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Quality of tree seedlings across different nursery ownerships in Central Gondar Zone, Ethiopia

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Qualities of planting stocks are critical factors for the success of forest plantations. Despite the huge number of annual seedling production in tree nurseries, awareness on quality of seedlings is very limited. This study evaluates the seedling quality across nursery ownership types in terms of morphological attributes and examines the effect of seedling quality on early growth and survival. Three nursery ownerships (private, GO and NGO) were selected from three districts of central Gondar zone with the assumption of different nursery management practices. Four tree/shrub species were selected purposively (common in all the nursery ownership types) and seedlings for quality assessment were sampled randomly. The study indicated that seedling qualities differ across the selected nursery ownership types and have significant effect on survival and early growth. Significant differences (α<0.05) were observed in the mean shoot length, root collar diameter, shoot and root dry masses among different tree nursery owners. These differences could be rooted from different management in different nursery ownership types. There were relatively higher seedling proportions having measured parameters out of threshold standards for height, root collar diameter, shoot to root ratio and height-diameter ratio in private owner. Generally, *Grevillea robusta* performed better in NGO, *Rhamnus prinoides* and *Cordia africana* in private nurseries and *Cupressus lusitanica* in GO nurseries. However, species, site, and management specific studies must be studied to clearly quantify seedling quality and the associated effect on early growth and survival.

Key words: Quality, tree seedlings, nursery ownerships, central Gondar zone.

INTRODUCTION

The forest sector in Ethiopia plays vital role in mitigating and adapting climate change (MEFCC, 2017a; Demisachew et al., 2018). Also various actors have been involved in tree-planting activities in the country for many decades. However, recent afforestation and reforestation programs were not as such successful due to low survival and establishment, due to inferior quality planting materials and species-site matching (Jaenicke, 1999; Abayneh et al., 2010; Kassim et al., 2016), limited information on quality of seedlings (Belay, 2007). Successful plantation depends on the use of quality seedlings (Bertin et al., 2012). However, forest development in Ethiopia is constrained by several factors (which include, lack of forest seed and seedling regulations, inappropriate site and

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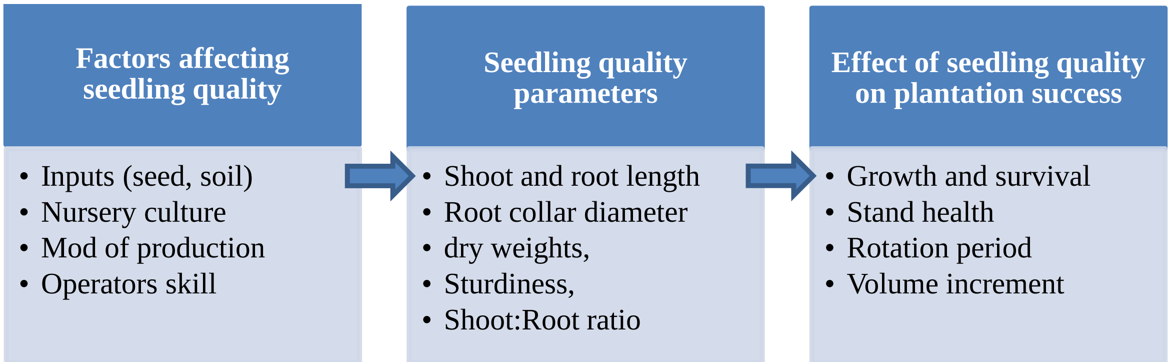

Figure 1. Conceptual framework.

species matching, free gazing, lack of land use planning system etc. (Million, 2011; MEFCC, 2017b). Central to the success of any plantation activity is the quality of the planting stock (Bertin et al., 2013). Seedling quality denotes ability of seedlings to express its full potential after out planted (McCreary and Duryea, 1985). A target seedling is a plant that has been cultured to survive and grow on a specific site (Bertin et al., 2013). It is targeting to meet specific seedling characteristics that can be linked with field performance, termed as "fitness for purpose". It has two main aspects, genetic and physical conditions. A quality tree seedling is one which is healthy, vigorous, and free of diseases, have a robust and woody (lignified) single stem free of deformities and has large root collar diameter that could have high out planting success (Jacobs et al., 2004; Wilson and Jacobs, 2006; Roeland et al., 2006). However, quality of seedling could be affected by species and nursery culture (Anne et al., 2008). Therefore, greater recognition of the role of nursery practices for quality seedlings and the subsequent field performance is needed.

Poor plantation success along with increasing seedling demand has promoted research interests in tree seedlings (Jacobs et al., 2004; Wilson and Jacobs, 2006). Seedling quality and subsequent field performance can be influenced by various management, genetic and environmental factors (Roeland et al., 2006; Pramono et al., 2011; Irawan et al., 2015). Quality standards for nursery crops and the subsequent nursery-planting site interaction are thus urgently needed to ensure reforestation success (Boaz et al., 2015). However, the growth of trees is influenced by a combined factors of genetic and environment (Pramono et al., 2011). Quality assessment can provide technical information to quantify and define minimum seedling attributes for informed decisions (Belay, 2007; Anne et al., 2008; Menzies et al., 2008; Elizabeth et al., 2001; Haase, 2006; Riyong et al., 2016). In order to take advantage of advances made in tree planting, seedling systems should be evaluated and improved. Hence, this study evaluates seedling quality across different nursery ownership types and management practices.

Conceptual framework

The study was guided by the following conceptual framework as depicted in Figure 1.

MATERIALS AND METHODS

Description of study areas

This study was conducted in three districts of central Gondar zone (Gondar zuria, Gondar city and Lay Armachiho) (Figure 2). Districts were selected for this study due to similar agro ecology, species and nursery practices. Major biophysical attributes of the study areas are presented in Table 1.

Description of species and nursery ownership types

Major nursery ownerships considered in this study were government (GO), non-government (NGO) and private nurseries (characterized in Table 2). Among the seedlings produced in the selected nurseries, two indigenous (*Cordia africana* and *Rhaminus prinoides*) and two exotic (*Cupressuss lustanica and Gravelia robusta*) tree species were selected to evaluate seedling quality. The selection of target species was based on their commonly availability in all nursery ownership types in all study areas and the current status of species in commercial plantation.

Experimental settings, data collection and analysis

The study involved an experiment to evaluate seedling quality based on sampled seedlings of selected species from three types of nursery ownerships. In each of the chosen species (*C. africana, R. prinoides*, *C. lustanica and G. robusta*) 100 seedlings per species (100*4 species*3nursery types*3 districts=3,600 seedlings) were selected randomly from all parts of the bed at the time of out planting (Roeland et al., 2006; Haase, 2006). Then, 30 out of 100 seedlings were randomly selected for destructive measurement of morphological traits. Thus, a total of 1,080 seedlings were used for destructive measurement. As indicators of the seedling qualities morphological traits such as shoot and root length, root collar

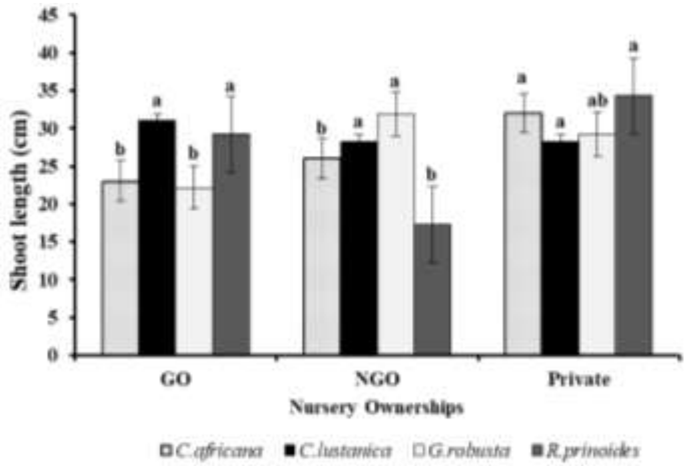

Figure 2. Mean shoot length (cm) across nursery ownership types.

Table 1. Major biophysical attributes of the study areas.

District	Geographical location	Average annual T0 (°C)	Average annual RF (mm)	Agro-ecology	Major soil type	Altitude range
Gondar zuria	12°39'24"N and 37°45'43"E	17.9	1100	Kolla W/Dega Dega	Vertisol, Cambisol	1107-3022 m. a.s.l
Gondar city	1235“60” N and 3728“0.120“”E	19.1	1161	W/Dega Dega	Cambisol	2160 m. a.s.l
Lay Armachiho	13° N and 37.167° E	16.9	1100-1300	Dega W/Dega	Cambisol	1500-3200 ma.s.l

diameter, shoot and root dry weights, leaf and branch numbers were measured from the sampled seedlings.

Data was subjected to one Way ANOVA using R-software version 3.5.1, to compare seedling quality parameters across the three nursery categories. Independent analyses were executed for *C. africana, R. prinoides, G. robusta and C. lustanica*. Fisher's LSD test was used for mean separation at α=0.05. The survived seedling was calculated as the proportion of surviving trees to total number of trees of the same species planted. The analysis of variance (ANOVA) was attributed to all data that were generated from the experiment. Also variability among means was described by using coefficient of variation (CV) and Standard deviation (SD). Pearson correlation coefficients (r) were also computed across variables to test the strength of linear relationships.

RESULTS AND DISCUSSION

Seedling quality across nursery ownerships-morphological characteristics

Shoot characteristics

There are some guidelines describing optimal seedling morphological characteristics (Jacobs et al., 2004). Shoot length of seedlings is one of the quality indicators (Haase, 2006). Figure 2 presents the ANOVA result of seedling mean shoot length variation across the three nursery ownerships and for the four types of seedlings investigated. This result concurrently agreed with that of Belay (2007) who reported that nursery management and respective skill of operators can greatly vary and affect nursery stock characteristics. The result indicates that there was a significant variation in the mean seedling shoot length across the nursery categories for *C. africana* (P=0.025) and *R. prinoides* (P=0.003). In both cases the highest mean shoot lengths were recorded in the private nurseries. There was no significant difference in mean shoot length was observed for the species *G.robusta* (P=0.081) and *C. lustanica* (P=0.544). However the highest mean shoot length for *G. robusta* was recorded in NGO nurseries and for *C. lustanica* in GO nurseries. The result could be associated with the specialization of the nursery type for instance indigenous tree species and seedlings with higher market demand have better shoot performance in private nurseries. This result is supported by the reason that private nurseries used better soil mix ratio (Table 2) while seedlings with high demand for industrial plantation is highly specialized and have the highest performance in Government nurseries. As

Table 2. Characterization of nursery ownerships under study.

Variables to characterize nurseries	Nursery ownership type		
	GO	NGO	Private
Average land area	0.5 ha	0.225 to 0.35 ha	0.1 to 0.125 ha
Production capacity (2018)	300,000 to 500,000 s	130,000 to 370,000	8,000 to 45,000 seedlings
Number of species raised	8-13 species	7 to 11 species	5 to 7 tree/shrub species
Major seed sources	Purchased and local collection	Purchased, local collection	purchased and local collection
Major nursery problems	Seed quality, input delay and salary, water	labor, input delay, skill, water,	labor, technical and financial, market
Sowing date for the selected tree/shrub species for the year 2018/2019	*C. africana* from March.1 to 30 *R. prinoides* from Nov.1 to Dec.15 *G. robusta* from Dec.1 to Jan.30 *C. lustanica* Nov.1 to Dec.30	*C.africana*April1 to 30 *R. prinoides* Jan.1 to 30 *G. robusta* Dec.1 to 30 *C. lustanica* Nov.1 - Jan.-30	*C. africana* from March.1 to 15 *R. prinoides* from Oct.1 to Nov.30 *G. robusta* from Dec.1 to Jan.15 *C. lustanica* Nov.1 to Jan.30
Number of workers	10 to 18 workers	8 to 18 workers	3 to 5, family members
Age of nursery	15 to 30 years.	7 to 16 years	2 to 10 years
Forman's education level	High school and below	High school and below	High school and below
Forman's experience	3-26 years	6-12 years	2-8 years
Average soil mix ratio used at different nurseries	2:2:1 (compost, local and sand)	2:2:1 (compost, local, sand)	3:2:1 (compost, local and sand)
Type of nursery	Generally, permanent	Mostly permanent	Mostly temporary
Document organization	Poorly organized	Well-organized	No document at all
Training and extension	Trainings to operators	Trainings to operators	Rare cases
Common nursery culture activities	Root pruning, watering, weeding, transplanting	Root pruning, watering, weeding, transplanting	Root pruning, watering, weeding, transplanting

reported by Belay (2007) the average shoot length of *G. robusta* seedlings was 18.3 cm which is lower than the result found in this study (27.8 cm).

Seedlings should be out planted as soon as they have reached their optimum size depending on the species and the site, but it will usually be a height of 15-30 cm. According to this assumption, seedlings coming out of the selected nurseries more or less meet the standard. However, initial shoot length alone has provided inconsistent ability to predict seedling field performance for some species (Haase, 2006).

Mean shoot dry weight is another indicator for seedling quality (Wilson and Jacobs, 2006). As illustrated in Figure 3, significant difference was observed in the mean shoot dry weight of *G. robusta* (P=0.007), *R. prinoides* (P =0.03). There was no significant difference observed in mean shoot dry weight for *C. africana* (P=0.063) and *C. lustanica* (P =0.151) among nursery ownership types (Appendix Table 1). The highest shoot dry weights were recorded in private nurseries for *C. africana* and *R. prinoides*. Likewise, for *G. robusta* the highest was recorded at NGO nurseries. Belay (2007) reported that the average shoot dry weight of *G. robusta* was 1.14 g per seedling which is lower than the result found in this study (3.9 g) Similarly, for *C. lustanica* relatively higher result was observed in GO nurseries. These could be directly related with shoot length.

Leaf and branch number could affect seedling quality. As illustrated in Figure 4, significant difference was not observed in mean leaf number of *C. africana* (P=0.34), *R. prinoides* (P =0.954), *G. robusta* (P=0.334) and branch number of *C. lustanica* (P=0.312) (Appendix Table 1). The highest mean leaf number was recorded in private nurseries. For *C. lustanica*, the highest mean branch was observed in GO nurseries. These

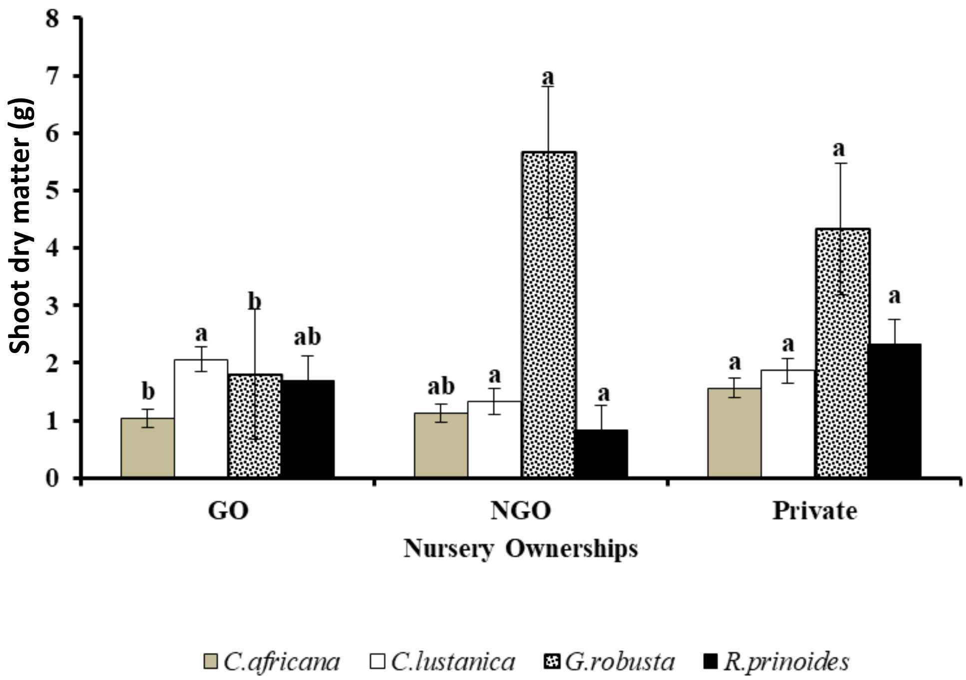

Figure 3. mean shoot dry weight (g) across different nursery ownership types.

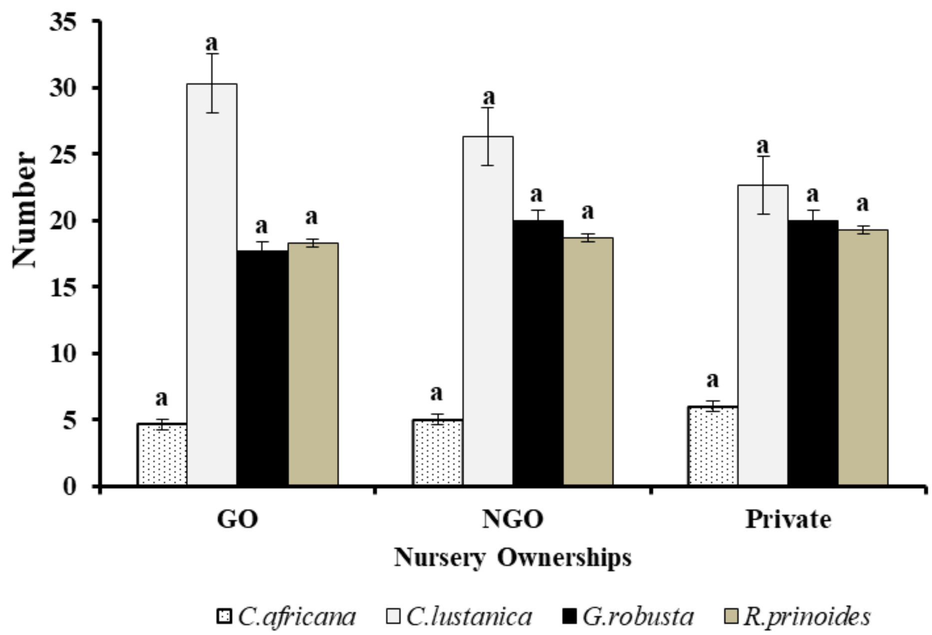

Figure 4. Mean numbers of leaves and branches (*C. lustanica*) of seedlings.

could be associated with shoot length and age of seedlings. Number of leaves ranged from five (*C. africana*) to 20 leaves per seedling in *G. robusta*. For *C. lustanica* number of branches per seedling ranged from 23 in private to 30 in GO nurseries.

Root characteristics

As illustrated in Figure 5, root collar diameter of *C. africana* (P=0.08), *R. prinoides* (P=0.02), and *G. robusta* (P=0.01) shows significant difference across the nursery

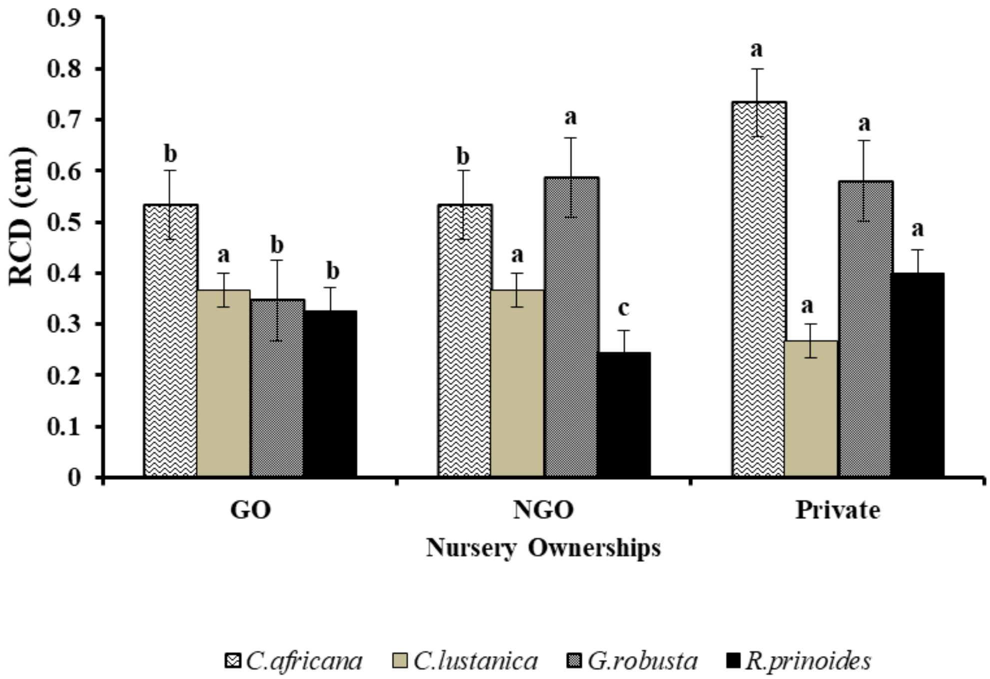

Figure 5. Mean root collar diameter of seedlings from different nursery types.

categories. Significant difference was not observed for *C. lustanica* (P=0.296). In the cases, Cordia (0.73 cm) and Rhaminus (0.4 cm) the highest root collar diameters of seedlings were recorded in private nurseries. For *G. robusta*, the highest root collar diameter was attained in NGO nurseries. This result could be associated with the special experience and species preference of the respective nurseries. On the other hand no significance difference were observed in root collar diameters of *C. lustanica* (P=0.296) seedlings across the nursery ownership types. MEFCC (2017a) and Belay (2007) reported that average root collar diameter of *G. robusta* seedlings was 0.25 cm, which is lower than the finding obtained in this study (0.5). According to the quality standard used for container-grown seedlings, minimum root collar diameter ranges from 3.0-4.0 mm (Menzies et al., 2008). Thus, seedlings from target nursery owners meet the standard except *R. prinoides* from NGO nurseries (0.24 cm). Discussing root characteristics provides a quantitative description of seedling root systems (MEFCC, 2017a; Demisachew et al., 2018). Using the same type of container, nursery owners result different data of root characteristics for tested species. This could be attributed to different management and sowing dates. Root collar diameter take part the entire morphological response of seedlings to the environment and its correlation with other attributes such as the shoot length, shoot length, shoot and root dry weight (Jacobs et al., 2005).

Mean root length was computed from the sampled seedlings as it is an indicator for seedling quality (Anne et al., 2008). However, this study showed that mean root length had negligible effect on early growth and survival except *C. lustanica*. Seedlings with well-developed and extensive root system can be considered as best quality. However, relationship between diameter and survival could be affected by root mass (Haase, 2006) which may be affected by management, root pruning. As illustrated in Figure 6, significant difference was observed in the mean root length of *C. africana* (P=0.002), *R. prinoides* (P =0.039), *G. robusta* (P =0.036), and *C. lustanica* (P =0.006). Similar trend was observed in the performance of seedlings in terms of root length. For *C. africana* (16.3 cm) and Rhaminus (15.3 cm), the highest root lengths were recorded in private nurseries. While the highest root length for Gravelia (17.3 cm) was observed in NGO nurseries. Cupressuss most dominantly produced in Government nurseries and attained the highest height (16 cm). Belay (2007) reported that average root length of *G. robusta* seedlings was 10.4 cm which is lower than the result found in this study (15.6 cm) (Figure 6).

Plants with higher plant dry matter had significantly greater early growth and survival (Elizabeth et al., 2001; Haase, 2006; Jacobs et al., 2005). As illustrated in Figure 7, significant difference was observed in the mean total dry weight of *C. africana* (P=0.035), *R. prinoides* (P =0.004), *G. robusta* (P=0.01) and *C. lustanica* (P=0.045). The highest total dry weights were recorded in private nurseries for *C. africana* and *R. prinoides*. Likewise, for *G. robusta* the highest was recorded at NGO nurseries. Similarly, for *C. lustanica* the highest result was observed in GO nurseries. These could be directly related with the

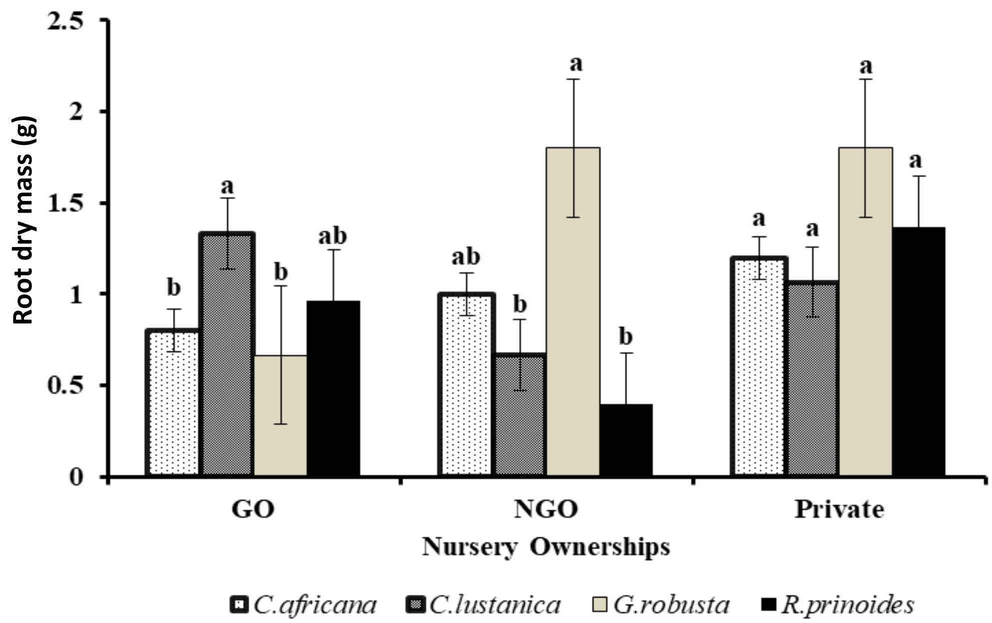

Figure 6. Mean root dry weight (gm) across nursery ownership types.

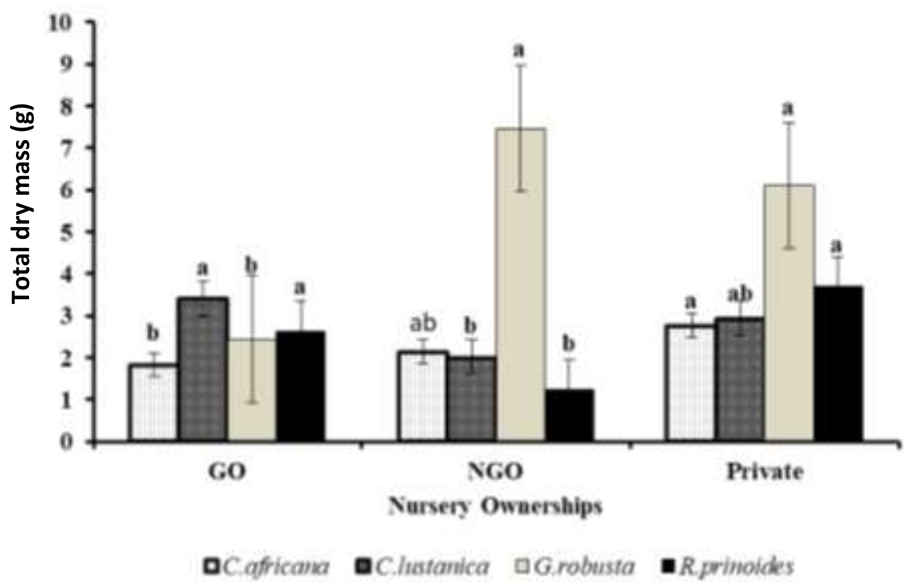

Figure 7. Mean total seedling dry matter (g) across nursery ownership types.

total seedling mass (shoot and root masses) and sturdiness.

Nursery stock quality indicators: Shoot: root length ratio

Seedlings with quality indicators out of the acceptable ranges do not perform well (Bertin et al., 2013; Nestor et al., 2015). Unbalanced plants have too many leaves and too few roots (Roeland et al., 2006). As illustrated in Figure 8, significant difference was not observed in the mean shoot to root length ratio of *C. africana* (P=0.765), *R. prinoides* (P =0.092), *G. robusta* (P=0.136) and *C. lustanica* (P=0.63). The highest mean shoot to root length ratio was recorded in private nurseries. These could be directly related with root pruning activities. NGO and GO nurseries have obviously a successful pruning concept.

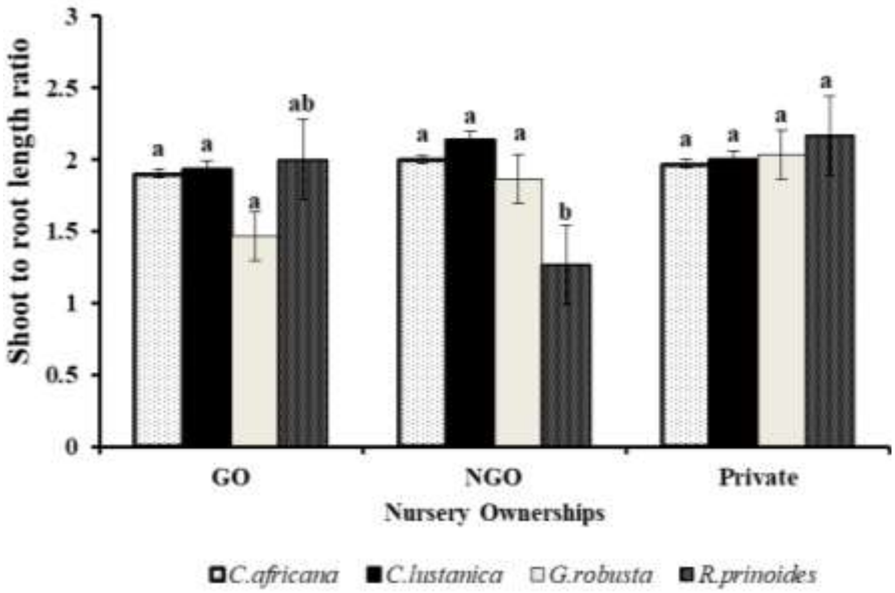

Figure 8. Mean shoot to root length ratio of seedlings across nursery ownerships.

Mostly, private nurseries have better root pruning concept. However, shoot to root length ratio may not be affected by root length only for container seedlings since pot size is similar, rather could be influenced by shoot length. This indicated that shoot and root lengths might not be related for container seedlings due to root pruning. In this study average shoot to root length result of 1.8 was observed for *G. robusta* seedlings from different nursery owners and this result agreed with that of Belay (2007), who found 1.73 for the same species.

Mean sturdiness ratio (sturdiness quotient (SQ) or height-diameter ratio) is an important seedling quality indicator (Jaenicke, 1999). As illustrated in Figure 9, significant difference was observed in the mean sturdiness ratio of *G. robusta* (P=0.035), *R. prinoides* (P =0.029). There was no significant difference observed in sturdiness ratio for *C.africana* (P=0.266) and *C. lustanica* (P =0.342) among nursery ownership types. The highest sturdiness ratios were recorded in NGO for *C. africana* (4.8) and GO for *R. prinoides* (8.9) and *G. robusta* (6.3). Similarly, for *C. lustanica* the highest result was observed in private nurseries (9.7). This could be directly related to shoot length and root collar diameter. According to Jaenicke (1999) small ratios of sturdiness show a sturdy plant with a higher expected chance of survival (<6). Based on this assumption, *C. africana* and *G. robusta* seedlings from all owners meet the general expectations while *R. prinoides* and *C. lustanica* do not in all the three ownerships. However, it differs from species to species and could be affected by the negative correlation between sturdiness ratio and root collar diameter. Average sturdiness ratio of *G. robusta* seedlings was 5.6, which is lower than the out the gate result reported by Belay (2007), which was 9.7.

Though it requires destructive methods, mean shoot to root ratio is an important predictor for survival and growth (Hasse, 2006a). As illustrated in Figure 10, significant difference was not observed in mean shoot to root ratio of *C. africana* (P=0.56), *R. prinoides* (P =0.539), *G. robusta* (P=0.277) and *C. lustanica* (P=0.244). The highest shoot to root ratios was recorded in NGO nurseries. These could be directly related with shoot and root characteristics. Also dry mass of seedlings might be affected by other factors such as age, branch and leaf numbers. Physical quality that should not be overlooked is seedling balance. Seedlings with a larger shoot mass have a greater photosynthetic capacity and potential for growth. However, a greater transpirational area may lead to moisture stress (Haase, 2006; Jacobs et al., 2005). Generally, quality container seedlings have shoot: root of 2:1 or less (Haase, 2006). Based on the computed results, *C. africana,* and *C. lustanica* from the three nursery categories fit to the general expectations of balanced shoot to root system. But, *G. robusta* from all owners and *R. prinoides* from NGO do not meet this assumption.

Mean shoot: root ratio for *G. robusta* was 2.8, agreed with the finding of Belay (2007) who found mean value of 2.91. *G. robusta* from GO and *C. africana* and *R. prinoides* from NGO nursery in general are produced as smaller plants lacking a suitable size of the shoots and roots, which resulted in a diminished survival after out planting. This agreed with the findings of Jacobs et al. (2005). Cao and Ohkubo (1998) also reported that shoot: root ratio can increase linearly with increase in plant height for the saplings <1.5 m. NGO nurseries were found

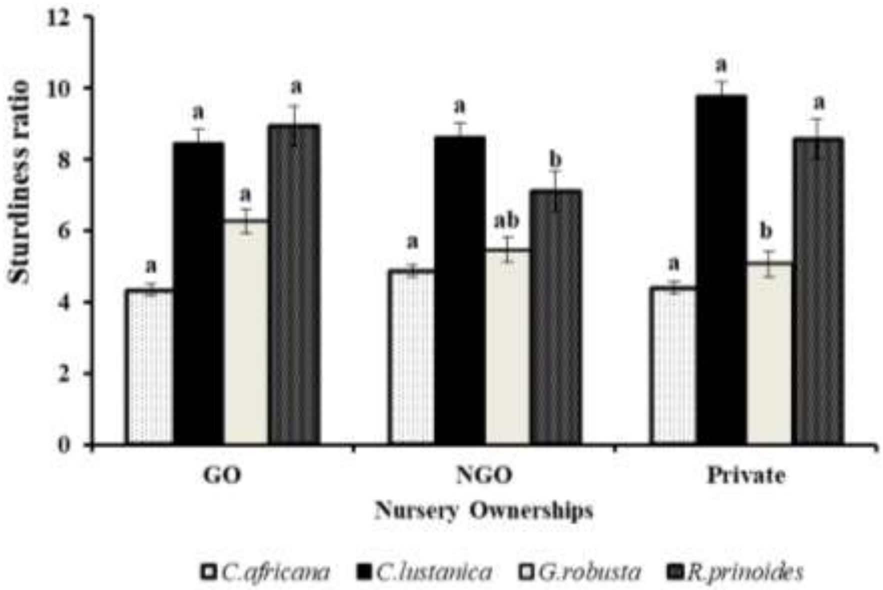

Figure 9. Mean sturdiness ratio.

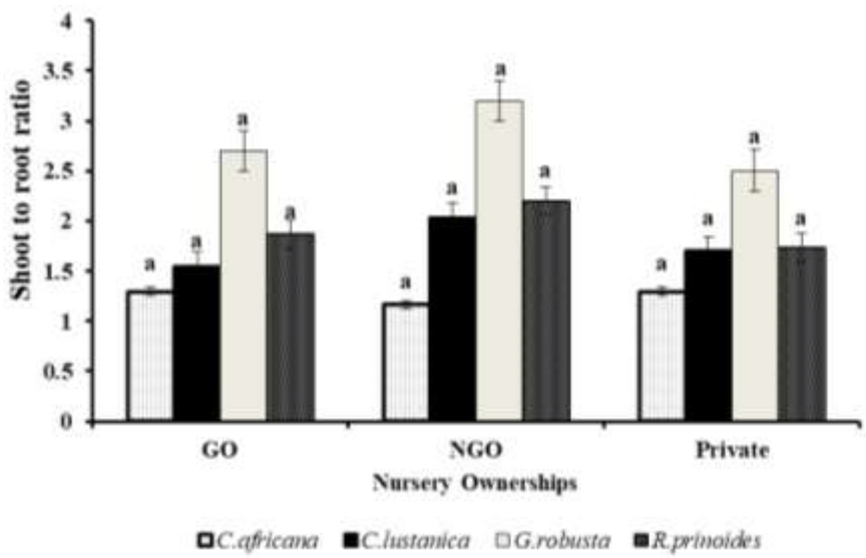

Figure 10. Mean shoot to root ratio.

to have more seedlings with values out of the acceptable range (SRDM) (Demisachew et al., 2018) meaning that shoot biomass is too high compared to root biomass. This can be explained by either a more intensive pruning practiced by nursery owners or the similarity of ratio per its respective seedling size.

CONCLUSION AND RECOMMENDATIONS

Tree nurseries produced millions of seedlings of different trees/shrub species in central Gondar. However, there are no established quality standards. This study evaluates quality of tree seedlings across different nursery ownership types indicating different nursery management practices. Various morphological variables were evaluated in order to examine seedling quality. Results showed that initial seedling attributes such as height, root collar diameter and shoot and root dry weights have significant effect on early growth and survival of tree seedlings. Thus, it is possible to conclude and prove that seedling quality greatly affects field performance. Significant variations were found among nursery owners for most of the morphological characteristics analyzed. Significant variations were not observed in growth and survival among nursery categories at three month after planting except, *R. prinoides*. It is possible to conclude from this study that potential field performance could be influenced and accurately predicted by morphological attributes of seedlings. In general, seedlings coming out of private nursery are with better qualities which could be due to the profit motives of private nurseries. Also small scale nature and absence of any beaurocracy and material delay like GO and NGO nurseries. Generally, the nursery stock characteristics of the observed tree species are not similar across tree nursery ownership types. This could be attributed to different operational exercise, different local expert knowledge of operators. Also there is no general guidelines for optimal nursery operation and are not clearly known. Thus, operational effectiveness of the sub sector is vital to improving quality of seedlings and the subsequent plantation development. Finally, this morphological seedling quality evaluation method is very important since it is practical and enables easy detection of the relationship between parameters.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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