DOI: https://doi.org/10.31357/jtfe.v9i1.3945

Suraj et al. /Journal of Tropical Forestry and Environment Vol. 9, No. 01 (2019) 7-18

Variation in Rooting Pattern of *Leucaena leucocephala* in Relation to Propagation System and Stock Mother Plants

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Date Received: 26-12-2018 Date Accepted: 20-04-2019

Abstract

Lateral shoot cuttings are used for multiplication of *Leucaena leucocephala* clones to control lodging in pulpwood plantations. Variability in rooting pattern was evaluated in lateral cuttings from four types of mother plants (a) sand beds in shade house (SH), (b) sand beds with overhead shade, (c) open sand beds and (d) open field hedges (CMA) in a commercial *Leucaena* clone. Rooting rate of SH cuttings varied significantly with propagation conditions across two mist chambers (87% in MC 1 versus 68% in MC 2). Rooting pattern also differed with 77% cuttings in MC 1 having long root zone (>2.5 cm length from stem base) compared to only 10% plants in MC 2. Application of rooting hormone (IBA 5000 ppm) increased number of roots by 46% and root zone length by 39% in SH cuttings. Rooting rate did not vary between winter and summer season. Lateral cuttings from open sand bed and CMA had comparatively thicker stem with anatomical configuration of larger pith region, large diameter vessels in low frequency and sclerenchyma bundles, compared to mother plants raised in shade (a and b). Rooting rate was high (83-87%) in covered sand beds (a and b) compared to those (c and d) in open sunlight (43-68%). Majority of cuttings from open sand bed (85%) and CMA (93%) had short root zone (<2.5 cm length) compared to covered sand beds (30%). Clonal propagules with good root system can be produced from *Leucaena* cuttings when mother plants are maintained in shade and provided suitable propagation conditions.

Key words: Vegetative propagation, clonal forestry, root system, stem anatomy, rooting hormone

1. Introduction

The tall variety K636 of *Leucaena leucocephala* is widely planted for pulpwood in peninsular India. Seed harvested from felled trees is traditionally used for planting which has high variability whereas clonal plantations can give at least 50% higher wood yield. Clonal forestry in *Leucaena* was hampered by low multiplication rate, poor root architecture and lodging in plantations. Propagation methods were developed (Victorio et al., 1998; Dick et al., 1999) to capture traits of *Leucaena* clones like tolerance to soil pH and psyllids. *Leucaena* improvement focussed on enhancing biomass production (Karim et al., 1991) for fodder whereas good root system is essential to support higher wood volume in clones for pulpwood production, compared to seed origin plantations. Application of rooting hormone and selection of juvenile cuttings from suitable stem positions were found to be critical for good rooting in *Leucaena* clones and hybrids (Shi and Brewbaker, 2006). A propagation technique was recently developed using lateral shoots from stock mother plants, maintained in sand beds, that give more than 80% rooting compared to conventionally used nodal stem cuttings (Suraj and Varghese, 2019). This propagation method was successfully implemented for large scale supply of clones to farmers for enhancing wood yield in plantations.

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ISSN 2235-9370 Print/ISSN 2235-9362 Online

Vegetative propagation methods in forest trees evolved from traditionally used coppice shoots of clonal multiplication areas (CMA) in open field, to clonal hedges maintained in sand beds. Clonal hedges gave several advantages like higher productivity and year round supply of cuttings, due to better nourishment and controlled environmental conditions (de Assis et al., 2004). Introduction of minicutting technology paved the way for intensive management of stock mother plants for improved rooting features in clonal propagules of *Eucalyptus* (de Assis, 2011). Minicutting technique has been employed in tree species like Neem and Teak (Gehlot et al., 2014; Badilla et al., 2016) with some modifications to suit the requirement of each species. In *Leucaena*, nodal cuttings from CMAs in open field, and minicuttings from intensively managed mother plants did not give similar success as in eucalypts due to specific characteristics of stem and turgor based responses in leaflets of Mimosaceae (Visnovitz et al., 2007). Lateral shoots produced by modification of shoot orientation in stock mother plants gave encouraging results compared to apical and nodal stem cuttings in *Leucaena* (Suraj and Varghese, 2019).

Management practice of stock mother plants can change the abiotic environment that influence root architecture in cuttings of the same genotype (Bellini et al., 2014), and hence play a crucial role in determining the quality of cuttings produced. Maturation in mother plants is usually associated with several changes in physiology and anatomical configuration of the stem, which influence juvenility and rooting ability of cuttings (Leakey, 2004). Environmental conditions of mother plants can influence lignification of cuttings that impact the endogenous hormone levels, and response of cutting to exogenous application of growth hormones (Ford et al., 2001). Temperature and humidity conditions of propagation chamber can also play a significant role in determining the root system of cuttings (Cunha et al., 2009). This paper aims to evaluate the role of propagation system, and type of stock mother plant on rooting pattern in clonal *Leucaena* plants, to reduce lodging in plantations.

2. Methodology

2.1 The study area and details of experiments

Based on management practice, four kinds of stock mother plants of a commercially planted *L. leucocephala* clone were used for the study: (a) Sand beds in covered shade house (SH), (b) Sand beds provided with shade of one layer of agro shade net (c) Open sand beds receiving direct sunlight, and (d) CMA-mother plants planted in open field. The study was conducted during the period November 2017-May 2018 in the commercial nursery of Paperboards and Specialty Papers Division (PSPD), ITC Ltd. located at Bhadrachalam (17°40′ N latitude and 81° E longitude) in Telangana state in India. Mother plants in sand beds and CMA were pruned to 15 cm height in November 2017 for production of lateral shoots that emanate from the dormant lower buds at 30-45 degrees angle to the main stem (Suraj and Varghese, 2019). Lateral shoots with apical bud were harvested after repeated pruning to ensure that shoots emerged at an angle to main stem. The nursery site has a tropical humid climate with mean annual temperature of 35° C, maximum temperature of 49° C during summer (April-June), minimum temperature of 10° C during winter (December-January), mean relative humidity of 70-80% and annual rainfall of 1,100 cm. The mother plants were provided nourishment (Suraj and Varghese, 2019) through controlled drip irrigation system. Lateral shoot cuttings of 25-30 cm length were harvested from each type of mother plant and planted in rooting medium (vermiculite-coirpith in 2:1 ratio) in 93cc hycotrays of 40 cells after dipping the base of cutting in IBA (5,000 ppm). The cuttings were subjected to misting for 20 days in mist chamber (holding capacity of 300,000 cuttings) where temperature (35-37° C) and relative humidity (80-85%) were controlled using sensors and cooling fans. Two mist chambers were used for the study-MC 1 (with fine misting) and MC 2 (coarse misting). Misting of one-minute duration was given from 9:30 am to 5:30 pm at 30 minutes interval. Light transmission into the chamber was controlled by a shade net provided below the polythene cover.

Experiments were conducted to evaluate the following.

(a) Impact of hormone (IBA 5000 ppm) treatment on root traits
(b) Variation in root traits across two mist chambers (holding capacity of 300,000 cuttings each)
(c) Impact of type of mother plant on rooting features of lateral shoot cuttings
(d) Anatomical configuration of lateral shoot cuttings from different types of mother plants

Experiment (a) was conducted from December 2017-January 2018, and (b), (c) and (d) were conducted during the period April-May, 2018. For experiments (a), (b) and (c) 2,000 cuttings each (10 trays of 40 plants each ×5 replications) were used and for (d), transverse sections were taken from the base of 15 cuttings of each category of mother plant. Nursery protocol developed for *Leucaena* clones (Suraj and Varghese, 2019) was followed.

2.2 Evaluation of cuttings and rooting pattern

Mother plants were established in sand beds at a spacing of 20×15 cm whereas in field CMA the mother plant spacing was 2.7 m×0.70 m. Diameter and angle of emergence of lateral shoot from main stem were measured in 120 cuttings (40 cuttings each in 3 replications) per category of mother plant. The length of the cutting was fixed as 25-30 cm based on inference from a previous study (Suraj and Varghese, 2019). Length of lateral shoot cuttings from CMA ranged from 20-30 cm. Diameter at the base of stem cutting was measured using a digital Vernier calliper. Each cutting had about 2-3 leaves trimmed to half the size.

Transverse sections (20-25µm) were taken from 15 cuttings of each category (5×3 replications) using a sledge microtome (Leica SM2000R) after fixing samples in FAA (formaldehyde-acetic acid-ethanol). Sections were stained with safranin (0.5%) and passed through ethanol series and Xylene. Anatomical parameters were recorded using a Leica (DM1000) light microscope and image analysis software Leica QWin Plus (V.3.5.0).

For estimating rooting rate 2,000 cuttings (10 trays of 40 plants each ×5 replications) of each category of mother plant were evaluated by observing root emergence from the base of the hycotray after 20 days in mist chamber and 10 days hardening in shade house. Root traits like number of roots, root distribution (scale of 1-5 based on spread of roots around the stem) and rooting pattern (length of root zone from base of cutting) were estimated by carefully removing the growth medium in 120 rooted cuttings (1 tray of 40 cuttings ×3 replications) of each category after 20 days in mist chamber. For evaluating rooting pattern, cuttings were classified into six groups based on length of root zone: Group 1 (0.5-1.5 cm), Group 2 (1.6-2.5 cm), Group 3 (2.6-3.5 cm), Group 4 (3.6-4.5 cm), Group 5 (4.6-5.5 cm) and Group 6 (>5.6 cm). Root traits were also estimated in 120 five month old seedlings of variety K636.

2.3 Experimental design and data analysis

As misting conditions of two mist chambers (MC 1 and MC 2) were different, rooting efficiency of each chamber was evaluated using lateral cuttings from sand beds of covered shade house (SH). All the other studies on root traits were conducted simultaneously in MC 1. Data were recorded from the following studies using randomised complete block design and analysed using one-way analysis of variance (ANOVA).

(a) Rooting pattern of SH sand bed cuttings, with and without IBA treatment in MC 1
(b) Root traits of cuttings from SH sand bed across two mist chambers (MC 1 and MC 2)
(c) Specifics and rooting of cuttings from four types of mother plants in MC 1
(d) Anatomical traits of cuttings from four mother plant sources.

Mean values were compared by Tukey HSD test when significant differences ($P<0.05$) were obtained in ANOVA. All percentage data were subjected to arcsine transformation ($\sqrt{x}/100$) and count data transformed using formula $\sqrt{x}+1$ (Snedecor and Cochran, 1980). The statistical package R (R core Team, 2013) was used for data analysis and the Tukey HSD test was performed with the package="Agricolae" (de Mendiburu, 2014). Cuttings from different mother plant sources were classified according to the proportion of roots in each category based on length of root zone.

3. Results

3.1 Impact of exogenous hormone application and season on root traits

IBA treated SH cuttings had significantly higher rooting rate and better root distribution than control. Rooting pattern also showed significant difference, with untreated cuttings having 40% lower mean root zone length and greater proportion (70%) of cuttings being in the lower root zone category (less than 2.5 cm length) compared to those treated with IBA (Table 1). Rooting rate of IBA treated SH cuttings (MC 1) did not differ much between summer (87.1%) and winter season (88.6%). Root distribution and the number of roots (21-22) were also more or less at par when multiplied in both seasons (Tables 1 and 2). There was slight difference in rooting pattern as cuttings rooted in summer had about 13% longer root zone than that in winter season.

Table 1: Impact of IBA treatment on root traits of lateral shoots from sand bed (SH) (after 20 days in mist chamber and 10 days in hardening chamber, N=2,000 each).

No.	Treatment	Root distribution	Root zone length (cm)	Proportion of roots (%) < 2.5 cm root zone	No. of roots	Rooting (%)
1	IBA 5,000 ppm	4.9 a	2.76 a	57.1	21.05a	88.6 a
2	No hormone	4.3 b	1.97 b	70.0	14.40b	81.4 b
	Significance Source	**	**		**	**

** Significant at $p<0.01$, Mean values of each trait with same letter do not vary significantly ($p<0.05$).

3.2 Specifics and root traits of lateral cuttings and seedlings

Basal diameter recorded from lateral shoot cuttings (25-30 cm length) in different types of mother plants revealed that cuttings from sand beds were at least 18% thinner than those from field CMA (Table 2). Among sand beds, cuttings grown under shade and covered shade house (SH) had atleast 14% lower diameter than sand beds laid out in open. Lateral shoots from sand beds in shade and SH had more horizontal orientation of about 10 degrees' higher angle than those of CMA and open sand beds.

Rooting was significantly higher in cuttings from sand beds in SH (87%) and under shade (82%) than open sand beds (68%) and field CMA (43%). Root distribution was also 53% better in covered sand bed cuttings than in open sand beds and field CMA. Cuttings from SH and shaded sand beds had significantly more roots (22-24) than open sand beds and CMA (19 and 14 roots respectively). Root zone length was at least 73% higher in cuttings from SH (3.11 cm) and sand beds with shade (3.14 cm), compared to open sand beds (1.79 cm), and CMA (1.44 cm). Seedlings had significantly higher number of roots (46) and longer root zone (6.7 cm) with good distribution (on par with SH cuttings).

Table 2: Details of lateral shoot cuttings from different mother plant sources and root traits with IBA treatment after 20 days in mist chamber.

No.	Source	Mist chamber	Spacing (cm)	Cutting Diameter (mm)	Root distribution	Root zone (cm)	Shoot angle (Deg)	No. of roots	Rooting (%)
1	Sand bed-SH	MC 1	20×15	2.58 a	5.0 a	3.11 b	45 a	22.0 bc	87.1 a
	Sand bed-SH	MC 2	20×15	2.58 a	4.8 a	1.67 c	45 a	15.6 de	68.2 b
2	Sand bed-Shade	MC 1	20×15	2.67 a	5.0 a	3.14 b	48 a	24.0 b	82.6 a
3	Sand bed-Open	MC 1	20×15	3.11 b	3.6 b	1.79 c	35 b	19.2 cd	68.0 b
4	CMA	MC 1	270×70	3.25 b	3.4 b	1.44 c	35 b	14.7 e	43.3 c
5	Seedlings			-	5.0 a	6.67 a	-	46.3 a	-
	Significance								
	Source			***	***	***	***	***	***

*** Significant at $p<0.001$, Mean values of each trait with same letter do not vary significantly ($p<0.05$). SH-Shade house, Mist chambers-MC 1 and MC 2.

3.3 Variation in rooting pattern with propagation system and mother plant

Propagation system had a significant impact on rooting, as rooting efficiency of MC 1 (87%) was significantly higher than that of MC 2 (68%) for the same set of SH cuttings (Table 2). Along with the difference in rooting rate, there was also a drastic difference in rooting pattern as 90% cuttings in MC 2 had root zone length of less than 2.5 cm whereas 77% of the rooted cuttings in MC 1 had root zone of more than 2.6 cm length (Figure 1).

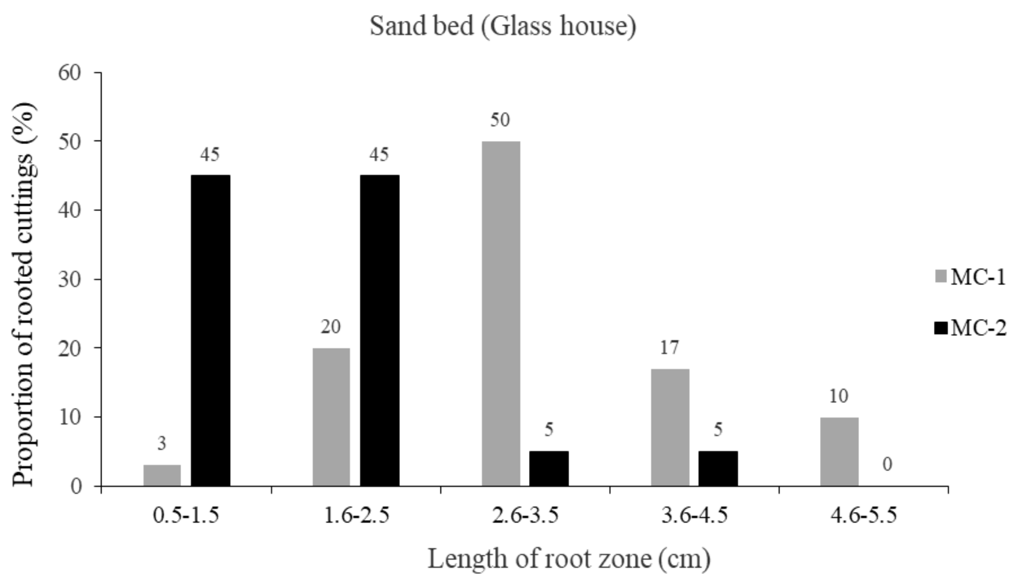

Figure 1: Rooting pattern of lateral cuttings (from sand beds in Shade House) across two mist chambers (MC 1 and MC 2).

Source of mother plant also had a big impact on rooting pattern (Figure 2). Cuttings from SH (78%) and covered sand beds (69%) had large proportion of plants with more than 2.6 cm long root zone. Majority of rooted cuttings from open sand beds (85%) and CMA (93%) had less than 2.5 cm root zone. SH cuttings rooted in MC 2 had about 46% lower root zone than those in MC 1, on par with that of open sand beds and CMA cuttings in MC 1. Root distribution was however more or less similar in SH cuttings rooted in both mist chambers (Table 2). Cuttings from both types of covered sand beds (SH and Shaded) had more or less similar root system with higher root zone length and number of roots compared to CMA but only half the number of roots and root zone as that of seedlings (Figure 3).

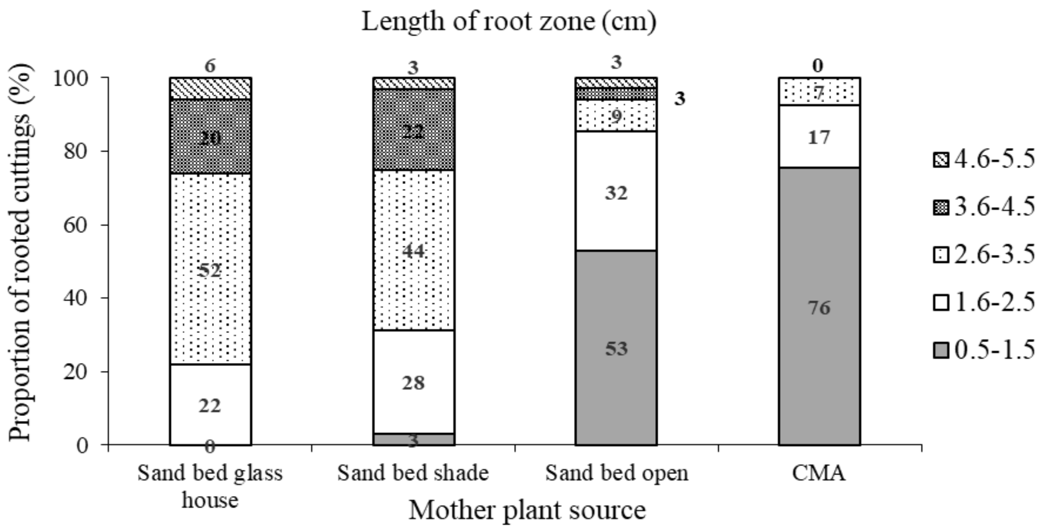

Figure 2: Rooting pattern of lateral cuttings from mother plants maintained in Shade House, Sand beds (open and with shade) and open field (CMA).

Figure 3: Root distribution in lateral cuttings treated with IBA 5000 ppm from (a) Sand beds in shade house (b) Sand beds in shade (c) Field CMA and (d) seedlings [Note the low root zone length in short cutting (c) from CMA].

3.4 Variation in anatomical structure of cuttings

Anatomical configuration of cuttings differed significantly based on source of mother plant. Cuttings from covered sand beds had different structure from that of open sand beds and CMA. Transverse stem sections revealed that cuttings from covered sand beds had at least 19% lower pith region

(Figure 4) and 9% lower vessel diameter than open sand bed and CMA (Table 3). Vessel frequency was 53% higher in cuttings from covered sand beds than open sand beds and 97% higher than that of CMA cuttings. Open sand bed and CMA cuttings had large sclerenchyma bundles in the bark region compared to covered sand beds (Figure 4).

Table 3: Anatomical configuration of lateral stem cuttings from different mother plant sources.

Cutting source	Pith (%)	Vessel Frequency (per mm^2)	Vessel Diameter (μm)
Sand bed-SH	40.47 a	74.11 a	33.45 a
Sand bed-Shade	42.46 a	78.44 a	31.07 a
Sand bed-Open	52.28 b	48.44 b	36.97 b
Field CMA	56.07 c	37.66 c	38.93 b
Significance			
Cutting Source	***	***	***

*** Significant at $p<0.001$, Mean values of each trait with same letter do not vary significantly ($p<0.05$).

4. Discussion

Adventitious roots are initiated in soft wood cuttings from certain focal cells in stem in response to wounding when removed from the mother plant. Endogenous regulatory factors and environmental conditions play a role in successful rooting of cuttings. Depending on the response different species can be classified as easy, difficult or moderately easy to root (Ford et al., 2001). There could be several factors that inhibit or enable root initiation in stem cutting. Juvenility of cutting plays a major role in deciding rooting response and root architecture of propagules of the same genotype. *Leucaena* was considered difficult to root by the conventional propagation method of coppice shoots from stumps and hedges (Litzow and Shelton, 1991). Exogenous application of rooting hormone, and selection of appropriate type of cuttings were identified to improve rooting rate in the genus (Victorio et al., 1998; Dick et al., 1999). Endogenous rooting hormone IAA is normally synthesised in apical leaves and buds and basipetally transported to the stem base where they accumulate to initiate root primordia formation (Ahkami et al., 2013). Rooting can be low or delayed due to factors like maturation of tissues or lack of focal cells that initiate primordia. It is important to identify the factors that control rooting in a species (Wilson, 1994) for addressing them through mother plant modification, exogenous hormone application or altering the environmental factors, and employing appropriate propagation conditions.

4.1 Role of propagation conditions in rooting Leucaena cuttings

In the present study MC 1 had fine misting compared to MC 2. This resulted in difference in spray volume delivered to cuttings despite maintaining the same humidity with sensors. Excess (or low) misting can affect water stress in cuttings which impact root initiation (Greenwood et al., 1980) as evidenced by 19% higher rooting rate and 41% more roots in cuttings propagated in MC 1. A similar trend of higher rooting and number of roots was reported in black walnut when propagated in fog chambers compared to mist system (Stevens and Pijut, 2017). Intermittent misting was less effective in controlling loss of turgor due to desiccation of compound leaves (like *Leucaena*) in black walnut. Cunha et al. (2009), reported a negative relationship between relative humidity and rooting rate in eucalypt minicuttings.

Dick et al. (1999), recommended use of small non mist propagators for successful rooting of *Leucaena* by maintaining appropriate temperature and humidity conditions required at each stage of rooting. However, they reported a negative correlation between length of new shoots produced in cuttings and rooting rate due to competition for assimilates in cuttings. Delay in root primordia initiation is likely to restrict the number of roots produced due to competition of emerging shoots from dormant buds. Basal accumulation of auxin in *Petunia* stem cuttings was reported to be maximum in the first 24 hrs of excision of cuttings (Ahkami et al., 2013) after which it declines. It is important to ensure that right temperature and humidity conditions are provided during the time of peak hormone accumulation for early root initiation in cuttings. This was quite evident in the present study where rooting rate and number of roots differed significantly between the two mist chambers indicating difference in propagation conditions of the two mist systems. There are no reports on the length of root zone or distribution of primary roots produced in *Leucaena* stem cuttings. Most studies used nodal cuttings from seedlings (Dick et al., 1999), coppice shoots (Shi and Brewbaker, 2006) or mature stems (Pandey and Kumar, 2013) and hence had lower number of roots than the current study. When propagation conditions are not ideal or when mature stem cuttings are used, rooting is delayed with callus formation in *Leuceana* (Pandey and Kumar, 2013) whereas direct emergence of primary roots is observed in lateral shoot cuttings (Suraj and Varghese, 2019). In such instances exogenous hormone application may help in root primordia initiation as seen in the current study. Exogenous IBA application was seen to enhance rooting rate in an earlier study in lateral shoots produced from field hedges (CMA) but not in covered sand beds (Suraj and Varghese, 2019). Rooting pattern was not evaluated in that study but rooting rate was high across seasons, which is also observed in the current study. This study clearly shows that appropriate propagation condition is very crucial for obtaining good quality root system in *Leucaena* cuttings, which may not be reflected from the rooting success (Leakey, 2004).

4.2 Mother plant management for improving root traits

It is observed that mother plant management has a significant impact on rooting in *Leucaena*. Juvenility status of cutting enhances the quantity of assimilates as well as endogenous hormone levels, compared to mature cuttings. Dick et al. (1999) reported that stem cuttings of diameter 2.9-5.5 mm from nodes 5 to 13 from shoot apex was ideal for rooting in *Leucaena*. Rooting would still be variable due to difference in maturity levels of the cuttings at different positions. The present study has compared lateral stem cuttings of the same length (25-30 cm) and diameter range (2.5-3.3 mm) from four types of mother plants maintained in different environmental conditions. Leakey and Mohammed (1985), observed that cuttings of same length would have uniform physiology based on diameter, stem lignification, carbohydrate content and leaf water potential. The current study shows that stock plant management is quite important to obtain uniform cuttings of same juvenility and physiological condition. Mother plants were cut to 15 cm height based on inference from a previous study (Suraj and Varghese, 2019), and pruned repeatedly to reorient the shoots to a horizontal angle for preventing competition from vertically growing shoots (Leakey, 1983).

Pruning helps to maintain juvenility in mother plant and prevent maturation of stem whereby cuttings of uniform anatomical configuration can be obtained. Light and heat conditions of mother plant play a role in controlling endogenous hormone levels (Greenwood and Hutchinson, 1993) and lignification in stem (Maynard and Bassuk, 1996). This trend was quite evident in the current study where thinner cuttings from sand beds maintained in shade had higher rooting and number of roots than those exposed to direct sunlight. It is evident that cuttings produced from field CMAs were of higher maturity as indicated by the sclerenchyma bundles in stems, which has affected rooting rate and number of roots produced. High irradiation also causes greater competition among stems for apical dominance as indicated by lower angle of lateral shoot emergence in mother plants without shade (Table 2). Hoad and Leakey (1996), reported higher rooting in *Eucalyptus grandis* stock plants maintained under shade due to less competition between shoots and improved physiology of excised cuttings. The same trend was seen in the current study where open sand bed and CMA cuttings had larger stem diameter and lower angle of emergence, and anatomical configuration of large pith region with low frequency of large diameter vessels. Mesen et al. (2001) reported a preconditioning influence of nutrition and light on rooting rate in *Albizia guachapele* stock plants.

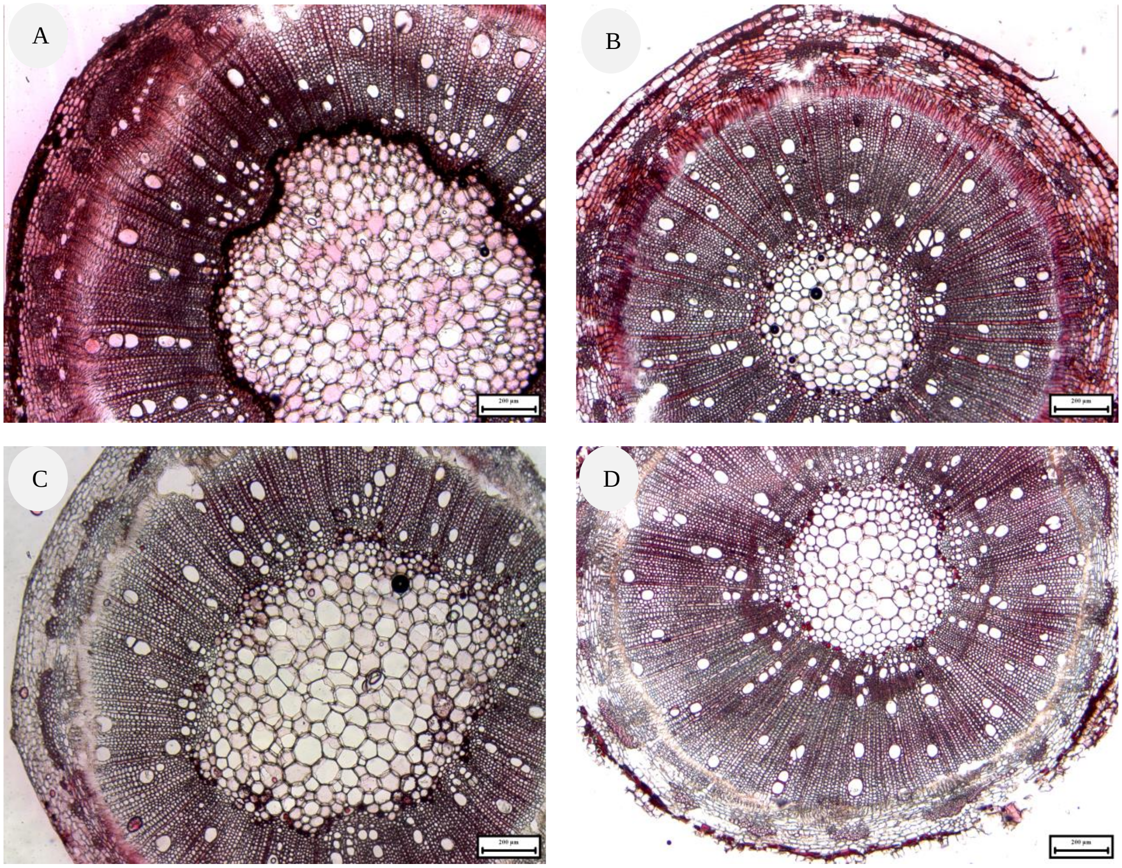

Figure 4: Transverse sections of stem cuttings at 25 cm length from shoot apex in (A) Field CMA (B) Sand beds in shade house (C) Open sand beds and (D) Sand beds with shade (Scale bar=200 µm). [Note the higher pith region, lower number of vessels per unit area and thicker sclerenchyma bundles in Field CMA and Open Sand beds compared to Sand beds in covered shade house and Sand beds under shade].

Adventitious roots in woody perennials originate mostly from parenchyma cells close to the vascular system (Bellini et al., 2014). Maturation of stem as seen in stock plants of CMA and open sand bed results in decrease of such focal cells due to reduction in number of vessels as well as increase in the lignified sclerenchyma tissues (Stevens and Pijut, 2017). This is probably the major reason for difference in rooting pattern (length of root zone) between the covered and open mother plants as there could be a reduction in the number of progenitor cells that give rise to roots. Lateral cuttings of 25-30 cm length have higher frequency of low diameter vessels at the basal position than younger tissues in *Leucaena* stem. Rooting is therefore low in small young cuttings from apical positions (Suraj and Varghese, 2019).

4.3 Management of lodging in Leucaena plantations

Good root system is essential for ensuring mechanical stability of clonally propagated trees. Adventitious roots formed within 20 days in mist chamber would be the major roots that support the above ground biomass of trees. Lateral roots produced from these primary adventitious roots (Bellini et al., 2014) would have less role in providing mechanical stability to the plant. Hence it is important that mother plants are managed to obtain ideal cuttings that give maximum primary roots distributed all around the stem with long root zone to support fast growth of clones. Vegetative propagules in *Leucaena* produce only about half the number of major roots compared to seedlings, without a prominent tap root. Poor root distribution and lop sided rooting are major problems encountered in nodal cuttings of *Leucaena* and *Eucalyptus* (Sachs et al., 1988) which can be addressed to an extent through minicuttings in *Eucalyptus* and lateral shoots in *Leucaena* (Suraj and Varghese, 2019). However, there is scope for improving rooting pattern by ensuring that a combination of right mother plant management practices, appropriate propagation conditions and best season for propagation is adopted. It is observed that almost 70% rooted cuttings from covered sand beds were of rooting category 3 to 5 (2.6-5.5 cm root zone) whereas in open sand beds and CMA more than 85% plants were of category 1 and 2 (Figure 2). This difference in root system can have an impact on the growth and stability of clonal plants. Optimisation of cutting quality and propagation conditions can enhance the proportion of cuttings in higher rooting category (3 and above). Most of the seedlings were of category 6 (>5.6 cm) whereas only about 6% SH cuttings were of category 5 (4.5-5.5 cm). Leakey (2004) observed that rooting rate is not an indicator of efficient propagation, since root system of propagules could be very different. Requirement of the species has to be evaluated for production of ideal propagules based on climatic conditions of nursery site. This was clearly demonstrated in a difficult to root African species *Cola anomala* where partial shading of mother plants gave higher rooting and more number of roots. Stock plants grown in high irradiance showed reduced sensitivity to exogenous hormone application and treatment with higher dose (10,000 ppm) increased rooting (Kangegne et al., 2017). In *Leuceana* the present study revealed that without IBA treatment, propagules had smaller root zone despite achieving high rooting rate (above 80%).

Suitable agronomic practices need to be adopted like deep planting, to ensure that root system is not exposed, along with minimal disturbance to soil during weeding to prevent root damage. Restricted irrigation may be given to ensure deeper growth of roots and reduced crown formation in first year after planting. It is observed that tree canopy can be restricted by providing close spacing (2 m×1 m) initially to give sufficient time for root growth followed by thinning to reduce stocking after establishment. Pruning lower branches helps to reduce the crown spread and improve form of trees.

5. Conclusion

Lateral shoot cuttings of *Leucaena* vary in thickness and anatomical structure depending on management practice of mother plants. Growth and environmental conditions like temperature and light influence rooting potential of cuttings. Mother plants maintained in shade produce desirable type of cuttings that have high rooting and good root distribution along greater length of stem, than those raised in direct sunlight. Propagation system has an influence on the proportion of rooted cuttings with long root zone. Application of rooting hormone improves root zone length and number of roots. A combination of best practices of mother plant management, propagation conditions and hormone treatment would be necessary to produce uniform clonal planting stock with good root system in *Leucaena* to reduce lodging in plantations.

Acknowledgment

The authors thank Mr. Viswakarma, Manager PSPD, ITC Ltd. for nursery support, and nursery staff of ITC PSPD for help in data collection.

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