manpower shortage. Local governments can facilitate shared labor systems, machinery cooperatives, or seasonal labor assistance to ease the burden on individual farmers. DENR should also address the responsibilities of mining companies in rehabilitating lands damaged by mining operations such as those mentioned in this paper.

More basic researches should be conducted involving heavy metals other than Cu since different heavy metals behave differently in plant systems. Hyperaccumulators, plants that can absorb from the nickel and other heavy metals from the soil and store them in leaves and other above ground tissues at concentrations 100 to 1000 times higher than normal without toxicity should be given attention. He et al. (2012) stated that these plants are useful in phytoremediation of Ni-contaminated soils. Therefore, the effectiveness of remediation efforts varies depending on the specific heavy metal targeted for removal. Studies focused on other bioremediation techniques that can serve as a guide in developing soil amendments, such as compost or chelators, that enhance metal uptake or immobilization (Yin et al. 2024) are needed. This integration of knowledge leads to more efficient soil rehabilitation approaches, especially as mining becomes increasingly vital for producing modern technologies. All these strategies lead to livelihood recovery and will help farmers to regain stable income. Reduced exposure to harmful chemicals also contributes to better household health. This institutional support emphasizes the importance of continued backing from government agencies to ensure the long-term sustainability and scalability of remediation efforts.

CONCLUSION

The study concludes that the use of *Trichoderma* Microbial Inoculant (TMI) and Rice Straw Compost (RSC) has positive impacts on the rice farming communities of Mogpog, Marinduque. Farmers from all five barangays observed improved soil quality and crop performance, leading to increased rice yields and relatively higher household incomes. The remediation approach not only helped in recovering contaminated soil but also fostered sustainable farming practices among the respondents. However, full rehabilitation remains a long-term process. Socioeconomic challenges such as labor shortages, ineffective pest control, and unreliable irrigation systems continue to hinder the full recovery of the farmers. These issues are further exacerbated by climate change, which alters rainfall patterns and increases the frequency of extreme weather events. Funding for pest research, development of climate-resilient infrastructure, and programs that encourage youth engagement in farming are critical. Effective remediation must be a holistic, integrated approach that promotes socio-environmental and economic sustainability

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Contribution of authors:

JH Pacheco— conceptualization, conduct of study, preparation of initial paper, analysis and discussion;

Merdelyn T. Caasi-Lit —assisted in the design of the study and conduct of the interview of the farmers;

Virginia C. Cuevas—conceptualization, supervision of study, analysis and discussion, and finalization of paper.

Declaration of conflict or competing interest:

The authors declare that there is no conflict of interest in the conduct of this study.

Declaration of author approval:

All authors agree to publish this paper.

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