Comparative growth behaviour and biomass production of exotic and native woody plantations on coal mine spoil in a dry tropical environment of India: A case study

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Abstract

The restoration of lands damaged by opencast coal mining is an increasingly important problem in a dry tropical region of India. Plantations are often employed as a measure of revegetation and management of mine spoil; thus, mitigating the mining effects on the environment. However, the choice of species for plantations has emerged as a challenge for the restoration ecologists due to insufficient data. Therefore, the primary objective of the present paper is to compare the efficiency of exotic and native species on the coal mine spoils. Previous studies on the Singrauli coalfields allowed us to compare the growth performance, standing biomass, net primary production (NPP), litterfall and decomposition rates of exotic and native species plantations. Our results showed that native species have significantly higher survival, stem-diameter, biomass and NPP as compared to exotic species plantations. However, leguminous nature of species did not affect these parameters significantly. Further, litterfall and decomposition rates were also not differed either between exotic vs native or leguminous vs non-leguminous species. Thus, exotic species either legume or non-leguminous is not very much useful in mine spoil rehabilitation as that of native species.

KEYWORDS *Ecological restoration - soil redevelopment - exotic species - native species - coal mine spoil*

1 INTRODUCTION

Coal is a major energy source for developing countries like India where it is used for power generation and therefore, considered as an essential component of the economy of many nations. India is one of the major producers of coal worldwide; however, the demand of coal for electricity generation and industrial production in India is so high that it needs to import substantial quantities of coal (IEA, 2019). Since the forests and natural vegetation often cover most of the coal reserves under open cast mining areas, therefore, mining for coal extraction cause unavoidable loss of biodiversity. Further, most of the coal in India is extracted by surface mining, which involves removal of the earth surface in the form of sheets resulting in a large amount of waste material usually referred as overburden or mine spoil (A. N. Singh & Singh, 2006; A. N. Singh, Zeng, & Chen, 2006; J. S. Singh, Singh, & Jha, 1995). Thus, mining drastically alters the physical and biological nature of the surroundings of the area where mining takes place (Pandey et al., 2016; A. N. Singh et al., 2006). The accumulation of overburden significantly alters the biological, chemical and physical attributes of the soil resulting in severe land degradation (Feng, Wang, Bai, & Reading, 2019). This leftover dump usually has a high concentration of metals and the limited amount of nutrients making it harsh for the development of vegetation and soil microbial communities (Novianti, Marrs, Choesin, Iskandar, & Suprayogo, 2018). Further, a large area becomes unproductive and wasteland due to the filling of overburden. Thus, the leftover waste poses a serious threat to ecological sustainability by disrupting the ecosystem structure and functions (Adibee, Osanloo, & Rahmanpour, 2013; Feng et al., 2019).

Growing concerns about environmental impacts of coal mining together with slow natural recovery of mine spoils urge technical solutions to restore these degraded ecosystems into their original state. But, restoration of such degraded lands is a challenging ecological problem (Lamb, Erskine, & Parrotta, 2005; A. N. Singh, Raghubanshi, & Singh, 2004b, 2004a; A. N. Singh & Singh, 1999; J. S. Singh et al., 1995; Vega, Covelo, & Andrade, 2005). However, a successful restoration programme attempts to accelerate the natural recovery processes to check the soil erosion, to restore the soil fertility and to enhance the biological diversity (A. N. Singh, Raghubanshi, & Singh, 2002). Therefore, the first step in any restoration programme, of course, is to protect the disturbed habitat and communities from being further wasted. Then follow attempts to accelerate the revegetation process for increasing biodiversity and stabilising nutrient cycling (A. N. Singh & Singh, 2006; A. N. Singh et al., 2006). The most important preconditions for ecosystem rehabilitation in post-mining landscapes are the processes of soil redevelopment (A. N. Singh et al., 2004a, 2004b). Once soil fertility is restored, it will be easier for the more desirable species to establish. Therefore, the soil is considered to be one of the primary agents in determining vegetation development and the importance of soil characteristics in ecological studies cannot be underemphasised (A. N. Singh et al., 2004a).

Plantations have been contemporarily used to effectively restore degraded lands worldwide (A. N. Singh et al., 2002). However, the suitability of species and their performance on coal mine spoil have remained a challenging task as the characteristics of coal mine spoils are highly heterogeneous, lacked with soil organic matter (SOM), so that regarded as a recalcitrant medium for plant growth. Therefore, an ideal species needed for planting on mine spoils must possess the following abilities:

(i) to grow on poor and dry soils,
(ii) to develop the vegetation cover in a short time and to accumulate biomass rapidly,
(iii) to bind soil for arresting soil erosion and checking nutrient loss, and
(iv) to improve the soil organic matter status and soil microbial biomass, thereby enhancing the supply of plant-available nutrients (A. N. Singh & Singh, 1999) and
(v) to provide ecosystem services to attract more wild floras and biodiversity development under plantations.

Some of the earlier studies have evaluated the growth and biomass production of several plant species on coal mine spoil (Badía, Valero, Gracia, Martí, & Molina, 2007; Bohre & Chaubey, 2016; Erskine, Lamb, & Borschmann, 2005; Jeżowski et al., 2017; A. N. Singh et al., 2004a; A. N. Singh & Singh, 1999; A. Singh & Singh, 2001). Although exotic woody species are often suggested for the restoration of coal mine spoil due to their fast growth and high economic or livelihood benefits, it often results in poor development of biodiversity (D'Antonio & Meyerson, 2002; Dutta & Agrawal, 2003; Lamb et al., 2005). Further, many previous studies have shown that exotic species can impart both positive and negative impact on soil fertility and native flora while restoring the degraded lands (Berger, 1998; D'Antonio & Meyerson, 2002; Yan et al., 2020). Exotic species may have higher survival (Citadini-Zanette et al., 2017) and improve soil properties (Yan et al., 2020). However, they often result in low carbon development as compared to native species (Citadini-Zanette et al., 2017). Furthermore, exotic species shows successful establishment and their fast-growth often outcompete the native species during the restoration (Huxtable, Koen, & Waterhouse, 2005). Another study showed that there are little differences in biomass production among the exotic and native plants established on degraded lands (Islam, Kamaluddin, Bhuiyan, & Badruddin, 1999). The biomass allocation to different plant parts can be controlled by environmental and biological (species-specific) factors (Boonman et al., 2020; Freschet, Swart, & Cornelissen, 2015; Poorter et al., 2012). Thus, the biomass allocation to different plant parts can vary between exotic and native species because species may have adapted to their native habitats and therefore may exhibit differential allocation strategies. Thus, there is a need for an increased understanding of the biology and impacts of exotic and native species on degraded lands. Therefore, a comparison of survival, growth and biomass production among exotic and native species becomes important to assess the suitability of plant species for the reclamation process.

The present study aims to compare the survival, growth performance, biomass accumulation, net primary productivity of 5-year old native and exotic woody plantations established on coal mine spoils. We expect that exotic species may have higher survival, growth and biomass production on coal mine spoils because these species usually exhibit higher competitive abilities. Therefore, they can sustain themselves on nutrient-poor and degraded lands. Specifically, we address the following four questions from our study: (1) Can native species have higher survival and growth performance on coal mine spoils? (2) What is the level of biomass and net primary production among native and exotic plantations at earlier stages? (3) What is the pattern of litterfall and litter decomposition among different type of species? and, (4) Whether biomass production and net primary production (NPP) are the species-specific?

2 MATERIALS AND METHODS

2.1 Study Site and Climate

The plantations under present study were located in the west section of Jayant block of Singrauli Coalfields in Singrauli district of Madhya Pradesh, India, which lies between latitudes 24° 6' 45" – 24° 11' 15" N and longitude 82° 36' 40" – 82° 41' 15" E. The study area is situated on a plateau above the plain (around 500 m above mean sea level) on its southwest side whereas the average elevation at the foot of the plateau is around 300 m above mean sea level. The climate of the area is tropical monsoonal and the year is divisible into a mild winter (November-February), a hot summer (April-June) and a warm rainy season (July-September). Data collected at a meteorological station present on the site showed that the mean monthly minimum temperature within the annual cycle ranges from 6 – 28 °C and mean monthly maximum from 20 – 40 °C. The rainfall annually averages 1069 mm, of which about 90% occurs from late June to early September. The rainfall is characterised by a high degree of inter-annual variation, as during the study period 1980–1996 it ranges from 700 to 1450 mm yr^{-1} (A. N. Singh et al., 2004b, 2004a).

2.2 Plantations and Experimental design

All the plantations (native species) were raised in July–August by planting nursery-raised seedlings in previously dug pits of 40 cm × 40 cm × 40 cm size at a spacing of 2 × 2 m. The plantations of three native species (*Albizia lebbeck* (L.) Benth., *Albizia procera* (Roxb.) Benth. and *Tectona grandis* L.f.) were raised in 1990 by planting 7 to 8 months old nursery raised seedlings. In contrast, the plantations of one native (*Dendrocalamus strictus* Nees) were raised in 1991 by planting eight months nursery-raised seedlings. These plantations have been raised for land rehabilitation as natural colonisation is very slow on the mine spoil. All the planted plots were seeded in 1994 at the rate of 6 kg ha^{-1} with Dinanath grass (*Pennisetum pedicellatum* Trin.) for preventing soil erosion and loss of runoff nutrients. The total planted area for *A. lebbeck* and *A. procera*, whereas the same for *T. grandis* and *D. strictus* was about 0.5 ha each. For sampling three permanent plots were established for each species. The size of the sample plots was 25 × 25 m for *A. lebbeck* and *A. procera* whereas 15 × 15 m plot size for *T. grandis* and *D. strictus.*

Five individuals of average height and diameter (clumps in case of *D. strictus*) were marked in each replicate plot by using waterproof paint for various measurements in 1993. The number of individuals (clumps in *D. strictus*) in each plot was inventoried in February 1993. Data collection was carried out annually in February–March since 1993.

2.3 Estimation of biomass and net primary production

For the measurement of tree biomass, allometric equations relating tree dimensions to the biomass of parts were developed. Twelve individuals of each species, representing a gradient of diameter, were felled from an area adjoining the permanent plots, and their diameter (D) and height (H) were measured. The felled individuals were separated into stem and foliage. The root systems of the felled plants were excavated to a depth of 1 m. The fresh weight of each component (stem, foliage and coarse roots with diameter greater than 5 mm) was recorded in the field. Sub-samples were brought to the laboratory for determining dry weights. The data were subjected to regression analysis to relate the dry weight of stem, foliage, rhizome and root with D or D^2H or with their natural log values. The equations with highest R^2 (correlation coefficient) were selected, which were also used in earlier studies (Dutta & Agrawal, 2003; A. N. Singh et al., 2004a; A. N. Singh & Singh, 1999). The standing biomass of different components (stem, foliage and root) was calculated by using the biomass estimation equations. These values were then multiplied by the density of tree species. Per hectare, biomass estimations were obtained separately for each plot and were averaged across the number of plots to obtain the mean estimates at different ages.

Fine root (less than 5 mm in diameter) biomass was quantified by digging out 20 cm × 20 cm × 20 cm monoliths at 20 cm intervals from the plant base to 1-meter distance.

Monoliths were washed with a fine jet of water and fine roots were collected, dried and weighed. Tree roots were separated from roots of herbaceous plants based on colour and appearance.

The net primary production was estimated using diameter increments and biomass data as described by Singh and Singh (1991), Dutta and Agarwal (2003), and Singh *et al*., (2004b).

2.4 Estimation of leaf litterfall and its decomposition rates

Problems in the estimation of leaf-litter fall were encountered due to human disturbance, lack of homogenous ground surface and wind action, which did not permit accurate estimation of leaf fall. Therefore, leaf litterfall was considered equivalent to estimate foliage biomass, as the plantation species are deciduous (J. S. Singh et al., 1995). Non-leaf litter (woody) was estimated by periodic collections from six permanent 1 m^2 quadrats marked on the ground in each plot. All the litterfall data are presented here on an oven-dry basis (80 ºC).

For leaf litter decomposition, mature, nearly senesced but attached leaves were collected from the mid-crowns of all plantations during the peak period of leaf fall and air-dried. The litter bag technique was used to quantify decomposition rates. Nylon litter bags (10 cm × 10 cm, 1 mm mesh) containing 5 g air-dried leaf litter were placed on the floors of respective tree plantations at the start of the rainy season in 1994. Three litter bags were recovered from each permanent plot at each of the six sampling dates. Immediately after recovery, the litter bags were placed in individual polyethene bags and transported to the laboratory. The recovered material was carefully separated from soil particles, dried at 80 ºC to constant weight and weighed. The daily instantaneous decay rate (*k*) of litter for the study period was calculated using the negative exponential decay model of Olson (Olson, 1963). The time required for 50% and 95% weight loss was calculated as $t_{50} = 0.693/k$ and $t_{95} = 3/k$, respectively.

2.5 Data for exotic species

Previous studies have investigated the restoration potential of some exotic species on the same study site and therefore, provided with an opportunity to compare the restoration potential of exotic and native species on coal mine spoils (Dutta & Agrawal, 2001, 2003; J. S. Singh et al., 1995). These studies considered four exotic species (*Casuarina equisetifolia* L., *Cassia siamea* Lam., *Grevillea pteridifolia* Knight and *Acacia auriculiformis* A. Cunn. ex Benth.). The total planted area for *C. equisetifolia* and *G. pteridifolia* was 1.5 ha each, whereas the same for *A. auriculiformis* and *C. siamea* was about 0.5 ha each. For sampling three permanent plots were established for each species. The size of the sample plots was 25 × 25 m for *C. equisetifolia* and *G. pteridifolia* and; 10 × 10 m for *A. auriculiformis* and *C. siamea* (Dutta & Agrawal, 2001, 2003; J. S. Singh et al., 1995).

2.6 Statistical analyses

SPSS-PC statistical software was used for all statistical analyses. To observe the effect of species the data were subjected to the General Linear Model (GLM) for analysis of variance (ANOVA). Mean values were tested for difference among plantation species with Tukey's honestly significant difference (HSD) mean separation test (SPSS, 2003, version 10.0). Regression equations were developed through the same statistical package. To observe the effect of origin (exotic vs native) student's t-test was conducted using the package *rstatix* (Kassambara, 2020) in the *R* statistical environment (R Core Team, 2020).

3 RESULTS

3.1 Survival

The survival of plantations has been estimated as the stocking density (Individual stem ha^{-1}) for each species (three plots) under exotic and native plantations and the results are tabulated in Table 1. The stocking density (individual stem ha^{-1}) at the time of plantation was 2500 in both types of plantations. After five years of plantation establishment, about 71-88% of individuals were survived in native and 63-74% in the exotic plantations. Among all plantations, the highest survival rate was observed in the native species (*A. procera*) and lowest in the exotic species (C. *equisetifolia*), therefore, ANOVA indicated significant differences in stocking density due to species (Table 6). However, the survival rates were significantly higher in native plantations as compared to exotic species (Figure 1).

3.2 Growth performance

The growth performance of exotic and native species was determined in terms of height and diameter. Height and diameter (growth parameter) were significantly varied among all plantations of exotic and native species (Table 6). Among all plantation species (native and exotics) the maximum height was attained by *G. pteridifolia*, whereas maximum diameter was observed for *A. lebbeck* after 5-years of their establishment. The values for height and diameter varied from 2.19 to 5.18 m and 4.32 to 7.58 cm, respectively in native and 2.75 to 5.88 m and 2.99 to 4.90 cm, respectively in exotic plantations (Table 2). However, the height was significantly higher and diameter was significantly smaller in exotic species plantations as compared to native species plantations (Figure 1). Consequently, the height to diameter ratio was significantly smaller in native species. Further, a significant positive correlation is observed for height and diameter in case of exotic species whereas selected native species did not exhibit any significant correlation (Figure 2a). Further, non-legumes showed a significant negative correlation (Figure 2b).

3.3 Biomass production

The observed values for the biomass of different components of the plant are summarised in Table 3 and it was noted that *D. strictus* has shown the highest total biomass production among all the species whereas *A. auriculiformis* exhibited highest total biomass production among the exotic species. The biomass of different components of plants was significantly varied due to species among all the plantations (Table 6).

Therefore, values in native plantations, significantly varied from 7.68 to 74.68 t ha^{-1}, being minimum for *T. grandis* and maximum for *D. strictus* plantation and 8.49-31.03 t ha^{-1} in exotic plantations, being maximum in *A. auriculiformis* and minimum in *C. siamea* (Table 3). Among plant parts, stem contributed more than 50% to the total biomass for both exotic and native species (Figure 3a) as well as for leguminous and non-leguminous species (Figure 3b). The share of aboveground components in the total biomass in the present study was 65.3-91.1% in native and 66.3-84.5% in exotic and belowground contribution was in the range of 8.9-34.7% in native and 15.5-33.7% in exotic plantations, respectively (Figure 3c). However, the belowground biomass was higher for leguminous species as compared to the non-leguminous species (Figure 3d). Moreover, relative contributions of short-lived components (foliage and fine root < 5 mm) were small as compared to long-lived tree component (stem) to the tree layer biomass for both types of plantations calculated at 5-yr age (Figure 3e) and a similar pattern was observed for the leguminous and non-leguminous species (Figure 3f). Further, biomass production of all components except fine root biomass was significantly higher in native species plantations as compared to exotic species plantations (Figure 1).

3.4 Net primary production

The net primary productivity of different components of plant species is given in Table 4. Total net production (above + below ground) among these plantations on mine spoil varied from 4.76 to 32.04 t ha^{-1} yr^{-1} in native and 3.72-18.24 t ha^{-1} yr^{-1} in exotic species (Table 4). The differences in net production of all components of plant values were significantly varied due to species as indicated by ANOVA (Table 6). The aboveground net production of present planted species ranged from 3.75-24.28 t ha^{-1} yr^{-1} in native plantations, being maximum in *D. strictus* and minimum in *T. grandis* where 2.55-12.55 t ha^{-1} yr^{-1} in exotic plantations, being maximum in *A. auriculiformis* and minimum in *C. siamea* plantation. Similar to biomass, relative contributions of short-lived (foliage and fine root <5 mm) was lower long-lived tree components (stem) to the tree layer biomass and NPP for both types of plantations calculated at 5-yr age. The contribution of foliage and fine root (<5 mm diameter) to the biomass was much smaller than that to NPP in all four native species while it was opposite in exotic species. For example, foliage component contributed in exotic plantations were in the range of 8.5-22.1%, being maximum by *G. pteridifolia* and minimum by *C. siamea*, and, fine roots were in the range of 1.8-9.8%, being maximum by *A. auriculiformis* and minimum by *C. equisetifolia*. Similarly, in case of native species, foliage contributed 12.7-32.1% being maximum by *T. grandis* and minimum by *A. lebbeck*, whereas fine root was in the range of 1.6-5.1%, respectively. Interestingly, the foliage and total net primary production of exotic species were significantly higher in native species than the exotic species (Figure 1). However, the net primary production of stem and roots did not significantly differ among the exotic and native species (Figure 1). Further, a significant positive correlation was observed for total and stem net primary production with the foliage biomass (Figure 4).

3.5 Leaf litterfall pattern and decomposition rates

Litterfall in exotic plantations was minimum in *C. siamea* (2.74 t ha^{-1} yr^{-1}) and maximum in *A. auriculiformis* (6.68 t ha^{-1} yr^{-1}), whereas, in case of native plantations, maximum was in *D. strictus* (10.68 t ha^{-1} yr^{-1}) and minimum in *T. grandis* (2.39 t ha^{-1} yr^{-1}), respectively (Table 5). The time required for 50% decomposition of leaf litter of all exotic species varied from 231 to 495 days and 1000-2142 days for 95% decomposition, which was lesser than the corresponding leaf litter of native species (Table 5). However, litterfall and decomposability did not vary significantly either between exotic and native species or between leguminous and non-leguminous species plantations (Figure 5).

4 DISCUSSION

4.1 Native species plantations had higher survival

The present study indicated that native species have better survival on degraded lands than exotic species which supported by earlier studies (Islam et al., 1999). Although some previous studies have investigated survivability of native species on coal mine spoil (Mosseler, Major, & Labrecque, 2014; A. N. Singh et al., 2004a, 2004b), very few studies compared survivability with exotic species (Huxtable et al., 2005; Islam et al., 1999). Another study conducted on saline soils of northern Australia also suggested the high survival of native species (D. Sun & Dickinson, 1995). Evidently, in this study, greater survival was observed in all native species indicating better adaptability of species for mine spoil restoration. Thus, higher survival of native species may be due to their pre-adaptation to the environmental conditions. However, a recent study contrasted the above commonly held view and reported that exotic species may also have greater survival. This suggests that survival may not be directly linked to the origin of species, rather it may be a legacy of function and life-history traits. Therefore, survival cannot be considered as the only indicator of ecological restoration.

4.2 Growth performance

Height and diameter of woody plant species are important structural parameters involved in the measurement of growth performance, which are affected by the environmental conditions (Lestari, Fiqa, Fauziah, & Budiharta, 2019; Sumida, Miyaura, & Torii, 2013). Our results suggested that exotic plants tend to invest more photosynthates in height growth whereas native plants invested more photosynthates in stem growth. Higher diameter in case of native species indicates the possibility of their adaptation to windbreak and endorse a longer establishment. Further, these observations indicate that exotic plants might be suffering from a limitation of light whereas native plants may be pre-adapted to environmental conditions and therefore invested more photosynthates in diameter for efficient supply of resources to the shoot (Boonman et al., 2020). However, this finding contrasts the reports of an earlier study in similar environmental conditions (Islam et al., 1999).

Height growth usually associated with the production of newer leaves and greater resource acquisition whereas the increase in stem diameter ensure the development of conducting tissues to support the leaves (Sumida et al., 2013). Thus, the increase in height should be accompanied by an increase in the diameter of the stem as suggested by biomechanical models (Henry & Aarssen, 1999; J. Sun et al., 2019). Our results also seemed to support this hypothesis at least in case of exotic species but contrasted by the non-leguminous species. This suggests that there is a trade-off between height and diameter in case of non-leguminous plants possibly due to limited resources. It is believed that the height growth of many trees occurs primarily at the expense of carbohydrates rather than products of current photosynthesis. In contrast to height growth, diameter growth depends primarily on current photosynthesis, although some reserve carbohydrates may be used for diameter growth very early in the season (Kozlowski, 1962). Thus, the greater height in case of exotic species can be attributed to their higher photosynthetic rate 12.1 (*A. auriculiformis)* to 30.14 µmol CO_2 m^{-2} s^{-1} (*C. equisetifolia)* as compared to native plantations in the present research site might be a promoting point to faster growth behaviour of exotic species (J. S. Singh et al., 1995). The smaller height to diameter ratio of exotic species indicates their higher competitive ability and rapid growth on degraded sites. This is supported by a study conducted on the degraded tropical pasture of southern Costa Rica, where it was shown that exotic species outperformed the native plantations (Carpenter, Nichols, & Sandi, 2004).

4.3 Biomass and net primary production

Biomass is a key parameter of structural attributes, while, net primary production is considered as a key functional parameter which helps to evaluate the quality of species because they directly contribute to organic matter, energy transformation and therefore maintain nutrient cycling between vegetation and soil. The present study indicated that native species produced higher biomass as compared to the exotic species. This suggests better adaptation and higher resource use efficiency of native species as compared to the exotic species on the coal mine spoil. In contrast to our finding, a previous study reported that there are little differences in biomass production among the exotic and native species

(Islam et al., 1999). Further, biomass partitioning into different plant parts revealed that native species produced significantly higher biomass for foliage, stem and coarse roots (diameter greater than 5 mm) as compared to exotic species whereas fine root biomass was higher in case of exotic species, though not significant. Higher biomass production of fine roots in case of exotic species suggests that these plants responded to the stressed environment of coal mine spoils to get available nutrient and water sources to maintain their growth performance especially height instead of diameter (Boonman et al., 2020).

Since the present study focused on woody tree species, the higher contribution of above-ground biomass to the total biomass is expectable and therefore supported by many previous studies (A. N. Singh et al., 2004b). However, exotic species invested more in below-ground components whereas native species invested more in above-ground components while responding to the same coal mine spoils. It is believed that plants tend to invest more in below-ground components during the disturbance or stressful conditions such as the nutrient-poor coal mine spoils (Poorter & Sack, 2012; Priest, Stovall, Coble, Oswald, & Williams, 2015). Further, both types of species invested more in long-lived components than in short-lived components; however, exotic species invested more in short-lived components especially the fine roots. Contribution of the long-lived component (stem) was much higher to biomass than to NPP in the all four native species but opposite in the exotic plantations. Thus, the short-lived components accounted for a greater proportion of ecosystem function than long-lived components which accounted for a greater proportion of structure in the native plantations indicating native species are the best fitting in the restoration theory that is required for mine spoil restoration at least during the initial stage of ecosystem development. Moreover, foliage accounted for a lower proportion of ecosystem function in all plantations of exotic species whereas native species showed considerably very high that indicates that production of more foliage biomass in such a stressed environment (degraded mine spoil) may provide more amount of soil organic matter to regulate the cycling of nutrient. Evidently, the native and exotic species have different allocational strategies.

According to functional equilibrium hypothesis, this suggests that exotic species may experience below-ground resource (water and nutrients) limitation whereas native species experience an above-ground resource (sunlight and CO_2) limitation (Boonman et al., 2020; Brouwer, 1983). Nevertheless, these changes may be more attributed to morphological adaptations or phenotypic plasticity rather than biomass allocation (Freschet et al., 2015; Poorter et al., 2012). However, if none of the resources is limiting or equally limiting then plants tend to allocate the resources optimally, this is referred as 'optimal partitioning hypothesis' (Gedroc, McConnaughay, & Coleman, 1996) or 'balanced growth hypothesis' (Shipley & Meziane, 2002). Thus, if both types of species faced equal environmental conditions (probably that was the case in the present study), those species which produce greater below-ground biomass during the initial stages may be better suited for reclamation of coal mine overburden. Following this, our results suggest that exotic and leguminous plants may be better suited for coal mine restoration, though these effects can be highly species-specific.

The net primary production or NPP is associated with the photosynthesis and biomass production as indicated by a strong positive relation between biomass and NPP. The present study suggested an overall NPP ranging from 3 to 32 t ha^{-1} yr^{-1}, which is comparable to earlier studies (Dutta & Agrawal, 2003; A. N. Singh & Singh, 1999; V. Singh & Toky, 1995). The early successional species are reported to exhibit net production of 8-21 t ha^{-1} yr^{-1} in natural dry tropical forests (Murphy & Lugo, 1986) whereas the above-ground net production of plantations on coal mine spoil and natural forests in the tropical zone ranged between 1.5 and 32.62 t ha^{-1} yr^{-1} (Dutta & Agrawal, 2003; L. Singh & Singh, 1991; P. K. Singh & Singh, 1998; V. Singh & Toky, 1995). However, our comparison suggested that native species had significantly higher total and foliage NPP as compared to the exotic species on coal mine spoils. This indicated that native species were much more efficient in resource utilisation possibly due to their pre-adaptation to the tropical environments. Thus, achieving an early vegetation cover and high biomass production on mine spoil can be approached through proper selection and planting of pioneer native tree species because such species are able to exist under harsh soil conditions and require less long term maintenance (A. N. Singh et al., 2004a; A. N. Singh & Singh, 2006).

4.4 Leaf litterfall pattern and decomposition rates

Litterfall and litter decomposition are important processes, which are associated with soil redevelopment and therefore, restoration of degraded habitats (A. N. Singh et al., 2006). Although litterfall and litter decomposition did not vary significantly among the exotic and native species, the litter of decomposed slightly faster than native species. Further, there is greater variation in decomposition rates of exotic species as compared to native species. This indicates that the decomposition rate in exotic species may depend on species identity. Earlier studies have also found that there is little variation in the decomposition rates of exotic and native species in different ecosystems (Jo, Fridley, & Frank, 2016; Patil et al., 2020), thus supporting the findings of the present study as well. Similar to exotic vs native comparison, the comparison between leguminous and non-leguminous species revealed non-significant differences among them; however, the decomposition rate of leguminous species was faster than non-leguminous species. This may be due to higher nitrogen content in litter from leguminous species, which might have promoted the decomposition rates.

5 CONCLUSIONS

The present study points out that native species may prove to be much more efficient than exotic species in rehabilitation and restoration of coal mine spoils. This conclusion is supported by the higher biomass and NPP for native species as compared to exotic species, though exotic species exhibited greater height growth. However, consideration of leguminous nature of species did not affect the biomass and NPP in the present study, though it may affect the redevelopment of soils in degraded habitats. Further, the effect of exotic species seemed to be highly variable and species-specific. Therefore, more comparative knowledge on the species-specific effects on ecosystem restoration, biodiversity reconstruction and its possible effects their services towards the ecosystem and local people is still required. Therefore, more future investigations on various scales of the ecological restoration are warranted with a greater number of species while inferring effects of exotic and native species for comparative restoration potential.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

Data Availability Statement

Data available on request from the authors

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Table 1. Stocking density of 5-yr old planted exotic and native woody species on coal mine spoil.

Planted species	**Originally planted (Individuals ha^{-1})**	**Surviving (Individuals ha^{-1})**			**Mean ± 1 SE**
		Plot 1	Plot 2	Plot 3	
Native					
A. lebbeck	2500	2192	2160	2208	2187 ± 14^{a}
		(89)	(86)	(88)	(87)
A. procera	2500	2224	2192	2208	2208 ± 9^{a}
		(89)	(88)	(88)	(88)
T. grandis	2500	1645	1822	1867	1778 ± 68^{b}
		(66)	(73)	(75)	(71)
D. strictus	2500	2000	2000	2088	2029 ± 29^{a}
		(80)	(80)	(84)	(81)
Exotic					
A. auriculiformis	2500	1600	1760	1670	1677 ± 46^{bc}
		(64)	(70.4)	(66.8)	(67)
C. equisetifolia	2500	1450	1600	1650	1566 ± 61^{bc}
		(58)	(64)	(66)	(63)
C. siamea	2500	1900	1778	1790	1822 ± 39^{abcd}
		(76)	(71)	(72)	(73)
G. pteridifolia	2500	1789	2000	1786	1858 ± 71^{bcd}
		(72)	(80)	(71)	(74)

Values given in parenthesis represent the per cent of survival of individuals.

Within the Mean ± 1 SE column, values followed by the same letter are not significantly different at $P < 0.05$, using the Tukey's HSD test.

Table 2. Growth performance of 5-yr old planted exotic and native woody species on coal mine spoil.

	Exotic†				Native			
Parameters	AA	CE	CS	GP	AL	AP	TG	DS
Height (m)	5.00^{d}	5.29^{e}	2.75^{ab}	5.88^{f}	3.38^{a}	2.97^{a}	2.19^{b}	5.18^{c}
Diameter (cm)	3.95^{bd}	4.90^{be}	2.99^{f}	3.87^{g}	7.58^{a}	7.32^{a}	5.22^{b}	4.32^{bc}
H/D ratio	126.59^{bc}	123.31^{bc}	91.97^{bc}	151.94^{b}	44.59^{a}	40.57^{ab}	41.95^{ab}	119.91^{b}
D^2H (cm^3)	7801^{a}	12701^{ab}	2458^{b}	8806^{a}	19420^{a}	15913^{b}	5967^{ca}	9667^{a}

Values are means of three replicates.

†Data were obtained from Singh et al., (1995) and Dutta & Agrawal (2003).

AA, *Acacia auriculiformis*; CE, *Casuarina equisetifolia*; CS, *Cassia siamea*; GP, *Grevillea pteridifolia*; AL, *Albizia lebbeck*; AP, *Albizia procera*; TG, *Tectona grandis*; DS, *Dendrocalamus strictus*.

Within the columns, values followed by the same letter are not significantly different at $P < 0.05$, using the Tukey's HSD test.

Table 3. Biomass production (t ha^{-1}) under 5-yr old planted exotic and native woody species on coal mine spoil.

	Exotic†				**Native**			
Parameters	AA	CE	CS	GP	AL	AP	TG	DS‡
Foliage	6.68^{a}	2.74^{b}	0.72^{bc}	5.06^{a}	6.59^{a}	7.26^{a}	2.39^{b}	10.68^{c}
Stem	16.77^{be}	15.69^{be}	4.91^{g}	11.46^{bh}	32.32^{a}	14.21^{b}	2.98^{c}	57.33^{d}
Coarse root	4.53^{de}	2.98^{fg}	2.56^{cg}	5.84^{dh}	12.05^{a}	10.65^{b}	1.94^{c}	5.27^{d}
Fine root	3.05^{bc}	0.40^{ac}	0.30^{a}	0.57^{a}	0.85^{a}	0.74^{a}	0.37^{a}	1.40^{ab}
Total	31.03^{be}	21.81^{f}	8.49^{cg}	22.90^{bh}	51.81^{a}	32.86^{b}	7.68^{c}	74.68^{d}

Values are means of three replicates.

†Data were obtained from Singh et al., (1995) and Dutta & Agrawal (2003).

‡Values of rhizome component included in the total biomass.

AA, *Acacia auriculiformis*; CE, *Casuarina equisetifolia*; CS, *Cassia siamea*; GP, *Grevillea pteridifolia*; AL, *Albizia lebbeck*; AP, *Albizia procera*; TG, *Tectona grandis*; DS, *Dendrocalamus strictus*.

Within the columns, values followed by the same letter are not significantly different at $P < 0.05$, using the Tukey's HSD test.

Table 4. Net primary production (t ha^{-1} yr^{-1}) under 5-yr old planted exotic and native woody species on coal mine spoil.

Parameters	**Exotic†**				**Native**			
	AA	CE	CS	GP	AL	AP	TG	DS‡
Foliage	1.38^{a}	1.07^{b}	0.31^{bc}	1.67^{a}	6.59^{a}	7.26^{a}	2.39^{b}	10.68^{c}
Stem	11.17^{be}	7.78^{be}	2.19^{g}	6.75^{bh}	11.26^{a}	8.07^{b}	1.36^{c}	13.60^{d}
Coarse root	2.64^{de}	1.62^{fg}	0.92^{cg}	3.31^{dh}	3.61^{a}	2.54^{b}	0.63^{c}	1.12^{d}
Fine root	3.05^{bc}	0.40^{ac}	0.30^{a}	0.57^{a}	0.85^{a}	0.74^{a}	0.37^{a}	1.40^{ab}
Total	18.24^{be}	10.86^{f}	3.72^{cg}	12.27^{bh}	23.86^{a}	19.30^{b}	4.76^{c}	32.04^{d}

Values are means of three replicates.

†Data were obtained from Singh et al., (1995) and Dutta & Agrawal (2003).

‡Values of rhizome component included in the total biomass.

AA, *Acacia auriculiformis*; CE, *Casuarina equisetifolia*; CS, *Cassia siamea*; GP, *Grevillea pteridifolia*; AL, *Albizia lebbeck*; AP, *Albizia procera*; TG, *Tectona grandis*; DS, *Dendrocalamus strictus*.

Within the columns, values followed by the same letter are not significantly different at $P < 0.05$, using the Tukey's HSD test.

Table 5. Leaf litterfall and decomposition parameters under 5-yr old planted exotic and native woody species on coal mine spoil.

	Exotic†				Native			
Parameters	AA	CE	CS	GP	AL	AP	TG	DS
Leaf litterfall (t ha^{-1} yr^{-1})	6.68	2.74	0.72	5.06	6.59	7.26	2.39	10.68
Decay constant (yr^{-1})	0.84	0.80	1.10	0.51	1.19	0.83	0.91	1.08
MRD (mg g^{-1} d^{-1})	2.37	2.20	3.00	1.48	2.42	2.12	2.20	2.28
T_{50} (days)	301	315	231	495	213	307	282	235
T_{95} (days)	1304	1363	1000	2142	922	1329	1221	1016

Values are means of three replicates.

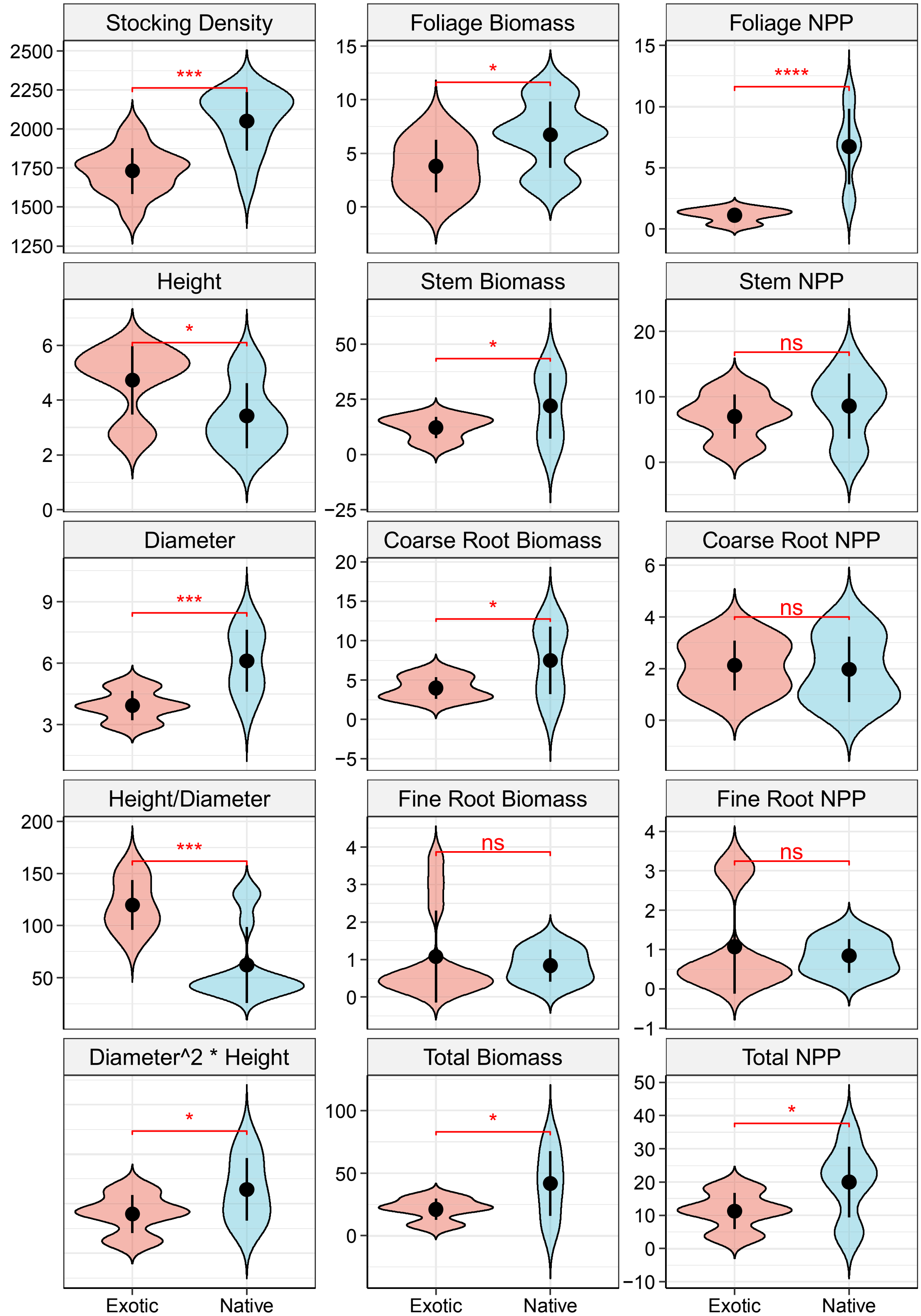
†Data were obtained from Singh et al., (1995) and Dutta & Agrawal (2003).

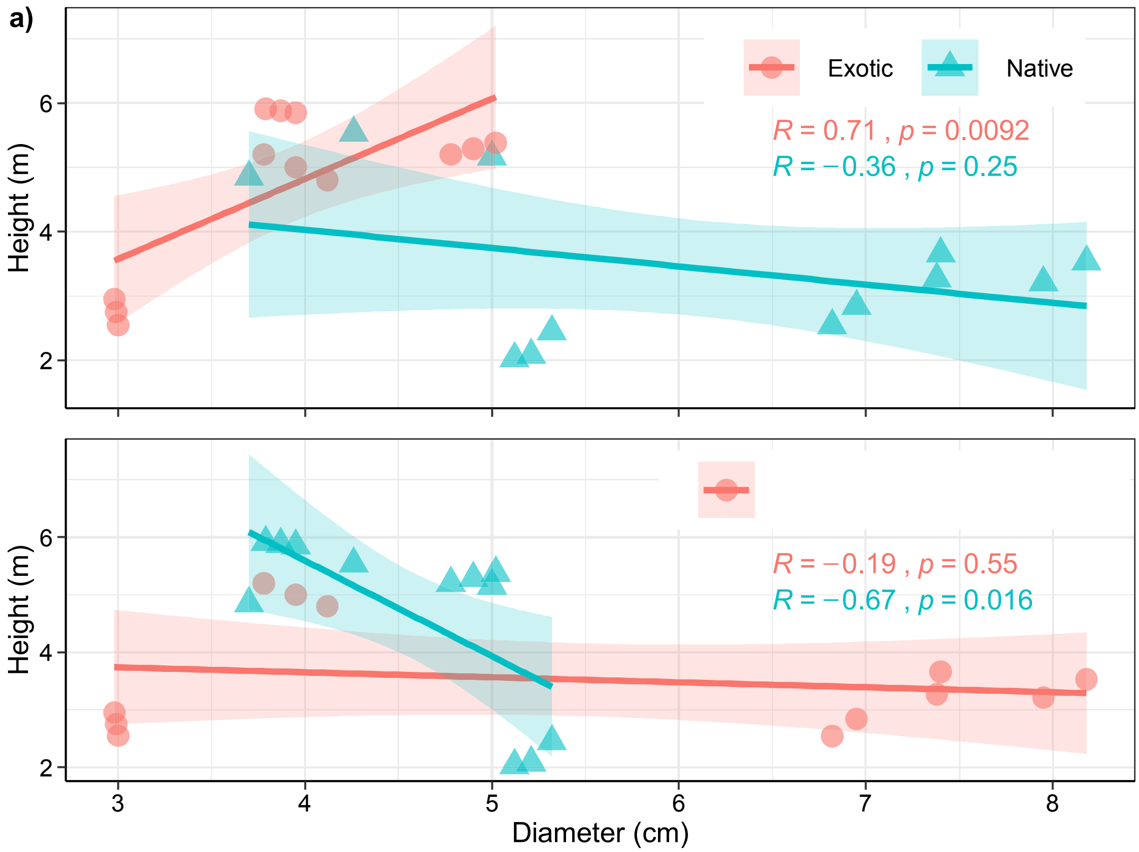
AA, *Acacia auriculiformis*; CE, *Casuarina equisetifolia*; CS, *Cassia siamea*; GP, *Grevillea pteridifolia*; AL, *Albizia lebbeck*; AP, *Albizia procera*; TG, *Tectona grandis*; DS, *Dendrocalamus strictus*.

Table 6. Summary of ANOVA for the effect of plantation species on growth parameters, biomass and net primary production components.

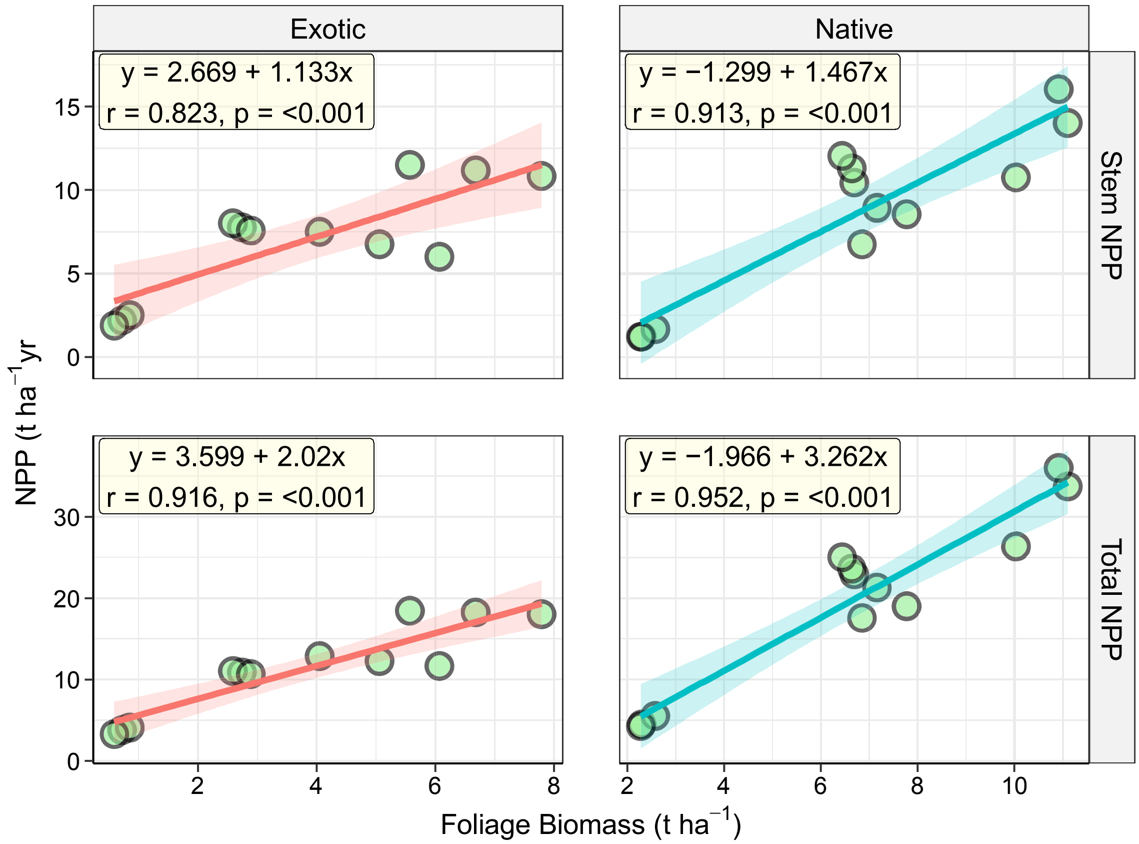
Components	**F- value ($F_{7,16}$)**	**Significance level (P)**
Height	82.051	0.0000
Diameter	56.333	0.0000
H/D	97.601	0.0000
D^2H	13.710	0.0000
Foliage biomass	86.147	0.0000
Stem biomass	220.673	0.0000
Coarse root biomass	266.112	0.0000
Fine root biomass	31.883	0.0000
Total biomass	304.449	0.0000
Foliage production	556.164	0.0000
Stem production	44.873	0.0000
Coarse root production	61.241	0.0000
Fine root production	98.281	0.0000
Total tree layer production	71.518	0.0000

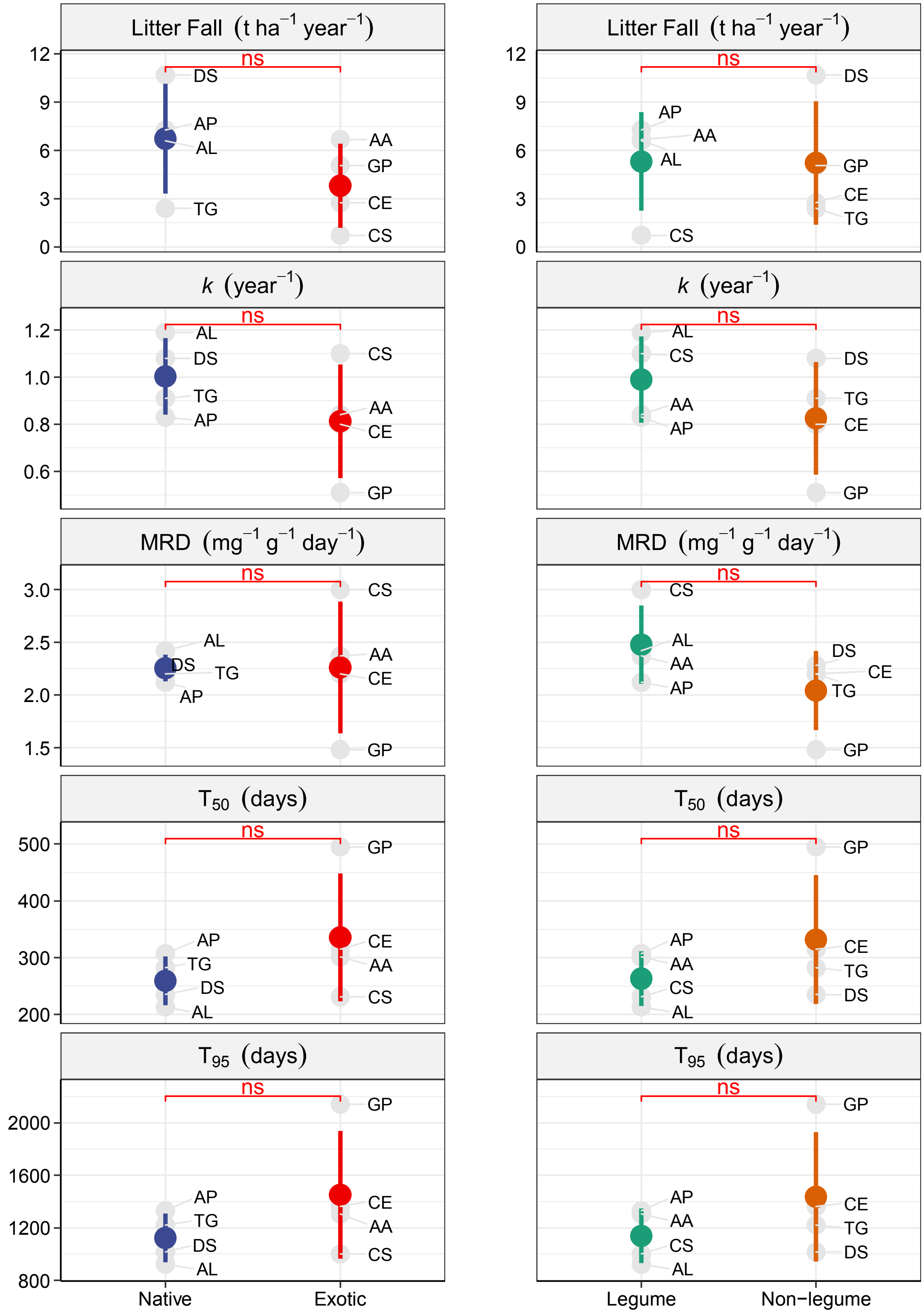
H/D, a ratio of plant height to diameter; D2H, estimated tree volume.


Stocking Density
***
Foliage Biomass
*
Foliage NPP
****
Height
*
Stem Biomass
*
Stem NPP
ns
Diameter
***
Coarse Root Biomass
*
Coarse Root NPP
ns
Height/Diameter
***
Fine Root Biomass
ns
Fine Root NPP
ns
Diameter^2 * Height
*
Total Biomass
*
Total NPP
*
Exotic
Native
Exotic
Native
Exotic
Native


a)
Exotic
Native
R = 0.71 , p = 0.0092
R = −0.36 , p = 0.25
R = −0.19 , p = 0.55
R = −0.67 , p = 0.016
Height (m)
Height (m)
Diameter (cm)
2
4
6
3
4
5
6
7
8


Stem
Foliage
FineRoot
CoarseRoot
a)
b)
100%
75%
50%
25%
0%
18.89%
5.12%
18.04%
57.95%
20.18%
2.27%
18.16%
59.39%
23.99%
3.97%
17.11%
54.93%
14.81%
2.53%
19.27%
63.39%
BelowGround
AboveGround
c)
d)
75.99%
24.01%
77.55%
22.45%
72.04%
27.96%
82.66%
17.34%
ShortLived
LongLived
e)
76.84%
23.16%
79.57%
20.43%
78.91%
21.09%
78.2%
21.8%
Exotic
Native


Exotic
Native
y = 2.669 + 1.133x
r = 0.823, p = <0.001
y = −1.299 + 1.467x
r = 0.913, p = <0.001
y = 3.599 + 2.02x
r = 0.916, p = <0.001
y = −1.966 + 3.262x
r = 0.952, p = <0.001
Stem NPP
Total NPP
NPP (t ha⁻¹yr)
Foliage Biomass (t ha⁻¹)


Litter Fall (t ha⁻¹ year⁻¹)
k (year⁻¹)
MRD (mg⁻¹ g⁻¹ day⁻¹)
T50 (days)
T95 (days)
ns
DS
AP
AL
TG
AA
GP
CE
CS
Native
Exotic
Legume
Non−legume
12
9
6
3
0
1.2
1.0
0.8
0.6
3.0
2.5
2.0
1.5
500
400
300
200
2000
1600
1200
800

Legend to Figures

Figure 1. Comparison of survival, growth, biomass and net primary productivity among the exotic and native woody species plantations on coal mine spoil. The units of the respective parameters are given in Table 1-5. The statistical significance was determined by using student's t-test and the p-values <0.0001, <0.001, <0.01, <0.05 and 0.1 corresponds to "****", "***", "**". "*" and "ns", respectively.

Figure 2. Relationship between Height and Diameter for exotic and native woody species (a), and legume and non-leguminous species plantations (b). The regression line was fitted using the linear model and Pearson's correlation coefficient values is represented as R with corresponding probability p-values.

Figure 3. Biomass partitioning among different plant parts (a), above-ground and below ground (b), and short-lived and long-lived components (c) for exotic vs. native and legume vs. non-legume species plantation.

Figure 4. Relationships between net primary production and foliage biomass for 5-yr old plantations of all exotic and all native woody species on coal mine spoil. The linear regression equation (y = a + bx), Pearson's correlation coefficient (r) and corresponding probability values (p) shown in the top-left corner of each subplot.

Figure 5. Litterfall and litter decomposition parameters among the exotic vs. native

species, and legume vs. non-leguminous species plantations. The abbreviations used for species are AA, *Acacia auriculiformis*; CE, *Casuarina equisetifolia*; CS, *Cassia siamea*; GP, *Grevillea pteridifolia*; AL, *Albizia lebbeck*; AP, *Albizia procera*; TG, *Tectona grandis*; DS, *Dendrocalamus strictus*. The statistical significance was determined by using student's t-test at 0.05 significance level and the p-values greater than 0.05 are represented as "ns" respectively.