Ethiop. J. Biol. Sci. 11(2): 105-116, 2012
 ISSN: 1819-8678

NURSERY GROWTH AND BIOMASS OF THE SEEDLINGS OF NINE TREE SPECIES PLANTED UNDER DIFFERENT POTTING MEDIA IN NORTHWEST ETHIOPIA

Yigremachew Seyoum[1,]*, Demelash Alem[2], Fikadu Getnet[2] and Behailu Kebede[2]

ABSTRACT: The production of quality seedlings depends on the potting media. A nursery experiment was conducted in Pawe Agricultural Research Centre, in the northwest part of Ethiopia in 2006. The study was aimed at investigating the impact of different potting media on biomass and growth and also identifying the properties that influence seedlings' nursery performance. Four types of potting media, three of them mixed from different proportions (farm yard manure, forest soil, sand), and the local soil were compared. A factorial experiment was laid out in Randomized Complete Block Design. ANOVA on growth and biomass data were performed for nine tree species using the GLM procedure of SPSS (Version 13). In most of the studied species, the seedlings planted in potting media with the un-amended local soil showed significantly highest ($p<0.05$) shoot height, root collar diameter, shoot and root biomass. The present results from biomass and growth analyses suggested that physical properties which determine plant water relations are essential to seedling growth during dry spells of the year, when most nurseries of Ethiopian drylands produce tree seedlings. Under such conditions, potting media calibration should aim at amending physical properties such as total porosity and bulk density. The notion of enhanced seedling growth in substrates of high organic matter content should be carefully considered in nurseries of dry areas.

Key words/phrases: Biomass, Bulk density, Growth, Potting media, Total porosity.

INTRODUCTION

An increasing demand for wood and non-wood forest products coupled with the acceptance of forests in the clean development mechanism as a feasible solution to tackle climate change problems (Jeker, 2009) has enhanced the emphasis paid to tree planting. The intergovernmental panel for climate change estimates that 12-15% of the fossil fuel CO_2 emissions between 1995 and 2050 could be offset through slowing tropical deforestation, allowing these forests to regenerate, and engaging in plantation establishment and other forms of agroforestry (Litynski *et al.*, 2006). Deforestation, apart from increasing global atmospheric CO_2 concentration,

[1] Ethiopian Institute of Agricultural Research, Kulumsa Research Centre, P. O. Box 489, Assela, Ethiopia
[2] Ethiopian Institute of Agricultural Research, Pawe Research Centre, P. O. Box 25, Pawe, Ethiopia
* Author to whom all correspondence should be addressed

causes a considerable loss of biodiversity consequently influencing the quality and quantity of ecosystem services which are important to humans and other organisms (FAO, 2001). Similar to other tropical regions, native forests of Ethiopia have dwindled at a huge pace and this seems to have occurred relatively early (2000 years ago), and was extensive in comparison to other East African countries (Bekele Lemma, 2006).

Rehabilitation of deforested lands is possible through afforestation with fast-growing trees species (Pohjonen and Pukkala, 1990) and it is possible to restore degraded forests through enrichment planting. However, afforestation efforts are often constrained by poor site conditions resulting in low seedling survival and early establishment (Mangaoang and Harrison, 2003). Survival and growth under inhospitable site conditions can be improved by species and provenance screening (Zobel and Talbert, 1984). Likewise, production of healthy and vigorous tree seedlings improves the performance of seedlings planted under marginal site conditions (Baiyeri and Mbah, 2006; Birge *et al*., 2006; West, 2006; Bashir *et al*., 2007; Oskarsson, 2010).

The production of quality seedlings depends on the physical, chemical and biological properties of the potting media (Tesfaye Wubet *et al*., 2003; Baiyeri and Mbah, 2006; Khan *et al*., 2006), which is a function of the base materials constituting the substrate. The effect of different growing media on growth and biomass accumulation of seedlings through their influence on mineral content, aeration, favouring activities of lower organisms and water holding capacity has been well documented (Heiskanen, 1993; Baiyeri and Mbah, 2006; Mhango *et al*., 2008; Kumar *et al*., 2009; Oskarsson, 2010). Factors that determine the suitability of potting media can vary with the species requirement and climatic conditions of a site (Sultani *et al*., 2007; Kaufmann *et al*., 2010).

In open nurseries of dry areas, drought stress may deteriorate seedling quality and elevate nursery costs by increasing watering frequency. However, despite extreme temperature and high moisture demand during the period of seedling production in northwestern Ethiopia, nurseries lack standardized potting media compatible with the climate. We hypothesized that under hot and dry conditions, less proportion of coarser growing substrate could favour growth and biomass accumulation of seedlings by minimizing moisture loss through percolation and evaporation. The objectives of this study were, therefore, to identify important properties of growing substrates that determine the nursery performance of nine commonly planted tree species and to show the impact of different potting media on seedling growth and biomass production.

MATERIALS AND METHODS

Study site

A potting media experiment was conducted in an open nursery of Pawe Agricultural Research Centre (PARC), Metekel, Ethiopia (11°18' N latitude, 36°24' E longitude), from February to May 2006. The average minimum and maximum temperatures were 17.7°C and 37.6°C, respectively. The mean annual rainfall of the study area is 1,600 mm. The mean potential evapotranspiration (PET) is about 1,300 mm. The altitude of the area ranges between 1,000 to 1,200 metres above sea level. The soils are broadly categorized as Vertisols, which account for 40 to 45% of the area; Nitisols that account for 25 to 30%, and intermediate soils of a blackish brown colour, which account for 25 to 30% (Dieci and Viezzoli, 1992).

Plant material

Seeds of nine commonly raised tree species (*Acacia saligna* (Labill.) Wendl. f., *Cordia africana* Lam., *Delonix regia* (Bojer ex Hook.) Raf., *Eucalyptus camaldulensis* Dehnh., *Jacaranda mimosifolia* D. Don, *Melia azedarach* L., *Schinus molle* L., *Sesbania aculeata* (Willd.) Pers, and *Leucaena leucocephala* (Lam.) deWit) collected from the surroundings were directly sown in plastic containers of 10 cm in diameter and 15 cm in height. Two to four seeds of each species were sown, and two weeks after germination, only one healthy and vigorous seedling was left in each pot. All nursery activities were carried out following the practices used in the nurseries of the studied area. That is, the seedlings were watered twice a day, weeded when necessary, and grown under shade of about 1 m high.

Potting media

The investigated potting media had farm yard manure (FYM), forest soil (FS) and sand (S) in proportions of 50%:35%:15% in potting media 1 (PM1), 60%:25%:15% in potting media 2 (PM2) and 50%:25%:25% in potting media 3 (PM3). These potting media represent the common practice applied in the study area. We have observed that these selected potting media are widely used in different nurseries of the study area irrespective of species type and the climate condition. Potting media 4 (PM4) was the local un-amended soil. FYM was obtained from the local livestock barn, FS was collected from the nearby forest, which was dominated by different *Acacia* spp., and sand was obtained from a river bordering the nursery. Total nitrogen and organic carbon (following Kjeldhal and Walkeley-Black methods, respectively) and pH of the base materials was analyzed in the soil laboratory of PARC. Bulk densities (BD) of the formulated potting media were analyzed following Blake and Hartge (1986). Total porosity (TP%) was calculated as [1-(BD/PD)]*100, where PD (particle density) was considered 2.65 g/cm^3 (Brady and Weil, 2002).

Experimental design and set up

A factorial experiment was designed in randomized complete block design (RCBD) with three blocks. Blocking was laid out against the slope of the nursery bed. Of the total 25 seedlings planted, the inner nine were sampled for measurements. Blocks were separated by 2 m while 0.5 m was left among tree species.

Determination of growth and biomass

Seedling height (SH) and root collar diameter (RCD) were recorded for each species. Measurements on these parameters were done 100 to 105 days after sowing since the majority of the seedlings reached planting size at this time. SH was measured from the surface of the container to the highest tip of seedlings using a millimetre graduated glass ruler. RCD was measured on the girth of the seedlings immediately after the surface of the container using a calliper. After measurement of SH and RCD, the seedlings were uprooted, and then the parts were separated into shoot and root components. After hand washing, shoot and root parts, including fine roots, were oven-dried at 80°C for 72 h to determine root dry weight (RDW) and shoot dry weight (SDW). The weight was measured using sensitive digital weight balance.

Statistical analysis

All the data were statistically analyzed using statistical software (SPSS Version 13). ANOVA was performed following the GLM procedure to detect significant mean growth and biomass differences among seedlings planted in different potting media. The data were checked for normality and homogeneity of error variance. When significant treatment effects were detected across potting media, means were compared by Tukey (HSD) test. Mean differences were considered significant when $p \leq 0.05$.

RESULTS

Chemical and physical properties of the growing substrates

Organic carbon varied significantly ($p<0.05$) among the base materials. The results show that pH and total nitrogen were statistically highest for FYM ($p<0.05$) (Table 1). BD and TP showed significant variation among potting media; the local soil had significantly high BD but low TP values (Fig. 1).

Table 1. Chemical properties of three base materials forming the potting media.

Base materials	pH (1:2.5 H_2O)	T.N%	OC%
Forest soil	6.95 (0.34) ^{b}	0.31(0.04) ^{b}	3.95 (0.50) ^{b}
Local soil	6.79 (0.08) ^{b}	0.19 (0.02) ^{c}	2.32 (0.12) ^{c}
Farm yard manure	7.87 (0.04) ^{a}	0.99 (0.02) ^{a}	7.66 (0.01) ^{a}

pH- acidity, T.N%- total nitrogen, OC%-organic carbon. While values indicate sample means, numbers in parenthesis represent ± S.E. Values followed by similar letters in the same column are not significantly different at $p\leq0.05$.

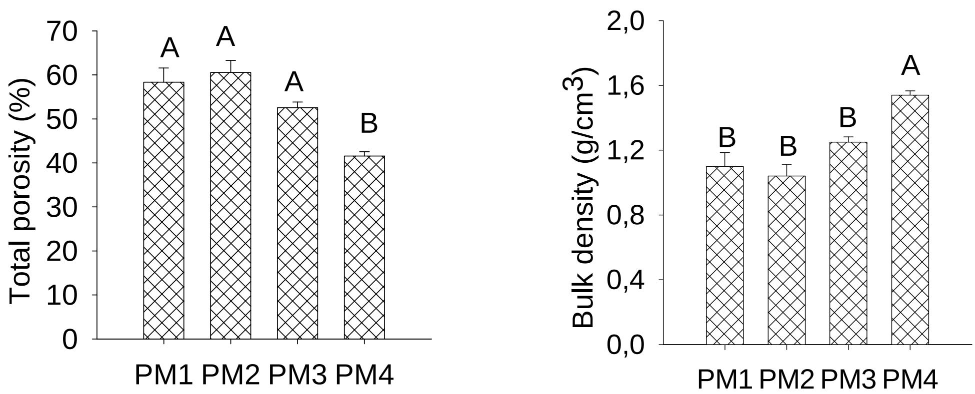

Fig. 1. Physical properties of potting media, total porosity (%) and bulk density (g/cm^3). Bars indicate mean values (n=5) followed by error bars showing ± standard error. Potting media values designated by similar letters are not significantly different at $p\leq0.05$.

Seedling height and stem girth

Seedling height was the highest in PM4 than the other potting media (Fig. 2) and differences were statistically significant ($p<0.05$). Among the experimented tree species, *S. aculeata*, *S. molle*, *C. africana* and *L. leucocephala* had significantly higher SH ($p<0.05$) in PM4 (Table 2). Though variations for the remaining tree species were not statistically significant, *A. saligna* had 39% higher height growth in the PM4 than in the PM1 while *M. azedarach* had 21% higher height growth in the PM4 than in the PM1. Similarly, stem girth was significantly different among the potting media, seedlings planted in PM4 showing the highest growth (Fig. 2).

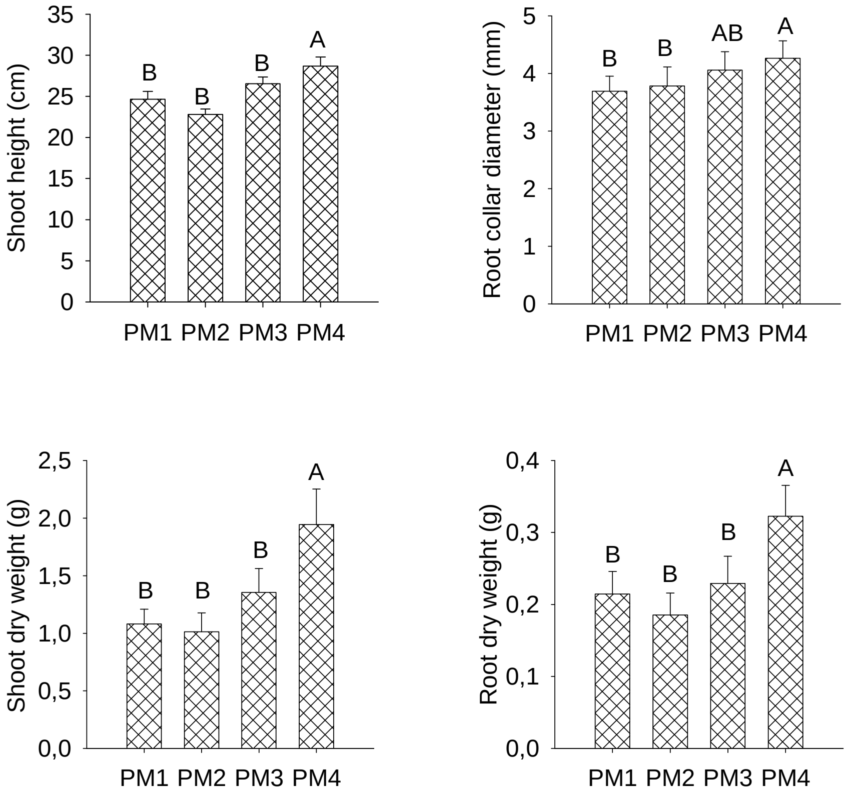

Fig. 2. Seedling growth and biomass accumulation of different tree species planted under differing potting media. Bars indicate mean values (n=9) followed by error bars showing ± standard error. Potting media values designated by similar letters are not significantly different at p≤0.05.

Table 2. Shoot height (cm) of nine tree species grown under four different potting media.

Tree species	**Potting media**			
	PM1	**PM2**	**PM3**	**PM4**
D. regia	25.61 (2.79)^{a}	23.69(0.56)^{a}	27.25(2.09)^{a}	24.89(1.19)^{a}
M. azedarach	24.9(2.2)^{a}	20.41(2.03)^{a}	25.55(1.85)^{a}	26.15(0.54)^{a}
S. aculeata	32.52(0.44)^{a}	26.72(0.92)^{a}	32.94(3.5)^{a}	41.48(0.75)^{a}
S. molle	22.94(1.61)^{ab}	21.39(1.32)^{b}	23.96(1.87)^{b}	29.03(1.27)^{b}
C. africana	23.53(1)^{b}	22.65(3.86)^{b}	27.98(2.56)^{ab}	36.04(2.16)^{a}
A. saligna	14.88(4.3)^{a}	20.68(1.35)^{a}	24.44(1.67)^{a}	24.4(2.7)^{a}
L. leucocephala	27.12(0.68)^{ab}	26.7(0.96)^{ab}	26.1(0.94)^{b}	29.96(0.58)^{a}
J. mimosifolia	23.58(1.77)^{a}	19.08(0.49)^{b}	23.04(0.68)^{ab}	21.96(0.39)^{ab}
E. camaldulensis	26.74(1.44)^{a}	23.98(0.68)^{a}	27.66(3.63)^{a}	24.27(0.77)^{a}

Values represent means (n=9) while numbers in parenthesis indicate ± standard error. Means within a row designated by similar letters are not significantly different at p≤0.05.

Among the studied tree species, *D. regia*, *S. aculeata*, *S. molle* and *J. mimosifolia* showed significantly higher ($p<0.05$) RCD growth in the PM4 (Table 3). *A. saligna* seedlings planted in the PM4 had 20% higher RCD than seedlings planted in the PM1.

Table 3. Root collar diameter (mm) of nine tree species grown under four different potting media.

Tree species	Potting media			
	PM1	PM2	PM3	PM4
D. regia	4.93(0.14)^{b}	4.8(0.32)^{b}	5.25(0.34)^{b}	6.55(0.41)^{a}
M. azedarach	3.78(0.35)^{a}	3.49(0.24)^{a}	3.4(0.3)^{a}	3.65(0.17)^{a}
S. aculeata	2.09(0.06)^{ab}	1.73(0.12)^{b}	2.16(0.18)^{ab}	2.5(0.11)^{a}
S. molle	2.44(0.15)^{b}	2.76(0.08)^{ab}	2.73(0.13)^{b}	3.43(0.22)^{a}
C. africana	7.18(0.38)^{a}	7.48(0.8)^{a}	8.4(0.64)^{a}	7.5(0.74)^{a}
A. saligna	3.9(0.16)^{a}	4.15(0.27)^{a}	4.66(0.34)^{a}	4.84(0.33)^{a}
L. leucocephala	3.24(0.14)^{a}	2.95(0.33)^{a}	3.58(0.35)^{a}	3.46(0.1)^{a}
J. mimosifolia	3.51(0.13)^{ab}	2.99(0.1)^{b}	3.78(0.18)^{a}	3.76(0.14)^{a}
E. camaldulensis	2.18(0.12)^{a}	2.13(0.23)^{a}	2.59(0.22)^{a}	2.49(0.06)^{a}

Values represent means (n=9) while numbers in parenthesis indicate ± standard error. Means within a row designated by similar letters are not significantly different at $p \leq 0.05$.

Shoot and root dry weight

Both SDW and RDW were significantly higher ($p<0.05$) in the seedlings planted in PM4 compared with the other three potting mixtures (Fig. 2). Among the tree species, *D. regia*, *S. aculeata*, *S. molle*, *J. mimosifolia* and *A. saligna* had significantly higher ($p<0.05$) SDW in PM4 (Table 4). SDW of *E. camaldulensis* seedlings was 40% higher in seedlings grown in PM4 than in PM2 and that of *L. leucocephala* was 19% higher in seedlings grown in PM4 as compared with seedlings grown in the PM1. Similarly, SDW of *C. africana* seedlings planted in PM4 were 45% higher than seedlings grown in the PM2.

Table 4. Shoot biomass (g) of nine tree species grown under four different potting media.

Tree species	Potting media			
	PM1	PM2	PM3	PM4
D. regia	1.9 (0.37)^{b}	1.73 (0.06)^{b}	2.18 (0.31)^{b}	4.88 (1)^{a}
M. azedarach	1.13 (0.2)^{a}	0.68 (0.12)^{b}	0.83 (0.13)^{ab}	0.95 (0.04)^{ab}
S. aculeata	0.35 (0.03)^{ab}	0.21 (0.03)^{b}	0.41 (0.08)^{ab}	0.56 (0.06)^{a}
S. molle	0.29 (0.05)^{b}	0.45 (0.05)^{b}	0.5 (0.12)^{b}	1.2 (0.23)^{a}
C. africana	2.58 (0.13)^{a}	3.1 (0.82)^{a}	4.14 (0.8)^{a}	4.65 (0.99)^{a}
A. saligna	0.98 (0.17)^{b}	0.88 (0.05)^{b}	1.23 (0.19)^{b}	1.97 (0.23)^{a}
L. leucocephala	0.94 (0.08)^{a}	0.98 (0.08)^{a}	1.1 (0.17)^{a}	1.17 (0.16)^{a}
J. mimosifolia	0.91 (0.13)^{ab}	0.62 (0.05)^{b}	1.04 (0.09)^{ab}	1.15 (0.13)^{a}
E. camaldulensis	0.66 (0.03)^{a}	0.47 (0.07)^{a}	0.77 (0.15)^{a}	0.79 (0.08)^{a}

Values represent means (n=9) while numbers in parenthesis indicate ± standard error. Means within a row designated by similar letters are not significantly different at $p \leq 0.05$.

On the other hand, RDW analysis showed that *D. regia*, *S. aculeata*, *S. molle*, *J. mimosifolia* and *A. saligna* had significantly higher growth ($p<0.05$) in the PM4 when compared with seedlings planted in the remaining potting mixtures (Table 5). Moreover, seedlings of *E. camaldulensis* planted in the PM4 had 50% higher RDW than seedlings planted in the PM2. Similarly, the seedlings of *L. leucocephala* planted in the PM4 had 38% higher RDW than the seedlings in the PM1.

Table 5. Root biomass (g) of nine tree species grown under four different potting media.

Tree species	**Potting media**			
	PM1	**PM2**	**PM3**	**PM4**
D. regia	0.3(0.04)[b]	0.33(0.06)[b]	0.3(0.04)[b]	0.83(0.14)[a]
M. azedarach	0.42(0.11)[a]	0.2(0.05)[a]	0.2(0.08)[a]	0.28(0.05)[a]
S. aculeata	0.05(0.01)[b]	0.03(0.01)[b]	0.04(0.01)[b]	0.09(0.01)[a]
S. molle	0.05(0.01)[b]	0.06(0.00)[b]	0.07(0.01)[b]	0.18(0.03)[a]
C. africana	0.48(0.08)[a]	0.57(0.12)[a]	0.75(0.14)[a]	0.5(0.14)[a]
A. saligna	0.15(0.02)[b]	0.18(0.02)[b]	0.21(0.05)[b]	0.37(0.05)[a]
L. leucocephala	0.11(0.01)[a]	0.12(0.02)[a]	0.19(0.049)[a]	0.18(0.03)[a]
J. mimosifolia	0.26(0.13)[b]	0.1(0.01)[b]	0.18(0.02)[ab]	0.27(0.04)[a]
E. camaldulensis	0.11(0.01)[a]	0.08(0.02)[a]	0.13(0.02)[a]	0.17(0.02)[a]

Values represent means (n=9) while numbers in parenthesis indicate ± standard error. Means within a row designated by similar letters are not significantly different at $p\leq0.05$.

Generally, *D. regia*, *S. aculeata*, *S. molle*, *C. africana*, *A. saligna*, *L. leucocephala* and *J. mimosifolia* showed significantly higher growth and biomass that were revealed in different plant parts (Tables 3-4). *M. azedarach* and *E. camaldulensis* not only differed from the other species by lacking significantly higher growth and biomass in PM4, they neither showed significantly higher values at any of the other potting media when compared with PM4 (Tables 2-5).

DISCUSSION

Analysis of chemical properties of the base materials of the potting media suggested that FYM constitutes favourable growing condition as evidenced from significantly high pH (less acidity), organic matter, and the total nitrogen it possessed (Table 1). Organic matter content is an important component of soil characteristics as it determines other chemical and physical properties such as mineralization, aggregate stability, aeration, and favourable water uptake and retention properties (Shirani *et al*., 2002; Sultani *et al*., 2007). It also plays an important role in the chemical behaviour of several metals in soils (Kumar *et al*., 2009). In the present study, however, these favourable features were not reflected in growth and biomass of the seedlings planted in potting media with more proportion of FYM and FS (PM1 and PM2). Seedlings grown in potting media with less

FYM and FS (PM4) showed better growth and biomass (Fig. 2). This observation implies that the availability of organic matter and nitrogen in PM1 and PM2 were in excess of the amount required for growth and the seedlings may not have responded to the additional organic matter available from the farm yard manure. In agreement with our observation, Mhango *et al*. (2008) and Shirani *et al*. (2002) reported that application of high organic matter substrates, despite their effect in improving the availability of N and P, failed to result in improved growth and biomass accumulation.

The BD of PM4 was significantly higher ($p<0.05$) than the other growing media (Fig. 1). High proportion of FYM and FS contributed to the low BD observed in PM1, PM2 and PM3. The effect of FYM and FS in lowering BD of growing substrates have been studied (Mosaddeghi *et al*., 2000; Shirani *et al*., 2002; Iqobal *et al*., 2005; Ewulo *et al*., 2008; Kumar *et al*., 2009; Osaigbovo *et al*., 2010). Soil bulk density has been considered as one of the major physical characteristics of growing media since it influences water retention capacity and drainage in growing substrates (Fernandes and Cora, 2004). In the present study, BD of PM1, PM2, and PM3 were in the lower range of the optimal soil bulk density for optimal growth reviewed by Kaufmann *et al*. (2010). Too low bulk density, because of large proportion of macropores, lowers the amount of moisture retained in the soil following irrigation or rainfall (Kaufmann *et al*., 2010). Moreover, low bulk density can reduce plant growth by limiting mobility of nutrients in the immediate vicinity of the root, because of higher void space that restricts the soil volume contacting the root surface (Stirzaker *et al*., 1996; Yahya *et al*., 2010). In agreement with the present result, Osaigbovo *et al*. (2010) and Yahya *et al*. (2010) reported that higher bulk density soils enhanced the production of pepper seedlings and palm fruit yield, respectively. A decision for an optimal BD favourable for available soil moisture should be accounted for the soil-plant-atmosphere continuum, which determines the plant’s water balance (Slatyer, 1967).

High porosity and air space enhances plant gas exchange by maintaining sufficient oxygen supply to the roots and facilitates the simultaneous removal of respiratory CO_2 (Heiskanen, 1993). However, growing media with excessively high porosity are less in their water retaining capacity. Pores with diameters between 0.1 and 15 micro metre are assumed to retain and store more plant available water for prolonged time than substrates with high proportion of macropores, while the latter are essential for readily transmission of water (Fernandes and Cora, 2004; Sultani *et al*., 2007; Yahya *et al*., 2010). In the present study, total porosity was significantly higher (52-60%) in the potting media with high proportion of FS and FYM likely leading to rapid loss of moisture exposing the seedlings to drought stress till the next watering. In agreement with this study, other studies reported that coarser growth substrates of high porosity with high proportion of macropores do not provide favourable soil moisture condition (Goldsmith *et al*., 2001; Mhango *et al*., 2008). Moreover, under dry conditions, as potting media gets dry, air gaps develop between the soil particles and the roots, and hydraulic conductivity decreases thus increasing resistance of water movement to the roots (Heiskanen, 1993).

We conclude that potting media characteristics induce significant growth and biomass change in seedlings of commonly planted tree species in northwest Ethiopia. Our finding demonstrates that physical properties that determine plant water relation such as total porosity and bulk density constrain seedling growth in open nurseries of arid areas. We recommend that seedlings of *D. regia*, *S. aculeata*, *S. molle*, *C. africana*, *A. saligna*, *L. leucocephala* and *J. mimosifolia* raised in open nurseries of dry areas should not be planted in potting media with a total porosity exceeding 40%, which is the value determined for PM4. The notion of enhanced seedling growth in substrates of high organic matter content should be carefully considered in nurseries of dry areas.

ACKNOWLEDGEMENTS

The cost of this study was fully covered by Ethiopian Institute of Agricultural Research. We would like to acknowledge Ato Gashu Mekonin, PARC management and soil laboratory technicians for their unreserved support in data collection and analysis. We thank the four anonymous reviewers for their critical comments on the previous version of the manuscript.

REFERENCES

Baiyeri, K.P. and Mbah, B.N. (2006). Effects of soilless and soil-based nursery media on seedling emergence, growth and response to water stress of African breadfruit (*Treculia africana* Decne). *Afr. J. Biotechnol.***5**:1405-1410.

Bashir, M.A., Ahmad, M. and Anjum, M.A. (2007). Effect of various potting media on growth of rooted jojoba (*Simmondsia chinensis*) cuttings. *Int. J. Agr. Biol.* **9**: 147-151.

Bekele Lemma (2006). Impact of exotic tree plantations on carbon and nutrient dynamics in abandoned farmland soils of southwestern Ethiopia. Swedish University of Agricultural Sciences, Doctoral thesis, Uppsala.

Birge, Z.K.D., Salifu, K.F. and Jacobs, D.F. (2006). Modified exponential nitrogen loading to promote morphological quality and nutrient storage of bare root-cultured *Quercus rubra* and *Quercus alba* seedlings. *Scand. J. Forest Res.* **21**: 306-316.

Blake, G.R. and Hartge, K.H. (1986). Bulk density. In: **Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods**, pp. 363-375 (Klute, A., ed.). 2nd ed. Soil Science Society of America, Madison, USA.

Brady, N.C. and Weil, R.R. (2002).**The Nature and Properties of Soils**. 3rd ed. Pearson Education Inc., Upper Saddle, New Jersey.

Dieci, P. and Viezzoli, C. (1992). Resettlement and rural development in Ethiopia: Social and economic, research, training and technical assistance in the Beles Valley, Addis Ababa.

Ewulo, B. S., Ojeniyi, S. O. and Akanni, D.A. (2008). Effect of poultry manure on selected soil physical and chemical properties, growth, yield and nutrient status of tomato. *Afr. J. Agric. Res.* **3**: 612-616.

FAO (2001). Forest genetic resources conservation and management. In: **Managed Natural Forests and Protected Areas (*in situ*). Vol. 2**. International Plant Genetic Resources Institute, Rome.

Fernandes, C. and Cora, J.E. (2004). Bulk density and relationship air/water of horticultural substrate. *Sci. Agric.* (*Piracicaba, Braz.*).**61**: 446-450.

Goldsmith, W., Silva, M. and Fischenich, C. (2001). Determining optimal degree of soil compaction for balancing mechanical stability and plant growth capacity. U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Heiskanen, J. (1993). Favorable water and aeration conditions for growth media used in containerized tree seedling production: A review. *Scand. J. Forest Res.* **8**: 337-358.

Iqobal, M., Hassan, A., Ali, A. and Rizwanullah, M. (2005). Residual effect of tillage and farm manure on some soil physical properties and growth of wheat (*Triticum aestivum* L.). *Int. J. Agri. Biol.* **7**: 54-57.

Jeker, R. M. (2009). Business opportunities in Africa for CDM projects and carbon trading. *Global Journal of Emerging Market Economies* **2**: 273-288.

Kaufmann, M., Tobias, S. and Schulin, R. (2010). Comparison of critical limits for crop plant growth based on different indicators for the state of soil compaction. *J. Plant Nutr. Soil Sc.* **173**: 573-583.

Khan, M.M., Khan, M.A., Abbas, M., Jaskani, M.J., Ali, M.A. and Abbas, H. (2006). Evaluation of potting media for the production of rough lemon nursery stock. *Pak. J. Bot.***38**: 623-629.

Kumar, A., Sharma, S. and Mishrab, S. (2009). Application of farmyard manure and vermin-compost on vegetative and generative characteristics of *Jatropha curcas*. *J. Phytol.* **1**: 206-212.

Litynski, J., Klara, S.M., Mcilvried, H.G. and Srivastava, R.D. (2006). An overview of terrestrial sequestration of carbon dioxide, The United States Department of Energy's Fossil Energy R and D program.

Mangaoang, E.O. and Harrison, S. (2003). Tree planting progress at four community forestry sites in Leyte: Some observations and lessons learned. *Ann. Trop. Res.* **25**: 1-10.

Mhango, J., Akinnifesi, F.K., Mng'omba, S.A. and Sileshi, G. (2008). Effect of growing medium on early growth and survival of *Uapaca kirkiana* Müell. Arg. seedlings in Malawi. *Afr. J. Biotechnol.* **7**: 2197-2202.

Mosaddeghi, M.R., Hajabbasi, M.A., Hemmat, A. and Afyuni, M. (2000). Soil compatibility as affected by soil moisture content and farmyard manure in central Iran. *Soil Till. Res.***55**: 87-97.

Osaigbovo, A.U., Nwaoguala, C.N.C. and Falodun, J.E. (2010). Evaluation of potting media for the production of pepper fruit (*Dennetia tripetala*) seedlings. *Afr. J. Gen. Agric*. **6**: 47-51.

Oskarsson, U. (2010). Potting substrate and nursery fertilization regime influence mycorrhization and field performance of *Betula pubescens* seedlings. *Scand. J. Forest Res.* **25**: 111-117.

Pohjonen, V. and Pukkala, T. (1990). *Eucalyptus globulus* in Ethiopian forestry. *Forest Ecol. Manag.* **36**: 19-31.

Shirani, H., Hajabbasi, M.A., Afyuni, M. and Hemmat, A. (2002). Effects of farmyard manure and tillage systems on soil physical properties and corn yield in central Iran. *Soil Till. Res*. **68**:101-108.

Slatyer, R.O. (1967). **Plant-Water Relationships**. Academic Press Inc., London.

Stirzaker, R.J., Passioura, J.B. and Wilms, Y. (1996). Soil structure and plant growth: Impact of bulk density and biopores. *Plant Soil* **185**:151-162.

Sultani, M. I., Gill, M.A., Anwar, M. M. and Athar, M. (2007). Evaluation of soil physical properties as influenced by various green manuring legumes and phosphorus fertilization under rain fed conditions. *Int. J. Environ. Sci. Tech.* **4**: 109-118.

Tesfaye Wubet, Kottke, I., Demel Teketay and Oberwinkler, F. (2003). Mycorrhizal status of indigenous trees in dry Afromontane forests of Ethiopia. *Forest Ecol. Manag.* **179**: 387-399.

West, W.P. (2006). **Growing Plantation Forests**. Springer-Verlag, Heidelberg.

Yahya, Z., Husin, A., Talib, J. and Othman, J. (2010). Soil compaction and oil palm (*Elaeis guineensis*) yield in a clay textured soil. *Am. J. Agri. Biol. Sci*. **5**: 15-19.

Zobel, B. and Talbert, J. (1984). **Applied Forest Tree Improvement**. John Wiley and Sons, Canada.