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Research article

Soil fertility and rice productivity in shifting cultivation: impact of fallow lengths and soil amendments in Lengpui, Mizoram northeast India

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ABSTRACT

An exponential increase in the human population has drastically reduced the length of fallow period (<5 years) in widely spread shifting cultivation (*Jhum*). This has increased the invasion of weeds and decreased soil fertility and crop productivity, and consequently raised concern of food security for the local farming communities. The present study was conducted in two *jhum* fallows (FL-10 and FL-15) to understand the response of fallow length and applications of indigenous soil microbes and rock phosphate on the levels of soil fertility and crop productivity. The results showed greater soil physicochemical properties in FL-15 compared to FL-10. Burning significantly increased the levels of soil pH, avail P, avail N in the soil, whereas, the same decreased the levels of soil C, MBC and SM in both the sites. Among treatments, the synergistic effect of rock phosphate and microbial inocula showed greater improvement in soil biochemical properties, and showed a climactic increase over control in crop productivity and rice yield in all sites. Maximum rice grain yield and productivity was recorded in FL-15 followed by FL-10. This study concludes that a mixture of rock phosphate and microbial inocula from the rhizosphere soil of early regenerating plant is effective in increasing soil fertility and crop productivity, and can be used as an important tool to sustain crop productivity and food security in the region.

1. Introduction

Shifting cultivation commonly known as *'Jhumming'* is said to be one of the most ancient farming system, which is believed to be originated in the Neolithic period around 7000–8000 B.C (Tripathi et al., 2017; Layek et al., 2018), and has witnessed the remarkable and revolutionary change in man's history from hunting to food producer (Hazarika, 2006). The system is practiced as the principal method of farming by tribal farmers in different parts of the tropical world, which involves clearing of forest vegetation from a selected plot by slashing and burning, and cultivating the land for a period of one or two years followed by abandonment as fallow for recovery of soil fertility through natural vegetation regeneration (Yadav, 2013; Tripathi et al., 2017). Shifting cultivation, also known as *'slash and burn'* and *'bush fallow'* is practiced in different parts of the world and called variously *Ladcmg* in Indonesia, *Caingin* in the Philippines, *Ray* in Vietnam, *Roca* in Brazil, *Masole* in the *Congo,* and Central Africa, in the highlands of Manchuria, Korea and southwest China (Layek et al., 2018).

In India, shifting cultivation is widely practiced by tribal people of many states including Assam, Meghalaya, Arunachal Pradesh, Nagaland, Manipur, Tripura, Mizoram, Madhya Pradesh, Orissa, Andhra Pradesh, and Kerala. In northeast India, shifting cultivation is known as *Jhum*, whereas, *punamkrishi* in Kerala, *podu* in Andhra Pradesh and Orissa, *bewar*, *mashan*, *penda* and *beera* in different parts of Madhya Pradesh. Every year, approximately 2 M ha of forest vegetation are slashed and burnt *in situ* followed by cropping for 1 and/or 2 years depending on the soil fertility after that abandonment of land to recover soil fertility through natural regeneration. The agricultural crops like paddy, buckwheat, maize, millets, tobacco, some vegetables, and banana are grown on the burnt over clearings, and the products are shared jointly by the clan. Rice is the major crop grown in shifting cultivation-dominated landscape throughout northeast India (Grogan et al., 2012; Wapongnungsang, 2018). Nearly 90% of the population of the region depends on agriculture as the sole source of livelihood. Among the workers of the region, 60.1% are cultivators, 9.3% are agricultural laborers, while 7.3% are connected with livestock, forestry, fishery, and other allied activities (Das et al., 2012; Wapongnungsang et al., 2018). Slashing and burning remained to be the easiest way of cultivation not only to sanitize the soil, minimize the weeds and soil pathogens but also to release the locked nutrients within the biomass

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as ash load to provide more readily available soil nutrients (Juo and Manu, 1996; Wapongnungsang et al., 2018; Wapongnungsang, 2018).

Mizoram, one of the northeastern states in India located in tropical hilly areas and dominated by Mizo tribes involved in shifting agricultural practice for their livelihood through centuries. The system is an age-old primitive method of slash and burn and becoming less sustainable due to a shortened cultivation cycle owing to population pressures (Tripathi et al., 2017; Wapongnungsang et al., 2018). During shifting cultivation, forested plots are slashed by the farmers followed by *in-situ* burning of dried biomass and sowing seeds of desired crops manually without tilling the soil (Grogan et al., 2012; Yadav, 2013). Crops are grown for 1–2 years depending on the soil condition supplanted by the abandonment of land for a few years to restore soil fertility (Tripathi et al., 2017). The physical position of ~70% of the state's total land area sloped at angles steeper than 33° makes Mizoram's topography exceptional compared to many other areas in the Tropics, where shifting cultivation is practiced (Grogan et al., 2012). Approximately half of all households in Mizoram are engaged in shifting cultivation, and mainly located in relatively undeveloped remote villages (Singh et al., 2010). Remote sensing-based estimates of the total area burned each year by farmers and wildfires range from 40,000–110,000 ha (Tawnenga et al., 1997).

Cropping in Mizoram on *jhum* lands is predominantly practiced for one year and the second year cropping is scarce, and if done, it is only on old *jhum* fallows (Tawnenga et al., 1997). Even in other parts of north-eastern India, the land is often abandoned after the first year of cropping, and second-year cropping is sometimes practiced with plantations of banana and pineapple (Kushwaha and Ramakrishnan, 1987). Typical shifting cultivation crops include upland rice (*Oryza sativa*), sugarcane (*Saccharum officinarum*), maize (*Zea mays*), chilies (*Capsicum annuum*), eggplant or ‘brinjal’ (*Solanum melongena*), lady's fingers/okra (*Abelmoschus esculentus*), squash (*Sechium edule*), pineapple (*Ananas comosus*), Cassava (*Manihot esculentum*) and herbs such as Mustard (*Brassica juncea*). Besides, ginger (*Zingiber officinale*) and turmeric (*Curcuma longa*) are frequently planted in recently burned sites because they grow well on steep slopes and are considered high-value crops (Grogan et al., 2012; Wapongnungsang, 2018).

In 2010, the Government of Mizoram has initiated a New Land Use Policy intending to tackle the *Jhum* problems by providing small monetary support to *Jhumias* to create productive assets in each family through livelihood activities like promotion of agri-horticultural, plantation crops, animal husbandry, and fishery. However, the scheme was limited to a few farmers and hence the majority of them continue *Jhuming*. Being organic state, resource-intensive agriculture i.e. the excessive use of chemical fertilizer will be a major concern of the public and the Government in this region as they may contaminate the water through leaching and runoff losses of nutrients due to steep slopes. This present research demonstrates low-cost locally available soil amendments like microbial inoculums, rock phosphate, and the combined effect of microbial inoculums and rock phosphate. The basic concepts behind the amendment were to accelerate the recovery of soil microbial growth hampered due to burning that may lead to improve soil fertility and crop productivity. Decreasing soil fertility and crop productivity in the northeastern region, particularly, Mizoram has become a matter of concern for the Government and people. In general tropical soils are phosphorus limited (Tripathi et al., 2008, 2012). Therefore, this study hypothesizes that the application of rock phosphate and inoculation of rhizosphere microbes from the early regenerating plants enhances the soil fertility and crop productivity in shifting cultivation in the moist tropical region of northeast India. The major objective of the present study is to estimate crop productivity and to measure the changes in soil physicochemical properties with different soil amendments in two fallows of shifting cultivation in Mizoram, northeast India.

2. Materials and methods

2.1. Study site and the area

The study was conducted on two fallow lands: FL-10 with 10 years fallow length (23.858ºN and 92.641° E; elevation 263 m) and FL-15 with 15 years fallow length (23.860ºN and 92.640° E; elevation 242 m). The sites were located in the Lengpui village of Mizoram, a hilly northeast Indian state with 85.41% of its geographical area under forest cover (ISFR, 2019). The forests in Mizoram is characterized by "East-Himalayan subtropical wet hill forests", at higher hills, whereas, "tropical wet evergreen forests" at lower side. The area experiences humid subtropical climate with mean monthly temperature of ~20 °C and total rainfall of 2412 mm (Figure 1). Mizoram soils are acidic in nature with low base saturation and vary from sandy loam to clayey loam with loamy skeletal, mixed, hyperthermic, typic dystrochrepts (Kumar et al., 2008). As per USDA classification system, Mizoram soils are distributed into soil orders viz. Inceptisols (36.0%), Entisols (28.0%), Ultisols (26.0%), Alfisols (2.0%) and others (8.0%) (Bhattacharyya et al., 2013; Bhattacharyya and Pal, 2015). Ultisols are commonly found on hilly slopes, Entisols in valley areas and inceptisols both in hills and valleys (Kumar et al., 2008). About 77% Ultisols, 57–71% Entisols and 42–100% Inceptisols are high in available N and K, however, they are low to very low in available P which is fixed on an average 82.6% to 96 % of added P (1000 ppm). The phosphate fixation was positively related with clay, organic carbon and oxides of Fe and Al contents of soil and negatively with pH, and therefore, the most limiting nutrient for plant growth (Misra and Saithantuaanga, 2000; Kumar et al., 2008). Shifting cultivation is a major agricultural practice carried out in Mizoram witnessing considerable decrease in *jhum* cycle (<5 years) due to increasing population pressure does not allow the recovery of soil fertility through natural regeneration (Grogan et al., 2012; Tripathi et al., 2017). The regenerating forest vegetation of *Jhum* fallow is a secondary successional type and mainly dominated by the Bamboo species *Melocanna baccifera* (Tawnenga, 1990). During shifting cultivation, the vegetation is generally slashed during November–December and burnt in March followed by rice sowing in April–May. Generally, upland varieties of rice viz. "buhpui" (*Oryza collina*) and "Idaw" (*Oryza sativa*) are grown along with other crops like Maize, *Colocasia*, *Brassica*, Chillies, *Sesamum*, Cucumber, Brinjal, Wing bean, Pumpkin to sustain crop productivity and fulfill the family requirement (Tripathi et al., 2017). Additionally, some farmers also grow Ginger, Turmeric, Banana, Mango, Sugarcane, Tapioca, etc. depending upon field size, family needs, and working capacity.

2.2. Experimental design

Selected sites were almost similar in terms of topography, slope, aspect, hydrology, soil types, and have been managed using the same shifting cultivation practices until the onset of the current fallow period. Vegetation at both sites was slashed in December 2015 and biomass was burnt after drying on the forest floor between 10 and 15th of March 2016. The treatments were established after the burning event in the first week of April 2016. In each site, about 0.5 ha area was marked developing 4 similar representative plots of about 5 m × 5 m running perpendicular to the slope. Out 4, three plots received different treatments such as rhizosphere microbes (T_m), rock phosphate (T_{rp}), and a mixture of microbial inocula and rock phosphate (T_{m+rp}) along with a control (C). The microbial inocula was obtained from the ICAR Research Complex for North Eastern Hill Region, Umiam, Meghalaya (Thakuria, 2015). Rice (*O. sativa*) was sown using the dibbling method in the last week of April 2016. In case of T_{m+rp} treatment, rice seeds were pretreated with microbial inoculants and rock phosphate for about 2–3 h and sown along with an additional amount of microbial inoculants and rock phosphate. Besides, all the plots were seeded with common vegetable crops during the first year of cropping.

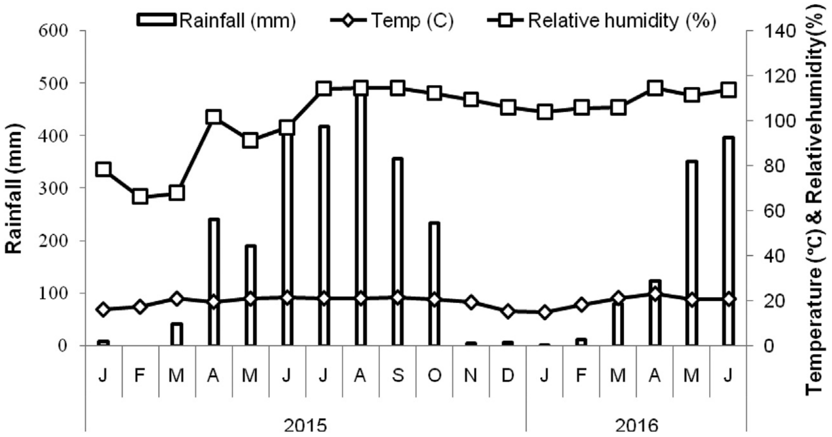

Figure 1. Climatic diagram of the study areas. Data obtained from Meteorological Station, Department of Environmental Studies, Mizoram University.

2.3. Soil sampling and analysis

Soil samples (0–10 cm depth) were randomly collected in triplicate making 12 composited samples from each site. Soil samples were collected before burning (BB) and after burning (AB) of biomass to understand the changes in initial soil characteristics. Similarly, 24 composited samples were collected from both sites after the establishment of treatments. Collected samples were brought to the laboratory using polythene bags and divided into two parts, one part was used afresh to determine soil moisture (SM), available nitrogen hereinafter N_{avail} (NH_4–N and NO_3–N), and microbial biomass carbon (MBC). Whereas, the other part was air-dried and used for the analysis of soil carbon (SC), total nitrogen (TN), available phosphorus (P_{avail}) and pH.

Soil pH was determined in soil-water suspension (1:2.5 w/v H_2O) employing a digital pH meter. Gravimetric soil moisture was measured adopting the method described by Anderson and Ingram (1993). SC and TN were analyzed using Heraeus CHN–O–S Rapid Auto-analyzer employing Sulphanilamide ($C_6H_8N_2O_2S$) standard. Ammonium molybdo-blue color method was used to estimate the bicarbonate available P (Allen et al., 1974), while, NH_4–N was determined by Indophenol Blue color Method (Rowland, 1983). The supernatants obtained from the extraction of fresh soil for ammonium determination were further used to estimate NO_3–N as per the method described by Jackson (1958). MBC was determined using the chloroform fumigation method (Brookes and Joergensen, 2006).

2.4. Biomass and production of rice

The total biomass of rice at maturity was measured by harvesting 5 random sampling plots (1 m × 1 m) from each subplot making a total of 20 sampling plots from each site. The harvested crop was separated into different plant parts (leaf, stem, roots, and seeds) and weighed fresh. Further, small sub-samples of each part (~100 g) were brought to the laboratory and oven-dried separately at 70 °C for 48 h to constant weight. Rice biomass was reported on an oven-dry weight basis (g m^{-2}) for all components. Total above-ground production was calculated using the biomass of different aboveground components of rice at maturity. Similarly, the economic yield was calculated by collecting the rice grains with husk at the time of crop maturity. Belowground production was also calculated as the root biomass at the time of crop maturity. The biomass of different aboveground components was summed up to calculate total aboveground net productivity (ANP). Whereas, root biomass at maturity was considered as below-ground net productivity (BNP). Total net productivity (TNP) was computed as the sum of ANP and BNP.

2.5. Statistical methods

All results were reported as means ±1 standard error. One-way ANOVA was performed between fallow periods and sampling time. One-way ANOVA was employed to assess the statistical difference between the soil fertility and crop productivity parameters in two fallows followed by Duncan's multiple range test ($p < 0.05$) to compare the means of different treatments. All statistical analysis was carried out using SPSS version 16.00.

3. Results and discussion

3.1. Changes in initial soil physicochemical properties in different fallows

Soil physicochemical and biological properties play an important role in determining the growth of plants (Sarkar et al., 2015; Ma et al., 2020). Higher SM content in FL-15 compared to FL-10 (Table 1), indicates conservation of moisture due to greater soil organic matter (Wapongnungsang, 2018). The strongly acidic nature of the soil in both fallows (4.7–5.1, Table 1) denotes the addition of cations during burning and the formation of humic acid during organic matter decomposition (Granged et al., 2011; Wapongnungsang, 2018). The runoff and leaching losses of carbon and nutrients in older fallow may not have significantly affected crop productivity compared to younger fallow because of the considerable accumulations during recovery (Yadav, 2013; Tripathi et al., 2017). A significant ($p < 0.01$) increase was noticed in P_{avail} and MBC, whereas, others showed a marginal increase in longer fallow age (Table 1). In the present study, the increment in carbon storage in FL-15 compared to FL-10 could be regarded as rapid carbon buildup as a result of vegetation growth and development (Wapongnungsang, 2018). Increasing of secondary forest fallow period up to ~25 years enhanced soil nutrient availability in terms of N_{avail}, total N, and P_{avail} in the soil (Ramakrishnan and Kushwaha, 2001; Wapongnungsang et al., 2020). Enhanced soil nutrient content as a result of the increasing length of the fallow periods (from FL-10 to FL-15) has also been recorded in the present study. A decline in soil nutrients from the topsoil to the subsoil can also be attributed to their leaching losses caused by heavy rainfall in the area, which promotes the rapid growth of invasive weeds (Wallbrink et al., 2005; Wapongnungsang, 2018), a common phenomenon in *jhum* fields across Northeast India (Wapongnungsang et al., 2019). Further, significantly higher MBC in FL-15 compared to younger fallow can be attributed to greater soil carbon. Jia et al. (2005) reported a gradual increase in MBC from the first year to the seventeenth year of secondary forest succession. Similar results were observed in the present study with a gradual increase in MBC from FL-10 to FL-15 (Saplalrinliana et al., 2016; Wapongnungsang, 2018).

Table 1. Initial soil characteristics in two fallow (FL-10; 15) chronosequence sites immediately before burning and after burning, Lengpui village, Mizoram. Values are means ± 1SE; n = 5. Abbreviation 'BB'-Before Burn; 'AB'-After Burnt in fallow lands. Small letters indicate significant ($p < 0.05$) differences among fallows and capital letters represent significant ($p < 0.05$) increased between two stages.

Seasons	Fallows	pH	SC (%)	TN (%)	P_{avail} (mg kg^{-1})	NH_4–N (mg kg^{-1})	NO_3–N (mg kg^{-1})	MBC (mg kg^{-1})
BB	FL-10	$4.73^{aA} \pm 0.09$	$2.55^{aA} \pm 0.27$	$0.08^{aA} \pm 0.01$	$7.85^{aA} \pm 0.28$	$49.05^{aA} \pm 3.93$	$41.81^{aA} \pm 0.45$	$411.46^{aA} \pm 13.69$
	FL-15	$5.15^{aA} \pm 0.11$	$2.83^{aA} \pm 0.14$	$0.11^{aA} \pm 0.01$	$10.18^{bA} \pm 0.20$	$66.04^{aA} \pm 2.30$	$45.25^{aA} \pm 2.45$	$466.97^{bA} \pm 1.54$
AB	FL-10	$6.54^{aB} \pm 0.11$	$2.14^{aB} \pm 0.18$	$0.16^{aB} \pm 0.01$	$10.44^{aB} \pm 1.07$	$57.24^{aB} \pm 4.92$	$48.00^{aB} \pm 0.72$	$105.84^{aB} \pm 17.41$
	FL-15	$6.98^{aB} \pm 0.07$	$2.49^{aB} \pm 0.15$	$0.19^{aB} \pm 0.01$	$14.78^{bB} \pm 3.17$	$71.63^{aB} \pm 4.66$	$53.66^{aB} \pm 0.56$	$128.74^{bB} \pm 7.19$

About one-third increase in soil pH value in both the fallows in the present study after burning is in accordance with the reports of Kong et al. (2019). Similarly, about one and a half to two times increase in other soil nutrients like TN, P_{avail}, NH_4–N, NO_3–N, and a small decline in SC and MBC was recorded in both FL-10 and FL-15 after the burning. All changes were statistically significant (Table 1). Soil carbon and microbial biomass were negatively impacted during the burning, whereas other soil nutrients were appreciated during the process. This is quite obvious that the nutrients locked in the organic matter were converted into inorganic form during burning, which decreased organic matter content in the soil (Wapongnungsang and Tripathi, 2019). The increase in soil pH after burning was observed to be contributed by loss of OH, oxide formation, and release of alkaline cations (Certini, 2005; Kong et al., 2019). The older fallow accumulates more litter quality compared to younger fallow and henceforth, the burning of random litters in mature fallow land produces more alkaline ash materials and might be the possible reason for higher pH under burnt situation (Saplalrinliana et al., 2016; Wapongnungsang, 2018). The heating of soil due to burning activity alters the content of SOC and the present findings corroborated with the past findings of Lenka et al. (2012) and Sarkar et al. (2015). The study indicated that SC content increases significantly with the increase in fallow length (Table 1). The content of available N was higher after burnt and the longer length contained a higher content of available N than that in shorter fallow (Neff et al., 2005; Parro et al., 2019). The effect of burning was significant on the content of available N, but the length of the fallow period did not show significant difference (Table 1). Similar results were also reported by Saplalrinliana et al. (2016). The content of P_{avail} increased after burning. The older fallow length supported higher content of P_{avail} as compared to that in shorter fallow (Table 1). Researchers (Ramakrishnan and Toky, 1981) described an increasing trend of P_{avail} with the lengthening of *jhum* cycle. The present study revealed that the increase in P_{avail} can be attributed to the incorporation of P from the slashed biomass in the form of ash as indicated by earlier researchers (Phongpan and Mosier, 2003; Adeyolanu et al., 2013; Butler et al., 2018). MBC was found to be negatively affected after burning in each site (Table 1). The decrease in MBC caused by the burning event was also reported by Ajwa et al. (1999) and Wang et al. (2019). Moreover, MBC has also increased with the increase in fallow length (Table 1), which was also reported by Saplalrinliana et al. (2016) and Wapongnungsang (2018). Past findings indicated that many of the soil decomposer communities would get reduced or die because of the burning effect. The remaining species that may have survived would also be suppressed because of the sudden change in the environment and changes in soil pH, temperature, and the low soil moisture content, which are the outcome of the burning activities. Reduction in microbial activity may also be attributed to the loss of SOC and N after burning operations (Saplalrinliana et al., 2016; Wapongnungsang, 2018).

3.2. Soil physicochemical properties as affected by treatments and fallow lengths

A significant increase in soil pH over control was observed in various treatments (T_m, T_{rp}, and T_{m+rp}). Similarly, a significant increase occurred in the amount of SC, TN, and MBC over control in these treatments (Table 2). The level of P_{avail}, N_{avail} (NH_4–N; NO_3–N), and MBC also significantly appreciated over control in these treatments (T_m, T_{rp}, and T_{m+rp}). The mixture of rock phosphate and microbial inocula slightly increased soil pH in the present study sites. Similar observations were reported by Osman (2015) and Khalil (2013). The highest increase in key soil nutrients in T_{m+rp} indicated that the combination of rock phosphate and microbial inocula significantly ($p < 0.01$) increased the soil fertility among all treatments, which is in agreement with previous studies (Abbasi et al., 2015; Brahim et al., 2017). In addition to rock phosphate, microbial inoculation treatment in the present study indicated a positive response to changes in chemical and biological properties of soils and reducing stress impacts on crop physiology. Positive responses were more pronounced in FL-15 compared to those in FL-10 as the microbial inoculation promoted the PGP activities (e.g. IAA production, P solubilization, pectinase and cellulase activities, N2- fixation) through rhizobacteria in the soil. Further, microbial inoculant was developed using the native microbes from *jhum* soils which were well adapted to burnt soil conditions. Therefore, the positive impacts of microbial inoculation could provide adaptive benefits to crops against environmental stresses associated with *jhum* soils (Thakuria, 2015).

3.3. Impact of treatments and fallow lengths on rice productivity and grain yield

The fallow length has significantly ($p < 0.01$) increased the rice grain yield during 1st year cropping in the Lengpui site of Mizoram. The grain

Table 2. Effect of the soil amendment/treatments on soil physico-chemical properties and microbial biomass in two fallow chronosequence sites (n = 3). Abbreviation T_c-control; T_m-microbial inocula; T_{rp}-rock phosphate and T_{m+rp}-microbialinocula + rock phosphate in the fallows. Small letters represent significant ($p < 0.05$) differences among ages and treatments, respectively.

Treatments	pH	SC (%)	TN (%)	P_{avail} (mg kg^{-1})	NH_4–N (mg kg^{-1})	NO_3–N (mg kg^{-1})	MBC (mg kg^{-1})
T_c	$4.47^{a} \pm 0.04$	$2.04^{a} \pm 0.07$	$0.11^{a} \pm 0.01$	$6.54^{a} \pm 0.41$	$25.44^{a} \pm 4.86$	$34.87^{a} \pm 2.00$	$539.89^{a} \pm 6.50$
T_m	$4.89^{a} \pm 0.09$	$2.15^{a} \pm 0.06$	$0.16^{a} \pm 0.01$	$7.41^{a} \pm 0.16$	$29.14^{a} \pm 4.30$	$39.33^{a} \pm 1.66$	$547.02^{a} \pm 8.98$
T_{rp}	$5.34^{a} \pm 0.05$	$2.37^{a} \pm 0.06$	$0.20^{a} \pm 0.01$	$8.65^{b} \pm 0.18$	$33.84^{b} \pm 3.79$	$45.01^{b} \pm 1.30$	$555.28^{b} \pm 21.13$
T_{m+rp}	$5.56^{b} \pm 0.11$	$2.58^{b} \pm 0.08$	$0.23^{b} \pm 0.02$	$9.48^{b} \pm 0.05$	$37.55^{b} \pm 4.48$	$53.89^{b} \pm 1.00$	$567.40^{b} \pm 10.00$
T_c	$4.98^{a} \pm 0.20$	$2.35^{a} \pm 0.08$	$0.13^{a} \pm 0.01$	$8.45^{a} \pm 0.24$	$34.48^{a} \pm 2.75$	$40.03^{a} \pm 1.29$	$552.26^{a} \pm 30.37$
T_m	$5.23^{a} \pm 0.03$	$2.46^{a} \pm 0.08$	$0.19^{a} \pm 0.01$	$9.52^{a} \pm 0.14$	$37.26^{a} \pm 4.55$	$45.49^{a} \pm 1.04$	$560.21^{a} \pm 24'86$
T_{rp}	$5.67^{a} \pm 0.09$	$2.58^{a} \pm 0.06$	$0.24^{a} \pm 0.01$	$10.67^{b} \pm 0.12$	$43.74^{b} \pm 4.54$	$51.26^{b} \pm 1.50$	$569.86^{b} \pm 24'82$
T_{m+rp}	$5.70^{b} \pm 0.11$	$2.83^{b} \pm 0.06$	$0.26^{b} \pm 0.02$	$11.71^{b} \pm 0.15$	$47.46^{b} \pm 4.56$	$59.92^{b} \pm 0.53$	$578.49^{b} \pm 28.09$

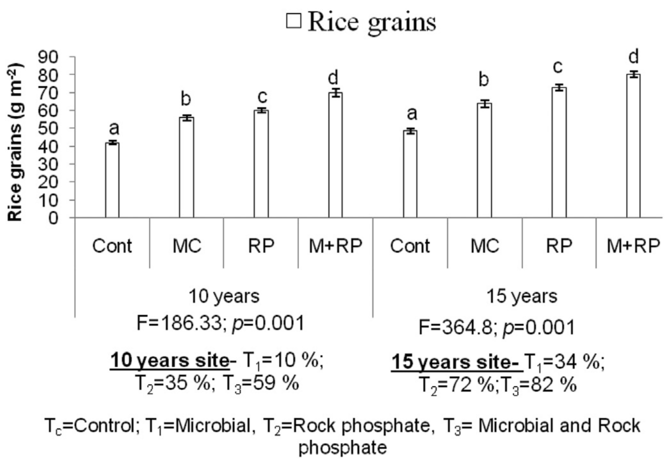

Figure 2. Effects of the soil amendments in two fallow chronosequence sites on rice grain yield (g m^{-2}) in 2016 cropping. Different small superscript letters in columns show significant difference between treatments.

yield was significantly ($p < 0.01$) greater in the FL-15 compared to FL-10. Among the different treatments, T_{rp} and T_{m+rp} showed a significant ($p < 0.01$) upsurge in the grain yield at both sites. A total yield of 269 g m^{-2} rice grain was recorded in FL-15 compared to 226 g m^{-2} rice grain in FL-10. In two fallows, T_{m+rp} recorded the highest grain yield (80 g m^{-2} and 70 g m^{-2}) followed by T_{rp} (63 g m^{-2} and 57 g m^{-2}), T_m (65 g m^{-2} and 56 g m^{-2}), and control (48 g m^{-2} and 43 g m^{-2}) in FL-15 and FL-10 (Figure 2). The total rice production (aboveground and belowground) significantly declined in FL-10 compared to FL-15. The total rice biomass was estimated at 872 g m^{-2} and 691 g m^{-2} in FL-15 and FL-10 respectively. Among the different treatments, T_{m+rp} significantly increased the total rice productivity (TRP) (262 g m^{-2} and 214 g m^{-2}) in both sites. Further, TRP was also significantly higher in T_{rp} (228 g m^{-2} and 197 g m^{-2}) and T_m (213 g m^{-2} and 156 g m^{-2}) treatment compared to control (169 g m^{-2} and 125 g m^{-2}) in FL-15 and FL-10 (Figure 3).

The effect of treatments on total net productivity (TNP) of rice crops was in the order of $T_{m+rp} > T_{rp} > T_m$. Considerable increase in rice productivity in T_{m+rp} in all fallows reflects the major limitations of phosphorus in these soils as this treatment contains the combinations of rock phosphate and indigenous phosphate solubilizing bacteria as inoculum which makes the availability of phosphate fixed in the *jhum* soil. Further, treatments (T_m and T_{m+rp}) with microbial inoculants include rhizospheric microbes responsible for phosphate solubilization, plant growth promotion, and N fixation that enhanced the soil nutrients and crop growth in treated soil. The rice grain yields (2260–2690 kg ha^{-1} $year^{-1}$) in this study were towards the higher side of the range reported in Indian dryland conditions i.e. 600–1800 kg ha^{-1} $year^{-1}$ by Ghoshal and Singh (1995) and 800–1200 kg ha^{-1} $year^{-1}$ by Kushwaha and Singh (2005). Zhang et al. (2019) found an enhancing effect of straw biochar on SOC and TN, which increased rice grain yield from 29.1–34.2% under wet rice cultivation. In our study, T_{m+rp}, T_{rp}, and T_m have significantly enhanced grain yields in all fallow periods. This may be due to the addition of rock phosphate and microbial inocula containing phosphate sulubilizing microbes in P limited soils, which was reported by previous studies (Thakuria, 2015; Wapongnungsang, 2018; Osman, 2015). Fallow length significantly ($p < 0.01$) increased the rice grain yield during the first-year cropping (Figure 2). In the present study, significant enhancement of crop productivity with the length of fallow periods is related to the organic matter accumulation. The addition of greater soil nutrients through previous organic matter accumulation following burning in older fallow may enhance the level of crop productivity in longer fallow (Saplalrinliana et al., 2016; Wapongnungsang, 2018). In the present study, maximum rice productivity was recorded in FL-15 compared to FL-10 (Figure 3). Higher crop productivity in longer fallow was also reported earlier by Wapongnungsang et al. (2018).

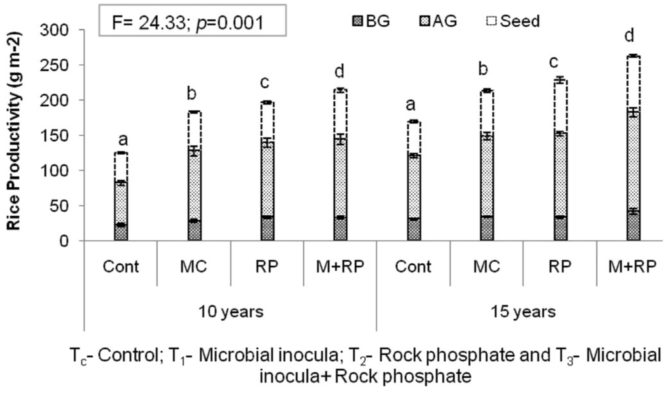

Figure 3. Aboveground (Seed, shoot), belowground (root) (g m^{-2}) in different treatments and fallow stands in Lengpui, Mizoram. Different small superscript letters in columns show significant difference between treatments. Vertical lines represent ± 1SE ($n = 3$).

4. Conclusion

This study demonstrates the significant effect of various soil inputs on soil fertility, rice yield, and productivity. The synergistic effect of rock phosphate and indigenous microbial inocula proved considerable improvement in crop productivity (55–71%) and rice grain yield (59–82%) in both fallow lands and can be recommended for application by the farmers under shifting cultivation in the region for better livelihood. This synergistic effect will hold equally good for cropping with lower fallow age classes e.g. 5 years.

Declarations

Author contribution statement

Wapongnungsang: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Etsoshan Yinga Ovung; Keshav Kumar Upadhyay: Analyzed and interpreted the data; Wrote the paper.

S.K. Tripathi: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data associated with this study has been deposited at Zenodo with New https://doi.org/10.5281/zenodo.4561988.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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