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Plant community regulates soil multifunctionality in a tropical dry forest

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ABSTRACT

Tropical dry forest (TDF) covers large areas of tropics and characterized by a mosaic type of plant communities that occur as the co-dominant multi-species sites to predominant mono-species. Previous forest management practices leading to incorporation of certain alien species and recombination or modification of the forest communities. However, we know little about the relative effect of multi-specific, mono- (here *Shorea robusta*, *Hardwickia binate* and *Tectona grandis*) and an alien-specific (*Lantana camara* L.) sites on soil multiple (ecosystem) functions (or soil multifunctionality). We were assessed soil individual functions including status of soil nutrients (N and P), fractions of soil organic carbon (SOC) and glomalin related soil protein (GRSP), microbial biomass C, CO_2 efflux and extracellular hydrolytic (acid and alkaline phosphatase, β-glucosidase, dehydrogenase and fluorescein diacetate) and oxidative (phenol oxidase and peroxidase) enzymes to topsoil and subsoil layers on the seasonal basis (summer, winter, and rainy) in a highland TDF of India. Soil multifunctionality index was further calculated by averaging Z-scores of these parameters. Irrespective of soil-depth and season, we found the extent of a majority of soil individual functions and soil multifunctionality was higher at the multi-specific sites followed by mono- and alien-specific sites. It suggests that under similar soil type and climatic condition higher plant diversity promote soil multifunctionality. However, particularly we found that soil pH, alkaline phosphatase and phenol oxidase activity were higher at the alien-specific sites compared with native mono- and multi-specific sites. The multivariate principal component analysis also showed the discrimination of alien-specific sites from intermixed mono- and multi-specific sites. These results suggest that *L. camara* sites alter the soil environment as they are very different from those created by native species. We also conclude that *L. camara* sites are least important in regards to promote soil multifunctionality. Eventually, this study has broad implication in understanding revegetation of tropical forest aimed to expedite maximum ecosystem benefits.

1. Introduction

In terrestrial ecosystems, soil is a natural component that proximately contributes to multiple ecosystem functions and services including net primary production, climate and water regulation, nutrient cycling and carbon sequestration (Ushio et al., 2010; Prescott and Grayston, 2013; Aponte et al., 2013). Given that the nature and composition of aboveground plant community can influence soil processes and functions through alteration of microclimate (buffering canopy-level temperature variation and holding soil moisture level), production of litter and root exudates, and by providing habitat and/or resources for macro- and microorganisms (Ushio et al., 2010; Prescott and Grayston, 2013; Aponte et al., 2013; Putten et al., 2013). For instance, studies revealed that plant community traits (species composition and diversity) have a significant influence on soil physicochemical properties (e.g., soil aggregation and soil water content), substrate supply to the soil microbes (e.g., C, N and P concentrations, C/N ratio) through plants (Prescott and Grayston, 2013; Martin et al., 2016) and in turn soil microbial diversity and activity (Thakur et al., 2015; Barbi et al., 2016). However, such information regarding the interaction of plant community and soil or microbial properties are still under development because of rapid changes in plant assemblage in the majority of terrestrial ecosystem as a consequence of afforestation or deforestation, species invasion and climate change (Franklin et al., 2016). Moreover, in recent, there has been emphasized on extending plant-soil or plant-microbial interaction studies to understand multiple ecosystem functions and services together (i.e. multifunctionality), which provides better informed decision to implement management plans for

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ecosystems (Maestre et al., 2012; Peco et al., 2017). Thus, it is of great value if we understand how the plant community influence soil multifunctionality (or ecosystem functions that are linked to soil) in an ecosystem.

Spatial heterogeneity in the plant community assembly is a common feature in a forest ecosystem, and they are able to produce a species-specific influence on soil functions (Prescott and Grayston, 2013; Aponte et al., 2013). Most of our understanding of the effects of plant community on soil functions is based on measurement of individual soil attributes, while evaluations of soil multifunctionality are rare (Peco et al., 2017). In general, studies have independently addressed the effect of plant community composition on soil nutrients (N and P), soil organic C (SOC), glomalin, microbial functional indices and extracellular enzyme activity (Turk et al., 2008; Ushio et al., 2010; Lange et al., 2014; Singh et al., 2016). Moreover, available literature also indicates that if a plant community type improves certain soil function in an ecosystem, it may also impair some other functions. For instance, *Lantana camara* invasion in a tropical forest increases the process of nitrogen cycling (Sharma and Raghubanshi, 2009); it may reduce glomalin and SOC accumulation in soil. The important management concern of an ecosystem is to reconcile the loss of one ecosystem function with the gain in other ones, and incorporate potential tradeoffs in land use or plant community decisions (Chandregowda et al., 2018). Another concern is implementation of appropriate management plans for the ecosystem, particularly by taking advantage of few positive effects of plant communities (Sharma and Raghubanshi, 2009; Slade et al., 2017).

There is a general consensus that virtually all terrestrial ecosystem functions are directly or indirectly mediated by microbial processes in soil (Singh et al., 2010; Delgado-Baquerizo et al., 2016). Inter-linked indices of soil such as pH, SOC, glomalin, N, P, microbial biomass C, microbial respiration and hydrolytic and oxidative enzymes (release nutrients), together expresses the status of soil functions. These variables are also considered as important indicators of ecosystem health and disturbances (Burns et al., 2013; Singh et al., 2016, 2017; Kumar et al., 2018). Thus, an approach to produce an index derived from an integration of these variables and assesses how plant community influence multifunctionality index, could be better for understanding the management of ecosystem (Maestre et al., 2012; Delgado-Baquerizo et al., 2016).

Here, we assess whether changes in plant community composition are associated with differences in soil chemical environment and microbe-mediated soil biochemical functions in a tropical dry forest. This forest covers the large areas of tropics (1×10^6 km^2) and represents nearly 42% of all tropical forests in the world (González-M et al., 2018). Here, plant community mainly consists of deciduous trees (they losses their entire leaves in the dry season to prevent water losses through evapotranspiration process), which comprises mono- and multi-specific dominance sites across the forest (Kushwaha and Singh, 2005). Moreover, the heedless deforestation, overgrazing and revegetation lead to reassociation of the plant communities, and the introduction of some new and invasive plant species in this ecosystem (Chaturvedi et al., 2011; Sharma and Raghubanshi, 2007; Singh and Singh, 2015). Eventually, *L. camara* is a shrub that originated from Central and South America, now widespread invaded nearly entire tropical dry forests of the world (Sharma and Raghubanshi, 2007; Singh and Singh, 2015).

This study was conducted in a tropical dry forest of central India. Here, we have selected two multi-specific sites (sites co-dominated by the multiple species), three predominant mono-specific sites (*Shorea robusta*, *Hardwickia binata* and *Tectona grandis*) and an alien-specific or invasive species (*L. camara*) dominant site. Particularly, our objective is to investigate the effect of these plant communities on soil properties including pH, fractions of SOC and glomalin, N, P, microbial biomass C, microbial respiration (or potential of CO_2 efflux) and soil enzymes (both hydrolytic and oxidative enzymes) in the topsoil (0–15 cm) and subsoil (15–30 cm) layers. Because functional traits of plants could differ in terms of seasonal phenophases (e.g. period of leaflessness) and may cause variation in soil feedback at a given time (Nord and Lynch, 2009). To remove such type of biases in the assessment of plant communities, these ecologically important parameters were also investigated on a temporal seasonal (summer, winter and rainy) basis. We further calculated soil multifunctionality index for each plant community by integrating these ecological variables. The results from this study will help to understand the better-informed decision in plant community selection during afforestation or revegetation in dry tropics.

2. Materials and methods

2.1. Study site

The present investigation was carried out in Vindhyan highland forest in the Sonbhadra district of Uttar Pradesh, India (21° 29′–25° 11′ N and 78° 15′–84° 15′ E). The topography of the region is rocky plateau with slightly sloping terrain and valley at the bottom (altitude ranging between 225 and 450 m a.s.l.). The climate of the area is tropical monsoon type that causes rainy season from July to October, winter from November to February and summer from March to June. Mean annual air temperature of 27 °C and mean annual precipitation of 1215 mm (1980–2010) (Chaturvedi and Raghubanshi, 2015). The region is experiencing a dry period from November to June with little or no rain (Singh et al., 2017). We have selected six different forest communities inside the Sonbhadra forest. The description of forest community and physiognomy are given in Table 1 and Supplementary Fig. S1. These forest sites are primarily separated by species composition. The native forest sites are naturally established old growth forests that have a minimum anthropogenic disturbance history. Here the forest vegetation is categorised as Northern Tropical dry deciduous type (subgroup 5-B of Champion and Seth, 1968). The trees are of moderate height (15–20 m). The information regarding the Teak planted site was collected from divisional forest office Renukoot (Sonbhadra). The Teak plantation was carried out in a 1.2 Km^2 deforested land during the rainy season in 1980. The *L. camara* invaded forest site was also a deforested site where its invasion possibly happened by the self-perpetuation and establishment process (Singh and Singh, 2015). This previously deforested land likely resulted from a sporadic illegal tree felling by the local

Table 1
Location and plant community composition of the study sites.

Site notation	Location	Plant community
Dry Miscellaneous Forest*	Ele-338 m, N-24° 14.879′, E- 83° 05.731′	*Anogeissus latifolia*, Diospyros melanoxylon, Lagerstroemia parviflora, *Terminalia tomentosa*, *Schleichera oleosa*,
Sal Forest*	Ele-313 m, N- 24° 16.591′, E- 83° 08.840′	***Shorea robusta***, Lagerstroemia parviflora, *Diospyros melanoxylon* (Roxb.),
Moist Miscellaneous Forest*	Ele-296 m, N-24° 17.992′, E- 83° 06.313′	*Shorea robusta*, *Aegle marmelos*, *Madhuca longifolia*, *Terminalia arjuna*, *Briedelia retusa*
Hardwickia Forest**	Ele-346 m, N-24°15.200′, E- 83° 05.556′	***Hardwickia binata***
Teak Planted forest**	Ele-314 m N-24°14.195′, E- 83°03.400′	***Tectona grandis***
Lantana Invaded forest***	Ele-284 m N-24° 15.519′, E- 83° 05.215′	Dense cover of ***Lantana camara*** and few scattered tree of *Hardwickia binata*

* Multi-specific forest.
** Mono-specific forest.
*** Alien-specific forest.