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

Wapongnungsang, Etsoshan Yinga Ovung, Keshav Kumar Upadhyay, S.K. Tripathi*

Department of Forestry, Mizoram University, Aizawl, 796004, India

ARTICLE INFO

Keywords:
- Shifting cultivation
- Soil fertility
- Rice grain yield
- Rice productivity
- Fallow lands

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.
as in-situ shifting cultivation, forested plots are slashed by the farmers making Mizoram’s topography exceptional compared to many other areas in the Tropics, where shifting cultivation is practiced (Grogan et al., 2012; Yadav, 2013). Crops are grown for 1–2 years depending on the soil condition supplemented 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 demanding compared to many other regions in 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 (Cucurbita pepo), 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.
2.3. 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 $N_{\text{avail}}$ (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 ($P_{\text{avail}}$) and pH.

Soil pH was determined in soil-water suspension (1:2.5 w/v H$_2$O) employing a digital pH meter. Gravimetric soil moisture was measured adopting the method described by Anderson and Ingram (1993). SC and TN were analyzed employing Heraeus CHN-O-S Rapid Auto-analyzer employing Sulphanilamide (C$_6$H$_8$N$_2$O$_2$S) 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 $\times$ 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 measured 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 $P_{\text{avail}}$ 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 $N_{\text{avail}}$, total N, and $P_{\text{avail}}$ 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. Jha 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).
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, Pπavail, NH4–N, NO3–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 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 litter 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 SOC content increases significantly with the increase in fallow length (Table 1). The content of available N was higher after burning 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 Pπavail increased after burning. The older fallow length supported higher content of Pπavail as compared to that in shorter fallow (Table 1). Researchers (Ramakrishnan and Toky, 1981) described an increasing trend of Pπavail with the lengthening of jhum cycle. The present study revealed that the increase in Pπavail 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 (Tm, Trp, and Tmπrp). Similarly, a significant increase occurred in the amount of SC, TN, and MBC over control in these treatments (Table 2). The level of Pπavail, Nπavail (NH4–N; NO3–N), and MBC also significantly appreciated over control in these treatments (Tm, Trp, and Tmπrp). 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 Tmπrp 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 (Abbas et al., 2015; Braham 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 12th year cropping in the Lengpui site of Mizoram. The grain

| Seasons | Fallows | pH  | SC (%) | TN (%) | Pπavail (mg kg⁻¹) | NH4–N (mg kg⁻¹) | NO3–N (mg kg⁻¹) | MBC (mg kg⁻¹) |
|---------|---------|-----|--------|--------|-------------------|-----------------|-----------------|--------------|
| BB      | FL-10   | 4.73 ± 0.09 | 2.55 ± 0.27 | 0.08 ± 0.01 | 7.85 ± 0.28 | 49.05 ± 3.93 | 41.81 ± 0.45 | 411.46 ± 13.69 |
|         | FL-15   | 5.15 ± 0.11 | 2.83 ± 0.14 | 0.11 ± 0.01 | 10.18 ± 0.20 | 66.04 ± 2.30 | 45.23 ± 2.45 | 466.97 ± 1.54  |
| AB      | FL-10   | 6.54 ± 0.11 | 2.14 ± 0.18 | 0.16 ± 0.01 | 10.44 ± 1.07 | 57.24 ± 4.92 | 48.00 ± 0.72 | 105.84 ± 17.41 |
|         | FL-15   | 6.98 ± 0.07 | 2.49 ± 0.15 | 0.19 ± 0.01 | 14.78 ± 3.17 | 71.63 ± 6.66 | 53.66 ± 0.56 | 128.74 ± 7.19  |

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) increase between two stages.
yield was significantly (p < 0.01) greater in the FL-15 compared to FL-10. Among the different treatments, Tm \( \times \) Trp 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, Tm \( \times \) Trp recorded the highest grain yield (80 g m\(^{-2}\) and 70 g m\(^{-2}\)) followed by Trp (63 g m\(^{-2}\) and 57 g m\(^{-2}\)), Tm (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, Tm \( \times \) Trp 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 Tm (228 g m\(^{-2}\) and 197 g m\(^{-2}\)) and Tm \( \times \) Trp (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 Tm \( \times \) Trp > Trp > Tm. Considerable increase in rice productivity in Tm \( \times \) Trp in all fallows reflects the major limitations of phosphorus in these soils as this treatment combines 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 (Tm and Tm \( \times \) Trp) with microbial inoculants include rhizosphere 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\(^{-1}\)) 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, Tm \( \times \) Trp, Tm \( \times \) Trp, and Tm have significantly enhanced grain yields in all fallow periods. This may be due to the addition of rock phosphate and microbial inocula containing phosphate solubilizing 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).

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; Contributed reagents, materials, analysis tools or 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.

Funding statement

The work was supported by the Department of Biotechnology, Government of India, New Delhi vide Grant ID- DBT-NER/Agri/14/2012.

Data availability statement

Data associated with this study has been deposited at Zenodo with New https://doi.org/10.5281/zenodo.4561968.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

We thank Dr. Dwipendra Thakuria, College of Post Graduate Studies, CAU, Umiam, Meghalaya for providing microbial inocula. We are
thankful to Dr. C. Lalnunzira for his assistance in the fieldwork. We also thank farmers for their open-hearted cooperation for sharing and access to fields.

References

Abbasi, M.K., Musa, N., Manzoor, M., 2015. Mineralization of soluble P fertilizers and insoluble rock phosphate in response to phosphate-solubilizing bacteria and poultry manure and their effect on the growth and P utilization efficiency of chilli (Capsicum annuum L.). Biogeosciences 12 (15), 4607.

Adeyelola, O.D., Are, K.S., Oluwatoni, A.G., Ayoola, O.T., Adelana, A.O., 2013. Evaluation of two methods of soil quality assessment as influenced by slash and burn in tropical rainforest ecology of Nigeria. Arch. Agric. Soil Sci. 59 (12), 1725-1742.

Ajwa, H.A., Dell, C.J., Rice, C.W., 1999. Changes in enzyme activities and microbial biomass of tallgrass prairie soil as related to burning and nitrogen fertilization. Soil Biol. Biochem. 31 (5), 769-777.

Allen, S.E., Grimshaw, H.M., Parkinson, J.A., Quarmby, C., 1974. Chemical Analysis of Ecological Materials. Blackwell Scientific Publications.

Anderson, J.M., Ingram, J.S.I. (Eds.), 1993. Tropical Soil Biology and Fertility - A Handbook of Methods, second ed. CAB International, Wallingford.

Bhattacharyya, T., Pal, D.K., Mandal, C., Chatterjee, P., Dey, M., Tripathi, A.K., Das, S., Kumar, M., 2012. Natural resource conservation and access to

Bhattacharyya, T., Pal, D.K., Mandal, C., Chatterjee, P., Dey, M., Tripathi, A.K., Das, S., Kumar, M., 2012. Natural resource conservation and access to

Butler, O.M., Elser, J.J., Lewis, T., Mackey, B., Chen, C., 2018. The phosphorus-rich

Brookes, P.C., Joergensen, R.G., 2006. Microbial biomass measurements by fumigation–extraction. In: Bloem, J., Hopkins, D.W., Benedetti, A. (Eds.), Microbiological Methods for Assessing Soil Quality. CAB International, Oxfordshire, UK, pp. 77–83.

Budler, O.M., Elner, J.J., Lewis, T., Mackey, B., Chen, C., 2018. The phosphorus-rich

Chapra, S.C., 1997. Surface Water and Ground Water. McGraw-Hill.

Colbeck, S., 2000. The use of cropping rotations to manage ecosystems. In: Walling, D.E., Horowitz, A.J. (Eds.), Sediment Budgets 2. IAHS Publication, Wallingford, UK, pp. 132–143.

Dahal, H.P., Badola, J.K., Pradhan, S.N., 1994. Effect of fallow periods and treatments on the pattern of

Ecosyst. Environ. 150, 54–62.

Ehrlich, R., Ehrlich, P., 1992. The size of the human family. In: pastryk, M. (Ed.), Mini-Reviews in Botany: 2. Elsevier, pp. 1–10.

Elsayed, M., Neuhoff, D., Scherer, H., 2017. Effect of combined fertilization with rock phosphate and elemental sulphur on yield and nutrient uptake of soybean. Plant Soil Environ. 63 (2), 89–95.

Jackson, M.L., 1958. Soil Chemical Analysis Englewood Cliffs. NT Prentice Hall Inc.

Kong, J.J., Yang, J., Cai, W., 2019. Topography controls post-

Kushwaha, S.P.S., Ramakrishnan, C.P., Singh, K.P., 2005. Crop productivity and soil fertility in a tropical dryland agro-ecosystem: impact of residue and tillage management. Exp. Agric. 41 (1), 39–49.

Ma, L., Xiong, Z., Yao, L., Liu, G., Zhang, Q., Liu, W., 2020. Soil properties alter plant and microbial communities to modulate denitrification rates in subtropical riparian wetlands. Land Degrad. Dev.

Misra, U.K., Saithantuangsua, H., 2000. Characterization of acid soils of Mizoram. J. Indian Soc. Soil Sci. 48 (3), 437–446.

Neff, J.C., Harden, J.W., Gleixner, G., 2005. Fire effects on soil organic matter content, composition, and nutrients in boreal interior Alaska. Can. J. For. Res. 35 (9), 2178–2187.

Oman, M.A., 2015. Studies on the possible use of rock phosphate in agriculture. Int. J. ChemTech. Res. 8 (10), 53–68.

Parro, K., Köster, K., Jogiste, K., Seglinit, K., Simins, A., Stantaur, J.A., Metzlund, M., 2019. Impact of post-fire management on soil respiration, carbon and nitrogen content in a managed hemboreal forest. J. Environ. Manag. 253, 371–377.

Phongan, S., Mosier, A.R., 2003. Effect of crop residue management on nitrogen dynamics and balance in a lowland rice cropping system. Nutr. Cycl. Agroecosyst. 66 (2), 133–142.

Ramakrishnan, P.S., Kushwaha, S.P.S., 2001. Secondary forests of the Himalaya with emphasis on the north-eastern hill region of India. J. Trop. Forest Sci. 13 (4), 727–747.

Ramakrishnan, P.S., Toky, O.P., 1981. Soil nutrient status of hill agro-ecosystems and recovery pattern after slash and burn agriculture (jhum) in north-eastern India. Plant Soil 60 (1), 41–64.

Rowland, A.P., 1983. An automated method for the determination of ammonium-N in ecological materials. Commun. Soil Sci. Plant Anal. 14 (1), 49–63.

Sapalirinilana, H., Thakuria, D., Changkijia, S., Hazarika, S., 2016. Impact of shifting cultivation on litter accumulation and properties of Jhum soils of North East India. J. Indian Soc. Soil Sci. 64 (4), 402–413.

Sarkar, D., Meitei, C.B., Baindhy, L.K., Das, A., Ghosh, S., Chongloi, K.L., Rajkhowa, D., 2015. Potential of fallow chromosome in shifting cultivation to conserve soil organic carbon in northeast India. Catena 135, 321–327.

Singh, K.D., Sinha, B., Ashutosh, S., 2010. Techniques of Survey and Planning for Conservation and Sustainable Use of Biodiversity in Mizoram. Ministry of Environment and Forests, Delhi.

Tawnenga, T., 1990. Studies on Ecological Implications of Traditional and Innovative Approaches to Shifting Cultivation in Mizoram. Doctoral dissertation. Mizoram University, Mizoram.

Tawnenga, T., Shankar, U., Tripathi, R.S., 1997. Evaluating second year cropping on jhum falls in Mizoram, north-eastern India using dynamics and primary productivity. J. Biosci. 21 (4), 563–575.

Thakuria, D., 2015. Impact Assessment of Jhumming on Native Plants and Soil Microbiota and Restoration of Sustainable Jhum Agroecosystem in Northeast India. An annual research progress report of the project submitted to the NER-BPMAC, DRT, GOI, New Delhi.

Tripathi, S.K., Kushwaha, C.P., Banu, S.K., 2012. Application of fraxiary theory in assessing soil aggregates in indigenous tropical ecosystems. J. For. Res. 23 (3), 355–364.

Tripathi, S.K., Kushwaha, C.P., Singh, K.P., 2008. Tropical forest and savanna ecosystems show differential impact of N and P additions on soil organic matter and aggregate structure. Global Change Biol. 14 (11), 2572–2581.

Tripathi, S.K., Vanlalfakawma, D.C., Lahnsumawina, F., 2017. Shifting cultivation on steep slopes of Mizoram, India. In: Cairns, M. (Ed.), Shifting Cultivation Policies: Balancing Environmental and Social Sustainability. CAB International Wallingford, UK, pp. 139–143.

Wallbrink, P., Blake, W., Doerr, S., Shakesby, R., Humphreys, G., English, P., 2005. Using tracer based sediment budgets to assess redistribution of soil and organic material after severe bush fires. In: Walling, D.E., Horowitz, A.J. (Eds.), Sediment Budgets 2. IAHS Publication, Wallingford, UK, pp. 223–230.

Wang, Y., Liu, X., Yan, Q., Hu, Y., 2019. Impacts of slash burning on soil carbon pools vary with slope position in a pine plantation in subtropical China. Catena 183, 104212.

Wapongnungsang, 2018. Impact of fallow periods and treatments on the pattern of recovery of soil fertility and plant productivity in shifting cultivation sites. Doctoral dissertation. In: Aizawl District, Mizoram. Mizoram University, Mizoram.

Wapongnungsang, Manpong, C., Tripathi, S.K., 2018. Changes in soil fertility and rice productivity in three consecutive years cropping under different fallow phases following shifting cultivation. Int. J. Phys. Sci. 25 (6), 1–10.

Wapongnungsang, Sapalirinilana, H., Tripathi, S.K., 2020. Impact of low cost indigenous soil inputs on soil fertility in different fallow lands following shifting cultivation in Muallungthu, Mizoram. J. Indian Soc. Soil Sci. 68 (2), 210–220.

Wapongnungsang, Singh, B.B., Tripathi, S.K., 2019. Changes in weed diversity and biomass during crop growth in three age chromosome of forest falls in Muallungthu village, Mizoram. J. Indian J. Ecol. 46 (1), 70–75.

Yadav, P.K., 2013. Slash-and-burn agriculture in north-east India. J. Expert. Opin. 2, 2–5.

Zhang, J., Zhou, S., Sun, H., Lü, F., He, P., 2019. Three-year rice grain yield responses to coastal muliflilt soil properties amended with straw biochar. J. Environ. Manag. 239, 23–29.