ARTICLE

Trichoderma technologies: a complete toolkit for sustainability, resilience, and environmental rehabilitation in Cu-contaminated lowland rice and vegetable areas in Mogpog, Marinduque, Philippines

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ABSTRACT

The farming community of Mogpog, Marinduque has been beset by problems caused by soil contamination from mine tailings since two mining disasters happened in 1993 and 1996 alongside current fall-out from a mined-out site undergoing rehabilitation. Crop productivity declined due to copper toxicity and farmer incomes have diminished as a result, thus contributing to the poverty in the area. This is on top of the problems with pests, diseases, and climate-related phenomena even while the farmers are continuously impoverished by the effects caused by mine tailings spill that occurred >24 years ago. A project funded by DA-BAR (2017-2021) was conducted to help alleviate the constraints to crop productivity due to heavy metal toxicity, mitigate the effects of pests, diseases and other abiotic stressors, and increase crop yields and farmer incomes through the use of ecological management practices involving the use of two *Trichoderma* technologies (TT) namely, *Trichoderma* compost activator (TCA) and *Trichoderma* Microbial Inoculant (TMI).

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KEYWORDS

Trichoderma, bioremediation, growth-promotion, *in situ* composting, resilience, sustainability

During the three years of project implementation, the farmers experienced the effects of El Niño and the pandemic. Through it all, *Trichoderma* technologies have helped increase their harvests by 12-81%, promoted resilience of crops to drought and pest pressure as attested by the farmers in interviews and surveys, saved money through reduced inputs of fertilizers and pesticides, and helped to manage crop residues through *in situ* composting that added organic matter in the field thus promoting sustainable use of natural resources. A field study conducted in 2020 showed that the technologies aided in the partial remediation of soil copper through the combined action of compost and TMI. The research project showed that *Trichoderma* technologies are instrumental in promoting sustainability, resilience, and environmental rehabilitation in copper-contaminated agricultural areas. These technologies help address concerns related to poverty, food security, health, economic growth, and responsible production.

INTRODUCTION

The objective of this paper is to give an overview of major results, learnings, experiences, and insights gleaned from community engagements, surveys, and observations from five seasons of rice cropping and two seasons of vegetable cropping as well as present soil and socio-economic survey data that have not been previously published. The field experiments and surveys were part of a 3-year project funded by DA-BAR entitled "Use of Agriwaste Compost and *Trichoderma* Microbial Inoculant (TMI) for LGU and Community-based Rehabilitation of Agricultural Lands Damaged by Mine Wastes in Mogpog, Marinduque" (hereafter referred to as Mogpog Project), that was extended for another year due to constraints posed by the CoViD-19 pandemic. This paper also aims to provide information on how *Trichoderma* technologies can help support sustainability goals, increase resilience of crops and communities, and help rehabilitate heavy metal-contaminated agricultural soils.

The Mogpog story is a tale of two disasters related to mining accidents that affected several towns in Marinduque especially Mogpog. It is also a story of recurring contamination with fall-out from a mined-out area. The first disaster occurred in 1993 when a mine tailings dam collapsed and spilled contaminated water onto the surrounding land. The second one happened in 1996 when a drainage tunnel of a mine tailings pit burst and inundated the Mogpog River and surrounding lands with heavy metal-contaminated water. Presently, a CMI (Consolidated Mining & Investments, Ltd.) mined-out area continues to contribute to the heavy metal contamination in lowland agricultural areas. The result is a phenomenon called Acid Mine Drainage (AMD).

A few studies were conducted to look into the effects of these two mining disasters on the community and the environment (Lindon et al., 2014; Regis, 2006). Results from the study of Regis (2006) showed that the environment was negatively affected as seen in highly acidic soil, heavy metal contamination, pollen grain abortion, and accumulation of arsenic, lead, and copper in an indicator plant. Since then, several studies have been conducted on the rehabilitation of the CMI mined-out areas mainly in Barangay Capayang (Aggangan and Anarna, 2019; Aggangan et al., 2017, Cadiz et al. 2012, Mante et al., 2019). While the previous studies focused on the rehabilitation of the forest in the mined-out site, the rehabilitation of affected agricultural lands was not addressed.

In the aftermath of the two mining disasters coupled with the intermittent fall-out from the CMI mined-out site, the Mogpog story continues as a series of unfortunate events. Heavy metal toxicity reduced the yield of crops and resulted to several health concerns as mentioned by residents during a survey. Reduced crop yield means reduced income so they have fewer resources to buy inputs and support farm operations as well as family needs. In addition, various abiotic and biotic factors put more pressure on the situation. This has led to increased poverty in the area.

A 2008 survey of Mogpog (Lindon et al., 2014) showed that rice yield was reduced to 1.5 t ha^{-1}, and among the local community, 48% are income poor and 30% are experiencing food poverty. In a survey conducted at the start of the project in 2017, poverty has grown to 67%. More than half of the households have 4-6 members and almost half are relying on single farmer incomes.

The situation in Mogpog has worsened through the years precipitated by the mining disasters that happened more than 25 years ago. Science-based interventions are needed to help the community overcome the effects of heavy metal contamination. Figure 1 shows an area in Barangay Ino with the CMI mined-out area adjacent to a rice field with moderate levels of soil Cu contamination (150 ppm). The fall-out from this site continues to contaminate the agricultural fields in Barangay Ino and Capayang. The figure illustrates and implies that while rehabilitation of mined-out areas are being carried out, rehabilitation of affected agricultural lands need to be addressed also.

Figure 1: Mined-out area above a lowland rice field in Barangay Ino, Mogpog, Marinduque, Philippines.

MOGPOG PROJECT ACTIVITIES & METHODS

The project consisted of five main courses of action as follows (and shown in Figure 2):

1. Coordination with the Mogpog Local Government Unit headed by its Mayor, ably assisted by the MAO (municipal agricultural officer), MENRO (municipal environment and natural resource officer), barangay officials, and the farmer leaders in the community;
2. Conduct of surveys consisting of two components, namely: (a) initial survey to gather information from the local community regarding the mining accidents, ensuing effects, and assistance received, and (b) socio-economic surveys of farmer cooperators (baseline and exit surveys);
3. Delivery of seminars, trainings, and workshops to inform stakeholders about the technologies introduced, preparation of "home-made" biofertilizers as alternative cheap inputs, and lectures on integrated nutrient and pest management;
4. Analysis of baseline soil parameters and categorization of areas based on soil Cu concentrations as well as determination of Cu levels in crops already grown in the area;

Figure 2: Plan of action undertaken to address constraints to crop productivity in Cu-contaminated agricultural areas in Mogpog, Marinduque

5. Field experiments consisting of five seasons of rice cropping and two seasons of vegetable cropping to compare crop productivity between the farmer's usual practice versus the use of *Trichoderma* technologies (TT) – *Trichoderma* compost activator (TCA) and *Trichoderma* microbial inoculant (TMI). The last season, conducted in 2020, consisted of a limited number of farmers that aimed to specifically assess the bioremediation potential of the technology.

Coordination with stakeholders was accomplished through e-mails, phone calls and in-person meetings. Monthly trips to Mogpog were done during the first year of the project for meetings with the Mayor, MAO, MENRO, barangay officials and farmer communities. On three occasions, the Mayor invited the project leader to present the project objectives and activities to a gathering of all barangay officials.

Two science aides who are residents of Mogpog were hired as full-time staff. These two aides monitor and assist in the conduct of project activities in their respective barangay assignments. Since they are natives of Mogpog, farmer cooperators know them, and good working relationships were easily established. A series of 13 farmer meetings, seminars, and trainings were conducted with the help of the science aides.

A survey was conducted among 19 LGU staff including the Mayor and Vice Mayor of Mogpog and 23 farmer leaders on the impacts of mining in Marinduque particularly on the local environment and on the agricultural performance of the municipality. The main objective of the survey was to get information from the point of view of the residents who are directly affected by the mining disasters. This survey gathered information directly from those who have first-hand experience of the disasters. Several questions were also asked about the current project and its objectives.

Socio-economic surveys were also conducted that included farm-level data on production, costs, and income. A total of 200 rice farmers were interviewed. They were divided into two categories: cooperators and non-cooperators. Complete enumeration was employed for the cooperators, while convenient sampling in terms of availability and proximity of residence was done for the non-cooperator list. Enumerators conducted face-to-face interview of respondents from nine different barangays in Mogpog, Marinduque in December 2017. Specific data gathered were based on last cropping of rice. The survey was repeated in 2020 without replacement to be able to determine the impact of the intervention package to rice production, at the least, to the respondents/cooperators.

Seminars and trainings were conducted in the Mogpog municipal hall conference room and then later in the barangays during the monthly visit of the project research team in the project site. A holistic approach in rice cropping was adopted during the trainings. Rapid composting and use of TMI were not the only topics discussed. Rather these two topics were incorporated as part of the integrated nutrient and pest management. Other topics included are water management and land preparation processes. *In situ* composting was discussed in relation to land preparation. Farmer cooperator volunteers were recruited for the project during the meetings.

The specific methods used for the soil and plant analyses and field experiments have been described previously (Banaay and Cuevas 2022, Cuevas and Banaay, 2022a, 2022b). In addition, soil labile amino nitrogen (SLAN) and soil microbial respiration measured as soil CO_2-burst (SCB) were determined in the same soil samples described in the paper by Banaay and Cuevas (2022) through a one-step chemical conversion method and a CO_2-burst protocol, respectively. The tests were performed using soil test kits following the manufacturer's instructions (https://solvita.com/soil/). Both the SLAN and SCB tests provide indicators of soil chemical and biological processes, which form the basis for healthy soil functioning. SLAN is organic nitrogen that is potentially available to organisms over time while the SCB indicates microbial respiration. SCB has been shown to be proportional to microbial biomass as well as to potential C and N mineralization, thus it is an indicator of soil health and nutrient release. ANOVA and correlation analysis were conducted for the SLAN and SCB data in relation to the baseline soil analysis data.

BASELINE INFORMATION AND INITIAL ACTIVITIES

Initial baseline soil analysis indicated that many areas are severely Cu-contaminated with more than 200 ppm of soil Cu. Of the 43 soil samples collected from 16 barangays, 28% have normal soil Cu levels of <50 ppm; 9% have low Soil Cu contamination of 50-100 pm; 23% are moderately Cu-contaminated with 101-200 ppm; and 40% have severe Cu-contamination levels of >200 ppm (Banaay and Cuevas, 2022). In the whole duration of the study, severe Cu-contamination levels of up to 1,300 ppm were observed (Cuevas and Banaay, 2022a). Severe contamination was also observed from samples taken one meter below the soil surface (Banaay and Cuevas, 2022). It is highly possible that the contamination reaches much deeper into the soil profile. Furthermore, soil contamination seems patchy as seen in the patchy growth of rice seedlings (Figure 3) and the varying soil Cu concentrations in the different sampling areas (normal, low, moderate, and severe Cu-contamination in adjacent sampling areas).

SLAN and SCB data analysis showed that microbial respiration is significantly higher ($P<0.05$) in soils with normal Cu levels (<50 ppm) compared to contaminated soils (Cu>50 ppm) regardless of contamination level (Figure 4A). Previous studies

Figure 3: Patchy growth of rice seedlings in the Cu-contaminated lowland paddy in Brgy. Bintakay, Mogpog, Marinduque.

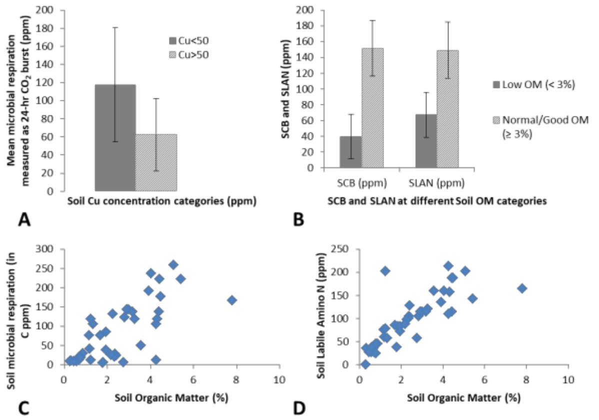

Figure 4: (A) Mean soil microbial respiration measured as soil CO_2-burst (SCB) in soils with normal Cu levels is significantly higher (P<0.01) than SCB in soils with high Cu levels (B) Highly significant differences (P<0.001) in SCB and soil labile amino nitrogen (SLAN) between soils with different organic matter (OM) content; (C) Highly significant strong positive linear correlation (P<0.001; r=0.73) between soil OM and SCB; (D) Highly significant strong positive linear correlation (P<0.001; r=0.79) between soil OM and SLAN.

have likewise demonstrated significant changes in microbial activity even at low to moderate Cu concentrations of 60 to 150 ppm and that the effects are more pronounced after longer time exposures (Banu et al., 2004; Keiblinger et al., 2018). The soil in Mogpog has been exposed to high Cu concentrations for more than two decades so differences between normal and contaminated soil can be observed. Dumestre et al. (1999) likewise showed that significant effects can still be observed even after 50 years of soil Cu contamination. However, contrary to previous cited studies, no differences in microbial activity can be observed between minimally, moderately, and severely contaminated soils. Apparently, after many years of exposure, soil microbial communities are able to function at a certain level despite the presence of toxic levels of Cu. Because respiration rates do not show the level of diversity, a clearer picture of effects of toxic soil Cu levels may be seen if metagenomic approaches are employed.

Baseline soil health analysis (based on microbial respiration and soil labile amino N measurements) suggest that the primary factor influencing Mogpog soil health is organic matter content (OM). Both SCB and SLAN levels in low OM are significantly lower than SCB and SLAN in high OM soils (Figure 4B). In addition, soil OM is positively correlated to both SCB and SLAN (Figure 4C and 4D). The analysis implied that organic matter amendment could help restore impaired functions or increase resilience of microbial communities in soils affected by toxic compounds as it affects microbial activity and N reserves in the soil. In this regard, amendment with rice straw compost may be a viable option for rehabilitating degraded lowland rice fields impaired by low OM and high soil Cu concentrations.

Due to the soil contamination, crop yields dwindled. Initial surveys with farmers reported a 50% reduction in the rice yields. Field experiments confirm this yield decline with data showing a reduction of 21-66% compared to the control plots and a 72% reduction compared to the potential yield (Banaay and Cuevas, 2022). The farmers also reported reduced harvests from other crops such as vegetables, root crops, and fruits. The farmers claimed that this has led to increased poverty due to reduced income from harvests.

There were also problems with various biotic and abiotic factors such as pests, diseases, and El Niño. Although monitoring of the occurrence of pests and diseases were not part of the objectives of the project, the team closely coordinated with farmers through the science aides to help address these concerns hence the conduct of seminars on integrated pest and nutrient management. The farmers have a reduced capacity to cope with these problems because of lack of resources so the project team offered assistance through capacity-building not only on alternative cost-efficient production of pesticides and fertilizers but also on rapid composting of municipal wastes that will be used for the rehabilitation of mined-out areas that are planned for conversion to Eco-Tourism sites (Figure 5).

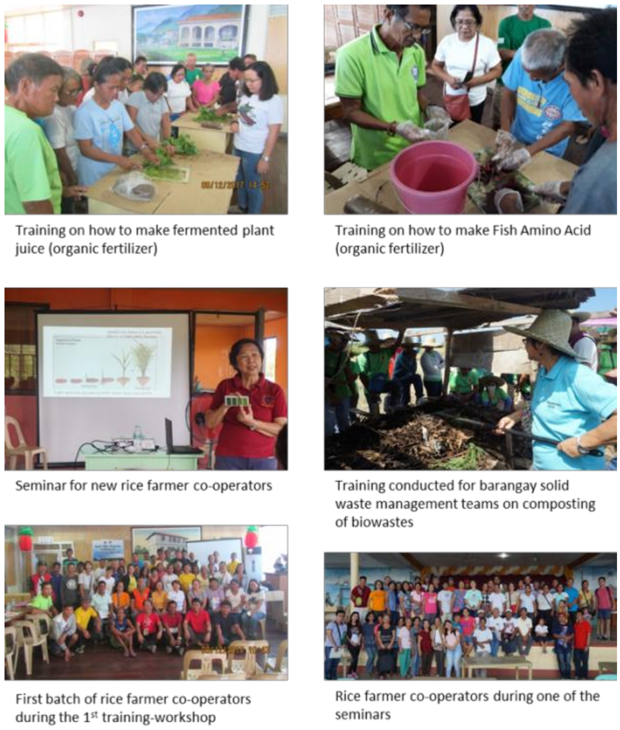

Figure 5: Farmer cooperators and capacity-building acivities conducted in Mogpog, Marinduque, Philippines.

BENEFITS GAINED FROM THE PROJECT

UPLB-LGU-Community Partnerships

To ensure the sustainability of positive actions to address the constraints to crop productivity in heavy metal-contaminated agricultural lands, community-based engagements and inclusive partnerships are a requirement (Figure 6).

Partnerships, coordination, and collaboration are crucial for successful transfer, dissemination, and diffusion of environmentally sound technologies. Local partnerships and employment strengthen cooperation, responsibility, accountability, ownership, and good governance. Employing

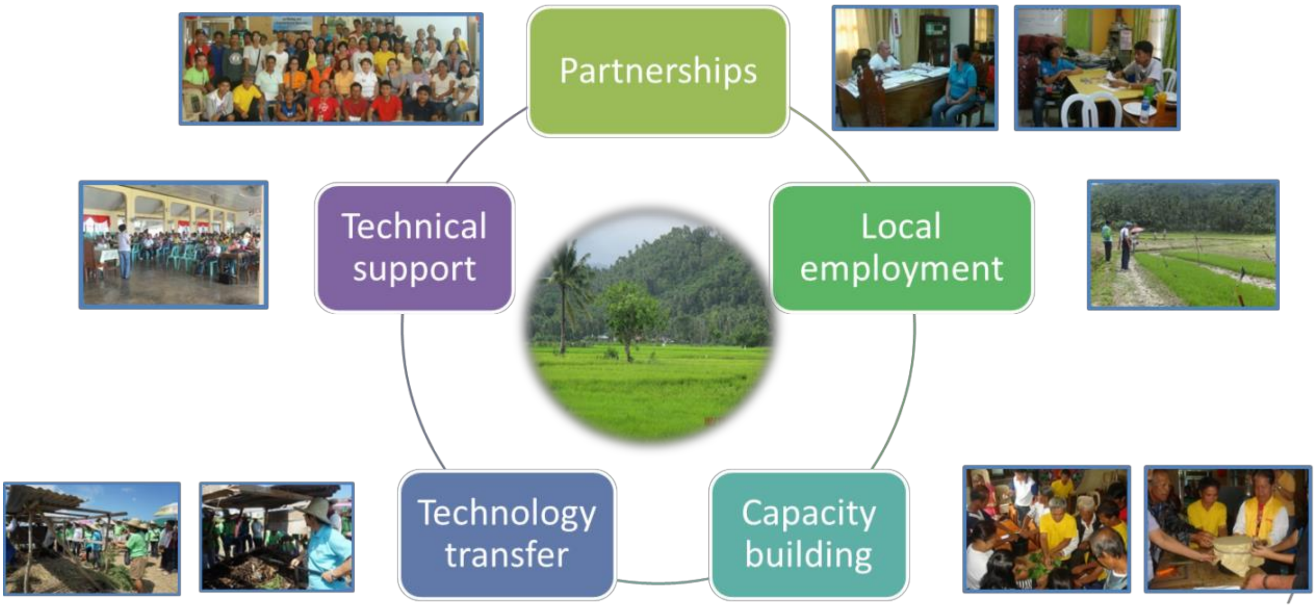

Figure 6: Ensuring sustainability of project benefits through community-based engagement and partnerships involves coordination with stakeholders, local employment, capacity building, technology transfer, technical support and discussions.

locals in the project makes building relationships easier because they know the place and the people. Capacity-building empowers and enables stakeholders, and supports equitable involvement and knowledge-sharing. Technology transfer and technical support meetings are avenues for airing and addressing concerns, demonstrating the use of the technologies, and sharing of experiences and testimonies. Farmer meetings encourage good relationships, build confidence and trust, strengthens camaraderie and cooperative spirit, and helps build an enabling environment.

Crop growth-promotion and biocontrol

The *Trichoderma* strains (*T. ghanense* and *T. harzianum* strains) used in the TT employed in the project have been studied since the 1980s. These strains enhance the decomposition process (Cuevas et al., 1988), solubilize nutrients in the soil (Cuevas, 2006), promote root and shoot growth (Banaay et al., 2012; Cuevas et al., 2005), control crop pathogens (Cuevas et al., 1995, 2001, 2005, 2011, 2012; Cuevas and Bul-long, 2009), induce systemic resistance against foliar pathogens and insects (Banaay et al., 2011; Silva et al., 2019), and assist in the remediation of heavy metals in soil (Cuevas, 2009; Fontanilla and Cuevas, 2010). Particularly in rice, TT strains have been shown to promote crop growth in normal and in heavy metal-contaminated soils (Cuevas, 2006; Cuevas et al., 2014, 2019), and suppress soil-borne pests and diseases and induce systemic resistance (Banaay et al., 2011, 2012, 2013).

In the Mogpog Project, the growth-promoting effects of TT were confirmed. Crop productivity increased as shown by increased yield and faster growth despite high levels of soil Cu contamination (Banaay and Cuevas, 2022; Cuevas and Banaay, 2022a, 2022b). Higher yield is attributable to greener flag leaves, more productive tillers, and more filled-up grains (Banaay and Cuevas, 2022). Farmers have also reported greener leaves and more tillers in *Trichoderma*-treated plots.

Farmers have likewise shared observations on the other beneficial effects of TT such as better resistance to pests and diseases, and greater seedling vigor. Regarding seedling vigor, farmers have shared that the rice seedlings inoculated with TMI were taller, stronger, and had longer roots (consistent with results from Banaay et al., 2012). They also reported that there were fewer diseases (consistent with results from Banaay et al., 2011) and that snails were unable to eat the TMI-treated seedlings apparently because the seedlings were tougher.

Resistance to abiotic stressors and bioremediation

Mogpog experienced drought during the El Niño years (2018-2019), which coincided with the implementation of the project. This complicated the field experiments, so the water scarcity aspect was factored into the experiments and incorporated into the data analysis (Cuevas and Banaay 2022a). The results showed that TT was able to confer crop resistance to severe water stress such that instead of zero harvest (in control plots) farmers were able to harvest 0.9 to 2.4 t ha^{-1} of rice (Table 1).

Table 1: Differences between yield of *Trichoderma*-treated and untreated (control) rice paddy set-ups under different levels of water stress.

Season and Year	Mean Yield (t ha^{-1})		Mean water stress level**
	Trichoderma-Treated	Control (farmer's practice)	
DS 2018	3.386	3.006	2.5
WS 2018	2.825	1.926	3.5
DS 2019	1.447	0***	5
WS 2019	3.260	2.501	3.5
Average*	***2.730***	***1.858***	

*47% increase in yield of treated paddies over the control
** Water-stressed paddies were categorized into 6 groups starting with 0 – no water stress from sowing to harvest.
Level 1 – water throughout the cropping period was present but was reduced compared to average years. Level 5 was designated when water was severely reduced throughout the cropping season. All levels between 1 and 5 depended on water availability during the different stages of crop growth.
***Paddies were severely affected by the El Niño event that caused rice plants to be arrested in growth hence no grains were harvested.

Drought tolerance is an important trait in crops especially since intensity of drought stress has increased for the past decades. Research has shown that *Trichoderma* spp. enhance drought tolerance through induced changes in the host plant relating to stomatal conductance, net photosynthesis, reactive oxygen species scavenging, water-use efficiency, dehydrins-related gene expression, and expression of various antioxidant activities and osmolyte production (Doni et al., 2022; Harman et al., 2021). During the seminars and meetings, farmers have likewise reported that TMI-treated seedlings were able to overcome transient submergence of seedlings. It was suspected that because the seedlings were taller and sturdier, they should be more able to tolerate submergence. Although there are no published research on the effects of TMI specifically on submergence stress response in host plants, data from existing literature shows that *Trichoderma* spp. are able to alleviate waterlogging stress through influences on the host plant's gene expression and metabolism (Rauf et al., 2021). It is likely that the same mechanisms are at play in the TMI-treated rice seedlings. This hypothesis remains to be explored in future studies.

Phytobial remediation refers to microbe-assisted phytoremediation. Results presented by Cuevas and Banaay (2022b) indicate that TT were instrumental in bringing about phytobial remediation of Cu from soil. The remediation may have occurred through removal by sequestration in plant roots and fungal hyphae, stabilization as metal-organic matter complexes, or solubilization with concomitant leaching. The results are still preliminary hence more studies are warranted to support the claims and elucidate the mechanisms behind this activity. Nonetheless, the study showed that while soil remediation benefits were observed, the plants also benefitted through growth promotion and increased yield. The ability of TT to assist in the bioremediation of heavy metal-contaminated rice paddy fields is likewise supported by previous studies (Cuevas et al., 2014, 2019).

Impact on farmer incomes

One of the key objectives of the Mogpog Project is to demonstrate the economic benefits that the TT can provide the farmers. A financial impact analysis was conducted towards the end of the project in 2020. Using the modest assumption of 27% yield improvement based on the results of trials, a partial budget analysis was conducted. The analysis indicated a potential net financial impact of ₱22,338.00 ha^{-1} for farmers who used TT (Table 2).

Table 2: Partial budget analysis of using *Trichoderma* Technologies (*Trichoderma* Microbial Inoculant and *Trichoderma* Compost Activator) in lowland rice production

A. Income Reducing	(₱)	B. Income Increasing	(₱)
Added input cost a. 0.25 Kg TMI @ Php700.00 b. 0.5 Kg Activator @ Php700.00 c. 20 Kg Triple 14 @ Php480		Added returns 1216 kg (27% higher yield) @ Php 17.12/kg (as of Sept. 2020)	20,817.92
Total input cost	1,880.00		
		Reduced costs fertilizer application: 1 bag Urea @ Php1000/bag	1,000.00
		2 bags triple 14 @ Php 1200/bag	2,400.00
Subtotal (A)	**1,880.00**	**Subtotal (B)**	24,217.92
net financial impact (B-A) =		***22,337.92***	

RELEVANCE TO UN SDGs & RESILIENCE

Supporting Sustainable Development Goals

The adoption of *Trichoderma* technologies for agriculture supports the United Nations Sustainable Development Goals. The experiences in the Mogpog Project exemplify the relevance of TT to the achievement of the UN SDGs as elaborated in Table 3.

Table 3: Relevance of the *Trichoderma* Technologies (*Trichoderma* compost activator and *Trichoderma* microbial inoculant) to the achievement of the United Nations Sustainable Development Goals.

SUSTAINABLE DEVELOPMENT GOALS	**Description of the relevance of *Trichoderma* Technologies (TT) to achieving the UN SDGs as seen in the Mogpog Project**
1 NO POVERTY; 2 ZERO HUNGER	Crop growth-promotion, biocontrol, and soil health-enhancing activities of TT lead to increased productivity and harvests that translate to more food on the table and also higher incomes to support the needs of the family
3 GOOD HEALTH AND WELL-BEING	TT support good soil health as it helps increase soil organic matter that redounds to beneficial effects on increasing soil nutrients, water holding capacity, good structure, and better disease-suppression
11 SUSTAINABLE CITIES AND COMMUNITIES; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION	TT support SDG#s 11 and 12 because it is based on ecologically-sound principles that contribute to the following: 1. waste management (through composting of crop residues and other municipal wastes), 2. resource efficiency (through reduction of fertilizers and pesticides), 3. adaptation to climate change (through induced resistance to abiotic stressors such as drought), and 4. sustainable crop production systems (through plant growth promotion with less inorganic fertilizers and pesticides and promoting soil health through addition of organic matter and enhancement of beneficial microbial interactions, thus reducing the damaging effects of agriculture on the environment)
13 CLIMATE ACTION	TT is compatible and is supportive of Climate-Smart Agriculture as it helps in strengthening the resilience and adaptive capacity of farmers to climate-related hazards such as drought.
15 LIFE ON LAND	*Trichoderma* technologies promote soil health by capitalizing on beneficial microbial interactions and activities; and help in the rehabilitation of degraded soils damaged by pollutants such as mine tailings.

17 PARTNERSHIPS FOR THE GOALS	The project implementation supported SDG 17 as it relied on healthy partnerships between the university, LGU, farming community, and business sector (provider of the commercialized TT) to achieve the goals of the project.

Tool-kit for Resilience and Environmental Rehabilitation

From all the benefits observed from the Mogpog Project, and also from previous studies, it can be said that *Trichoderma* Technologies (TMI and TCA) comprise a complete tool-kit for crop resilience. It serves many functions such as plant growth-promoter, biocontrol agent, biofertilizer, compost activator, bioremediation agent, and inducer of systemic resistance in plants against pests, diseases, and detrimental abiotic factors.

The *Trichoderma* technologies used in this project are also effective agents of soil rehabilitation. It functions for bioremediation, enhancement of beneficial plant-soil-microbe interactions, agent of decomposition and nutrient cycling, and alleviates soil sickness through biocontrol and promotion of soil health.

With the many climate- and environment-related constraints to crop productivity, multi-stress mitigation and priming of adaptive stress response in crops become highly desired outcomes. Continued research on the benefits conferred by *Trichoderma* technologies in various systems and situations are proving to be most valuable as they constitute an arsenal of evidences that support the usefulness and efficacy of the technologies. Table 4 presents the multiple applications of TMI and TCA as revealed in various studies through the years.

Table 4: Applications of UPLB's *Trichoderma* Technologies (*Trichoderma* Compost Activator and *Trichoderma* Microbial Inoculant) as supported by basic and applied research through the years (1988-2022)

APPLICATION	CROPS	REFERENCE PUBLICATION
Rapid composting	NA	Cuevas et al., 1988
Plant growth-promotion (including yield increase, and better seed germination); biofertilizer	Vegetables (pechay, tomato, eggplant, celery)	Cuevas et al., 2005
	Tomato and lowland rice	Cuevas, 2006
	Jatropha curcas	Cuevas, 2009
	High-value crops (Head cabbage, Chinese cabbage, broccoli, potato, carrot, celery, Chrysanthemum)	Cuevas et al., 2012
	Aerobic rice	Banaay et al., 2012
	Lowland rice	Cuevas et al., 2019
	Lowland rice	Banaay and Cuevas, 2022
	Lowland rice	Cuevas and Banaay 2022a, 2022b
Direct biocontrol	Vegetables (tomato, pechay, mustard, lettuce) – control of damping-off agents (*Sclerotium, Rhizoctonia, Fusarium*)	Cuevas et al., 1995
	Brassica chinensis – control of pre-emergence damping-off (*Sclerotium*)	Cuevas et al., 2001
	Vegetables (pechay, tomato, eggplant, celery) – control of damping-off (*Sclerotium, Rhizoctonia*)	Cuevas et al., 2005
	Crucifers (cabbage and Chinese pechay) – control of club root disease	Cuevas and Bul-long, 2009
	Crucifers (head cabbage and Chinese cabbage)– control of club root disease (*Plasmodiophora brassicae*)	Cuevas et al., 2011
	High-value crops (Head cabbage, Chinese cabbage, broccoli, potato, carrot, celery, Chrysanthemum)	Cuevas et al., 2012
	Aerobic rice – control of root-rot oomycete (*Pythium arrhenomanes*) and root knot nematode (*Meloidogyne graminicola*)	Banaay et al., 2012 Banaay et al., 2013
Induced systemic resistance	Aerobic and upland rice – control of rice blast and bacterial blight pathogens (*Pyricularia oryzae, Xanthomonas oryzae* pv. *oryzae*)	Banaay et al., 2011
	Lanzones – control of scale insect (*Unaspis mabilis*)	Silva et al., 2019
	Capsicum annuum – control of anthracnose (*Colletotrichum*)	Taguiam et al. (in press)*
	Coconut – recovery from scale insect	Cuevas et al. (submitted)**
Abiotic stress tolerance	Lowland rice – heavy metal and drought stress	Cuevas and Banaay, 2022a

Bioremediation and rehabilitation of problematic soils	*Jatropha curcas* – acidic, low-fertility grassland soil from Tanay, Rizal	Cuevas, 2009
	Jatropha curcas – Cu-contaminated soil from Mogpog, Marinduque	Fontanilla and Cuevas, 2010
	Lowland rice – Cu-contaminated soil in Mankayan, Benguet	Cuevas et al., 2014
	Lowland rice – Cu-contaminated soil in Mankayan, Benguet	Cuevas et al., 2019
	Lowland rice – acidic, low-OM, low-N, Cu-contaminated soil in Mogpog, Marinduque	Cuevas and Banaay, 2022b
Compatibility with other soil organisms	Aerobic rice – soil microorganisms	Banaay et al., 2013
	Cabbage – soil arthropods and microorganisms	Zarate et al., 2015
	Cabbage – springtail (Collembola)	Sotto-Alviola et al., 2017
Economic benefits to farmers	Crucifers	Cuevas and Bul-long, 2009
	Crucifers	Cuevas et al., 2011
	High-value crops (Head cabbage, Chinese cabbage, broccoli, potato, carrot, celery, Chrysanthemum)	Cuevas et al., 2012
Reforestation and Agroforestry Projects & other unpublished studies on trees	Microbial Inoculants to Enhance Reforestation and Rehabilitation of the Forest Ancestral Land of Aytas (Magbukün Tribe) of Morong, Bataan. DOST- PCAARRD, July 2013- June 2015.	
	Science &Technology Farm on the Use of *Trichoderma* Microbial Inoculant (TMI) for Increased Survival and Early Establishment of Tree Crops in Cacao - Coffee Agroforestry System for the Aytas (Magbukún Tribe) in Kanawan Negritos Reservation Area (KNRA) in Morong, Bataan. PCAARRD. October 28, 2016 – October 27, 2018.	
	Control of gummosis caused by *Phytophthora* in mango Control of die-back disease caused by *Phytophthora* in Durian	

* Taguiam JDW, Ancog RC, Pangga IB, Adorada JR, Cuevas VC. Biological Control of Chili Anthracnose Using *Trichoderma* Microbial Inoculant and Citronella Essential Oil Under Field Condition. Phillip. Agric. Sc. (submitted, under review)
**Cuevas VC, Caasi-Lit MT, Lit IL Jr., Banaay CGB, Salazar AM. 2022. Early Recovery of Coconut Trees from Scale Insect Infestation and Faster Coco Seedlings Growth with Salt and *Trichoderma* Microbial Inoculant (TMI)- (submitted, under review).

Undoubtedly, the *Trichoderma* Technologies (TMI and TCA) developed in UPLB have many uses and applications that are now being determined from basic and applied research. Even as studies continue to be conducted, the information presented in this paper show the immense value of the technologies for promoting sustainability, resilience, and environmental rehabilitation.

CONCLUSION

Trichoderma technologies (*Trichoderma* Microbial Inoculant and *Trichoderma* Compost Activator) help promote the achievement of sustainable development goals, increase resilience of crops and communities to various biotic and abiotic stressors, and help rehabilitate degraded and damaged soils.
In the Mogpog Project, TT adoption has led to increased rice and vegetable harvests, higher farmer income, tolerance of rice plants to drought and high soil Cu concentrations, phytobial remediation of heavy metal contamination in the soil, and rapid composting of municipal wastes and crop residues.

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