https://doi.org/10.26525/jtfs2021.33.1.69

SPACING, PIT SIZE AND IRRIGATION INFLUENCE EARLY GROWTH PERFORMANCES OF FOREST TREE SPECIES

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Submitted May 2020; accepted August 2020

This experiment is a standardisation of plantation techniques of four native, promising forestry species, namely, *Dalbergia latifolia*, *Terminalia arjuna*, *Terminalia bellirica* and *Gmelina arborea*, with respect to effects of tree spacing, pit size and irrigation. The experiment was set up in a tropical mixed deciduous forest patch of Madhya Pradesh, central India. We tested three spacings (2 m × 2 m, 3 m × 3 m and 5 m × 5 m), three pit sizes (30 cm × 30 cm× 30 cm, 45 cm × 45 cm × 45 cm and 60 cm × 60 cm × 60 cm) and two moisture regimes (rainfed and irrigated). Growth data were recorded for four years, from the first year of plantation in 2013 to 2017. From the four-year growth performance, *D. latifolia*, *T. arjuna* and *T. bellirica* performed better in irrigated conditions, whereas *G. arborea,* performed well under rainfed condition. *Terminalia bellirica* performed best with largest pit size, i.e. 60 cm × 60 cm × 60 cm, while the other three species performed best with 45 cm × 45 cm × 45 cm pit size. In terms of tree spacing, *G. arborea* and *D. latifolia* responded best to 3 m × 3 m spacing while *T. arjuna* and *T. bellirica* performed best with 5 m × 5 m spacing.

Keywords: Rainfed, irrigated, collar diameter, seedling height, central India

INTRODUCTION

Plantation forests represent about 4% of the global forest area and have potential to meet the world's entire wood requirements (Fenning & Gershenzon 2002) and, therefore, are now taken up as systematic programmes by many countries and are expected to increase with time (Putz 2015). Presently, India is the second most populous country in the world and fails to meet the population's large demand for wood from its own resources and is a net importer of timber and allied products. India's timber imports in 2025 and 2030 are projected to be 27.01 and 31.5 million m^3 respectively. In India, Forest Development Corporations (FDCs) are entrusted with the mandate to raise plantations of economically important species to fulfil the timber demand of the country. Although, the FDCs have not been able to fulfil this demand, they contribute significantly (~60%) to the total annual production of timber from forest (Agarwal & Saxena 2017). Until recently, FDCs, wood-based industries and plantation companies were more inclined towards the introduction and cultivation of exotic trees such as *Eucalyptus*, *Casuarina*, *Poplar* and *Leucaena* to fulfil the requirement for raw wood. However, cultivation of exotic species is not a permanent solution as they vigorously invade over indigenous species. Besides, exotic tree species have many limitations such as site specificity and higher moisture and nutrient requirements. Additionally, arguments surrounding the negative effects of monoculture of exotic trees on soil health, ground water and ecological threats to native vegetation lead to more ambiguity.

In this context, indigenous species such as *Dalbergia latifolia, Terminalia arjuna, Ailanthus excelsa, Pterocarpus marsupium, Terminalia bellirica, Melia dubia, Gmelina arborea, Azadirachta indica, Shorea robusta, Anogeissus latifolia, Lagerstroemia parviflora, Toona ciliata, Mangifera* spp., *Quercus* spp., *Dalbergia* spp., and *Bombax* spp. are promising species and have great potential to fulfil both timber and biomass demands of the country, with added advantage of being native. However, there exist many hurdles in promoting these species for commercial cultivations, including absence of improved planting stock, lack of standardised plantation techniques, package of practices and cost-benefit economics. Due to the government's recent emphasis on the importance of native species, considerable progress has been made to prioritise native species over exotics.

There are many reports indicating significant effect of irrigation, spacings and pit sizes on the overall growth rate of forest tree plantations. Such reports are ample for temperate trees (Linder et al. 1987, Neilsen et al. 1997, Albaugh et al. 2004), but limited for indigenous multipurpose tropical forest trees species such as *D. latifolia, T. arjuna, T. bellirica* and *G. arborea* (Priya & Bhat 1999, Zahabu et al. 2015).

The present study was aimed at raising an experimental plantation with different planting designs so as to investigate the effect of inter-tree spacings, pit sizes and irrigation on early growth parameters of *D. latifolia, T arjuna, T. bellirica* and *G. arborea* for better understanding and optimising standard plantation techniques. We hypothesised that appropriate spacing, pit size and moisture availability in early growth years would determine the success of native forest tree plantations.

MATERIALS AND METHODS

Site selection and procurement of planting stock

Suitable site for the establishment of plantation was finalised after consultation with the State Forest Department of Madhya Pradesh. The site chosen was a tropical mixed deciduous forest patch located in Moyanala village of Bijadandi range, Mandla (West) Forest Division (Figure 1). The plot was cleared of weeds and debris in April–May 2013. Quality planting stocks of the targeted species, i.e. *D. latifolia, T. arjuna, T. bellirica,* and *G. arborea* were procured from the nursery of the Forest Research and Extension Circle (Jabalpur), Madhya Pradesh Forest Department.

Experimental design

Factorial experiment was designed with three factors, namely, A (condition): A_1 = irrigated and A_2 = rainfed; B (spacing): B_1 = 2 m × 2 m, B_2 =

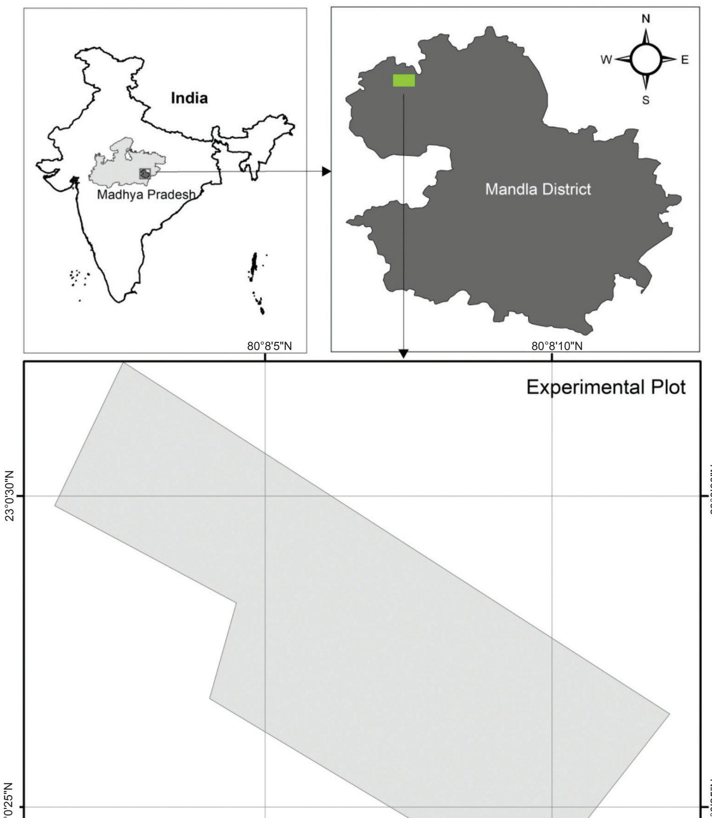

Figure 1 Location of the experimental site in Mandla (West) Forest Division, Madhya Pradesh, India

3 m × 3 m and B_3 = 5 m × 5 m; and C (pit size): C_1 = 30 cm × 30 cm × 30 cm, C_2 = 45 cm × 45 cm × 45 cm and C_3 = 60 cm × 60 cm × 60 cm. Thus, factor A had two levels and factors B and C had three levels each. For each forestry species, 18 treatment combinations were tested (Table 1). The experiment was laid out in randomised complete block design with two replications. One-year-old seedlings were planted in June 2013. Irrigation was provided once a week in summer using buried clay pot method (Bainbridge 2001), which is one of the most efficient traditional systems of irrigation. All standard package of practices were followed to raise a healthy plantation.

Data recording and statistical analysis

Height and collar diameter were measured on 12 seedlings per plot in December every year till 2017, i.e. up to four years. Three factor analyses of variance (Tucker 1966) was performed to assess the effects of conditions (rainfed/irrigation), spacings and pit sizes of growth parameters using statistical package OPSTAT, version 1998.

RESULTS AND DISCUSSION

Average performances of *D. latifolia*, *T. arjuna*, *T. bellirica* and *G. arborea* for the four years (2013–2017) are presented in Figure 2. Statistical significances of the effects of irrigation/rainfed, spacings, pit sizes and their interactions on growth parameters of the four species studied for 2013–2017 are presented in Table 2. Seedling height and collar diameter of *D. latifolia* were not affected by the three factors, i.e. condition, spacing, pit size and their interactions during the four years period. Highest average seedling height (148.62 cm) was recorded under irrigated condition with 3 m × 3 m spacing and 45 cm × 45 cm × 45 cm pit size (i.e. $A_1 \times B_2 \times C_2$). Lowest height (100.62 cm) was observed under rainfed condition with 5 m × 5 m spacing and 60 cm × 60 cm × 60 cm pit size. Under rainfed condition, highest average height was recorded with 5 m × 5 m spacing and 30 cm × 30 cm × 30 cm pit size (Figure 2). Earlier published reports indicate that full light, porous soil, free of weeds infestation and adequate moisture in the soil are the decisive factors for overall development of the *D. latifolia* seedlings (Kadambi 1954). *Dalbergia latifolia* survives up to temperatures of 37–50 °C and is well known as a drought tolerant tree, but at seedling stage, it is sensitive to drought (Troup 1921). However, in the present investigation, irrigation did not influence the growth significantly, but its effect on *D. latifolia* seedling height was evident and maximum average height was recorded with irrigated condition. Therefore, irrigation was recommended for the first three years of planting. Linear increase in dry weight was observed for *Dalbergia sissoo*, *Eucalyptus camaldulensis* and *E. grandis* after irrigation (Hunter 2001). Similarly, *D. sissoo* seedlings also showed better growth and biomass production in an experiment to assess the effect of soil water stress regimes on biomass production (Singh & Singh 2009).

Although *T. arjuna* and *T. bellirica* have varied uses such as timber, biomass and medicine, research on standardisation of plantation techniques and package of practices for raising healthy plantations of this species are lacking. Conditions (irrigated/rainfed), and their interaction with spacings and pit sizes had significantly affected *T. arjuna* seedling

Table 1 Three factorial experiments designed to assess the effects of spacing, pit sizes and irrigation on four different indigenous forestry species

			Irrigated (A_1)			Rainfed (A_2)		
			Spacing (B)			Spacing (B)		
		Replicate	B_1 (2 m × 2 m)	B_2 (3 m × 3 m)	B_3 (5 m × 5 m)	B_1 (2 m × 2 m)	B_2 (3 m × 3 m)	B_3 (5 m × 5 m)
Pit size (C)	C_1 (30 cm × 30 cm × 30 cm)	R-1	T_1	T_4	T_7	T_{10}	T_{13}	T_{16}
		R-2	T_1	T_4	T_7	T_{10}	T_{13}	T_{16}
	C_2 (45 cm × 45 cm × 45 cm)	R-1	T_2	T_5	T_8	T_{11}	T_{14}	T_{17}
		R-2	T_2	T_5	T_8	T_{11}	T_{14}	T_{17}
	C_3 (60 cm × 60 cm × 60 cm)	R-1	T_3	T_6	T_9	T_{12}	T_{15}	T_{18}
		R-2	T_3	T_6	T_9	T_{12}	T_{15}	T_{18}

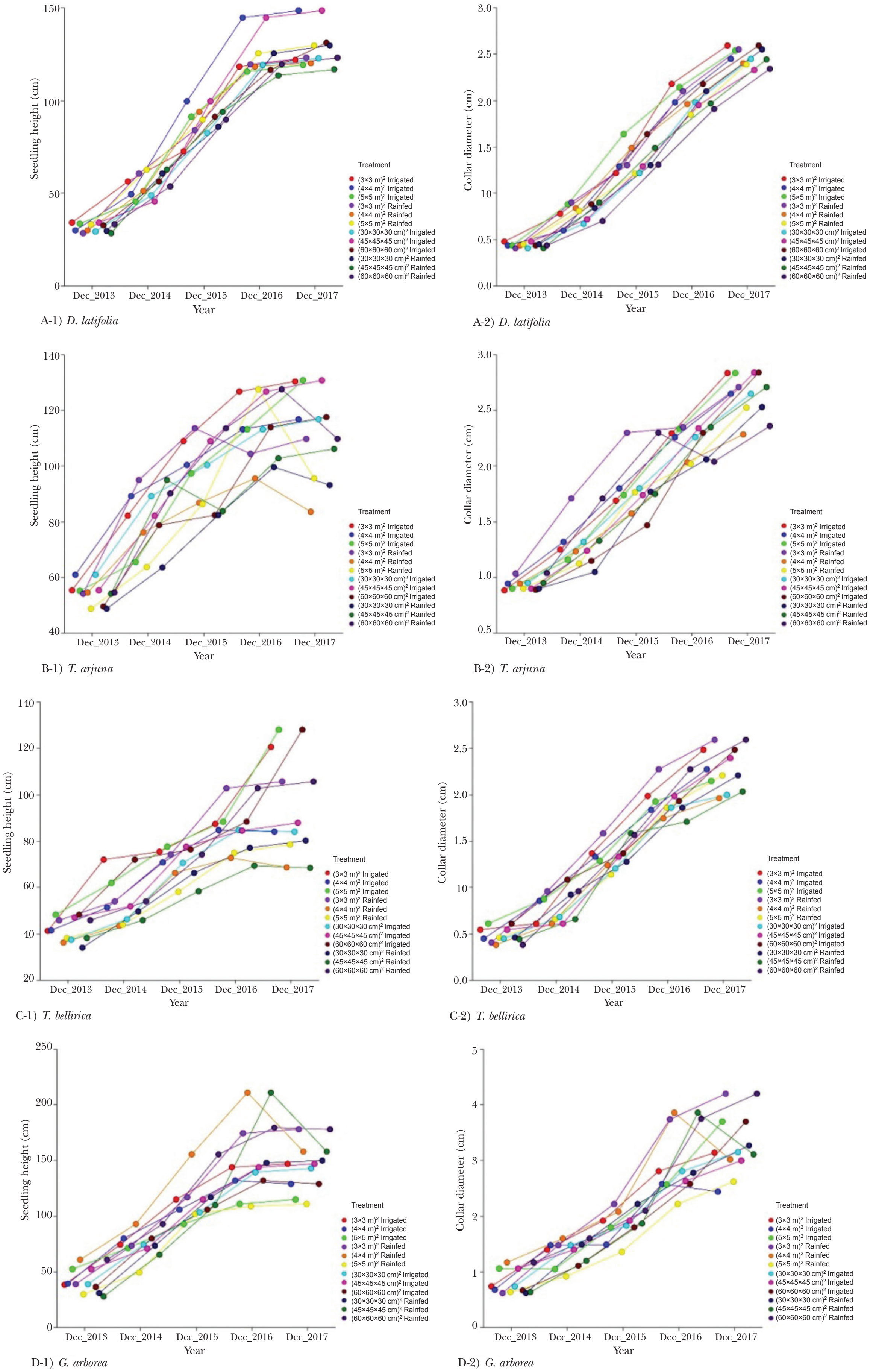

Figure 2 Yearly growth performance of *Dalbergia latifolia* (A-1 & 2), *Terminalia arjuna* (B-1 & 2), *T. bellirica* (C-1 & 2) and *Gmelina arborea* (D-1 & 2) under different planting spacings, pit sizes and moisture regimes

Table 2 Summary of the statistical significance of different factors (irrigation/rainfed, spacing, pit size) and interactions on growth parameters of four indigenous forestry species over a period of four years

Source of variation	Critical difference values for seedling height																			
	Dalbergia latifolia					*Terminalia arjuna*					*Terminalia bellerica*					*Gmelina arborea*				
	Dec-13	Dec-14	Dec-15	Dec-16	Dec-17	Dec-13	Dec-14	Dec-15	Dec-16	Dec -17	Dec-13	Dec-14	Dec-15	Dec-16	Dec-17	Dec-13	Dec-14	Dec-15	Dec-16	Dec-17
Replication	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Factor A	ns	ns	ns	ns	ns	4.8	ns	ns	ns	ns	5.00	ns	7.2	ns	13.95	ns	ns	ns	ns	ns
Factor B	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
A × B	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Factor C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	17.09	ns	ns	ns	ns	ns
A × C	ns	ns	ns	ns	ns	ns	ns	21.5	ns	ns	ns	ns	ns	ns	ns	12.73	ns	ns	ns	ns
B × C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
A × B × C	ns	ns	ns	ns	ns	14.53	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Error	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Source of variation	Critical difference values for collar diameter																			
	Dalbergia latifolia					*Terminalia arjuna*					*Terminalia bellerica*					*Gmelina arborea*				
	Dec-13	Dec-14	Dec-15	Dec-16	Dec-17	Dec-13	Dec-14	Dec-15	Dec-16	Dec-17	Dec-13	Dec-14	Dec-15	Dec-16	Dec-17	Dec-13	Dec-14	Dec-15	Dec-16	Dec-17
Replication	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Factor A	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Factor B	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.37	0.55	0.53
A× B	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Factor C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
A × C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
B × C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
A × B × C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Error	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

ns = non-significant

height in one or more years during the study period. However, the effect of irrigation and its interaction with pit spacings and pit sizes became insignificant as growth progressed. At the end of fifth year, only factor spacing exhibited significant influence on the seedling height. Highest average seedling height (130.87 cm) was recorded in irrigated condition with 5 m × 5 m spacing with 45 cm × 45 cm × 45 cm pit size ($A_1 \times B_3 \times C_2$) followed by 130.50 cm in irrigated condition with 2 m × 2 m spacing and 45 cm × 45 cm × 45 cm pit size ($A_1 \times B_1 \times C_2$). A similar trend was recorded for collar diameter. Highest value (2.83 cm) was recorded in $A_1 \times B_3 \times C_2$ and in $A_1 \times B_1 \times C_3$ followed by 2.53 cm in $A_1 \times B_1 \times C_2$. However, these values were not significantly different (Figure 2).

Seedling height of *T. bellirica* was also significantly affected by condition (irrigated/rainfed) and pit size, but effects of spacing and interactions were statistically insignificant. Highest average height (128 cm) was obtained under irrigated condition with $A_1 \times B_3 \times C_3$ followed by 120.5 cm in $A_1 \times B_1 \times C_3$ treatment combination. Under rainfed condition, highest average seedling height (105.62 cm) was observed in $A_2 \times B_1 \times C_3$ treatment. None of the factors and their interactions exhibited significant effect on collar diameter.

Our findings concur with the recommendation by NMPB (2008) that 6 m × 6 m spacing and 45 cm × 45 cm × 45 cm pit size should be applied for *Terminalia* spp. Olaoye and Oyun (2019) investigated early growth of indigenous tree species in response to watering regimes and found that *Terminalia* spp. require watering thrice a week for optimal growth. *Terminalia* spp. prefer moist physical environment and are largely distributed along the bank of streams (Paarakh 2010) and riparian forests (Nagaraja et al. 2014). The present investigation also showed better results of growth parameters with irrigated condition and a wider planting spacing of 5 m × 5 m was best for *T. arjuna* and *T. bellirica*.

Height and collar diameter of *G. arborea* were significantly affected by spacing but not irrigation and pit size. However, in the second year of planting, interaction between irrigation and spacing had significant effects on height and collar diameter, but these effects became non-significant in later years. At the end of fifth year, highest average height (260.87 cm) was recorded under rainfed condition with 3 m × 3 m spacing and 45 cm × 45 cm × 45 cm pit size followed by 192 cm in 2 m × 2 m spacing and 60 cm × 60 cm × 60 cm pit size. Under irrigated condition, highest average height (146.75 cm) was recorded in 2 m × 2 m spacing and 45 cm × 45 cm × 45 cm pit size. For *G. arborea*, Mayavel et al. (2014) recommended 3 m × 3 m spacing and 45 cm × 45 cm × 45 cm pit for optimal growth. It is a light-demanding and drought-resistant species and can adapt well to a wide range of soil and climatic conditions of tropical and subtropical regions (Chaturvedi et al. 2017). This could be one of the reasons for the insignificant difference in growth performance of *G. arborea* between rainfed and irrigated conditions in the present study.

Seedling collar diameters of the four species were not significantly affected by the studied factors and their interactions. Seedling height was generally more affected by irrigation and spacing compared with collar diameter. Effect of the spacing will be more visible in later years after full canopy development due to competition (Smith & Reukema 1986, Hebert et al. 2016). Determination of proper spacing is important for producing more quality wood (Kerr 2003, Rais et al. 2014).

It is difficult to raise successful plantations in the tropics, because tropical trees are highly sensitive to site conditions, and several plantations in the tropics have poor rates of success. Therefore, with a high degree of confidence, assessments from the current study can be applied elsewhere in the tropics with parallel land contexts. Findings of the study are not only valuable for foresters and plantation managers, but also for cross-sectoral approaches such as agroforestry. Species such as *G. arborea* and *D. latifolia* have high prospects for rural livelihood improvement through agroforestry (Parthiban et al. 2014), especially when countries are prioritising towards climate solutions (Deb et al. 2018) for achieving their Nationally Determined Contributions in mitigating climate change through afforestation, reforestation, sustainable forest management and improved forest plantations.

CONCLUSIONS

Restoration of degraded land is gaining importance as never before and is becoming top priorities of respective governments.

Therefore, it is necessary to intensify relevant and practical field research into plantation techniques of forestry species. It is in this context that the findings of our study, especially the species-wise recommendations, are vital. We concluded that *D. latifolia*, *T. arjuna* and *T. bellirica* performed better in irrigated conditions, whereas *G. arborea* performed well under rainfed condition. This suggested that *G. arborea* was suitable for agroforestry system. *Terminalia bellirica* performed best with largest pit size, i.e. 60 cm × 60 cm × 60 cm, while the other three species performed best with 45 cm × 45 cm × 45 cm pit size. In terms of tree spacing, *G. arborea* and *D. latifolia* responded best to 3 m × 3 m spacing while *T. arjuna* and *T. bellirica* performed best to 5 m × 5 m spacing. Irrigation, pit size and spacing with periodic silvicultural thinning are highly recommended for mid-term economic returns.

ACKNOWLEDGEMENTS

The authors are grateful to The Director, Tropical Forest Research Institute, Jabalpur (Madhya Pradesh) for extending the required field and laboratory support. Authors are also thankful to Subramanyam P and Chandra G for helping in designing the experiment; Kunjam KK, Jhariya S and Joshi M for helping in data collection; and Gupta D for preparing the site map. Financial grant extended by the Madhya Pradesh State Forest Department, Bhopal is duly acknowledged.

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