Indian Forester, **144** (1) : 54-65, 2018
http://www.indianforester.co.in
ISSN No. 0019-4816 (Print)
ISSN No. 2321-094X (Online)

EFFECTS OF LIGHT, NUTRIENT AND GRASS COMPETITION ON GROWTH OF SEEDLINGS OF FOUR TROPICAL TREE SPECIES

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ABSTRACT

The seedling stage is a sensitive and important stage in plant life. Hence, a thorough understanding of the ecology of individual species and environmental characteristics affecting seedling growth is necessary. Resources such as water, nutrient and light are the most important limiting factors that influence seedling survival and establishment. However, the effect of these environmental factors is modified by grass competition in tropical dry forests. In this study, we examined the effects of light and nutrient with and without grass on the growth of seedlings of four common dry tropical plant species, viz., *Acacia catechu, Acacia nilotica* ssp. *indica, Ziziphus mauritiana* and *Terminalia arjuna*. The growth parameters including height, girth, total dry weight, leaf area and number of leaves, relative growth rate in terms of height, diameter and dry weight were recorded for each species under different treatment combinations. All the species behaved differently under studied treatment combinations. Seedlings were more responsive to the nutrient addition in presence of light. Presence of grass had overall negative effect on growth of tree seedlings. Survival was found highest for *A. nilotica* ssp. *indica* and lowest for *Z. mauritiana* while reverse trend was observed for overall growth. We infer from the results that supplementation of nutrients have strong positive effect over the seedling survival and growth even under reduced light and presence of grass competition. Moreover, the findings also revealed that the regular weeding and nutrient supplementation under the existing forest vegetation may help in regeneration of the dry tropical vegetation by reducing seedling mortality even under dense canopy conditions.

***Key words**:* Grass, Light, Nutrient, Plant ecology, Seedlings, Tropical dry forest.

Introduction

Dry tropical forests are among the most exploited and endangered ecosystems of the world (Murphy and Lugo, 1986; Dirzo *et al.,* 2011). On global basis, 52% of total forest are tropical and over 42% of tropical forests have been classified as dry forest (Holdridge, 1967; Brown and Lugo, 1990). In India, dry tropical forests account for about 38% of the total forest cover (Singh and Singh, 1988). In recent years, increasing proportions of tropical dry forest have been modified into open secondary forest or savanna or completely destroyed through activities such as mining, agriculture, herbivory, and fire (Jha and Singh, 1990). Although dry tropical forests are not as diverse as moist or wet tropical forests (Kalacska *et al.,* 2004), their conservation and restoration is a high priority because they contain many endemic and economically valuable species (Sanchez-Azofeifa *et al.,* 2005). The vegetation recovery is either very slow or unpredictable due to interactions among propagules, site characteristics and climatic conditions (Khurana and Singh, 2001). The vegetation recovery options can only be assessed after thorough examination of how seedlings of individual species perform under changed climatic conditions and by identifying key regulatory environmental factors for seedling survival and growth.

Seedlings are an important and sensitive stage of plant life. The studies conducted on dry tropical tree seedling growth have mostly focused on spatio-temporal pattern of seedling recruitment and the response has been studied for the disturbance events such as fire and herbivory (Bond *et al.,* 2000; Bhadouria *et al.,* 2016, 2017a; Tripathi *et al.,* 2017). The growth response of seedlings varying in life history traits has been investigated in relation to the availability of light (Rican and Huante, 1993; Huante and Rincón, 1998; Walter and Reich, 2000), soil nutrients (Milberg *et al.,* 1998), soil water (Lieberman and Lieberman, 1984; Ceccon *et al.,* 2002), and elevated CO_2 (Khurana and Singh, 2004). Limited research has been performed for elucidating the importance of different resources to seedling growth for competitive inhibition versus resource limitation (Brown and Archer, 1999; Kraaiz and Ward, 2006; Bhadouria *et al.,* 2016, 2017b).

Biotic-abiotic interactions affecting seedlings growth in dry tropics.

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Light availability on the forest floor has been recognized as a key factor that influences growth traits of tree seedlings in dry tropical ecosystems (Jones *et al.,* 1994; Kitajima and Tilman, 1994; Walters and Reich, 1996; Sagar *et al.,* 2008). The forest in dry tropics experiences a flush of leaves in pre-monsoon period forming a dense canopy (Singh and Singh, 1992; Gerhardt, 1993), thus reducing and modifying quality of light for the seedlings emerging in the ensuing rainy season. This may lead to stress condition for seedlings. In the rain forest species, physiological and life-history trade-offs exist between pioneers and shade-tolerant tree species in their degree of dependence on light and gaps for growth and survival (Hubbell *et al.,* 1999; Goodale *et al.,* 2012, 2014). Studies conducted on the natural gap understory gradients suggest an inverse association between light and soil nutrient availability (Bazzaz and Wayne, 1994; Bhadouria *et al.,* 2016). Grubb *et al.* (1996) suggested that growth rates were low under low-light conditions but generally similar in both tolerant and intolerant species. However, Khurana and Singh (2006) suggested that dry tropical forest species cannot be strictly categorized into two distinct groups (shade tolerant vs. intolerant), rather shade preference and gap preference would be the more expressive terms.

Grasses, in general, suppress the seedling growth (Kambatuku *et al.,* 2011) possibly due to competition for above- and below-ground resources. However, some studies suggest that seedling growth is independent of grass competition (O'Connor 1995; Brown and Archer, 1999), and others have reported that grasses may facilitate the growth of seedlings by moderating microclimatic conditions (Barbosa *et al.,* 2014). Therefore, the interactive grass-seedling growth dilemma still prevails and it further gets impetus under variable resource availability (van der Wall *et al.,* 2009). For example, in India most of the dry tropical forest occurs in nutrient poor soils (Singh *et al.,* 1989) and traits such as nitrogen fixing ability, tree size, habitat preferences, etc., may respond differently to resource (light, water, nutrient) availability and disturbance gradients (Chapin *et al.,* 2003; Bhadouria *et al.*, 2016, 2017a,b). Several fertilization experiments have been conducted throughout the tropics to show that many of the light demanding, pioneer and non-pioneer species respond positively to increasing nutrient availability (Lawrence, 2003; Khurana and Singh, 2004; Zhou *et al.,* 2011). However, limited studies are available elucidating the key determinants for seedling growth of individual tree species.

Determining seedling's response to variation in soil nutrient and light levels with or without grass competition will not only improve our understanding of how natural variation in nutrient availability affects forest dynamics, but may also help to understand the impact of the widespread human-induced fertilization, watering, and canopy cutting of natural ecosystems. In the present study, seedlings of four tropical tree species with varying life history traits (*viz.,* pioneer and non-pioneer; leguminous and non-leguminous) were selected to observe their responses to different combination of light and nutrient under presence and absence of grasses. Most of the experiments conducted in dry tropical environment suggested that nutrient shortage, shade and competition with grasses may limit survival and establishment of tree seedlings. We expected that all the species will respond positively with increased nutrient availability under full sunlight (*i.e.* gap condition) and negatively with grass competition as grasses may compete for above- (light) and below-ground (soil nutrient) resources (hypothesis 1). Because leguminous species have greater leaf N content than non-leguminous species (Singh, 2006), we expected the former species to perform better than non-leguminous species in terms of survival and growth under environmental stresses (hypothesis 2). Because non-pioneer species are less responsive to nutrient fertilization than pioneer species (Chapin, 1980), we expected, pioneer species to perform better under nutrient amendment condition (hypothesis 3).

Methods

Study plant species

Four tree species (*viz*. *Ziziphus mauritiana, Acacia nilotica* ssp*. indica, Acacia catechu* and *Terminalia arjuna*), commonly found in dry tropical forest of India (Sahu *et al.,* 2008; Chaturvedi *et al.,* 2011), with different life history traits, were selected for the present study (Table 1). Two species (*Ziziphus mauritiana* and *Terminalia arjuna*) are non-leguminous and two species (*Acacia nilotica* ssp*. indica* and *Acacia catechu*) are leguminous. *Ziziphus mauritiana,* a pioneer belonging to the family Rhamnaceae, is a small to moderate sized deciduous (almost evergreen) species and prefers disturbed areas. *Acacia nilotica* ssp*. indica* -, a pioneer, is moderate sized and almost evergreen early successional leguminous tree species. *A. catechu* -, is a pioneer, fast growing tree species and prefers large to medium-sized gaps, forest edges and human-disturbed areas. *Terminalia arjuna* is a large-seeded, non-pioneer, nearly evergreen, fast growing, late-successional tree species. All the studied species are light demanding. All the above species naturally occur in dry forests of India and also have economic value (Troup, 1921).

Table 1. Characteristics of the selected species based on Troup (1921).

Species	*Ziyphus mauritiana*	*Acacia nilotica* ssp. *indica*	*Acacia catechu*	*Terminalia arjuna*
Family	Rhamnaceae	Mimosaceae	Mimosaceae	Combretaceae
Growth	Fast	Slow	Moderate	Fast
Successional status	Pioneer	Pioneer	Pioneer	Non-pioneer
Tree size	Moderate	Small	Moderate	Large
Habitat preferences	Disturbed	Disturbed	Disturbed	Undisturbed
Functional group	Non-legume	Legume	Legume	Non-legume
Soil	Sandy/alluvium	Alluvium/black	Cotton sandy	Alluvial loam
IVI*	0.42-31.0	0.39-6.0	0.6-17.6	0.42-4.43

*Sahu *et al.,* 2008; Chaturvedi *et al.,* 2011

Experimental setup and growth conditions

Experiments were conducted in the Experimental plot of Botanical Garden, Banaras Hindu University (BHU), Varanasi (25^{0}18′ N, 83^{0}03′ E, 129 m asl) during 2011-2012. The climate of the study area is tropical monsoonal. Mean monthly temperatures during the experimental period varied from 17^{0}C to 39^{0}C and relative humidity from 42% to 87%. The year consists of a hot summer (April – June), a warm rainy season (July – September), and a cold winter (November–February). Summers are dry and hot with temperature ranging between 30 to 42 °C. May is the hottest month of the year having an average temperature of more than 40 °C. The mean annual rainfall averages 1100 mm, of which 85% falls during the rainy season (Srivastava *et al.,* 2016). There are often long breaks in rainy days even during rainy season. The study site was ploughed (about 20 cm deep) to homogenize the soil. Experimental setup contains three replicate blocks of 9×9m within an area of 9×31m. In each block, we prepared two plots of 4×4m separated by 1m gap. Inside each plot four subplots of 1×1m each separated by 0.5 to 1 m gap from the other were laid and four seedlings of each species were planted in this 1×1m subplot. In each plot different treatment combinations including grass competition [without grass (G0) or with grass (G1)]; availability of light [full sunlight (L0) or reduced light (20% of full sunlight) (L1)] and nutrient [no nutrient addition (N0) or added nutrient (N1)] were applied. Light was treated on plot level, whereas grass and nutrient treatments were applied at sub-plot level. The seedling density in the plots was 16 seedlings m^2 which is in conformity with field observations. All the plots were well-watered on five days intervals for 18 months of the experiment (July 2011 – December 2012).

L0 and L1 treatments were applied to test whether studied species differed in their response to shade as under closed canopy (L1) and to condition such as in large canopy gap (L0). To create reduced light level (L1) shade net (fine nylon mesh) was placed 2.5 m above earth surface in such a way that it had no effect over the light treatment plot where seedlings were planted. The light availability of the shaded area depicts the dense canopied forest vegetation.

To test whether seedlings of different species differed in their growth response to increased soil nutrients supply and whether this affects the competitive effect of grasses on tree seedling growth, we included two nutrient treatments: no added nutrients (N0) and added nutrients (N1). Sub-plots were supplemented with NPK based inorganic fertilizer in the ratio of 3:1:2 in N1 treatment plots. Fertilizer in these N1 plots was applied three times in equal amounts over the period of experiment at the interval of 6 months including a basal application. The fertilizer addition to the experimental plots was at the rate of 4 g N m^{-2}, representing a high dose of nutrient application in dry tropical forest (Kraaij and Ward, 2006).

To test the effect of grass competition for resources, we included plots with presence of grass (G1) and plots without grass (G0). A local grass species *Eragrostis tenella* was seeded one month before the transplantation of tree seedlings in G1 plots to evaluate competitive effect on tree seedlings for above- and below-ground resources. At the time of sampling, the height of the grass ranged between 30-35 cm. Manual weeding was done regularly to control other naturally germinated grasses in G0 and G1 plots.

Seeds of *Ziziphus mauritiana, Acacia nilotica* ssp. *indica, Acacia catechu* and *Terminalia arjuna* were collected from the nearby dry tropical forest. Seeds were surface sterilized for 30 sec by immersing in 0.1% $HgCl_2$, washed thoroughly with water. Seedlings were raised in Botanical Garden of Banaras Hindu University (BHU), Varanasi, India. Seeds of all tree species were sown in nursery bags filled with soil of the experimental area, one month before the commencement of experiment. At the start of the experiment four seedlings (of uniform size) of each species were randomly transplanted in each block for each treatment combination under the pre-grown grass layer. Thus, a total 12 seedlings of each species were planted for each treatment.

Soil samples, at the beginning of the study, were collected from 10 random locations from the experimental field. Samples were sieved to pass through a 2-mm mesh screen. Soil organic carbon was determined by Walkley-Black rapid titration method (Walkley and Black, 1934), total Kjeldahl-N by macro-Kjeldahl method and total P by perchloric acid extraction method (Olsen and Sommers, 1982). Sand, silt and clay contents of soil samples were determined as described by Sheldrick and Wang (1993). Soil pH was determined following Anderson and Ingram (1993). Organic carbon, total N and total P were 5.91±0.85 mg g^{-1}, 0.59±0.08 % and 0.17±0.05 %, respectively. The sand, silt and clay contents were 23.4±2.33%, 73.2±0.56% and 3.5±0.12%, respectively. Soil pH was 7.2±0.81.

Measurements

At the time of plantation, we harvested 10 seedlings of each species from the nursery bags. Initial measurements were recorded on these seedlings for stem length, root length, girth, number of leaves, leaf area, dry weight of each leaf and of whole plant as initial reading for calculating relative growth of tree seedlings. After the establishment of experiment, stem length (from soil surface to tip), girth (1 cm above the ground) and number of leaves were recorded for individual species at 1 month interval for 18 months. Six seedlings per species from each treatment were harvested after 18 months. Only six seedlings were considered at the final stage because in some of the treatment combinations, only 50% survival was recorded. At the end of the experiment, the number of surviving seedlings per species per treatment combination was recorded. Seedlings were partitioned into leaves and stems. Leaf surface area was measured immediately by a leaf area meter (SYSTRONICS leaf area meter-211, India). All plant parts were separated and oven dried to constant mass at 70 °C for 48 hours and weighed separately. In addition to these traits relative growth rate in height (RGR_H), stem diameter (RGR_D), dry weight (RGR_W) were also calculated in order to obtain response of these species in variability of light, nutrient and presence or absence of grass. Formulae to analyze relative growth rates are given below.

$$RGR_H = \frac{\mathrm{Log_e}\, H_f - \mathrm{Log_e}\, H_i}{t_2 - t_1}$$

$$RGR_D = \frac{\mathrm{Log_e}\, D_f - \mathrm{Log_e}\, D_i}{t_2 - t_1}$$

$$RGR_W = \frac{\mathrm{Log_e}\, W_f - \mathrm{Log_e}\, W_i}{t_2 - t_1}$$

Where H_f and H_i represent final and initial height, D_f and D_i represent final and initial stem diameter, W_f and W_i represent final and initial total dry weight of individual plant and t_2 and t_1 represent for final and initial time. Data collected for growth parameters after 18 months are presented and discussed here.

Statistical analysis

The effect of different treatments on seedling survival was analyzed by one-way ANOVA. ANOVA was performed after testing for homogeneity of the whole dataset. Effects of treatment combinations on growth parameters were analyzed using multivariate-ANOVA (MANOVA). Tukey's Post Hoc test was performed to observe the differences between means. All statistical analyses were performed using the SPSS (SPSS Inc., Chicago, USA, Ver. 16) statistical package.

Results

Seedling survival and growth parameters

Only data collected at the end of the experiment (after 18 months of growth) are presented here. Seedling survival was significantly (at P<0.05 and P<0.01 level) affected by species, nutrient addition and grass competition (Table 2). Seedling survival ranged from 50% to 100% (Fig. 1), and was higher for leguminous species than non-leguminous species. Maximum seedling survival was observed for *A. nilotica* ssp. *indica* followed by *A. catechu* and *T. arjuna* under all the treatment combinations.

Table 2. Summary of ANOVA for the effects of light availability, nutrient addition and presence of grass on survival of tree seedling of four dry tropical tree species. Here, S = species, L = light condition, N = nutrient addition, G = grass competition.

Source	*df*	*F*	*P*
S	3	5.96	<0.001
L	1	0.09	0.77
N	1	12.26	<0.001
G	1	19.15	<0.001
S × L	3	0.03	0.99
S × N	3	0.28	0.84
S × G	3	1.16	0.33
L × N	1	4.17	0.05
L × G	1	8.51	<0.001
N × G	1	0.77	0.38
S × L× N	3	0.14	0.93
S × L × G	3	0.06	0.98
S× N × G	3	0.14	0.93
L × N × G	1	5.45	0.02
S × L × N × G	3	0.28	0.84
Error	64		

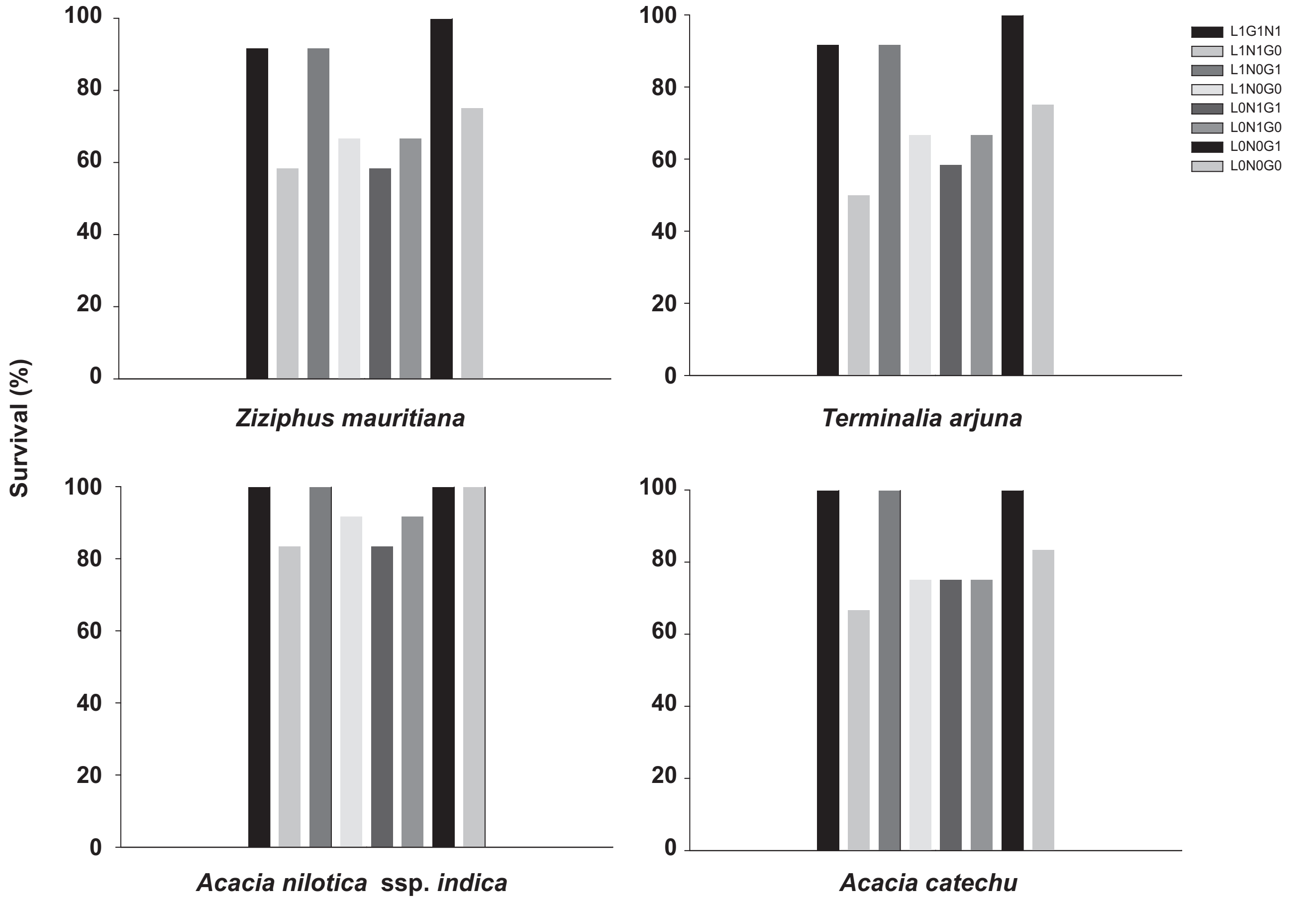

Fig. 1. Survival (%) of tree seedlings of four tree species (*Ziziphus mauritiana*; *Acacia nilotica* ssp. *indica*; *Acacia catechu* and *Terminalia arjuna*) under various combinations of light, nutrients, and grass. L0, full sunlight; L1, reduced light; N1, added nutrient; N0, no nutrient addition; G1, grass present; G0, grass absent.

Table 3. Summary of MANOVA for growth traits; height (cm), girth (cm), total dry weight (g), leaf area (cm^2), number of leaves, relative growth rate estimated by height (RGR_H), stem diameter (RGR_D), total dry weight (RGR_W) for seedlings of four dry tropical tree species with factors: species (S), Light (L), nutrient (N), grass (G) treatment. Degree of freedom (*df*), F-value for each factor are given, where * and ** represent significance at P<0.05 and P<0.01 levels.

Treatments/Factors	*df*	Height	Girth	Total dry weight	Leaf area	Leaf Numbers	RGR_H	RGR_D	RGR_W
S	3	115.4**	699.6**	0.22**	0.68**	0.4**	69.6**	61.88**	81.14**
L	1	105.8**	101.0**	257.0**	8.1**	45.7**	6.8**	17.9**	24.2**
N	1	231.3**	813.5**	1.3**	29.9**	177.1**	13.7**	152.5**	167.1**
G	1	168.5**	209.5**	378.0**	10.1**	178.7**	10.0**	34.7**	44.6**
S × L	3	8.3**	1.6^{NS}	51.4**	3.4*	16.5**	0.5^{NS}	0.2^{NS}	2.3^{NS}
S × N	3	1.5^{NS}	4.2**	48.7**	1.4^{NS}	5.5**	0.03^{NS}	2.4^{NS}	2.6*
S × G	3	2.7*	16.7**	26.1**	0.4^{NS}	28.6**	0.1^{NS}	1.6^{NS}	2.8**
L × N	1	0.02^{NS}	3.7*	26.0**	0.0^{NS}	11.9**	0.01^{NS}	0.004^{NS}	1.5^{NS}
L × G	1	2.4^{NS}	0.7^{NS}	49.6**	0.6^{NS}	4.9*	0.2^{NS}	0.03^{NS}	3.6*
N × G	1	16.0**	8.04**	174.0**	2.4^{NS}	25.4**	0.7^{NS}	0.5^{NS}	16.7**
S × L × N	3	0.8^{NS}	3.5*	6.5**	0.03^{NS}	1.9^{NS}	0.1^{NS}	0.4^{NS}	1.3^{NS}
S × L × G	3	0.7^{NS}	0.9^{NS}	13.7**	0.4^{NS}	0.3^{NS}	0.05	0.071	0.572^{NS}
S× N × G	3	0.8^{NS}	0.8^{NS}	15.0**	0.1^{NS}	1.6^{NS}	0.04^{NS}	0.3^{NS}	1.2^{NS}
L × N × G	1	5.04*	0.05^{NS}	0.7^{NS}	0.01^{NS}	38.3**	0.38^{NS}	0.07^{NS}	0.02^{NS}
S × L × N × G	3	1.6^{NS}	6.0**	19.5**	0.08^{NS}	8.4**	0.1^{NS}	0.8^{NS}	3.7**
Error	160								

* & ** represent significance at P < 0.05 and P<0.01 level, respectively.

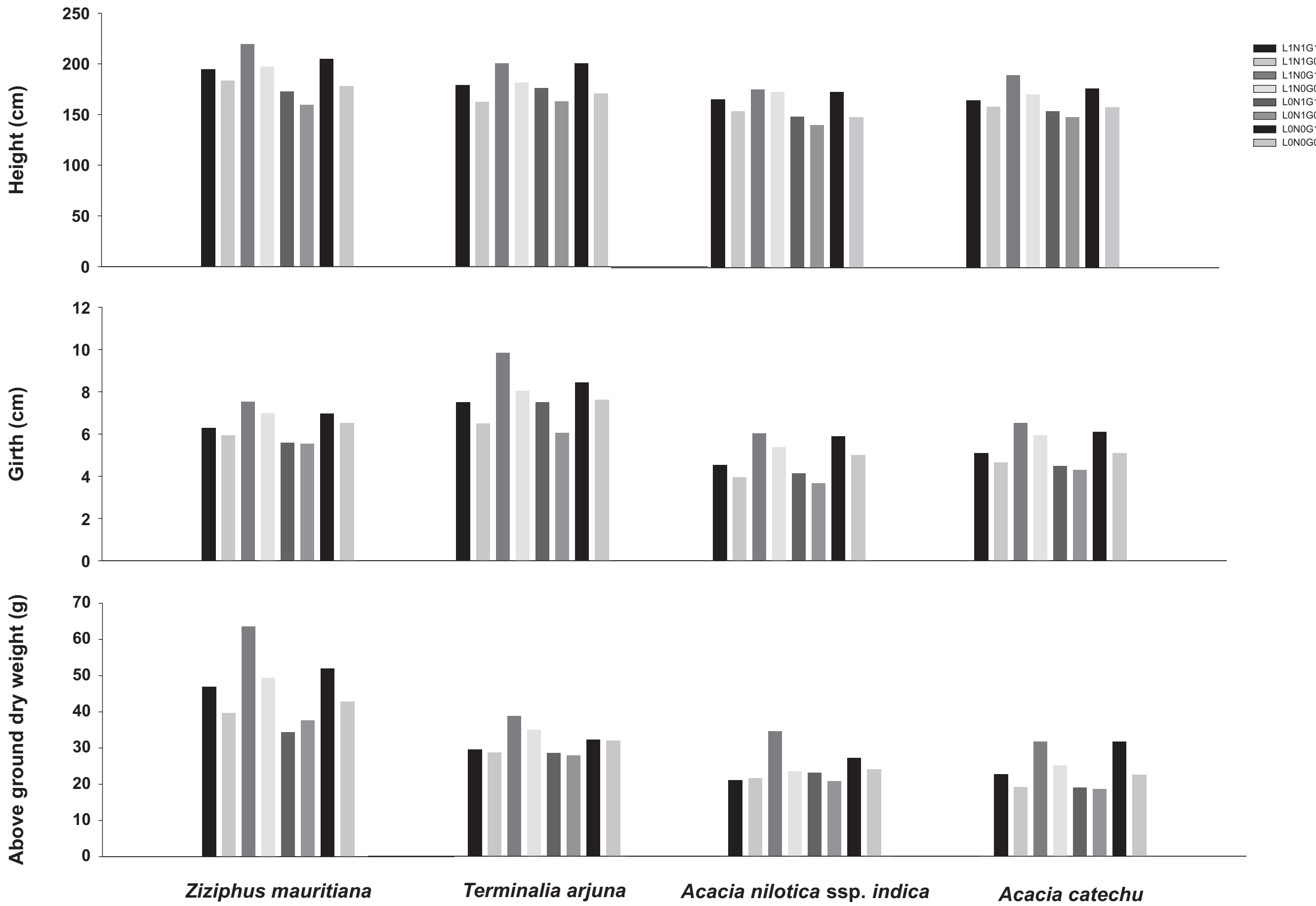

Fig. 2. Effect of different combinations of light availability, nutrients addition and grass competition on height (cm), girth (cm), and total dry weight (gm) of 18 months old tree seedlings of four dry tropical species (*Ziziphus mauritiana*; *Acacia nilotica* ssp. *indica*; *Acacia catechu* and *Terminalia arjuna*). L0, full sunlight; L1, reduced light; N1, added nutrient; N0, no nutrientaddition; G1, grass present; G0, grass absent.

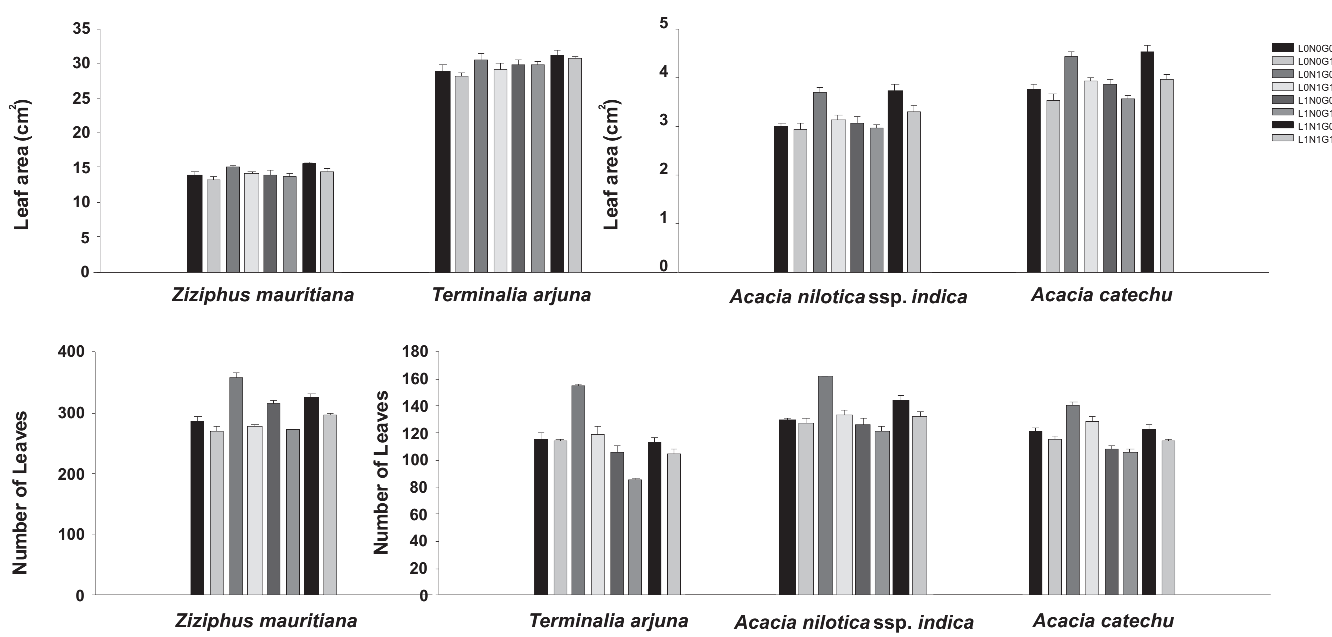

Fig. 3. Effect of different combinations of light availability, nutrients addition and grass competition on leaf area (cm^2) and number of leaves of 18 months old tree seedlings of four dry tropical species (*Ziziphus mauritiana*; *Acacia nilotica* ssp. *indica*; *Acacia catechu* and *Terminalia arjuna*); L0, full sunlight; L1, reduced light; N1, added nutrient; N0, no nutrient addition; G1, grass present; G0, grass absent.

Seedlings growth parameters

Height, girth, total dry weight, leaf area and number of leaves were significantly (at P<0.05 and 0.01 level) affected by species, availability of light, nutrient addition, and grass competition (Table 3). Increased level of light and nutrients generally had a positive effect on growth parameters, while competition from grasses tended to inhibit growth. Two way interactions of species × light for height, total dry weight, leaf area and number of leaves; of species × nutrient for girth, total dry weight and number of leaves; of species × grass for height, girth, total dry weight and number of leaves; of Light × nutrient for girth, number of leaves; light × grass for total dry weight, number of leaves; and of nutrient × grass for height, girth, total dry weight, and number of leaves were significant (at P<0.05 and 0.01 level). The values for height, girth, total dry weight and number of leaves were higher under L0N1G0 (Fig. 2). Leaf area was higher under shaded condition in all the species (Fig. 3).

Height of 18 month old seedlings ranged from 140.7 cm to 219.3 cm (Fig. 2) across the four species. Maximum height was attained by *Z. mauritiana* under L0N1G0 and minimum by *A. nilotica* ssp. *indica* under L1N0G1. Girth ranged from 3.7 cm to 9.9 cm. Maximum girth was displayed by *T. arjuna* under L0N1G0 and minimum by *A. nilotica* ssp. *indica* under L1N0G1. Total dry weight ranged from 18.6 g to 63.6 g, the maximum total dry weight was reflected by *Z. mauritiana* under L0N1G0 and minimum by *A. catechu* under L1N0G1. Leaf area ranged from 2.92 cm^2 to 31.11 cm^2 (Fig. 3). Maximum leaf area was displayed by *T. arjuna* under L1N1G0 and minimum by *A. nilotica* ssp. *indica* under L0N0G1. Number of leaves ranged from 85.5 to 357.2. Maximum leaf number was reflected by *Z. mauritiana* under L0N1G0 and minimum by *T. arjuna* under L1N0G1 (Fig. 3).

Seedling relative growth parameters

Relative growth rate estimated by height (RGR_H), stem diameter (RGR_D) and dry weight (RGR_W) was significantly affected by species, light availability, nutrient addition and grass competition (Table 3). RGR_H ranged from 0.127 cm cm^{-1} $month^{-1}$ to 0.173 cm cm^{-1} $month^{-1}$. Maximum RGR_H was displayed by *Z. mauritiana* under L0N1G0 and minimum by *A. nilotica* ssp. *indica* under L1N0G1. RGR_D ranged from 0.059 cm cm^{-1} $month^{-1}$ to 0.109 cm cm^{-1} $month^{-1}$. *T. arjuna* exhibited maximum RGR_D under L0N1G0 and minimum by *A. nilotica* ssp. *indica* under L1N0G1. RGR_W ranged from 0.254 mg mg^{-1} $month^{-1}$ to 0.302 mg mg^{-1} $month^{-1}$ (Fig. 3). Maximum RGR_W was displayed by *Z. mauritiana* under L0N1G0 and minimum by *A. catechu* under L1N0G1.

Discussion

Effect of light, nutrient addition and grass competition on seedling survival

All the experimental species are reported to be light demanding (Troup, 1921) and occur on nutrient poor soil (Singh *et al.*, 1989) with pronounced seasonality in nutrient release (Raghubanshi *et al.*, 1990). The species component of such nutrient limited dry tropical ecosystem, varying in life history traits, such as successional status (e.g. pioneer, non-pioneer), habitat preferences and nitrogen fixing ability, can be expected to respond differently to the availability of nutrient under different levels of light in heterogeneous forest environment (Tripathi and Raghubanshi, 2013). In this study, effect of light condition on survival was not significant; however, grass competition exerted pronounced negative effect under full sunlight conditions whereas nutrient addition improved seedling survival, in general for all the studied species. Though, survival of the seedlings of most species was not affected by reduced light, we may have seen different results if we reduced light levels further. Moreover, these results revealed the dry tropical species neutrality towards light conditions for the survival. Our study indicated that survival of leguminous species (*A. catechu* and *A. nilotica* ssp. *indica*) is higher than non-leguminous species (*Z. mauriatiana* and *T. arjuna*) in presence of grass (Fig. 1). This result is in agreement with our expectations (hypothesis 2) suggesting that competition by grass for nutrients would induce increased nodulation in leguminous species that would enable them to survive better than a non-leguminous species. N_2 fixing ability of leguminous species might be an important attribute allowing them to survive under competition with grasses (Stougaard, 2000). In accordance with our expectation under hypothesis 3, we found higher survival for pioneer species than non-pioneer species with added nutrient. Moreover, pioneer species showed higher survival than non-pioneer species even in the presence of grass competition. Facilitation by neighboring vegetation was also reported for pioneer species in several experiments in dry tropics (Hammoned, 1995). Facilitation might be due to the moderation of adverse environmental conditions experienced by seedlings. Indeed, both the fine leaved species are pioneer and can sustain/ survive in stressed environment (Winkler *et al.*, 2014).

Effect of light, nutrient and grass competition on growth

Marked differences were found in height, girth,

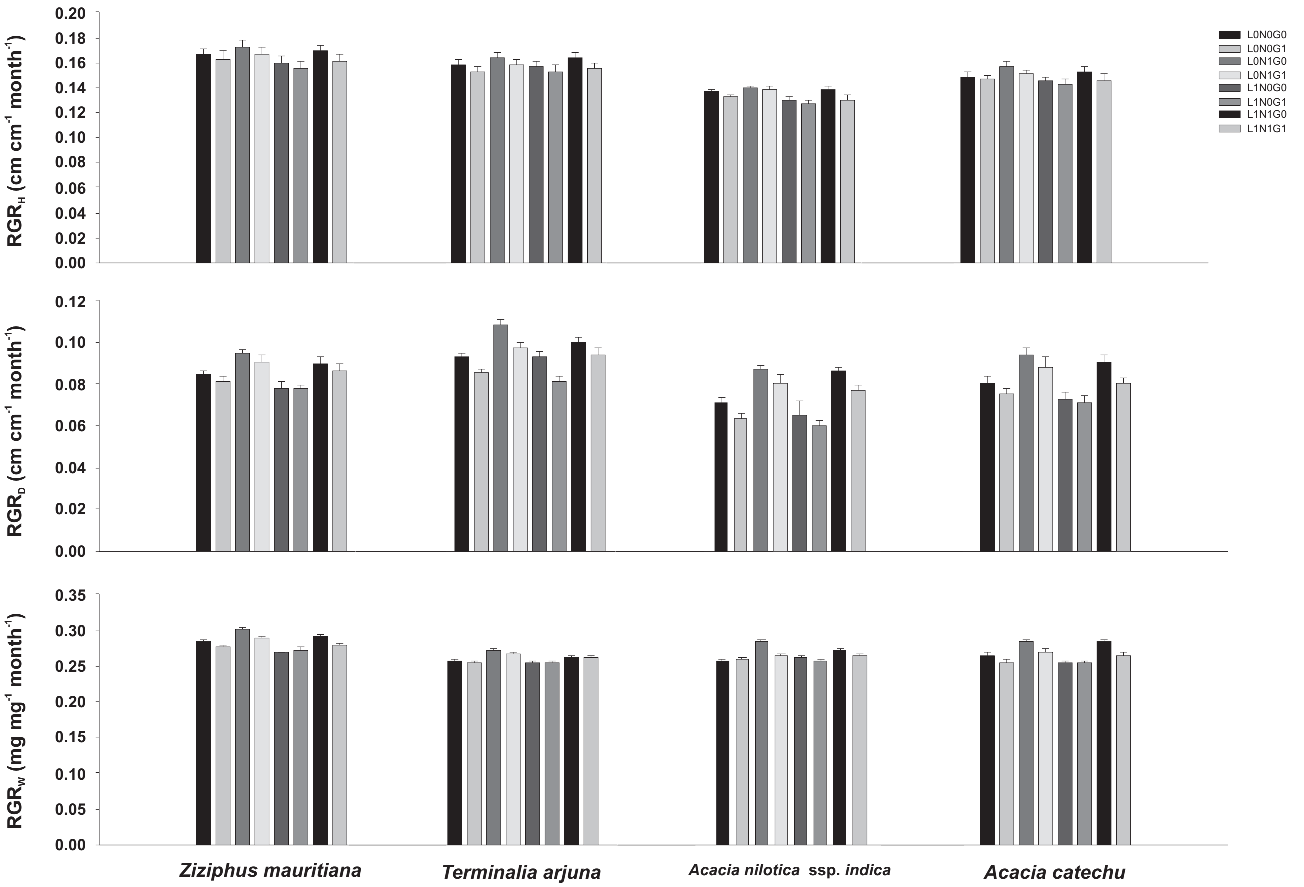

Fig. 4. Effect of different combinations of light availability, nutrient addition and grass competition on relative growth rate estimated by height (RGR$_H$), stem diameter (RGR$_D$) and total dry weight (RGR$_W$) of seedlings of four dry tropical tree species (*Ziziphus mauritiana*; *Acacia nilotica*; *Acacia catechu* and *Terminalia arjuna*). L0, full sunlight; L1, reduced light; N1, added nutrient; N0, no nutrient addition; G1, grass present; G0, grass absent.

total dry weight, leaf area and number of leaves of tree seedlings. In general, height, growth and dry weight were higher under full sunlight and added nutrient conditions. The effect of grass competition on seedling growth was more pronounced under reduced sunlight and no-added nutrient conditions as compared to full sunlight. We observed that all the species grew better under full sunlight with added nutrient (Fig. 2 and 3) as predicted by our hypothesis 1. Shade reduced shoot growth and accumulation of dry weight in tree seedlings of dry tropical tree species, as also reported by Curt *et al.* (2005); Madsen (1995); Van Hees and Clerkx (2003) and Tripathi and Raghubanshi (2013). Grass competition may be the main driving factor in modulating seedling growth and development in dry deciduous forest. In our study we found that seedling growth was negatively affected by grass competition even in favorable environmental conditions (full sunlight and nutrient addition) (Fig. 2 and 3). This suggests that tree seedlings in the dry tropical forest have the same ecological niche as grass and they are suppressed by the grass layer. Bloor *et al.* (2008) and Harmer *et al.* (2012) found that tree seedlings may be adversely affected by ground flora competition for above- and below-ground resources, which can cause significant reduction in height, girth and total dry weight. Kambatuku *et al.* (2011) and Vandenberghe *et al.* (2008) suggested that belowground competition for resources may play an important role in seedling establishment and growth. Further, no effect of light was observed in the present study on relative growth rate, such as height and diameter of tree seedlings. Contrary to the neutral effect of shade on survival, seedlings of all the species were negatively affected by reduced light in terms of height, girth and total dry weight. Lower light intensity as found under closed canopy of tropical forest, may limit carbohydrate accumulation in seedlings (Zhang *et al.,* 2013) and slow their growth rates. Contrary to our expectations under hypothesis 2, non-leguminous species showed higher growth under shaded condition in terms of height, girth, total dry weight, leaf area and number of leaves than leguminous species under presence as well as absence of grass (Fig. 2, 3 and 4). Our result is in agreement with the study conducted by Smith and Goodman (1987) who suggested that leguminous species are less tolerant to shade than non-leguminous species.

Conclusion

In the present study, seedling growth was found maximum under nutrient supplemented full sunlight treatment in absence of grass competition. Species belonging to different functional groups (namely legumes, non-legumes, pioneer, non-pioneer species) responded differently to the changed environmental conditions. Seedlings of all the studied species performed better under full sunlight (representing the gap condition) with nutrient addition. Non-leguminous tree seedlings showed higher growth as compared to leguminous tree seedlings. However, the leguminous species were more tolerant to grassy competition and resource stress conditions. Interestingly, *T. arjuna* seedlings exhibited less variation in height under all the light treatment combinations, supporting the observation that non-pioneer species are less affected by light availability under dry tropical environments. *A. nilotica* ssp. *indica* showed weight reduction under reduced sunlight treatments even under nutrient supplementation and absence of grass competition. Overall, results suggest that grass competition has significant effect over seedling survival under nutrient-limited conditions. Therefore, for regeneration of dry tropical forest a combination of plant species with nutrient supplementation and regular weeding during the seedling stage will be a wise strategy for enhancing woody cover of dry tropical forest.

Acknowledgements

RB gratefully acknowledged the financial support provided by University Grants Commission (UGC), New Delhi, India in the form of research fellowship. RB also gratefully acknowledged Dr. Hema Singh, Department of Botany, BHU, Varanasi for her thoughtful suggestions for the research work. Authors are highly thankful to Head, Department of Botany, Institute of Science, BHU for providing necessary infrastructure for experimental analysis.

चार उष्णकटिबंधीय वृक्ष प्रजातियों के पौधों की वृद्धि पर प्रकाश, पोषक और घास प्रति स्पर्द्धा का प्रभाव

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सारांश

पौध अवस्था पादप जीवन में एक संवेदी और महत्वपूर्ण अवस्था है। अतः एकल प्रजातियों की पारिस्थितिकी और पौध वृद्धि को प्रभावित करने वाले पर्यावरणीय अभिलक्षणों की पूरी तरह से समझ होना आवश्यक है। संसाधन जैसे–जल, पोषक और प्रकाश सबसे महत्वपूर्ण सीमित कारक हैं, जो पौध उत्तरजीविता और स्थापना को प्रभावित करते हैं। तथापि, इन पर्यावरणीय कारकों के प्रभाव को उष्णकटिबंधीय शुष्क वनों में घास प्रतिस्पर्द्धा द्वारा संशोधित किया गया है। इस अध्ययन में हमने चार आम शुष्क उष्णकटिबंधीय पादप प्रजातियों, यथा–*ऐकेशिया कैटेचू, ऐकेशिया निलोटिका* उप प्रजाति *इंडिका, जिजिफस मार्शियाना* और *टर्मिनेलिया अर्जुना,* की पौधों की वृद्धि पर घास के साथ और घास के बिना प्रकाश और पोषक के प्रभाव की जांच की है। विभिन्न उपचार संयोजनों के तहत प्रत्येक प्रजाति के लिए ऊँचाई, घेरा, कुल शुष्क भार, पत्ती क्षेत्र और पत्तियों की संख्या, ऊँचाई, व्यास एवं शुष्क भार के संदर्भ में सापेक्ष वृद्धि दर को सहित वृद्धि पैरामीटरों को अभिलिखित किया गया। अध्ययन किए गए उपचार संयोजनों के तहत सभी प्रजातियों ने अलग–अलग व्यवहार किया। प्रकाश की उपस्थिति में पोषक मिलाने से पौधे ज्यादा अनुक्रियाशील थे। घास की उपस्थिति का वृक्ष पौधों की वृद्धि दर पर समग्र नकारात्मक प्रभाव था। *ऐकेशिया निलोटिका* उप प्रजाति *इंडिका* के लिए उत्तरजीविता उच्चतम पाई गई और *जिजिफस मार्शियाना* के लिए न्यूनतम जबकि समग्र वृद्धि के लिए प्रतिकूल रूझान देखा गया। हमने परिणामों से निष्कर्ष निकाला कि पोषकों के सम्पूरण का, यहाँ तक कि घास प्रतिस्पर्द्धा की उपस्थिति और लघुकृत प्रकाश के तहत भी, पौध उत्तरजीविता एवं वृद्धि के ऊपर सशक्त सकारात्मक प्रभाव है। इसके अलावा, परिणामों ने यह भी दर्शाया कि विद्यमान वन वनस्पति के तहत नियमित निराई और पोषक सम्पूरण सघन वितान अवस्थाओं के तहत भी पौध मर्त्यता घटाकर शुष्क उष्णकटिबंधीय वनस्पति के पुनर्जनन में सहायता कर सकते हैं।

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