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Sustainable Intensification of Short fallows in Shifting Cultivation with Biopolymers

The sustainable intensification of the depleted fallow lands has been extensively researched to develop tailor-made management strategies. This synthesis involved a review of the literature and re-analyzing published data on changes in soil physical and chemical properties in land under shifting cultivation. Additionally, the impact of biopolymer application on soil health and plant growth improvement has been described. Present synthesis revealed soil macro-aggregates, water infiltration rate and hydraulic conductivity, and essential soil elements (N, P, K) declined substantially in soil under shifting cultivation practices. Furthermore, it was observed that biopolymer applications decreased total runoff and sediment yield while enhancing soil health and plant growth. Therefore, it is concluded that the biopolymer application is a sustainable method for improving soil properties and short fallow management.

Key words: Biopolymer, Fallow management, Land degradation, Land restoration, Soil properties, Sustainable intensification.

Biopolymer applications can restore soil health and plant productivity.

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Introduction

Shifting cultivation has been a basic form of agriculture for millennia and is a dominant land use in tropical Africa, Asia, Latin America, the Pacific, and the Caribbean (Cairns and Garrity, 1999; Craswell *et al*., 1997; Eastmond and Faust, 2006; Heinimann *et al*., 2017; Li *et al*., 2014; Mertz *et al*., 2009, Silva *et al*., 2011; Nath *et al*., 2021). However, the rapid increase in human population and more demand for farmland leads to a reduction of the fallow period for 2-3 years, which is insufficient for the regeneration of forests (Nath *et al*., 2021). The problem, however, is that it is often practised on fragile and slopping land with low-activity clay soils such as Acrisols, Alisols, Ferralsols, Luvisols and Lixisols (IUSS, 2014) that are prone to rapid degradation when cultivated (Ramakrishnan, 1992; Heinimann *et al*., 2017).

Acrisols are characterized by a clay accumulation in an argicsubsurface horizon in combination with low-activity clays, a distinct clay increases with depth, and a low base saturation (IUSS, 2014). The argic horizon has the ratio of cation exchange capacity to the clay content, identifying the dominance of low-activity clays. However, Acrisols tend to have poorly developed structures because of low cation exchange capacity and base saturation (Nachtergaele *et al*., 2000). Due to the strong acid subsoil root, penetration is usually poor. Acrisols generally have low levels of plant nutrients, but aluminium toxicity and P-sorption are usually stronger (IUSS, 2014). Aluminium saturation with values often exceeding 70 per cent. However, due to the low cation exchange capacity, the absolute amount of exchangeable aluminium is generally at most 2cmol (+)/kg fine earth. Regions having dry seasons usually have thin Acrisols on the surface horizon with a low amount of organic matter. In contrast, organic matter accumulation in tropical highlands may be high because of relatively humid conditions and/or low temperatures (Nachtergaele *et al*., 2000).

In the mountainous regions, acrisols can be found at the top of stable ridges and along the valley. It often occupies higher terraces (World Soil Resource Report, 2001). Although most of the tropical Acrisols are still under forest vegetation, the forests are cleared and put under cultivation in some regions. Due to the abundance of nutrients in the plants, various forms of 'slash and burn' were created to cultivate these soils under traditional farming. Therefore, the most common use of Acrisols is shifting cultivation.

The shortening of fallow periods causes the degradation of soil structure and the disintegration of the native ecosystem (Nath *et al*., 2021). Therefore, strategies to improve the depleted soil under fallow phases are needed to achieve faster ecosystem restoration. The sustainable intensification of the soil under fallow lands can maintain the integrity of the native ecosystems. Sustainable intensification is producing more output from the same land while reducing the adverse environmental impacts, increasing contributions to natural capital and the flow of ecosystem services (Pretty, 1997; Pretty *et al*., 2011).

Biopolymers are polymers that are produced from natural resources, including polysaccharides (starch, cellulose), proteins (gelatin, collagen) or either chemically synthesized from bio-derived monomers (*e.g.*, Polylactic acid and other polyesters) or microbial activities (*e.g.*, xanthan gum, gellan gum). Biopolymers are considered environmentally friendly; therefore, they can be widely used in food and medical applications and various soil treatments such as soil strengthening, permeability control, erosion reduction, dust control, and even water treatment (Chang *et al*., 2020). In addition, biopolymers are of biological origin and less harmful than other synthetic polymers.

In this regard, the application of biopolymers in soil stabilization and plant growth improvement was explored and summarized from the published literature. Therefore, the synthesis objectives were to (i) study the impact of short fallowing on soil properties and (ii) study the impact of biopolymer application on soil health and plant growth improvement.

Methods

This synthesis involved a review of the literature and re-analyzing published data on changes in soil physical and chemical properties in shifting cultivation. The studies were identified by searching through the Web of Science and Google Scholar. Search parameters were limited to papers whose title, abstract, or keywords referred to 'shifting cultivation,' 'fallow lands,' 'soil properties,' 'biopolymer,' in combination with 'biomass,' 'soil,' 'carbon,' or 'organic matter.' For data to be included in this analysis, the study must fulfil the following criteria: It must (1) have been published in a refereed journal, (2) have reported biopolymer

Table 1 : Changes in soil physical and chemical properties under fallow phases in comparison to native forests

Parameter	Site	Native forest	Fallow period	Change (%)	References
Physical Properties					
Soil Moisture (%)	Bangladesh	23.87	26.03	+9.04	Osman *et al*., 2013
Macro-aggregate proportion (%)	India	75.6	51.1	-32.41	Laskar *et al*., 2021
Bulk Density(Mg m^{-3})	India	1.58	1.62	+2.53%	Saplalrinliana *et al*., 2016
	Amazon Basin	1.05	1.19	+13.33	McGrath *et al*., 2001
	Nigeria	0.70	1.44	+105.7	Lal, 1996
	Malaysia	0.97 -1.25	0.91 -1.25	-6.19	Ying *et al*., 2018
Infiltration rate (cm/hr)	Nigeria	152	21	-86.18	Lal, 1996
Hydraulic Conductivity(cm/hr)	Nigeria	308	46	-85.06	Lal, 1996
Chemical properties					
Soil pH	Bangladesh	4.73	4.77	+0.84	Osman *et al*.,2013
	India	4.01	4.28	+6.73%	Saplalrinliana *et al*., 2016
SOC content (g/kg)	Amazon Basin	27.6	14.9	-46.01	McGrath *et al*., 2001
	Madagascar	64.1	40.3	-37.13	Vagen *et al*., 2006
	India	22.1	18.0	-18.55	Laskar *et al*., 2021
SOM(%)	Bangladesh	5.18	4.96	-4.24	Osman *et al*., 2013
Available N (kg/ha)	India	275	251	-8.73	Saplalrinliana *et al*., 2016
Total N (g/kg)	Madagascar	4.7	1.7	-63.83	Vagen *et al*., 2006
Available P (mg/kg)	Bangladesh	7.40	2.30	-68.92	Haque *et al*., 2014
	Madagascar	4.9	4.6	-6.12	Vagen *et al*., 2006
	Malaysia	13.9 -88.3	11.5-27.3	-17.27-69.08	Ying *et al*., 2018

+Increase; - Decrease

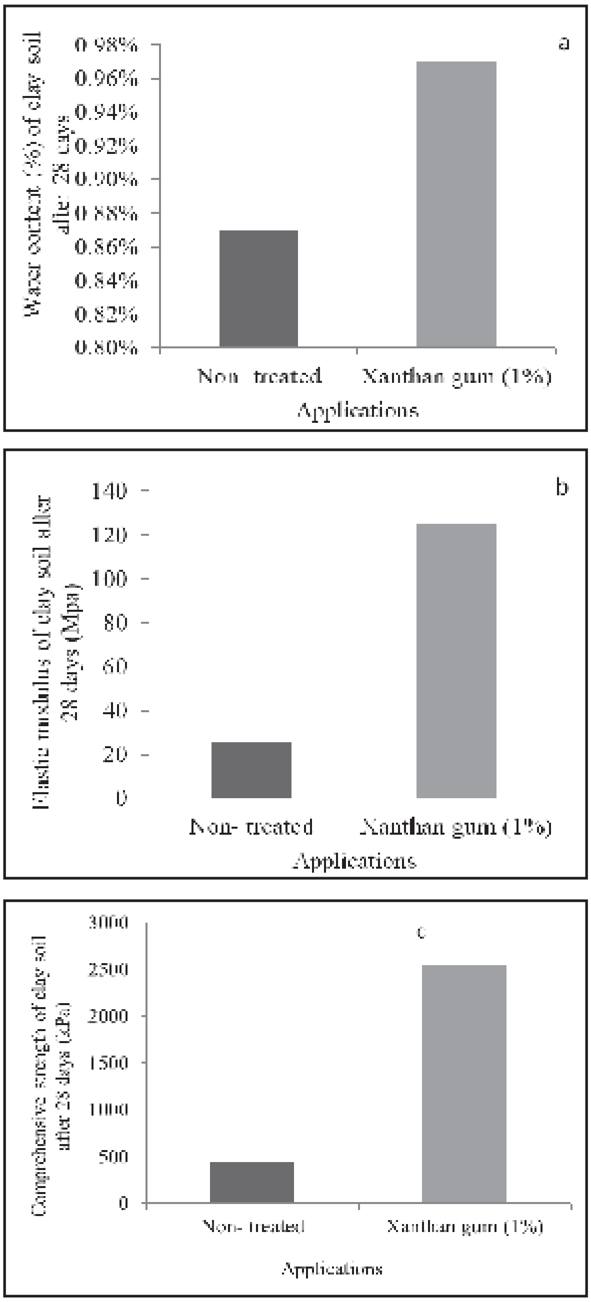

Fig. 1 : Effect of biopolymer application on soil properties- (a) water content, (b) Elastic Modulus (c) Comprehensive strength

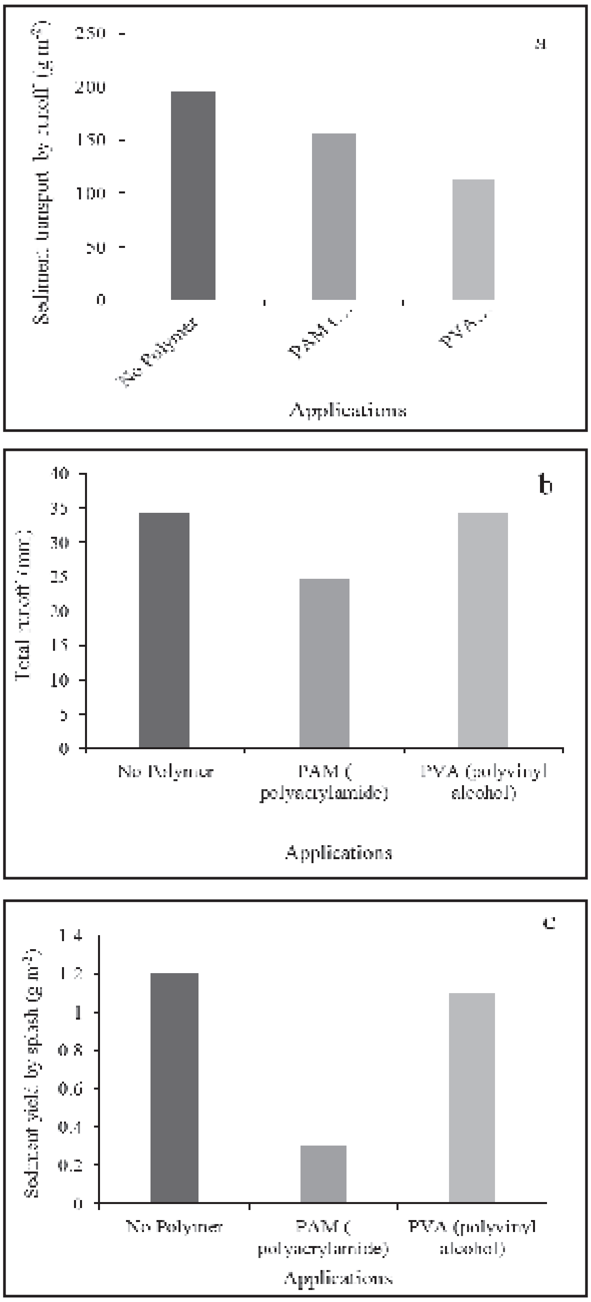

Fig. 2 : Effect of biopolymer application on (a) sediment transport by runoff (b) total runoff (c) sediment yield by splash

application, and (3) have reported data as mean in the numerical or graphical form.

Synthesis and Discussion

Effect of short fallowing on soil physical and chemical properties

Analysis of the results presented in Table 1 revealed the proportion of soil macro-aggregates (32.41%), infiltration rate (86.18%) and hydraulic conductivity (85.06%) declines substantially with the land-use transition from native forest to shifting cultivated lands. In contrast, bulk density increased by 2.53-105.7% under fallow phases compared to native forests. In addition, soil pH increased by 0.84-6.73% under the fallow phases, while the SOC content declined by 18.55-46.01%, SOM by 4.24%, N by 63.83-68.92%,

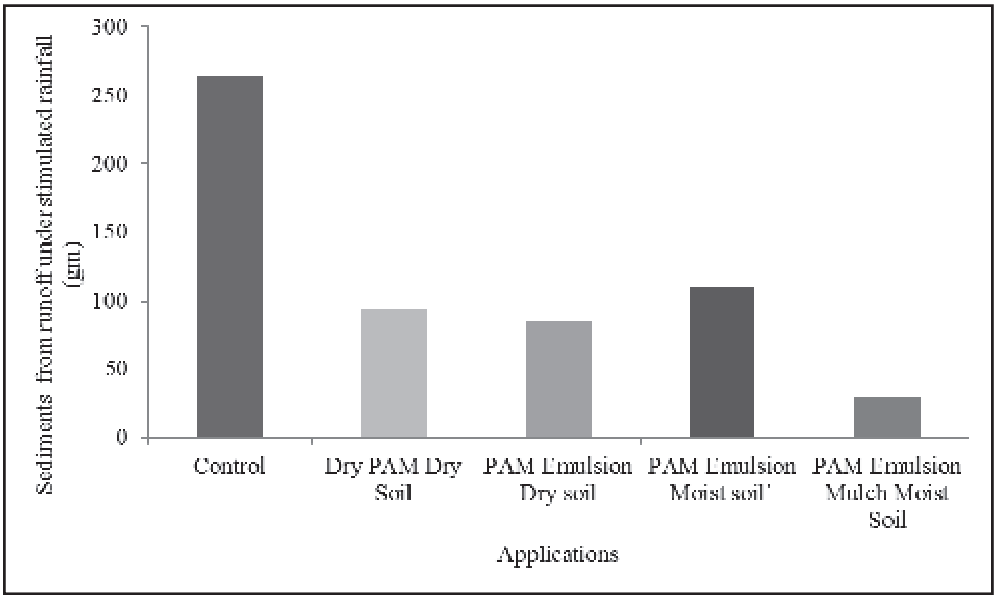

Fig. 3 : Effect of biopolymer application on sediments from runoff under simulated rainfall conditions.

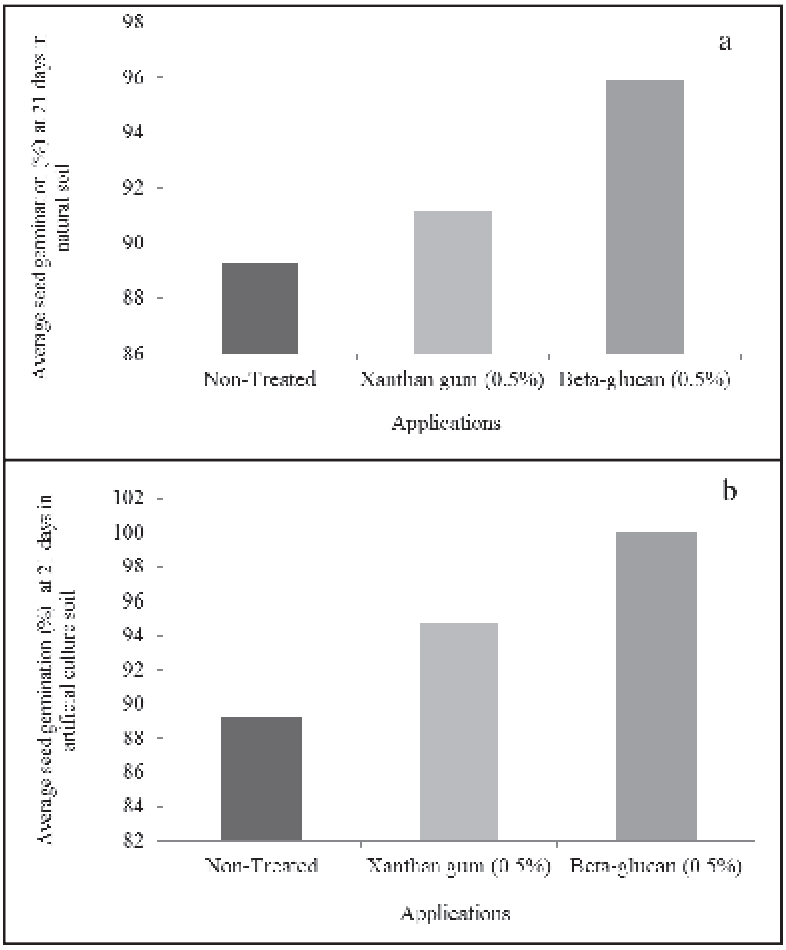

Fig. 4 : Effect of biopolymer application on seed germinationon (a) natural soil, and (b) artificial soil

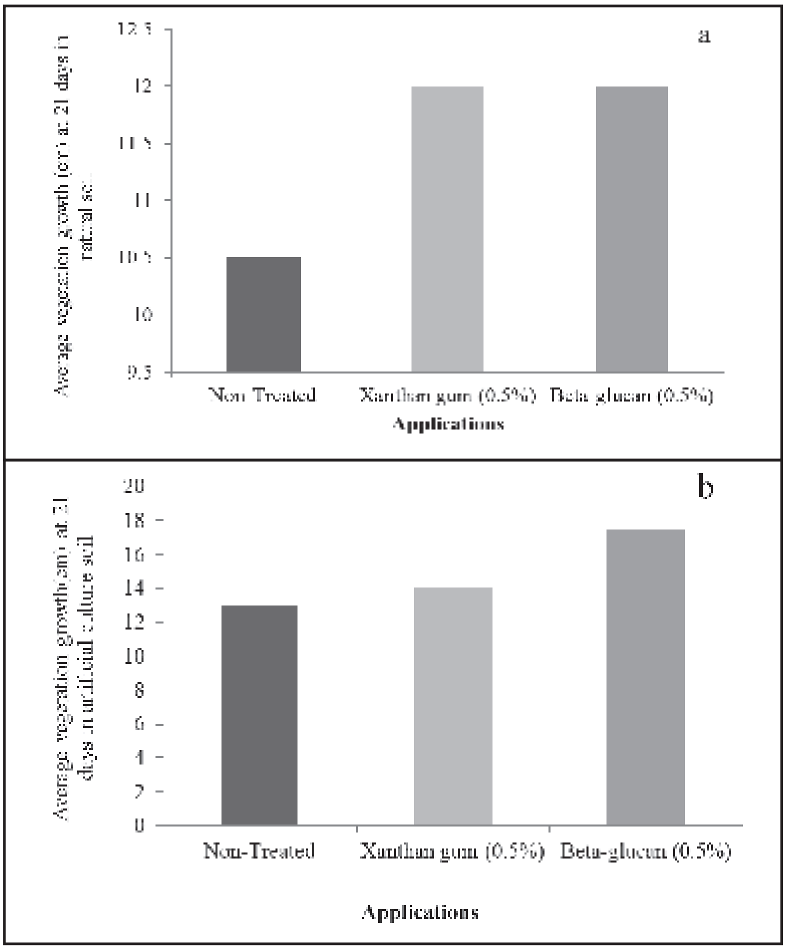

Fig. 5 : Effect of biopolymer application on vegetation growth in (a) natural soil, and (b) artificial soil

and P by 6.12-69.08% under fallow phases compared to native forests. The consequences of short fallow lead to depletion of SOC content (absence of vegetative cover lead to the lower input of organic matter from above ground and below-ground biomass), infiltration rate (disintegration of soil aggregates and disrupting the continuity of pores from surface to subsurface soil), hydraulic conductivity and erosion of N, P and other chemical elements from the system. Thus, the data presented suggest that agricultural land establishment through shifting cultivation severely depletes soil's physical and chemical properties. Shifting cultivation is generally practised in harsh tropical environments characterized by heavy rains of high erosivity and structurally weak soils with low-activity clay and prone to rapid degradation (Nath *et al*., 2016).

Impact of biopolymer application on soil restoration

Applying 1% xanthan gum improved the water content, elastic modulus, and comprehensive strength of clay soil in Belitung Island of Indonesia by 11.5%, 400% and 477.27%, respectively, than under non-treated soil (Fig. 1 a-c). The application of PAM and PVA decreased the sediment transported by runoff by 20.4% and 42.7%, total runoff by 27.27% and 0.87% and the sediment yield by splash by 75% and 8.3%, respectively, than that under non-treated soil in Kahramanmaras Province, Turkey (Fig. 2 a-c). The application of dry PAM, PAM emulsion in dry soil, PAM emulsion in moist soil and PAM emulsion mulch in moist soil decreased the sediment from runoff under stimulated rainfall by 64.15%, 67.92%, 58.49% and 88.67%, respectively, than that under non-treated soil in Dane Country, Wisconsin (Fig. 3).

Biopolymers can be used as an effective way to restore the soil. It enhances soil stability and reduces erosion via bio-aggregation, bio-crusting, bio-coating, bio-clogging, and bio-cementation (Stabnikov *et al*., 2015). Biopolymer effectively reduces soil erosion, especially xanthan gum, β-glucan, and chitosan biopolymers, which show significant erosion resistance with accumulated erosion ratios of less than 1% (Chang *et al*., 2015). Figure 1 shows that Xanthan gum

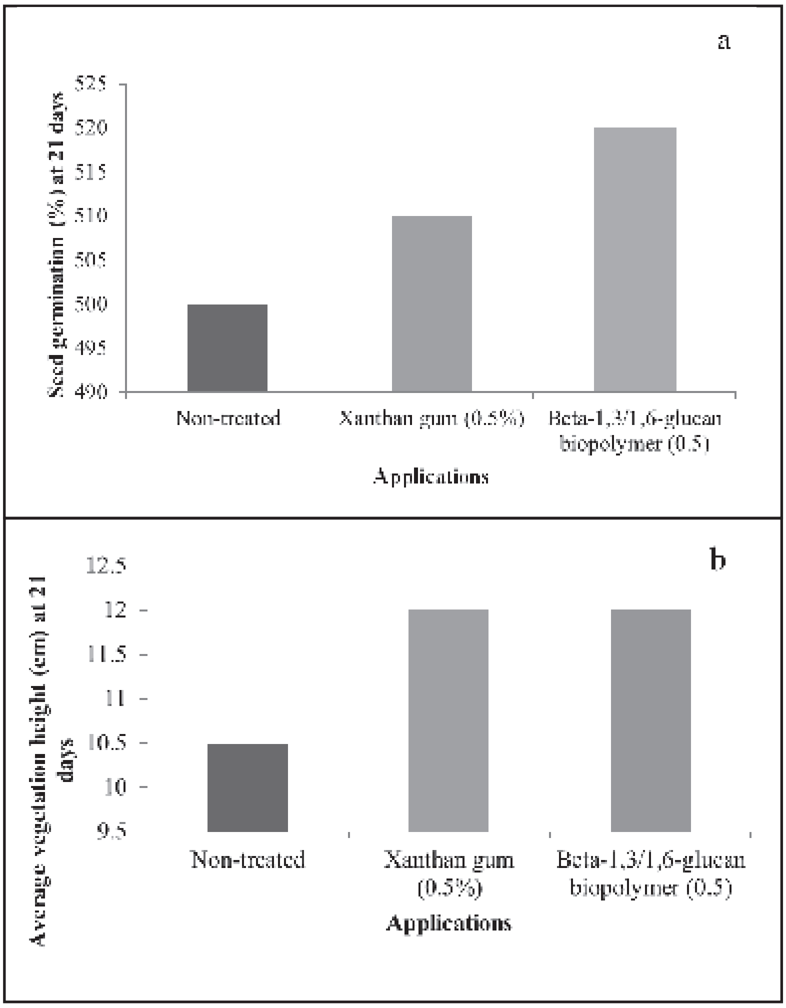

Fig. 6 : Effect of biopolymer application on (a) seed germination (b) vegetation growth

significantly strengthens on treated clay soil compared to untreated. This strengthening can be due to the inter-particle relations within the soil due to the cohesive forces. Due to hydrogen and electrostatic bonding between xanthan monomers and fine soil particles, the strength of Xanthan-treated clay soil increases (Chang *et al*., 2015). Fig. 2 shows that polymer, PAM, and PVA applications decreased total runoff, sediment yield, and sediment yield mobilized by splash compared to no polymer. The study showed that PAM and PVA application in agricultural practices enhance soil aggregate stability and reduce soil erosion. Therefore, the use of PAM and PVA is effective in increasing structural stability and decreasing runoff generation, splash and soil losses (Yakupoglu *et al*., 2019)

Impact of biopolymer application on vegetative growth

The application of Xanthan gum (0.5%) and beta-glucan (0.5%) improved the average seed germination of oats (*Avena sativa*) in the arid and semi-arid regions by 2.12% and 7.39% in natural soil (Fig. 4a) and by 6.16% and 12.10% in artificial culture soil (Fig. 4b) than that under non–treated soil. In addition, the application of 0.5% Xanthan gum and 0.5% beta-glucan improved the vegetation growth of oats sprouts at 21 days in natural soil by 14.29% and 14.29% (Fig. 5a) and in artificial culture soil by 7.69% and 34.61% (Fig. 5b) respectively, than that under non-treated. In Fig. 6(a), the application of 0.5% xanthan gum and 0.5% beta-1-3/1,6-glucan improved the germination of Oats seeds at 21 days by 2% and 4% and the growth behaviour of oats sprouts at 21 days by 14.28% and 14.28% (Fig. 6b) respectively, than that under non-treated soil.

The most feasible use of biopolymers in arid and semi-arid regions is to improve plant growth and soil erosion resistance (Hogan *et al*., 2004). The study showed that the biopolymer-based treatment is environmentally friendly to improve seed germination and promote vegetation growth. In Fig. 4a-5b, the beta-glucan biopolymer treatment of natural and culture soil induced a higher germination rate and vegetation growth than untreated soil. The untreated natural soil did not favour seed germination. This is because it has small pore spaces and huge desiccation crust on its surface, whereas biopolymer-treated soil showed larger pore spaces, *i.e.* higher porosity. Thus, due to larger pore spaces, the biopolymer treatment provides a suitable structural environment for root penetration inside the soil and vegetation growth (Chang *et al*., 2015). Specifically, biopolymer shows high water retention behaviour even with loose particle composition (density), providing an appropriate environment for seed germination and the accompanying root penetration of vegetation in soils (Chang *et al*., 2015; Larson *et al*., 2010; Tingle *et al*., 2007).

Implications of the study

The present study indicates the application of biopolymer is a sustainable method for the improvement of soil properties. The current biopolymer industry still occupies a small market. However, due to expanded applications of biopolymers in medicine, food, farmland irrigation, construction, geotechnical engineering, etc. and the increase in their production in the global market, they are expected to gradually decrease the cost of biopolymers as well as improve the economic feasibility. For example, the price of biopolymers was reduced to 80% during the last decade due to increased production and the further reduction will be possible with projected expanding demand (JEC Group, 2008). Moreover, in the 1960s, the price of xanthan gum was about 30,000 USD/ton. However, it has drastically dropped to 1500–4000 USD/ton nowadays due to its broad usage in various industries (Chang *et al*., 2015; Yegin *et al*., 2017; Chang *et al*., 2020). Hence, introducing biopolymers applications in soil preservation can reduce the cost of biopolymers through mass production and expand the global biopolymer market.

Conclusion

This review has provided evidence that biopolymers can be used as an eco-friendly and sustainable way to improve soil erosion resistance, retain soil moisture, and promote cultivation. Therefore, biopolymer application in short fallows may provide an opportunity for faster soil restoration. The expanding global biopolymer market also assures the feasibility of biopolymer application for the restoration of soil health.

जैव बहुलक के साथ झूम खेती में कम परती का सतत् सघनीकरण

अरुण ज्योति नाथ

सारांश

बंजर भूमि के स्थायी प्रबंधन रणनीतियों को विकसित करने के लिए बड़े पैमाने पर गहन शोध किया गया है। इस संश्लेषण में स्थानांतरण खेती के तहत भूमि में मृदा के भौतिक और रासायनिक गुणों में परिवर्तन पर साहित्य की समीक्षा और प्रकाशित आंकड़ों का पुनः विश्लेषण शामिल है। इसके अतिरिक्त, मृदा स्वास्थ्य तथा पौधों के विकास में सुधार पर जैव बहुलक (बायोपॉलिमर) अनुप्रयोग के प्रभाव का वर्णन किया गया है। वर्तमान संश्लेषण से पता चलता है कि स्थानांतरण खेती प्रथाओं के तहत मृदा के स्थूल समुच्चय, जल रिसाव दर, द्रव चालित प्रवाहिता तथा मिट्टी के आवश्यक तत्व (एन.पी.के.) में काफी गिरावट आई है। इसके अलावा, यह देखा गया कि जैव बहुलक अनुप्रयोगों ने मिट्टी के स्वास्थ्य और पौधों की वृद्धि को बढ़ाते हुए कुल अपवाह और अवसाद उपज में कमी की। अतः यह निष्कर्ष निकाला गया है कि मिट्टी के गुणों में सुधार और लघु परती प्रबंधन के लिए जैव बहुलक अनुप्रयोग एक स्थायी विधि है।

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