Annals of Agri-Bio Research **30** (2): 40–47, 2025

Impact Score: 0.4 (Scopus)

Diameter Distribution and Litterfall Dynamics of Dominant Tree Species in Manokwari Lowland Fallow Ecosystems, Indonesia

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(Received: 12 March 2025; Accepted: 07 August 2025)

ABSTRACT

In the lowlands of Manokwari, West Papua, Indonesia, shifting cultivation is still a prevalent practice among local Papuan communities. The secondary succession on abandoned shifting cultivation lands warrants investigation, given that these lands are typically reused for agriculture after a period of fallow. Key parameters for assessing the succession process include vegetation structure and litter production; however, information on these aspects in Manokwari, West Papua, remains limited. This research examined the distribution of stem diameters and developed a model for litterfall types across three different ages—age 5 year (LB-5), 10 (LB-10) and age 15 year (LB-15) in the lowland tropical ecosystems of Manokwari. Vegetation analysis with nested plots and litter trap methods were employed. Litterfall modeling utilized pseudo replication principles, combining principal component analysis and non-metric multidimensional scaling (NMDS) based on Bray-Curtis' similarity. Results showed distinct distribution patterns and diameter classes for each dominant type. Dominant species in LB-5 and LB-10 accumulated stem diameters below 25 cm, whereas LB-15 exhibited a more complex distribution with stem diameters exceeding 50 cm. Species such as *Macaranga aleuritoides*, *Macaranga tanarius*, *Kleinhovia hospita*, and *Ficus nodosa* exhibited higher diameter growth rates at early successional stages (e.g., age/DBH), indicating their fast-growing nature. The litterfall model explained 99.9% of data variability. LB-5 showed positive correlation with leaf litterfall production, while LB-10 and LB-15 correlated with branch, twig, and reproductive organ litterfall. This study demonstrates that vegetation structure and composition significantly influence litterfall quality, emphasizing the importance of long-term litterfall modeling.

Key words: fallow lands, NMDS, dbh, West Papua, litterfall type

INTRODUCTION

Fallow land refers to traditional gardens of local Papuan communities that have been abandoned for years. This land use pattern is a consequence of the intensive shifting cultivation system practiced by local communities. Papua's traditional agricultural system, based on shifting cultivation, has two distinct characteristics: small-scale farming and unique crop diversity (Hartemink, 2003; Allen and Filer, 2015). Additionally, agricultural lands are typically located far from residential areas, are relatively small in size, and situated within forested areas. Following years of abandonment, fallow lands evolve into ecosystems resembling forests.

The fallow period triggers a dynamic succession process, transforming the structure and vegetation of former plantation lands. This transformation affects plant stem size distribution, which can be accurately measured using tree diameter distribution analysis (Susanto, 2019; Gomes et al., 2020). The resulting growth pattern, characterized by an inverted J-shaped curve, indicates forest regeneration and disturbance levels (Samuel et al., 2019). Research suggests selective logging disrupts tree diameter classes (Hayward et al., 2021), while McRobert et al. (2008) found correlations between inverted J curve regression values and increased biodiversity. Habitat preferences also influence growth rates among plant species. Therefore, studying stem distribution patterns in dominant fallow land vegetation is crucial.

In addition to changes in vegetation structure and composition during succession, there are changes in organic matter returned to the soil through litter. Succession also alters organic matter returned to soil via litterfall. Litterfall, comprises dead plant material above the ground or separated from living plants (Krishna and Mohan, 2017; Giweta, 2020). Litter plays a crucial role in forest ecosystems, recycling nutrients from vegetation to soil (Vitousek, 1984). Accumulated litter on the soil surface, prior to decomposition, represents litter production. Nutrient input from litter depends on litter production rates and decomposition speeds (Sayer et al., 2020).

Research on fallow land vegetation typically focuses on dominant species' importance (bin Wasli et al., 2009; Budirianto et al., 2018; Mukul et al., 2020), diversity, biomass accumulation and litter production (Toky and Ramakrishnan, 1983; Salako and Tian, 2001; Hartemink, 2001; Fujii et al., 2020). However, studies examining tree diameter distribution in fallow lands of varying ages are scarce. Moreover, litter quantity impacts land productivity (Vitousek, 1984), and understanding litterfall types during succession informs soil nutrient input estimates (Londe et al., 2016; da Silva et al., 2018).

Kaironi Village, Sidey Manokwari District, hosts various natural fallow land ecosystems exemplifying true succession. The Meyah tribe's shifting cultivation practices prevail in this area. This study aims to address two research gaps: (1) How do tree size distribution and classes differ among dominant trees in fallow lands of varying ages? (2) What litterfall models characterize fallow lands aged 5–15 years?

METHODS

Study Site

This research was carried out on fallow land aged 5 years (LB-5), 10 years (LB-10) and 15 years (LB-15) in Kaironi Village, Sidey District, Manokwari Regency, West Papua Province, Indonesia (0°45′0.4″ S, 133°33.3′32″ E) (Figure 1). The research location is at an altitude of 65–75 m above sea level and the entire research plot is a flat area. All research locations are directly adjacent to natural forests.

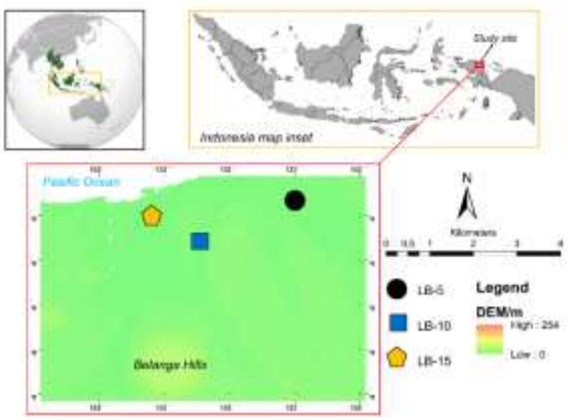

Fig. 1. Location of study sites in Manokwari lowland fallow lands, West Papua, Indonesia. LB-5: 5-year fallow; LB-10: 10-year fallow; and LB-15: 15-year fallow

The research area was previously a traditional agricultural land owned by the local Meyah tribe in Papua. The former agricultural land was initially planted with tubers such as cassava (*Manihot esculenta*), taro (*Colocasia esculenta*), and sweet potatoes (*Ipomoea batatas*), as well as secondary crops like peanuts (*Arachis hypogea*) and chili peppers (*Capsicum frutescens*). At the time of our survey, the three research locations had undergone significant vegetation succession, with trees and shrubs dominating the landscape. Tree density varied across the sites, with LB-5 having a relatively low density of 24 trees per hectare, compared to 233 and 283 trees per hectare at LB 10 and LB 15, respectively (Susanto et al., 2021).

The research location has a tropical rainforest climate, classified as Af, with an annual rainfall of approximately 1200 mm/year (Peel et al., 2007). According to the local Meteorological, Climatological, and Geophysical Agency's (BMKG):https://dataonline.bmkg.go.id/dataonline-home (accessed on 15 May 2024) records for the past five years (2019–2023), the average annual rainfall ranges from 1230 to 2452 mm/year. The average daily temperature over the same period ranges from a minimum of 23.7 °C to a maximum of 31.8 °C. Additional data from BMKG show that, over the 6-month research period (August 2020–January 2021), the peak average temperatures (27.8–29 °C) were recorded in October-November, while the highest monthly rainfall (139–259 mm) occurred in November-December. The research locations were geologically influenced by the Circum-Australian Orogenic System and ecologically characterized by tropical lowland evergreen rainforest vegetation, consistent with the FAO-UNESCO classification (1979).

The research location is situated in the Doberai Plains, characterized by Ferrasols soil type. Based on the FAO (1976) soil classification system, the research areas at LB 5, LB 10, and LB 15 are classified as District Fluvisols (Jd10-2/3a), which is associated with District Cambisols, including Humic Gleysols and District Regosols. Further analysis of soil physical and chemical properties revealed distinct differences in soil texture among the three locations, with clay fractions dominating LB 5 and sand fractions dominating LB 10 and LB 15 (Susanto et al., 2021).

Data Collections

Three 20 m × 20 m plots were randomly established in each fallow land. The distance between each fallow land (LB-5, LB-10, and LB-15) was approximately 3 to 5 kilo meters. The LB-5 site covered an area of approximately 1.5 hectares, while the LB-10 and LB-15 sites each covered around 1 hectare. Within each fallow land, the plots were spaced approximately 10–20 m apart and were not located at the edges of the land. The vegetation survey employed a nested plot methodology, wherein each 20 m × 20 m plot contained nested subplots of 10 m × 10 m, 5 m × 5 m, and 2 m × 2 m. This design enabled efficient plant sampling and enhanced the precision of species documentation across different growth stages (Stohlgren et al., 1995). Stem diameter measurements were taken at 130 cm above ground level, equivalent to Diameter at Breast Height (DBH).

This study employed a completely randomized design, treating different fallow lands ages as variables. Litter production was measured using 1 m × 1 m nylon mesh litter traps (Toky and Ramakrishnan, 1983). Three litter traps were randomly installed in each 20 m × 20 m plot, totaling 9 traps per fallow land age and 27 traps across all ages. The placement of litter traps was conducted purposively, considering vegetation canopy density (Tesfay et al., 2020). In each 20 m × 20 m plot, one litter trap was positioned at the center, and two additional traps were installed 5–7 m away from the center, without exceeding the plot boundaries. Traps of liiterfall were positioned 50 cm above ground level.

Litterfall production was measured over six consecutive months (August 2020–January 2021). Monthly harvests were sorted into leaf litter, stem/twig litter, and reproductive organs (flowers, fruits, buds) (An et al., 2020). Dry weights were determined by oven-drying plant organs at 80 °C until constant weight.

Data Analysis

To examine the structure and composition of tree vegetation (dbh ≥ 5 cm) in each fallow land, the Importance Value Index (IVI) was calculated. The IVI was determined by summing the relative density (RD), relative frequency (RF), and relative dominance (RDo), with calculations based on Curtis and McIntosh (1951). Subsequently, tree species with the highest IVI were selected for further analysis of diameter distribution using histograms (Guariguata et al. 1997). Species diversity was quantified using the Shannon-Wiener diversity index, calculated as $H' = -\Sigma\ pi\ \ln pi$, where pi denotes the proportion of each species relative to the total species count (Magurran, 2004). The index was calculated for each 20 m × 20 m plot.

The characteristics of litter types were modeled based on monthly litter production over a six-month period. Each month, nine litter type data points were collected for each fallow land age. Monthly litter proportions were calculated and transformed into percentage data (da Silva et al., 2018; Qiu et al., 2023). The types of litterfall, including leaf litter, woody litter (branches and twigs), and reproductive litter (flowers and fruits), were modeled using percentage data for each litter type. A total of 54 data points per fallow land age, representing 6 months of litterfall percentages, were used for non-metric multidimensional scaling (NMDS) and principal component analysis (PCA). The Principal Component Analysis (PCA) utilized correlation-based Eigenvalues with values exceeding 0.5, whereas Non-metric Multidimensional Scaling (NMDS) analysis, based on Bray-Curtis similarity, was employed to visualize the differences in litter types across the fallow lands (Ferreira et al., 2021). Data visualization and statistical analysis employed IBM SPSS v. 25 and Past v. 4.0.3.

RESULTS AND DISCUSSION

Dominant Tree Diameter Structure

A notable trend emerged where the Importance Value Index (IVI) of dominant species declined with increasing fallow age, whereas the diversity index (H') showed a corresponding increase (Table 1). This pattern implies that as fallow lands mature, they support a more diverse plant community, thereby mitigating the dominance of any single species. The relationship between IVI and diversity index (H') is inversely correlated, with high IVI values often associated with reduced diversity (Rambey et al., 2021).

The dominant vegetation in LB-5 comprises *Macaranga aleuritoides* F.Muell., *Piper aduncum* L., and *Mallotus* sp1 (Table 1). Stem diameter distributions for *Mallotus* sp1 and *M. aleuritoides* exhibit a uniform pattern (Figure 2), whereas *Piper aduncum*'s distribution is concentrated below 10 cm. Notably, *M. aleuritoides* individuals exceed 20 cm in diameter, contrasting with the predominantly smaller diameters (<20 cm) of LB-5's dominant tree vegetation. Following a five-year fallow period, *M. aleuritoides* exhibited larger stem diameters than *P. aduncum* and *Mallotus* sp1, suggesting rapid growth, consistent with Susanto et al. (2016) and Sakai et al. (2022).

The dominant species in LB-10 exhibit greater complexity than those in LB-5. This is supported by the differences in H' values in Table 1, where the diversity index in LB-5 is lower compared to LB-10 and LB-15. The higher H' values reflect a greater richness of plant species, leading to a more diverse distribution of stem diameters (Godlee et al., 2021). *Macaranga tanarius* (L.) F.Muell., and *Kleinhovia hospita* L., co-dominate LB-10 (Figure 3), consistent with Fibich et al.'s (2016) findings in Papua New Guinea's secondary forests, where *M. tanarius* predominated (22.5%) alongside *Ficus variegata* (18.3%) and *Trichospermum pleiostigma* (13.7%). *K. hospita's* comparable diameter class suggests competitive ability and shared habitat preferences with *M. tanarius*, echoing patterns observed in *Crecopia*, *Heliocarpus*, *Ochroma*, and *Trichospermum* (Guariguata and Ostertag, 2001).

Table 1. Diversity and dominance of plant species in fallow lands: a comparative study across different ages.

No	Type of Fallow	Plant species	Family	IVI (%)	H' ± SE
1	LB-5	*Macaranga aleuritoides*	Euphorbiaceae	68.97	1.63 ± 0.42
		Mallotus sp1.	Euphorbiaceae	37.10	
		Piper aduncum	Piperaceae	29.09	
2	LB-10	*Macaranga tanarius*	Euphorbiaceae	61.30	2.07 ± 0.21
		Kleinhovia hospita	Malvaceae	47.02	
		Intsia bijuga	Fabaceae	39.06	
		Alstonia scholaris	Apocynaceae	26.09	
3	LB-15	*Ficus nodosa*	Moraceae	44.66	2.49 ± 0.49
		Macaranga tanarius	Euphorbiaceae	26.28	
		Aglaia spectabilis	Meliaceae	25.97	
		Alstonia scholaris	Apocynaceae	17.95	

H' = Shannon-Weiner diversity index; SE= standard deviation

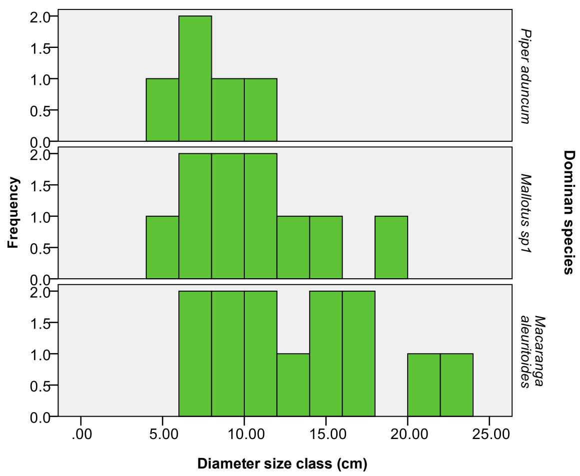

Fig. 2. Diameter (DBH) distribution of dominant tree species on LB-5.

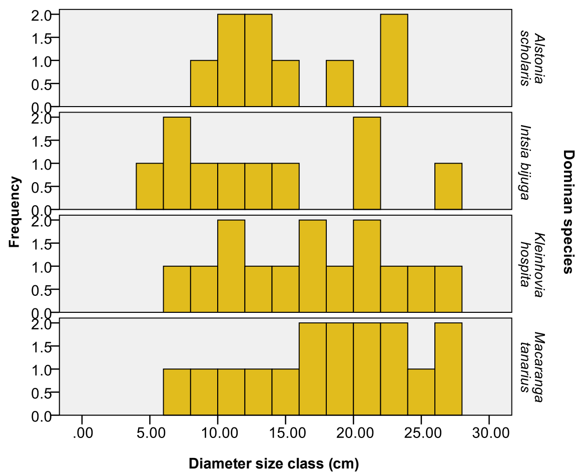

Fig. 3. Diameter (DBH) distribution of dominant tree species on LB-10.

Figure 4 illustrates that dominant tree diameters at LB-15 exceed those at LB-5 and LB-10. *Ficus nodosa* Teijsm. & Binn., exhibits a uniform stem diameter distribution. *Alstonia scholaris* (L.) R.Br., shows limited representation. *Aglaia spectabilis* (Miq.) S.S. Jain & S. Bennet., dominates diameters below 25 cm, while *Macaranga tanarius'* stem diameters remain below 50 cm. Notably, over 50% of stem diameters surpass 20 cm, with average dominant tree diameters ranging from 25–30 cm.

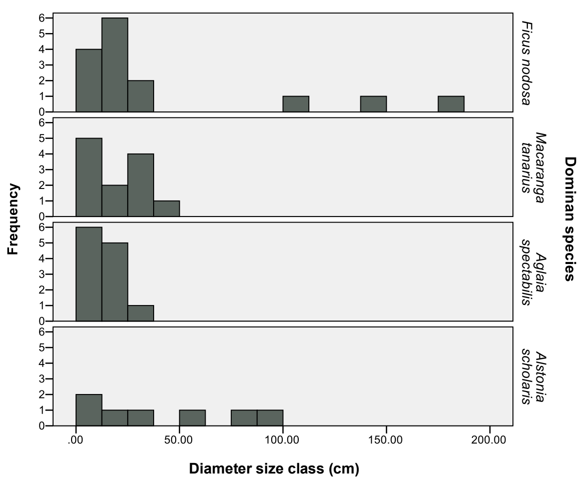

Fig. 4. Diameter (DBH) distribution of dominant tree species on LB-15.

The complexity of the vegetation structure is increasingly visible in LB-15, characterized by an increasingly widespread distribution of stem diameters (Figure 4). These results are similar to the research of Guariguata et al. (1997) which shows that former agricultural land that has become secondary forest aged 16–18 years tends to have a narrower diameter distribution when compared to secondary forest aged over 30 years. This research also highlights that *A. scholaris* in LB-15 can be used as an indicator of weak dominant plant species. Weakly dominant plant types are plant types that ecologically have a large level of dominance, but are still inferior to other plant types that have a high density. In tropical forest communities, weak dominant types usually have high relative dominance values due to large basal vegetation, but lower density and frequency values (Akatov et al. 2018; Subedi et al. 2019).

Litterfall Dynamic

Figure 5 illustrates peak litter production occurred during November-December (August 2020–January 2021) across fallow lands. Specifically, LB-5 and LB-15 peaked in November, whereas LB-10 peaked in December. Litterfall production increases sharply from November to December, following initial low values (August–October). Minimum and maximum production values occurred in October (32 g/m²/month, LB-5) and November (158 g/m²/month, LB-15), respectively.

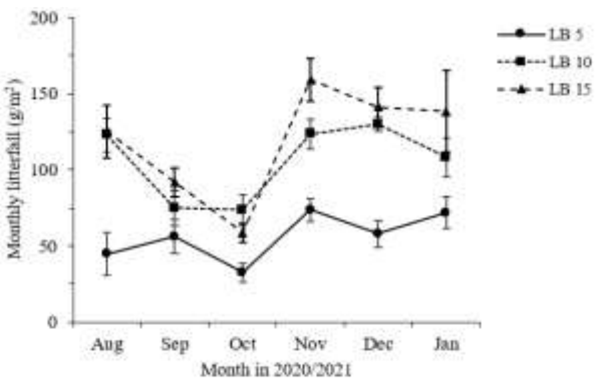

Fig. 5. Average monthly litter production (±SE, n = 9) on 5-year fallow (LB-5), 10-year fallow (LB-10) and 15-year fallow (LB-15) lands.

Litter production fluctuated across fallow lands (Figure 5). Maximum variability occurred in January 2021 for LB-10 and LB-15, and August for LB-5. Patterns differed: 10-year fallows showed steady growth from August to December, whereas LB-15 experienced decline (August–October), followed by sharp November increases and subsequent declines. Statistical analysis revealed significant differences in total litter production among fallow lands in specific months ($p < 0.05$, Figure 5). Significant variations were also observed in reproductive organ, leaf, stem, and twig litter production ($p < 0.05$). Notably, LB-5 exhibited distinct leaf litter production compared to LB-10 and LB-15 ($p < 0.05$), whereas LB-10 and LB-15 lands showed no significant difference ($p > 0.05$)

Litter production positively correlates with fallow land age (Figure 5), attributed to differences in tree density, basal vegetation area, and microclimate. Higher tree densities (fivefold) in LB-10 and LB-15 generate more organic material. Supporting findings (Huang et al., 2017; Souza et al., 2019; Machado et al., 2021) indicate successional forest age enhances plant diversity, tree density, and basal vegetation, increasing litter production.

The November peak in litter production (Figure 5) corresponds to post-dry season rainfall increases. This seasonal shift drives concurrent litter production increases across fallow lands (Figure 5), supporting observations of 45–48% increases in Ethiopian open forests (Tesfay et al., 2020) and 57.5% increases linked to temperature and rainfall fluctuations (Nakagawa et al., 2019).

Monthly litter production fluctuations are influenced by vegetation composition, environmental factors, and site-specific conditions. Variations in tree behavior, temperature, rainfall, and location contribute to significant differences (Sundarapandian and Swamy, 1999). Tropical regions' temperature and rainfall fluctuations elicit diverse phenological responses, affecting litter production (Paudel et al., 2015). Increased plant diversity with fallow age, reflected in varied tree diameter distributions, likely enhances tree phenology variability, influencing litter production. Consistent with Zhu et al. (2019), successional vegetation changes in tropical secondary forests impact monthly litter production variability and nutrient cycling.

Modeling Litterfall Types

We visualize Figure 6 using the X matrix function by utilizing a matrix X = $\{x_{ij}\}$ of dimension I × J, where I represents the number of samples and J represents the number of variables. This matrix is typically derived from the original data matrix X raw through preprocessing techniques such as centering, scaling, and normalization. This study's model effectively predicted litterfall types based on fallow land age. Principal Component Analysis (PCA) revealed Axis 1 (Eigenvalue: 2.38) explained 79.5% of data variability, while Axis 2 (Eigenvalue: 0.61) accounted for 20.4% (Figure 6). The model explained 99.9% of litter production variation. Non-metric Multidimensional Scaling (NMDS) analysis yielded a 2D stress value ≤0.05, indicating excellent model fit.

Principal Component Analysis (PCA) revealed distinct litterfall patterns: LB-15 separated from LB-10 and LB-5 due to differences in litter type. LB-5 correlated positively with leaf litter, whereas LB-10 and LB-15 overlapped, associating with branch, twig, and reproductive organ (flower, fruit, and bud) litter (Figure 6). Specifically, LB-10 correlated with branch and twig litter, while LB-15 correlated with floral and fruit litter.

Fallow lands age significantly influences litter production composition (Figure 6). As fallow age increases, leaf litter production decreases, while stem, twig, and reproductive organ litter production increases. This trend aligns with observations in Brazilian Amazon secondary forests (da Silva et al., 2018) and southeastern Mexico's tropical forests (Sánchez-Silva et al., 2018), where leaf litter production declines with age. Increased reproductive organ litter production correlates with rainfall (Barlow et al., 2007).

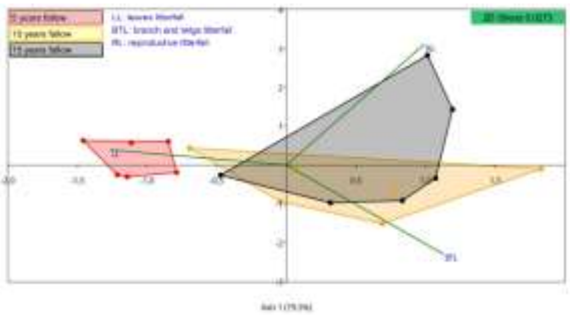

Fig. 6. 2D Biplot of correlation matrix based on Principal Component Analysis (PCA) and Non-Metric Multidimensional Scaling (NMDS), illustrating litter type attributes on three fallow lands, with Axis 1 (Eigenvalue: 2.38) and Axis 2 (Eigenvalue: 0.61) explaining data variability.

CONCLUSIONS

Divergent tree diameter classes and distributions among dominant species suggest unique ecological roles. This study reveals that diameter distributions (dbh) of fallow lands aged 5–15 years are concentrated below 30 cm. Our findings revealed that species such as *Macaranga aleuritoides*, *Macaranga tanarius*, *Kleinvovia hospita*, and *Ficus nodosa* exhibited accelerated diameter growth rates during early succession. Given their rapid growth rates, these species are suitable candidates for promoting ecological recovery in areas previously used for shifting cultivation. Litter modeling reveals age-specific variations in litterfalls quality, implying leaf litter's pivotal role in nutrient replenishment within young fallow lands.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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