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Influence of Different Cutting Positions and Rooting Hormones on Root Initiation and Root-soil Matrix of Two Tree Species

Mohammed Saifuddin[1*] Normaniza Osman[1] and M. Motior Rahman[1]
[1]*Institute of Biological Sciences, Faculty of Science, University of Malaya, 50603, Kuala Lumpur, Malaysia*
[*]For correspondence: saifuddin@siswa.um.edu.my; cushihab@yahoo.com

Abstract

The soil bioengineering technique, vegetation through stem cutting, is highly effective for soil reinforcement as well as in controlling surface erosion. But the success of this technique depends on the suitable plant species, their stem cutting position and their rooting ability. This study aimed at investigating the effects of different cutting positions and hormones on the formation of rooting of stem cuttings and root-soil matrix. According to the observations, *Leucaena leucocephala* was not suitable for propagation through stem cuttings. Even stem cuttings were treated by rooting hormones. In case of *Peltophorum pterocarpum* stem cuttings, a higher survival rate with higher stem number, leaf area index (LAI) and root initiation were observed in basal position cuttings than apical position. The soil moisture content was negatively correlated with root biomass and matric suction. Moreover, higher root length, volume and biomass were found in IBA treated stems than NAA and control, which presumably reduce more soil moisture content and increase matric suction. It can be concluded that stem cuttings should be taken from basal cutting position and IBA hormone should be applied to induce adventitious roots of *P. pterocarpum*. This technique will be suitable for practical application on soil bioengineering sites to improve root-soil matrix and reinforce soil.

Keywords: Cutting position; Rooting hormone; Survival rate; Moisture content; Matric suction

Introduction

Landslide is a major geological hazard to most regions of the world. The soil covering by vegetation, known as soil reinforcement methods, seems suitable for preventing shallow slope failures (Ji *et al.,* 2012). In soil bioengineering techniques, the use of vegetation is highly recommended as a structural element to stabilize natural and man-made slope due to their eco-friendly solutions (Bischetti *et al.,* 2010). Additionally, vegetation on slope helps to stabilize the masses of soil by holding soil particles in place and assists in preventing soil erosion by their root systems, root-soil matrix (Stokes *et al.,* 2009). Vegetation also works in removing the soil water through transpiration, which results in lower pore water pressures and reduced weight of the soil mass (Mafian *et al.,* 2009). But sometimes vegetative propagation by seed is difficult in wild slope conditions and shows complexities and undesirable characters too. Moreover, many species seedling also shows difficulties to grow in a low nutrient soil and takes many years to grow up.

To overcome this problem, numerous attempts have been taken to propagate the vegetation by stem cuttings (Kumar *et al.,* 2011). Among the various reproduction methods of plant species, stem cutting method is recommended for quicker establishment and faster production of many species on slope (Prasad *et al.,* 2012). In bioengineering techniques, stem cutting is used in stabilizing burned hill-slopes, road-cuts and fill-slopes and river banks (Bischetti *et al.,* 2010; Huat *et al.,* 2011). When stem cutting are planted, the roots are developed along their stems and increased their root-soil matrix, reinforcement action and pullout resistance too. The buds and leaves are shown to intercept rainfall, slow runoff and filter sediments as well (Guevara-Escobar *et al.,* 2007). In this technique, plants species conserved their innate desirable characters too. Opuni-Frimpong *et al.* (2008) and Kraiem *et al.* (2010) documented that the establishment and growth rate of the stem cutting depend upon age variation, position in stem and diameter of stem.

The effectiveness of different cutting position to induce rooting was different due to the unlike nutritional status of the stock cuttings. It was also reported by Smalley *et al.* (1991) that a minimal level of carbohydrate was needed of stock cutting for survival, to run physiological activity and to emerge roots. Below this level of carbohydrate, these activities may be possibly inhibited. In addition, many researchers recommended that the survival rate and root initiation can be increased by applying endogenous rooting hormones and nutrients before plantation (Soundy *et al.,* 2008; Mori *et al.,* 2011; Ahmad *et al.,* 2012). Among different types of rooting hormones, auxins play a vital role in influencing the sprouting, stem

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growth, root formation and survival rate of stem cuttings (Raju and Prasad, 2010; Severino *et al.,* 2011). Indole-3-butyric acid (IBA) and naphthalene acetic acid (NAA) are common auxins, which can control many aspects of plant development including root initiation and elongation (Shan *et al.,* 2012). These exogenous hormones normally act by signaling the proteins to stimulate new cell and resulting in the initiation of numerous lateral roots (Hameed *et al.,* 2004; Durbak *et al.,* 2012). Raju and Prasad (2010) showed that the rooting percentage is changed significantly depending on the types and concentrations of hormone used. Furthermore, semi-hardwood cuttings were suitable for successful plant propagation, while hardwood cuttings reduced the ability and softwood cuttings are too juvenile to induce roots. Additionally, Stokes *et al.* (2009) demonstrated that produced fine roots in stem cutting are capable to absorb relatively more water and minerals due to the increment of root surface area and root-soil interaction. As a plant absorbs more water, soil becomes less saturated, which makes the soil drier and thus reduce the possibility of slope failure. Therefore, vegetation through stem cutting treated by suitable rooting hormones are the most economical, easiest and fruitful method to establish live pole bioengineering technique on slopes and to reduce superficial landslide risk and erosion (Huat and Kazemian, 2010).

In view of the increasing demand of soil bioengineering techniques, there is a need to select new species and effective rooting hormone for vegetative propagation through stem cutting. A number of studies have stated that many shrub species can be propagated by leafy stem cuttings very easily (Tiwari and Kuntal, 2010) but the data on tropical woody species is limited. Moreover, the influence of auxin hormones and cutting positions on plant physiology, root initiation and soil behaviors are not well explained and understood. Therefore, the specific aims of this study are to (i) select the suitable tropical woody species for the vegetative propagation via stem cutting and (ii) find out the suitable cutting position and rooting hormone to induce adventitious roots and improve root-soil matrix.

Materials and Methods

Sample Collection and Auxin Treatments

The experiment was conducted under glasshouse conditions at ISB, University of Malaya, Malaysia during February-August, 2012. Disease free evenly matured *Leucaena leucocephala* and *Peltophorum pterocarpum* legume trees were selected for sample collection from the University of Malaya campus. One-year-old, healthy and straight branches were selected from mature plants (5-6 years old) during February, 2012. The branches were cut into two pieces namely basal and apical position. Stem length and diameter of both cutting positions are 42–44 (cm) and 30–38 (mm), respectively. The cuttings were immediately dipped into normal tap water and subsequently washed in distilled water before applying different hormonal treatments. Two types of auxins i.e., IBA and NAA were used as exogenous hormones and distilled water as control. Both hormones solution (1000 mg L^{-1}) were prepared individually by dissolving the appropriate amount of IBA or NAA in de-ionized water. Individual stem cuttings of both species were submersed (about 15 cm stem portion) into respective hormone formulations and kept for 24 h at room temperature. Then treated stem cuttings were vertically planted in polyvinylchloride (PVC) pots heaving slope soil.

In present study, slope soil was selected as a growing media to simulate a natural slope condition and to encourage similar growth rates in stem cuttings with a similar physiology. However, we acknowledge that the micro environmental conditions in a natural slope may be different. Based on the grain size distribution curve, the soil was described as silty sand, and its physical properties are provided in Table 1. The planted PVC pots were placed under glasshouse conditions (temperature of 21-32°C, maximum PAR of 2100 µE m^{-2} s^{-1} and relative humidity of 60-90%) and arranged in a completely randomized design (CRD), with 25 cm row to row distances and 25 cm pot to pot distances (Saifuddin and Osman, 2012). The experiment was conducted for six months. The plants were irrigated once every two days to avoid water stress. After 2 days of plantation, bud initiation, bud number and initial budding length of the each cutting was recorded. The initial survival rate of stem cuttings was recorded after 30 days of plantation and final survival rate was recorded after 6th month.

Leaf Gas Exchange and Leaf Area Index (LAI)

The rates of photosynthesis, transpiration and stomatal conductance were measured using a Portable Photosynthesis System (Model LI-6400XT, USA). These measurements were performed under greenhouse conditions at the optimum growth phase, at 6th month. The LAI was measured using a leaf area meter (AccuPAR-LP80, UK) at the 3rd and 6th month of age.

Measurements of Matric Suction and Soil Moisture Content

Matric suction was recorded using the soil moisture tensiometers (Model 2100F, Soil Moisture Equipment Corp., Santa Barbara, California), which can provide values from 0 to 100 kPa. To measure the soil moisture content, moisture probe (HH2 Moisture Meter, Delta T Devices, Cambridge, UK) was installed in each PVC pot at a depth of 3–5 cm from the soil surface. Both observations were taken two times, at the 3rd and 6th months of experimental periods.

Stem Diameter and Biomass

Stem diameter was measured at six months of growth using a Vernier calipers. The shoot fresh weight (SFW), root fresh weight (RFW) and dry biomass (oven-dried at 80°C for 12 h) were determined using a balance (Model-Mettle PJ3000,

Table 1: Physical properties of the soil used in this experiment

Soil properties	Slope soil
Specific gravity	2.62
Liquid limit	26.9%
Plastic limit	14.5%
Dry unit weight (kN/m^3)	13.1
Soil Field Capacity	20.3 %
pH	4.45
Color	6/8/Hue 10 [Bright yellowish brown]
Type	Size distribution
500 to1.0 mm	12.165 %
250 to 500 mic	29.45 %
100 to 250 mic	38.58 %
50 to100 mic	13.14 %
<2 to 50 mic	6.64 %

Japan) after end of experiment.

Water Absorbtion Rate (WAR)

The WAR was formulated based on the Baker's theory (Baker, 1984). According to this theory, 98% of the water absorbed by roots is transpired into the atmosphere trough transpiration. This statement leads to the formula as follows:

WAR = Water Absorption Rate by root/day = E^{θ} 100/98 (L H_2O/plant/day).

Where, E^{θ}=Transpiration rate (L H_2O/plant/day);

Root Profiles

The root profiles were analyzed by scanning and using the WinRHIZO Pro Software after end of experiment. This software was used to assess the total root length and root volume in different root diameter ranged (0.0– 4.5 mm).

Statistical Analysis

The experimental design was a completely randomized design (CRD) with six replications. The data was analyzed using SPSS 11.5 statistical software. A one-way ANOVA was applied to evaluate significant differences in the studied parameters in the different treatments. The LSD ($p < 0.05$) was calculated using the error mean squares of the analysis of variance.

Results

Auxins-induced Bud Initiation and Surviving Rate

The effects of different cutting positions and rooting hormones on days to bud initiation, bud number, bud length and survival rate of stem cutting (Table 2). The days taken to bud initiation of *P. pterocarpum* were significantly longer compared to *L. leucocephala* cuttings. After 30 days of treatment, *L. leucocephala* indicated no significant difference among different cutting position and rooting hormones. In case of basal and apical cutting position of *P. pterocarpum*, the highest bud number (per cutting stem) was noticed in IBA and the lowest was observed in control. Initial bud length of *L. leucocephala* and *P. pterocarpum* were 6 and 10 cm, respectively, in both cutting position and different rooting hormones. After 30 days, the survival rate of both positions of *L. leucocephala* stem cutting even treated in IBA and NAA hormones were not found. *L. leucocephala* was not suitable for vegetative propagation by stem cutting although it showed earlier emergence of buds and leaves than *P. pterocarpum* and cuttings were treated even by different rooting hormones. After 30 days, the survival rate of both cutting positions of *P. pterocarpum* was found to be 100% in the control or even NAA and IBA treatments.

Auxins Effect on Stem Number, Leaf Number and Surviving Rate

Of two species, stem cuttings of *L. leucocephala* did not show any bud growth after 2 weeks and died within 4 weeks, while initial bud initiation was observed within 2 days (Table 2). Contrarily, in *P. pterocarpum* after 4th weeks and onwards, shoot growth was observed only in stem cuttings (Table 3). The results showed that the cuttings treated with auxin hormones had significantly higher number of new stem, and leaves than those of control cuttings. The effects of different cutting position were highly significant ($p<0.05$) for stem and leaf number and survival percent. Cuttings taken from the basal position had significantly higher stem and leaf number than stem cutting taken from apical position. After six months, highest survival rate was also observed in basal cuttings. In case of basal position cutting of *P. pterocarpum*, the survival rate in IBA, NAA and control treatments were 100, 83, and 66%, respectively, whilst the survival of apical position cutting of *P. pterocarpum* in IBA, NAA and control treatments were 50, 50 and 33%, respectively. Moreover, IBA hormone applications on *P. pterocarpum* cuttings were more effective in terms of survival than the NAA or control (Table 3).

Biomass Production and LAI

In terms of root biomass production, basal position had significantly ($p<0.05$) higher root biomass than apical position. The weight of shoot biomass (new branches and leaves) was higher by 101% in IBA treated than control (Table 4). Thus, it can be said that the shoot growth is favored by triggering enough growth of root by IBA hormone than NAA and control. In this experiment, the ratio of root-shoot biomass was measured too to assess whether the *P. pterocarpum* has sufficient roots to absorb water and sufficient leaf surface for transpiration. In addition, WAR was higher by 24% in IBA also, implying that a greater relative increase in root biomass can absorb more water by utilizing a greater volume of soil.

Table 2: After 30 days, the effect of different cutting positions and hormone treatments on bud initiation, bud number and surviving rate of different species

Species and cutting position	Treatments	Bud initiation (days)	Bud number (per cutting stem)	Initial budding length: within 2 weeks^{ns} (cm)	Survival rate^{ns} (%)
L. leucocephala Basal	IBA	2±0.5ns	4.4±0.2^{ns}	6.4±0.4^{ns}	0
	NAA	2±0.4ns	4.8±0.3^{ns}	6.8±0.4^{ns}	0
	Control	2.2±0.3ns	4.8±0.2^{ns}	6.8±0.4^{ns}	0
L. leucocephala Apical	IBA	2.2±0.3ns	5±0.2^{ns}	6.4±0.5^{ns}	0
	NAA	1.8±0.3ns	4.4±04^{ns}	5.4±0.2^{ns}	0
	Control	2.2±0.5ns	4.6±0.4^{ns}	6.2±0.3^{ns}	0
P. pterocarpum Basal	IBA	7±0.4ns	3.4±0.2a	10.8±0.4^{ns}	100
	NAA	7±0.5ns	3.2±0.2ab	10.6±0.6^{ns}	100
	Control	7.4±0.7ns	1.2±0.2c	10.8±0.3^{ns}	100
P. pterocarpum Apical	IBA	7.6±0.6ns	2.2±0.2x	10.8±0.5^{ns}	100
	NAA	7.4±0.7ns	2±0.0xy	11±0.4^{ns}	100
	Control	7.2±0.3ns	1±0.0z	10.8±0.5^{ns}	100

Means (data are means ± standard error) with different letters were significantly different ($p < 0.05$, ANOVA); ^{ns}, not significant

Table 3: Effects of different cutting positions and rooting hormones on stem number, stem diameter and survival rate of *P. pterocarpum* after 6th month of growth

Treatments	Total stem number	Leaf number	Stem diameter (mm)	Survival rate (%) after 6th month
Control (Basal)	1.2±0.2c	11±1.2c	7.4±0.1^{ns}	66c
IBA (Basal)	3.4±0.2a	25±1.4a	7.7±0.3^{ns}	100a
NAA (Basal)	3.2±0.2ab	20±1.4b	7.6±0.2^{ns}	83b
Control (Apical)	1.0±0.0c	6±0.5c	7.0±0.4^{ns}	33b
IBA (Apical)	2.2±0.2a	13±1.4a	7.6±0.2^{ns}	50a
NAA (Apical)	2.0±0.0ab	11±0.6ab	7.4±0.2^{ns}	50a

^{ns}, non-significant

Table 4: Biomass and WAR of different treatments of *P. pterocarpum* stem cuttings

Treatments	Shoot biomass (g)	Root biomass (g)	Ratio	WAR
Control (Basal)	107.6±4.3c	21.0±1.5c	5.1±0.1	19.4±0.5c
IBA (Basal)	212.0±6.6a	61.3±3.5a	3.4±0.2	24.2±0.6a
NAA (Basal)	196.6±8.8b	28.3±2b	7.0±0.8	21.2±2.2ab
Control (Apical)	70.6±3.1c	16±1.8c	4.2±0.3	14.0±0.8c
IBA (Apical)	166.0±3.4a	34±2.3a	4.9±0.2	20.3±1.6a
NAA (Apical)	151.3±3.7b	29±2b	5.2±0.5	17.4±0.6ab

Means (data are means ± standard error) with different letters were significantly different ($p < 0.05$, ANOVA)

Table 5: Effects of different cutting positions on LAI

Treatments	LAI 3rd month	6th month
Control (Basal)	0.34±0.02c	0.45±0.07c
IBA (Basal)	0.59±0.05a	0.7±0.02a
NAA (Basal)	0.43±0.02b	0.57±0.02b
Control (Apical)	0.24±0.04c	0.26± 0.04c
IBA (Apical)	0.37±0.02a	0.47± 0.01a
NAA (Apical)	0.3±0.02b	0.38± 0.01b

Means (data are means ± standard error) with different letters were significantly different ($p < 0.05$, ANOVA)

The effects of different cutting positions and hormones on LAI are shown in Table 5. Basal cuttings indicated increased LAI compared to apical stem cuttings. Additionally, IBA treated cuttings of basal or apical cutting positions revealed significant increments in LAI. The LAI was increased as the number of leaf increase (Table 3), reaching a peak at 6th month in case of each treatment.

The LAI values of IBA treated cuttings were higher in both 3rd and 6th months than the NAA treated cuttings. This observation may reflect that IBA has initiated more to vegetative growth than NAA. Additionally, interactive effects of cutting positions were found to be highly related to vegetative growth or LAI.

Treated Stem Cutting Interaction with Soil Moisture and Matric Suction

Table 6 showed the soil moisture content and matric suction at 3rd and 6th months. It was observed that uses of basal position cuttings are more effective for the reduction of soil moisture content than the apical position of stem cuttings. Moreover, IBA rooting hormone has more promising effects on the reduction of soil moisture than NAA and control treatments.

Additionally, the ranges of matric suction and their variation with cutting position at three treatments during 3rd and 6th month were also investigated. Same results like soil moisture go to matric suction of soil in both positions of stem cuttings. It was observed that at 6th month, the matric suction in basal position of control stem cuttings rooted soil was 35% greater than apical position cutting. Moreover, higher matric suction was found in the IBA than NAA and control soil. Higher LAI, vegetative growth and root biomass were observed for rooting hormones and basal position cuttings (Table 4 and 5), implying that higher LAI, vegetative growth and root biomass increased water absorption capacity and matric suction.

Root Profiles, Length and Volume

After harvesting the stem cuttings of *P. pterocarpum*, it was observed that different treated cuttings showed different types of adventitious rooting system. The responses in root length and root volume varied with different types of hormone and positions of stem cutting. In case of cutting position, the highest root length was noticed in basal

Table 6: The soil moisture content (%) and matric suction at 3rd and 6th months

Parameters	Month	Control	Basal position IBA	NAA	Control	Apical position IBA	NAA
Moisture content (%)	3rd	25.8±0.7a	16.8±0.7c	21.5±0.7b	27.1±0.5a	20.7±0.5c	25.3±0.6b
	6th	21.3±0.6a	13.6±0.3c	17.9±0.5b	23.6±0.6a	16.4±0.7c	18.2±0.8b
Matric suction (kpa)	3rd	17±0.6c	22±1a	19±0.8b	16±0.5ns	17±0.8ns	16±0.3ns
	6th	23±0.6c	30±0.8a	26±0.5b	20±0.5c	26±0.8a	24±0.5b

Means (data are means ± standard error) with different letters were significantly different ($p < 0.05$, ANOVA); ns, not significant

position cutting with IBA treatment and the lowest root length was observed in apical position with control treatment (Fig. 1 and 2). This indicates that the basal cutting position with IBA rooting hormone was most effective in promoting root length of this species. Regarding the root volume, different hormones had different effects too. Best results were achieved in IBA treated stem of basal position cuttings. Additionally, root volume was significantly higher within the root diameter ranged from 0.5 mm to 2.5 mm in each treatment (Fig. 3). According to the present observations, the best position for higher root length and volume are basal position and the best hormone for rooting success is IBA. Therefore, it was assumed that a higher root length and volume due to fine roots (0.5-2.5 mm) increased root-soil matrix area, which ultimately increased its capability to absorb sufficient water. As a result, removal of excessive water would lead to drying of soil.

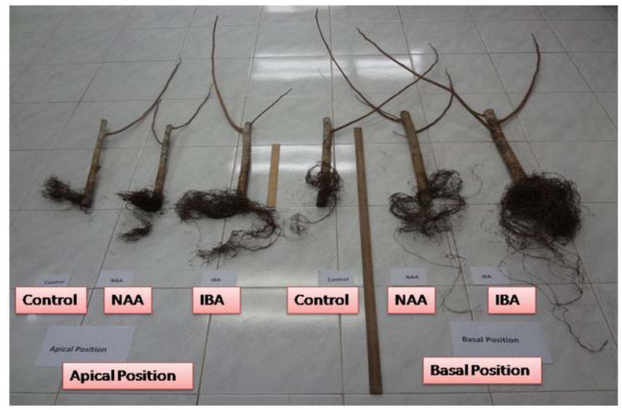

Fig. 1: Photograph of different root systems of *P. pterocarpum* stem cutting. Basal and apical position of stem cuttings are treated in IBA, NAA and control

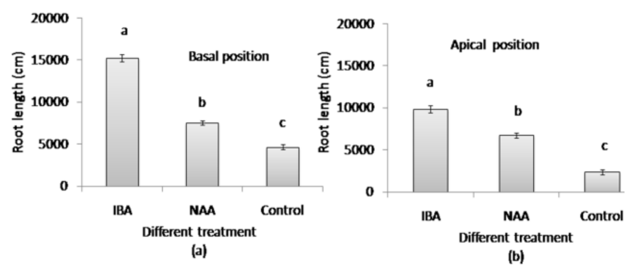

Fig. 2: Effects of different treatments on the *total root length; (a)* Basal position and (b) apical position. Vertical bars represent the LSD at the 5% level. Means (data are means ± standard error) with different letters were significantly different ($p < 0.05$, ANOVA)

Cutting Position and Hormones on Photosynthesis, Stomatal Conductance, Transpiration Rate and Water Use Efficiency (WUE)

Net photosynthesis, stomatal conductance and transpiration rate of all stem cuttings of *P. pterocarpum* were measured in a greenhouse condition at 6th month of planted age. Lower photosynthetic rates, stomatal conductance and transpiration rates were observed in apical position cuttings than basal position cuttings (Fig. 4). Auxins, especially IBA, increased net photosynthesis of both position of stem cuttings, while the cuttings treated without auxins (control) showed less photosynthetic rates, stomatal conductance and transpiration rates**.** Additionally, the increase in WUE with basal and apical position treatments was similar to photosynthesis. In IBA treatment, the WUE of basal and apical cuttings were increased by 69 and 43%, respectively. However, in NAA treatment, the WUE of basal and apical cuttings were increased by 18 and 9%, respectively. A positive correlation among photosynthesis, stomatal conductance and transpiration rate were observed. The significant correlation between photosynthesis and WUE suggested that high WUE seems to be attributed to high assimilation rate (Fig. 5).

Discussion

Vegetative propagation by stem cuttings is a useful method for growing plants with desired characteristics. In this study, it was observed that vegetative reproduction was possible from stem cuttings of *P. pterocarpum* but not for *L. leucocephala*. Auxins are widely applied in stem cutting of various woody plants. Generally, quick-dipping in IBA and NAA hormone has been used mostly to propagate plants by any stem cutting (Dhillon *et al.,* 2011). In this study, survival rate, adventitious root-shoot initiation and plant physiology such as photosynthesis were greatly affected by cutting position, although there was a hormonal effect in initiating the adventitious roots, leaves and new branching as well. Huat and Kazemian (2010) discussed that the rooting success and physiology of a stem cuttings were depended on the types of plant species. Their studies also showed that rooting success of any species was directly related to the growth stage of parent plants and position of stem cutting. Balestri and Lardicci (2006) reported that rooting and survival variations were dependent on season of a year.

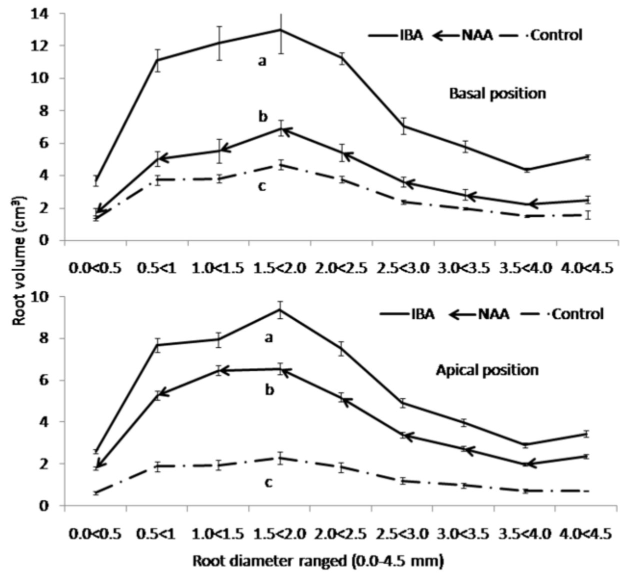

Fig. 3: *E*ffect of different *treatments* on the root volume. Root volume is also classified according to various diameter ranges; fine roots (0.0-2.0 mm) and thin roots (2.0<4.5 mm). Vertical bars represent the LSD at the 5% level. Means (data are means ± standard error) with different letters were significantly different ($p < 0.05$, ANOVA)

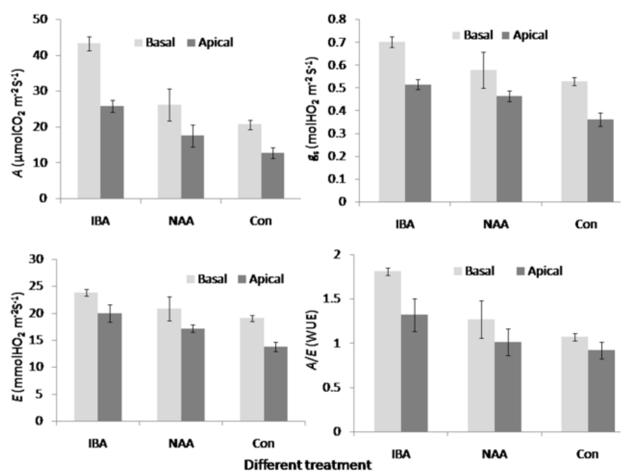

Fig. 4: Effects of different treatments on the photosynthetic rates, stomatal conductance, transpiration rates and WUE. Vertical bars represent the LSD at the 5% level. Means (data are means ± standard error) with different letters were significantly different ($p < 0.05$, ANOVA)

In case of plant survival rate, basal position of cuttings treated with IBA, NAA and control showed 100, 83 and 66%, respectively but apical position cutting showed poor response to survive. Basal position cuttings had significantly more leaves than apical cuttings. Additionally, the cuttings collected from apical positions also showed the lowest vegetative growth. Variations in survival rate and root-shoot growth between cuttings taken from different portions of the

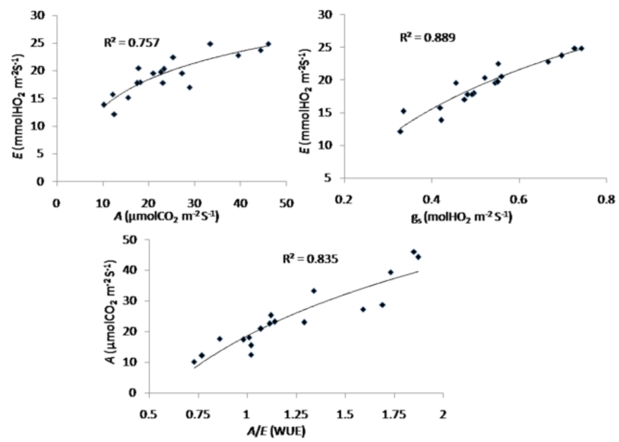

Fig. 5: A positive correlation among photosynthetic rates, stomatal conductance, transpiration rates and WUE

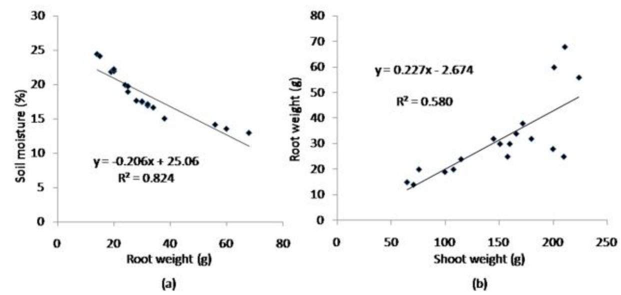

Fig. 6: (a) Negative correlation between soil moisture content and root biomass; **(b)** Positive correlation between shoot weight and root weight

shoot were in agreement with other studies conducted by Husen and Pal (2007). Zalesny *et al.* (2003) documented that better root-shoot growth was observed in cuttings collected from basal position than those made from apical position. In this study, root formation was intensified with cutting position too. Higher root length and root volume were observed in cuttings taken from basal positions followed by those taken from apical cutting position (Fig. 2 and 3). This was potentially related to different carbohydrate storage and organogenic activity of different positions of stem cutting. Ezekiel (2010) showed that basil position had more sugars which were necessary for nutrient supply in initiating new root-shoot tips. Therefore, the cuttings made from apical position showed lowest survival rate and root-shoot biomass.

Like many other species, rooting ability of *P. pterocarpum* was susceptible to the hormone application too. Cuttings treated with IBA produced higher root length and volume than NAA and control cuttings. Ezekiel (2010) documented that a higher number of roots, root length and root volume per cutting with was observed in IBA treatment than control. Many researchers for example Opuni-Frimpong *et al.* (2008) and Husen and Pal (2007) reported that IBA has an important role in the development of adventitious roots, improving quality of roots and increasing root biomass. Signaling due to IBA and other hormones enhanced polysaccharide hydrolysis to provide energy for meristematic tissues of roots (Ezekiel, 2010). Moreover, this may be due to the hormonal action to regulate several physiological activities in proper way such as transpiration and plant development including root-shoot initiation and elongation (Shan *et al.*, 2012). The results of this present study such as high rooting ability and survival rate of cuttings taken from the basal position are in agreement with Ezekiel (2010) studies conducted on a tree species such as *Dalbergia melanoxylon*.

Different cutting positions and the application of auxins affected the photosynthetic rate, stomatal conductance, transpiration rate and WUE. The basal position cuttings had higher physiological activities than apical position cuttings. The increase in photosynthetic rate may be associated to the presence of carbohydrate content in stem and water absorption capacity by produced roots. According to Ezekiel (2010), this happened due to the availability of carbohydrates as a nutritional source and stem maturity of basal position. Smalley *et al.* (1991) documented that some carbohydrates are necessary for the rooting of stem cuttings. Moreover, increase in photosynthetic rates might be due to higher water absorption rate of roots by the basal position cutting. In addition to the carbohydrate content, promotion in rooting is also associated with the application of exogenous rooting hormones too, which is a direct source of additional nutrient (Ezekiel, 2010). Therefore, the potential contribution of IBA hormone is increase in photosynthesis rate and root initiation. Moreover, low photosynthetic rates and poor root initiation might be caused by nutritional stress, which was in control plants and apical position of stem cuttings.

Rooting hormones treated cuttings showed better root-shoot growth, which ultimately had better effects on soil physical properties such as reduction in soil moisture content and increase in matric suction. It was observed that moisture content was lower in hormone treated and basal position cuttings grown soil. Furthermore, there was a positive correlation between shoot and root biomass, implying that the underground biomass would be higher if the above ground biomass higher (Fig. 6). On the other hand, soil moisture content and root biomass are negatively correlated, implying that the higher the underground biomass referred the lower soil moisture content. Additionally, soil matric suction was affected by different cutting positions and hormone treatments as well. It was observed that the soil matric suction was lower at the 3rd month of growth phase than the 6th month of age. This could be because the LAI and vegetative growth was lower in the 3rd month of age among the vegetated soils. Additionally, in the 6th month of age, the soil matric suction was higher due to the availability of root biomass to absorb higher amount of water. Therefore, the higher matric suctions is also attributed to its vegetative growth and root biomass. Present results also indicated that soil moisture content (%) was strongly correlated with matric suction i.e., high matric suction was attributed to low soil moisture content (Fig. 7). A spider correlation chart was constructed to observe the overall impacts of different hormones and cutting positions on plant-root-soil relations (Fig. 8). According to the spider chart, when root biomass gradually increased, the moisture content of soil was progressively decreased with the increase of matrix suction. Moreover, increased LAI, leaf number and root volume were associated with WAR to remove more water in transpiration process improving plant-root-soil interaction and root–soil matrix (Fig. 9).

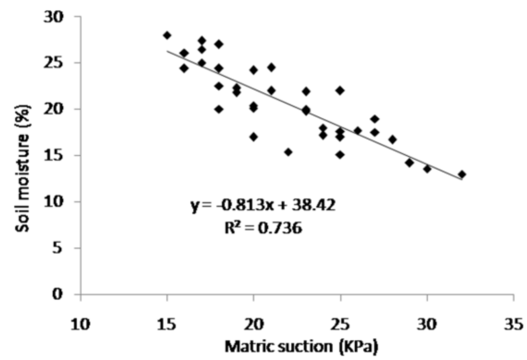

Fig. 7: Negative correlation between soil moisture content and matric suction

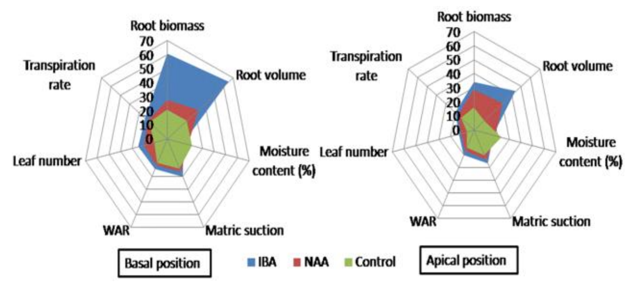

Fig. 8: Spider correlation charts among the studied parameters of basal and apical position stem cuttings

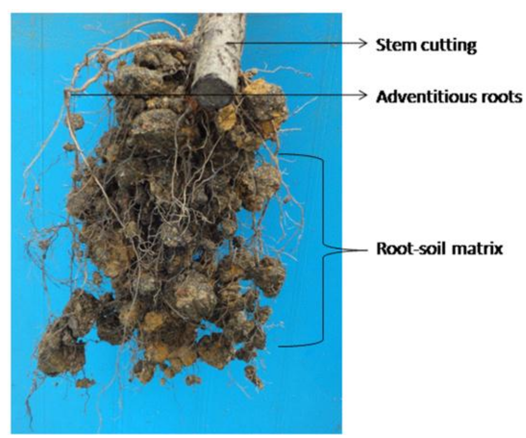

Fig. 9: Roots emerging from a stem cutting, fibrous root systems and root-soil matrix

In this study, the root biomass and volume were significantly higher in basal position and IBA treated cuttings, respectively than apical position and NAA or control. Al-Salem and Karam (2001) also have found that the rooting ability was lowest when the cuttings made from apical positions. In IBA treatment, maximum root volume was observed in 1-2 mm of root diameter, which was considerate as fine roots. These fine roots were comparatively beneficial for the reduction of soil moisture content and supportive to increase the soil matric suction. Osman and Barakbah (2006) developed a relationship as an indicator to predict highly reinforced soil observing lower moisture content and high root length density in soil. In stem cuttings, water is absorbed through the roots, while growing. As stem cutting roots absorb water, soil will be less saturated which will result in the soil of being drier and thus increased matric suction and soil reinforcement.

In conclusion, vegetative propagation through stem cuttings was not suitable for *L. leucocephala*. While, vegetative propagation by stem cuttings was possible for *P. pterocarpum*. Based on the vegetative growth, root profiles and root-soil interaction (matrix) screenings, the present stem cutting technique could be an alternate way in propagating *P. pterocarpum* as a large-scale to enhance root-soil matrix and reinforce soil. Basal position of a stem cuttings and IBA hormone were the most effective in initiating adventitious roots. Rooting hormones are recommended to use before plantation of stem cuttings. However, more stringent screening will be conducted on *P. pterocarpum* to examine further their potential as soil-bioengineering materials on slope condition.

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