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Dedicated to the late
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Foreward

Forestry Research Directorate is one of the six directorates standing as a directorate since 2008 in Amhara Agricultural Research Institute (ARARI). The directorate is responsible to conduct research focusing on agroforestry, plantation, natural forest, rehabilitation of degraded land, non-timber forest product and dryland forest. Identifying thematic areas, preparing a research proposal, conducting demand-driven research, collecting the necessary data and finalizing an experiment is not an end. The technology, information and knowledge adapted or generated have to be documented, conveyed and communicated to the end users. The results should be presented in printing media to demonstrate the relevance of the technologies for forest development as well as to monitor and evaluate the achievement and the efforts of the directorate. Therefore, publishing research results in the form of proceedings is equally important as conducting research.

In the 9th proceedings of forestry research directorate, a total of 24 completed research activities are compiled in forestry and agroforestry case teams. This proceeding can be used by the end users and would also be used as reference material for researchers, development workers, students and other professionals. At this juncture, I would like to thank researchers and research assistants who put endeavours and contributed their research results to be published in the 9th proceeding. I also would like to thank the reviewers and the editors to finalize the 9th proceeding for printing. Using this opportunity, I would like to encourage forestry researchers to have quality data and publish the findings on time to push forward the forestry science in the region.

Menale Wondie (PhD)
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The Rhamnus prinoides in North West Ethiopia: Production, Contribution and Constraints

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Abstract

Rhamnus prinoides is a widespread shrub species in different agro-climatic zones of Amhara. It is used for local beverage preparation, medicinal values and income generation. The contribution of this species has grown persistently due to the demand in its products. It is promoted also for maintaining soil and water conservation structures. Besides, its economic value, the production and constraints of Rhamnus prinoides is not well documented in Ethiopia. This study was, therefore, conducted to assess the production constraints of Rhamnus prinoides and its contribution to farmers. Data were collected using formal household survey and field observation and analyzed by descriptive statistics and linear regression model. The result revealed that the households of the study areas have on average 508 seedlings/plants of Rhamnus prinoides mainly around the homestead. Cutting the stem from the bottom of the tree, cutting the new branch by sickle, rolling the shoots and leaves by hand and picking only the leaf by hand are the harvesting techniques practiced by the households. The farmers harvest at a rate of 2.48 per annum with average marketable leaf yield of 13.8 kg per tree per harvest. The presence of provenance was reported based on the morphology of leaf, stem and fruits. Diseases management, support in initial investment and investigation of the provenances of R. prinoides are crucial to increase the benefits for smallholder.

Key words: Benefits, harvesting technique, opportunities, provenance, Rhamnus prinoides
Introduction

*Rhamnus prinoides*, Gesho in Amharic, is a widespread plant species in Africa. It is a native plant to Ethiopia, East and South Africa. The plant grows best in areas where the mean annual temperature is between 14-22°C, and can tolerate 8-32°C. It prefers a mean annual rainfall of 600-800 mm per year. It can grow also at a range of 500 to 1200 mm of rainfall. Generally, it grows slowly in areas where the rainfall is low, though it can grow 1 meter per year in wetter areas. *Rhamnus prinoides* (RP) is widespread in Ethiopia from medium to high altitudes on the margins of every green forests in moist and wet Kolla, woina Dega and moist Dega agro climatic zones (Nagari and Abebaw, 2013; Amare et al., 2017). CSA (2015/16) indicated RP in Amhara Region is produced by 1462206 holders in an area of 20664 ha with annual yield of 21761.3 tons. The production of RP and its economic contribution was documented by Amare et al. (2017) and Tefera et al. (2014). Farmers’ preference ranking indicated that RP was the second most preferred shrub species among farmers in northern Ethiopia (Tefera et al., 2014).

*Rhamnus prinoides* is used for a variety of purposes, including flavoring of local beer, as medicine, treat respiratory systems (Bekele, 2007; Gebre, 2012; Amare et al., 2017). In Ethiopia, it is commonly used for preparation of traditional alcoholic beverages, “tella” and “tej” (Abebe, 2011). The concentrations of the metals were also compared with recommended maximum permissible limits and some international reports; and found to be in a good agreement indicating no exposure risk of using the leaves and stems of RP under the current situation (Nagari and Abebaw, 2013). Berhanu (2014) concluded that total resin, soft resin, hard resin and essential oil of RP were found to be comparable with values of varieties of hops. This indicated that RP can substitute hops for beer production.

The demand for RP has been increasing due to a growing demand for local beverages. Concurrently, the production of RP has been rising as it is incorporated as a biological measure in the effort of natural resources management activities widely implemented in the country. Even if there are sporadic reports (Amare et al., 2017; Tefera et al., 2014; Amabye, 2015), there is no as such detailed information on the current state and constraints of RP production. Hence, this study aimed at a) exploring the production of RP, b) assess the provenances of RP, and c) investigate the production and marketing constraints in the production of RP under smallholder farmers in western Amhara.
Materials and Methods

Study area description

This study was conducted in Amhara Regional State, Ethiopia. The areas covered south west of Amhara Region on four administration zones; viz West Gojjam, East Gojjam, South Gondar and Awi zones. Farta, Estie, Dera from south Gonder; Basoliben, Huletejuenebsie, Gonchasisoenebsie from East Gojjam; Quarrt, Mecha; GonjiKolela; and FagitaLekoma and Guagsa from Awi zones. The altitudes range from 1938 to 2564 m a.s.l.

Method

Multi stage sampling procedure was used to select RP producing kebeles. Purposive sampling method was employed to select respondent farmers. Sample size was determined based on information saturation technique. The potential districts were selected within each zone based on the secondary data of zone department of agriculture annual seedling distribution and tree coverage reports. Similarly, highly potential kebeles were selected from each woreda’s report and 10 farmers who have knowledge about RP use and management were selected from each kebele purposively.
Household survey data were collected using structured and semi-structured questionnaire. The household questionnaire consisted of questions on demographic and socio-economic conditions, livelihood strategies, and RP plantation activities. The questionnaire was also pre-tested prior to the actual survey and correction has been made based on the information received. The questionnaire was translated into the local Amharic and Agewigna languages and for respondents who only speak Agewigna. Development Agents were used as interpreters while conducting the interview. In addition to the informant interviews, information was collected from Kebele office, field observation, and informal discussions. Among the respondents, 18.18% were from Awi Zone while 27.27% from each administration zone of West Gojjam, East Gojjam, and South Gondar, respectively. The female respondents represented 14.5% of the total sample population while the rest, 85.5%, were male respondents.

The survey data were analyzed using descriptive statistics and a linear regression model. SPSS 16 and Stata 12 software packages were used for analysis.

Results and discussion

Household Characteristics

The average family size of the respondents was 6.3 with minimum 2 and maximum 12 members per family. The average age of the respondents was 47.47 years with a range of 24 to 80 years. About 44.5% of the respondents were illiterate and the rest attended formal education (i.e., primary, secondary, and preparatory schools).

Intensity of *Rhamnus prinoides* production

The numbers of RP plant per farmer was a minimum of 6 in Gawana (Awi) and maximum of 5000 in Enegodie (East Gojjam). A household cultivated on average 508 RP plants. Most of the farmers have 50 to 200 RP plants but only 11% of them have above 1000 plants. The income contribution of RP ranges from 150 Birr up to 20,000 ETB annually with average income of ETB 3822.43 (±389.39). RP is also used for home consumption in varying volumes.

Sizeable proportions of the farmers (47.71%) involve in commercial RP seedling production and earn averagely ETB 7356 (±106) by producing bare root (76.36%), potted (3.64%), and both bare root and potted (20%) seedlings.
Planting trends of *Rhamnus prinoides*

The farmers planted *Rhamnus prinoides* for the last five years (Table 1). The average annual planted RP seedlings were maximum in East Gojjam (Enegodie) and minimum in Awi (Gawana) and South Gondar (Gindatemem). On average the survival rate of planted RP seedlings was 72% indicating a better management or suitable environment for the growth of RP.

Table 1. Planting number of trees per year

<table>
<thead>
<tr>
<th>Zone</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Gojjam</td>
<td>10</td>
<td>200</td>
<td>58</td>
</tr>
<tr>
<td>East Gojjam</td>
<td>10</td>
<td>300</td>
<td>95</td>
</tr>
<tr>
<td>Awi</td>
<td>5</td>
<td>60</td>
<td>24</td>
</tr>
<tr>
<td>South Gondar</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Management activities

RP is produced at different land uses (Table 2). According to farmers, the management of RP requires additional effort compared to other traditionally known agroforestry species or trees (e.g., eucalyptus). From the total respondents, 89.1% agreed that RP production requires additional effort or management activities such as, hoeing, weeding, watering, mulching with straw and fencing than other agro-forestry species. Due to this, most of the farmers grow RP near to their residence place while 70.9 % of the respondents indicated that humus soils are more preferable for RP cultivation. Water logged soils have negative effect on the productivity of RP, according to the farmers.

Table 2. Farmers planted RP in different plots and land use.

<table>
<thead>
<tr>
<th>Types of land use</th>
<th>No of respondents</th>
<th>Respondents (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Around homestead</td>
<td>100</td>
<td>91</td>
</tr>
<tr>
<td>On croplands</td>
<td>23</td>
<td>20.9</td>
</tr>
<tr>
<td>On irrigated lands</td>
<td>2</td>
<td>1.8</td>
</tr>
<tr>
<td>On soil and water conservation structures</td>
<td>19</td>
<td>17.3</td>
</tr>
</tbody>
</table>
Harvesting frequency and harvesting techniques

Harvesting frequency is the harvesting time of one plant per year. Accordingly, 44.55% of the farmers harvest twice per year. Others, 30.91%, 12.73%, 8.18%, 0.91% and 2.73% of the respondents harvest 3, 4, 5 and 6 times a year, respectively. Harvesting frequency depends on harvesting technique, tree management practice and the site of plantation. Picking only the leaves by hand harvesting techniques have better harvesting frequency than the other techniques. Average yield per tree per harvest was 13.6 kg.

Harvesting technique

There are four different types of harvesting techniques (Fig.2), namely, (a) cutting the stem from the bottom of the tree (e.g., in Yelemelem); (b) cutting the new branch by sickle (e.g., in Quarit and Engode); (c) rolling the shoots and leaves by hand (e.g., in Gawana, chiguale); and (d) picking only the leaves by hand (e.g., Biraqat, Gonji, and south Gondar). In general, there was no a single harvesting technique practiced by the farmers.

Figure 2. Yields in different harvesting technique

The yield of *Rhamnus prinoides* depended on the harvesting technique employed (Table 3). Picking only the leaf by hand gave better yield per year per tree. This was due to the increase in harvesting frequency while yields per harvest per tree were almost similar across different harvesting techniques.
Table 3. Yield in different harvesting frequency

<table>
<thead>
<tr>
<th>Harvesting frequency</th>
<th>Average yield per harvest</th>
<th>Std error.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.82</td>
<td>0.08</td>
</tr>
<tr>
<td>2</td>
<td>0.83</td>
<td>0.04</td>
</tr>
<tr>
<td>3</td>
<td>0.67</td>
<td>0.06</td>
</tr>
<tr>
<td>4</td>
<td>0.64</td>
<td>0.06</td>
</tr>
<tr>
<td>5</td>
<td>0.75</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>0.86</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Provenance of *Rhamnus prinoides*

Most of the respondents (72.7%) agreed on the presence of provenance and characterized the difference by plant morphology such as; leaf size, stem length and thickness, fruiting potential and growth rate. The farmers expressed the number of RP varieties they ever know and are producing as single variety (27.27%), two varieties (59%) and three varieties (13.64%). Based on the focus group discussions and field observation, two types of provenances were identified in the study areas. They are; (1) long in stem length, wider leaf size and have more leaves, fast growth and non or less fruited and, (2) dwarf, smaller in leaf size, more fruited and give less yield. The farmers (73.79%) indicated that there is a difference in variety. The broad leaved RP is indicated as more productive (91.35%) than the small leaved RP species. Leaf thickness is one of the preference criteria reflected in the market as reported by farmers (56.88%). The farmers described that broad leaved (60.87%) and small leaved (18.84%) are generally preferred by the market, respectively.

Opportunity

There are different opportunities for the production of RP in the study areas (Table 4). In addition to home consumption (using “Tella”, “Teji” and “Katikala” preparation), RP is one major source of income, which means market demand is the first opportunity to push farmers for production. Market demand, land suitability and water availability are major opportunities for the production of RP and its benefits for smallholder farmers.
Table 4. Opportunities of cultivation and production *Rhamnus prinoides*

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<th>Opportunity</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
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<tr>
<td>Market demand</td>
<td>63</td>
<td>57.2</td>
</tr>
<tr>
<td>Land suitability and availability</td>
<td>42</td>
<td>29.2</td>
</tr>
<tr>
<td>Water accesses</td>
<td>24</td>
<td>21.8</td>
</tr>
<tr>
<td>Labor availability</td>
<td>18</td>
<td>16.4</td>
</tr>
<tr>
<td>Seedling accesses</td>
<td>2</td>
<td>1.8</td>
</tr>
<tr>
<td>SWCS constriction</td>
<td>3</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Constraints

Insect and disease (as described by 92.7% of the respondents) are major problems indicated by farmers that limit production and local beer quality. Seasonal market problem, limited extension supports and request of additional labor or effort for the management of the plant (weeding, watering, mulching, hoeing and fencing) are the most frequently constraints put forward by farmers.

Factors affecting income from *Rhamnus prinoides* leaf

Income from production of RP constitutes 18.33% of the total household annual incomes (ETB 20850) while the income from other agroforestry practices is in the ratio of 0.91. Age and total income of the household head, and extension support for RP production were significantly and positively correlated to income from RP production (Table 5). Age was positively correlated due to the management and more dependency of older households. Older households acquired vast knowledge and skill on better management of RP and hence gain better benefits or income from RP production. Furthermore, due to labor shortage, older households lean more on permanent crops like RP and other agroforestry practices. Hence, the positive correlation of age and income from RP is perfectly explained by the knowledge and skill possessed as well as the limited labor availability in older households. These situations forced older farmers to shift away from crop production and engage in permanent crops like RP production.
Table 5. Determinants of RP income

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coef.</th>
<th>Std. Err.</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total income</td>
<td>0.180</td>
<td>0.031</td>
<td>5.85***</td>
</tr>
<tr>
<td>Age</td>
<td>45.616</td>
<td>27.846</td>
<td>1.64**</td>
</tr>
<tr>
<td>Sex</td>
<td>412.688</td>
<td>1082.872</td>
<td>0.38</td>
</tr>
<tr>
<td>Formal education</td>
<td>828.098</td>
<td>750.26</td>
<td>1.10</td>
</tr>
<tr>
<td>Extension support</td>
<td>2832.221</td>
<td>699.077</td>
<td>4.05***</td>
</tr>
<tr>
<td>Total land size owned</td>
<td>-37.031</td>
<td>689.142</td>
<td>-0.05</td>
</tr>
<tr>
<td>Constant</td>
<td>-3975.183</td>
<td>1749.343</td>
<td>-2.27*</td>
</tr>
</tbody>
</table>

N=104; F(6, 97) =9.99; prob > F= 0.000; R-squared = 38.19; Adjusted R-squared = 34.36; Root MSE =3301.8

Further, extension support was positively correlated to income from RP. This is due to farm households that gained better knowledge and skill on the management, will manage their RP trees and hence better benefit compared to other households that manage traditionally. Also, extension support could have delivered farm households better information on market information, use of the tree for natural resources management activities, and hence the farmers could have planted more RP seedlings compared to those households that did not get extension support.

**Conclusion and implications**

The result indicated that the farmers in western Amhara used RP for income generation and as soil and water conservation tool. The niche for cultivation is mainly around homesteads due to management and fertilization purpose. Different types of RP provenance or morphological characteristics were identified. Hence, further study is suggested to identify and characterize the existing provenances. Also, investigation of the chemical composition of the RPs compared to hop that is used for brewery companies is necessary. Knowing the chemical composition of this species may likely replace the import of hop from abroad. Besides, exploring the benefits and trade-offs the four different harvesting techniques is crucial. The positive correlation of total income of the households indicates that RP production as manifested by the management activities is investment intensive activity. Hence, provision of financial or seedling backed by the
government or other stakeholders may be desirable, especially for the needy and households that are of short labor (e.g., women-headed households, older families).

Insects and diseases influence the production of RP. Management activities targeted towards diseases and pests should be delivered by the stakeholders. Although tree planting is increasing, there is a need to work on market linkage, harvesting technique, frequency determination and provenance selection.

Acknowledgment
We thank all experts at Zone, Woreda and Kebele level that helped in selection of respondent farmers and delivery of secondary information. We are indebted to our farmers that were patient and willing enough to offer their knowledge in RP production-marketing-consumption.

References
Development of Form Factor Function for *Acacia decurrens* willd tree species in Northwestern Amhara.

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**Abstract**

Volumetric estimation is very important for sustainable management of forest resources, prediction of yield and growth rates. It is the product of DBH, tree height and form factor. *Acacia decurrens* Willd is extensively grown as rotational crop for charcoal and productivity improvement in Awi Zone. Thus, the objective of this research was to develop the form factor function that can be used to estimate the volume of wood from *A. decurrens*. Pollanschutz’s, F. Evert’s, Short Swedish’s, Mayer’s and Rosset’s form factor functions were tested to select the best one. The data were collected from 58 destructed trees from five years old farmer’s woodlots and one community managed plantations. All functions were evaluated by Root mean square error (RMSE), mean absolute deviation (MAD), coefficient of variance (CV) and the characteristics of the graph developed from observed form factor and that of predicted. The performance of all functions were almost similar, even though we chose Mayer’s and Pollanschutz’s functions. We chose these models because of their lowest value of RMSE, MAD and the graph nature. Based on this, 0.4875 is recommended to estimate the stand volume of DBH range of 8-14 cm and five years old woodlots.

**Key words:** form factor function, form factor, *Acacia decurrens* woodlot and Southwestern Amhara
Introduction

Stand volume estimation is important for decision making and sustainable management of forest resources. According to Laar and Akea (2007) bole volume estimation is a crucial work in forest inventory because the volume of a timber is the basic management unit of forests. Knowing the volume of the wood resources, their rates of growth (Adekunle et al., 2013) and yield is necessary at national and stand level. Ability to measure tree growth and volume can provide forest owners with an understanding of forest productivity and a basis for planning forest management actions and decision making (Philip, 1963). Data needed to estimate tree volume can only be collected through field inventory but that is time-consuming and expensive. Volumetric measurement of trees requires recording of diameter and height along the bole of each tree. Volume estimates based only on DBH and total height is subject to error resulting due to the variation of the stem form of a tree (Socha and Kulej. 2007).

\[ V = g \times h \times f \]  
where \( V \) is tree volume (in m\(^3\)), \( g \) is basal area at breast height (in m\(^2\)), \( h \) is tree height (in m), and \( f \) is form factor of a tree, which shapes the cylindrical volume of a tree to its actual form. The form of a stem varies with height of a tree due to stand density, climate, site quality, management practices (Heather K et al., 2000, Laar and Akça, 2007). It is the main determinant factor next to diameter at breast height and tree height for accurate volume estimation of a species and/or stands. Basal area measurement is a relatively cheap and easy method. However, measuring form factor and height is critical time-consuming and expensive (Sharma, 2009).

*Acacia decurrens* Willd (Green wattle) a belongs to the family Fabaceae and it grows well in moist and Wet Weyna Dega and Dega Agro-climatic zones of Ethiopia (Tesemma, 2007), at altitude of 1800 to 2950 meter above sea level (Achamyeleh K et al., 2016). It has great potential for charcoal, poles and firewood (Tesemma, 2007, Priyono S et al., 2010). It stabilizes soil in five years (Tadele et al., 2017). Currently, in the highlands of Awi Zone, the species is extensively cultivated as rotational crop for charcoal/firewood production and rehabilitation of degraded land in the form of woodlot as taungya system (Achamyeleh et al., 2016, Zerihun et al., 2016, Yazie and Anteneh, 2015). *A. decurrens* woodlots generates a net present value of 26,682.68 ETB/ha with benefit-cost ratio of 1.94 and internal rate of return of 60% (Yazie and
Anteneh, 2015). It also improves the soil fertility of the ecosystem including soil organic carbon
(Tadele et al., 2017). The area coverage of farmer managed *A. decurrens* woodlots has been
expanded from 720ha to 4083ha from 2009 to 2014 in Fageta Lekoma district (Yazie and
Anteneh, 2015).

However, the volume of *A. decurrens* trees, woodlots and stands has been estimated as the
product of measured DBH, tree height and the constant form factor i.e. 0.44 as a blanket
recommendation for all DBH of a species (Amhara Forest Enterprise, Personal communication).
Hence, actual modeling using field data is required to provide better estimate of form factor. This
helps to give the right decision on estimating the volume of wood produced and better decision
on taxation. Gezahegn (2015) develops a form factor function for 20 broadleaved tree species in
the selected 4 natural forests of Amhara but not for commercial plantation including *A.
decurrens* tree. In general, there is a limited experience of developing a tree form factor function
in Ethiopia. Therefore, the objective of this research was to develop form factor function that can
give a good estimate of *Acacia decurrens* wood volume for better decision in forest management
and taxation.

**Materials and Methods**

**Study area**

The study was conducted in two districts of Awi Zone, Amhara Regional State, Ethiopia at
Ankesha Guagusa and Fageta Lekoma (Figure 1). Geographically Ankasha is located at
36о36'18" and 36о59'33" E and 10о31'46" and 10о41'32" N (Kebede, 2014) and Fageta Lekoma is
situated at 10о57'23" - 11о11'21"N, and 36о40'01" to 37о05'21"E. The elevation ranges from 1800
to 2900 m.a.s.l. The farming system of the study districts is mixed cropping system mainly
potato and livestock husbandry. Bamboo also contributed in the livelihood of the households.
However, *Acacia decurrens* woodlots are becoming the most important economic sector to
generate income. *A. decurrens* is harvested both for charcoal and firewood (Yazie and Anteneh,
2015). Based on the reports of Central Statistical Agency (2015), Fageta Lekoma and Ankesha
Guagusa districts have a total population of 146,848 (90.5% are rural inhabitants) and 233,257
(92.6% are rural inhabitants), respectively.
Sampling methods

Based on the existing extensive production system of *A. decurrens*, two woodlots were selected purposively at Amesha Shenkuri Kebele (from Fageta Lekoma) and one community managed plantation at the Tuleta Kebele (from Ankesha Guagusa) districts of Awi Zone (Figure 1). The age and spacing of the sampled sites/stands were five years and 0.75m x 0.75m, respectively. Sampled trees were selected purposively depending on their diameter at breast height (1.3m) ranges that is \( \geq 8 \) cm. During data collection, trees having multi stems, broken tops and branches and clear cankers or crooked boles were not included. Destructive method was used to develop the form factor. Felled tree were used during harvest time for charcoal production (Figure 2A, 2B, and 2C).

Data collection techniques

A total of 58 trees of *A. decurrens* were sampled in both districts. The stump heights and DBH (cm) at 1.3m, total tree height (m), and height to live crown (m) were measured. The minimum diameter threshold for the terminal leader and branch were determined to be 4.5cm, due to the purpose of woodlots harvested that is for charcoal production. Starting from the base, the diameter of all sample trees were measured at every 2-meter interval sectional length.
The diameter and length of each branch were measured by using Caliper and measuring tape for Diameter (cm) and height (m), respectively.

Data Analysis

Calculation of observed form factor
The measured DBH in cm were changed into the meter. Then, calculation of cylindrical volume for each section and branches of a tree were carried out based on Huber's formula;

\[ V_i = \frac{\pi D_i^2}{4} \times H_i \]  

Equ. 1.

Where the \( V_i \) = volume of the section, \( D_i \) = diameter of the section, \( H_i \) = length of the section, \( \pi \) = 3.14. Then, all sectional and branch volumes of a tree were summed up.

Cylindrical volume of each sampled trees was calculated as;

\[ V = \frac{\pi D^2}{4} \times H \]  

Equ. 2.

Where \( V \) = volume of a tree, \( D \) = diameter at breast height of a tree, \( H \) = total height of a tree.

Then the observed form factor of a tree was calculated as

\[ \text{Obs. ff} = \frac{\sum \text{sec. vol}}{\text{cylinder vol}} \]  

Equ. 3.

Where \( \text{Obs. ff} \) = the observed form factor of a tree, \( \sum \text{sec. vol} \) = sum of \( n \) sectional volume of a tree and cylinder. \( \text{Vol} \) = is the cylindrical volume of a tree.

Table 1. Descriptive statistics on diameter at a height of 1.3 m (DBH, cm), total height (Ht, m), and observed form factor (FF) for A. decurrens in woodlots Agroforestry system of Awi Zone.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sample</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>CV (%)</th>
<th>Altitude Range (m.a.s.l)</th>
<th>Slope (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DBH</td>
<td>58</td>
<td>9.874</td>
<td>1.3266</td>
<td>8</td>
<td>13.7</td>
<td>13.44</td>
<td>1800-2900</td>
<td>5-25</td>
</tr>
<tr>
<td>Ht</td>
<td></td>
<td>12.8</td>
<td>1.4</td>
<td>9.8</td>
<td>15.3</td>
<td>10.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FF</td>
<td>4.875</td>
<td>0.0423</td>
<td>0.369</td>
<td>0.603</td>
<td>8.68</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Selection of Form Factor Equations
The use of the same equation for all tree species is not ideal. Therefore, five commonly used different form factor equations were selected to obtain the coefficients which are to be used as the basis for volume calculations (Gezahegn, 2015 and Tensin et al., 2016). The statistical
analysis were performed by using R statistical software version 3.1.3, the Non-linear regression model with 5% a significance level were used to computed each equation.

Selected equations for this study were:

A - Pollanschutz's form factor function (pollanschutz, 1965).

\[
F = b_1 + b_2 \ln^2(DBH) + \frac{1}{H} + b_4 \cdot \frac{1}{DBH} + b_5 \cdot \frac{1}{DBH^2} + b_6 \cdot \frac{1}{DBH \cdot H} + b_7
\]

Equ. 4.

Diameter at breast height (DBH) and height (H) in decimeters

B - F. Evert's (Australian) form factor function (Evert, 1976).

\[
f = a + b_1 \cdot \frac{1}{DBH^2 \cdot H} + b_2 \cdot \frac{1}{H} + b_3 \cdot \frac{1}{DBH^2}
\]

Equ. 5.

Diameter at breast height (DBH) in centimeter and height (H) in decimeters

C - Short Swedish's form factor function

\[
f = a + b_1 \cdot \frac{1}{H} + b_2 \cdot \frac{H}{DBH} + b_3 \cdot \frac{H}{DBH^2}
\]

Equ. 6.

Diameter at breast height (DBH) in centimeter and height (H) in decimeters

D - Mayer's form factor function

\[
f = a + b_1 \cdot \frac{1}{DBH^2 \cdot H} + b_2 \cdot \frac{1}{DBH \cdot H} + b_3 \cdot \frac{1}{DBH} + b_4 \cdot \frac{1}{H} + b_5 \cdot \frac{1}{DBH^2}
\]

Equ. 7.

Diameter at breast height (DBH) in centimeter and height (H) in decimeters

E - Rosset's form factor function (Rosset, 1998)

\[
\ln(f) = a + b \cdot \ln(DBH) + c \cdot \ln(H)
\]

Equ. 8.

Diameter at breast height (DBH) in centimeter and height (H) in meters

Comparison of Models

Based on the following criteria, all functions (Equ. 4-8) were evaluated and then compared using the non-linear regression of R statistical software, version 3.1.3.

1 - Root mean square error (RMSE) has been the mostly used to describe well the model goodness of fit with the lower value (T. Chai and Draxler, 2014), calculated as:

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{n}(f_i - \bar{f})^2}{n}} \quad \text{-----Equ. 9.}
\]
Where \( f_i \) is observed form factor, \( \hat{f}_i \) is predicted form factor and \( n \) is the sample number.

2 - Mean Absolute Deviation (MAD), it describes the average distance between each data value and the mean (T. Pham-Gia and Hung, 2001) with the lower the value of it is the preferred one. It is calculated as:

\[
\text{MAD} = \frac{\sum_{i=1}^{n} |y_i - \hat{y}_i|}{n} \quad \text{Eqn. 10.}
\]

3 - The coefficient of variance (CV %) can be used to compare distributions obtained with different units (Abdi, 2010), how large the standard deviation (SD) in relation to the mean of our data. The lower the CV, the smaller the residuals relative to the predicted value, is suggested as a good model fit and it is calculated as:

\[
\text{CV}(\%) = \frac{\text{SD}}{\text{mean}} \times 100 \quad \text{Eqn. 11.}
\]

Finally, the graphical illustration for residuals and the behaviors of observed and predicted form factor versus DBH and tree height for the selected functions were carried out for further validation.

**Results and Discussions**

**Comparison and validation of functions**

Based on the result of this finding, statistical fitting criteria for comparison of all 5 form factor functions, the RMSE (0.0369) and MAD (0.0266) of Mayer’s and Pollanschutz’s functions being approximately equal, coefficient of variance (CV%) of Meyer’s function (4.12%) and Pollanschutz’s (4.13%) is slightly greater than that of others (Table 2). Even though, when we have seen further the sum rank of all criteria, Mayer’s and Pollanschutz’s functions were ranked as first and the second respectively than others. Furthermore, the graphical presentation of observed form factor and that of predicted by Mayer’s and Pollanschutz’s functions against the diameter at breast height (cm) and tree height (m) indicated that as relatively stable and almost similar than other functions. Based on these reasons, Mayer’s and Pollanschutz’s form factor functions were selected as an alternative function to estimate the stem profiles of *Acacia decurrens* Willd. tree by calculating its form factor. According to the reports of Tensin et al., (2016), Pollanschutz’s function was selected for commercial trees like: (Abies densa (fir), *Picea spinulosa* (spruce), *Pinus wallichiana* (bluepine), *Tsuga dumosa* (hemlock), *Pinusroxburghii* (chirpine), *C. tribuloides*, *Quercus glauca*, *Quercus lanata* and *Quercus lamellosa*) species in
Bhutan, this finding is in line with our result. But on the contrary Mayer’s function is ranked as the third next to the Pollanschutz’s and Short Swedish’s function. Similarly, Gezahgen (2015) revealed that the F. Evert’s (Australian) function has been selected for 20 broadleaved tree species dominated in 4 selected natural forests of Amhara region, Ethiopia. The graph of residuals versus diameter at breast height (cm) and tree height (m) illustrated normal distribution and almost the same for selected functions, which supports our decision to select the best one (Figure 2-4).

Table 2. Comparison results of all five Form Factor functions by Root mean square of error (RMSE), Mean Absolute Deviation (MAD) and Coefficient of Variation (CV) to select the best one.

<table>
<thead>
<tr>
<th>DBH Range</th>
<th>Mean Form Factor functions</th>
<th>RMSE</th>
<th>Rank</th>
<th>MAD</th>
<th>Rank</th>
<th>CV (%)</th>
<th>Rank</th>
<th>Sum(Rank)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-14</td>
<td>Pollanschutz’s</td>
<td>0.0369</td>
<td>1</td>
<td>0.0266</td>
<td>1</td>
<td>4.13</td>
<td>5</td>
<td>7(2)</td>
</tr>
<tr>
<td></td>
<td>F. Evert’s</td>
<td>0.0397</td>
<td>5</td>
<td>0.0293</td>
<td>5</td>
<td>2.79</td>
<td>1</td>
<td>11(5)</td>
</tr>
<tr>
<td></td>
<td>Short Swedish’s</td>
<td>0.0382</td>
<td>3</td>
<td>0.0291</td>
<td>3</td>
<td>3.58</td>
<td>3</td>
<td>9(3)</td>
</tr>
<tr>
<td></td>
<td>Mayer’s</td>
<td>0.0369</td>
<td>1</td>
<td>0.0266</td>
<td>1</td>
<td>4.12</td>
<td>4</td>
<td>6(1)</td>
</tr>
<tr>
<td></td>
<td>Rosset’s</td>
<td>0.0392</td>
<td>4</td>
<td>0.0291</td>
<td>3</td>
<td>3.08</td>
<td>2</td>
<td>9(3)</td>
</tr>
</tbody>
</table>
Figure 2. Shows the relationship between observed form factor and that of predicted for each Equation (A-E) against the Diameter at 1.3m (DBH in cm) and tree height (m).

Table 3. Value of Coefficients of Mayer’s and Pollanschutz’s functions selected to estimate the stem profiles of
*A. decurrens* tree species.

<table>
<thead>
<tr>
<th>Model</th>
<th>Coefficients</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>b₁</td>
<td>b₂</td>
<td>b₃</td>
<td>b₄</td>
<td>b₅</td>
<td>b₆</td>
<td>b₇</td>
<td>R²(%)</td>
<td></td>
</tr>
<tr>
<td>Mayer’s</td>
<td>-2.81</td>
<td>34386.12</td>
<td>-6841.02</td>
<td>67.46</td>
<td>325.49</td>
<td>-332.26</td>
<td>-</td>
<td>-</td>
<td>22.56</td>
<td></td>
</tr>
<tr>
<td>Pollanschutz’s</td>
<td>-3.78</td>
<td>0.07</td>
<td>329.75</td>
<td>76.10</td>
<td>-358.66</td>
<td>-6920.92</td>
<td>34753.77</td>
<td>22.57</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 3. Distribution of residuals against Diameter at Breast Height (DBH in cm) and Tree Height (m) of A. decurrens by the selected (Pollanschut's (A) and Meyer's (D)) functions.

Figure 4. Shows the relationship between observed form factor and that of predicted for the selected Mayer's (Pred.D) and Pollanschutz's (pred. A) Functions against the Diameter at breast height (DBH at 1.3m) and tree height (m).
Predicted Form Factor

The trend of the predicted form factor of *A. decurrens* gradually decreases with increasing DBH and height. But form factor had shown a constant trend when DBH attained its maximum. This result is concurrent with the findings of Tensin et al., (2016) who did for nine commercial trees of Bhutan and Gezahegn (2015) for 20 broadleaved trees of the selected natural forests in Ethiopia. This may be due to *A. decurrens* doesn’t reach at its growth potential (maximum DBH) as a result of short rotation times of woodlots/stands (commonly five year) (Figure 3). According to the report of Intia V et al. (2016) for *Pinus taeda* stands, the form factor is greatly affected by the age of the stand. If the age of stands extended, the species will reach at its growth potential and the graph may show in a constant way. For functions good to fit, the predicted form factor by the selected functions is approximately equal to that of the observed that is 0.4875 for a DBH class of 8-14cm. Amhara Forest Enterprise uses 0.44 form factor value to estimate the volume of *A. decurrens* plantations in Amhara (AFI, personal communication) and 0.8 in Indonesia (Priyono S et al., 2010). Estimating a tree and stand volume of *A. decurrens* in Southwestern of Amhara by using the form factor of 0.44 (AFI) may lead to an error or underestimate and then, using 0.4875 (our result) is appropriate to increase the level of accuracy.

Conclusion and Recommendations

Meyer’s and Pollanschutz’s functions are relatively efficient to estimate the stem profile of *A. decurrens* woodlot/plantation in Amhara Region. Both functions were recommended to use alternatively by determining *A. decurrens* form factor at the given DBH and tree height. The estimated mean Form Factor of *A. decurrens* was 0.4875 to estimate the volume of *A. decurrens* woodlot as a correction factor for a diameter range of 8-14cm. However, further research should be done to see the effect of planting density and age of the stands on *A. decurrens* wood volume and stem form.

Acknowledgment

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Assessing the Effect of Coppicing on Wood Yield of *Eucalyptus globulus* in the Highland of North Gondar

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Abstract

This research was conducted in Wegera and Debark districts of North Gondar. The study sites were selected based on the presence of *E. globulus* planting experience. Sample households were selected purposively based on the presence of Eucalyptus woodlot. The ages of the plantation were stratified in to four. The first groups are the un-harvested up to three years, and the subsequent groups are 1st, 2nd, and 3rd stages of coppicing. The sampling plot size was of 10 m x 10 m (0.01 ha). The Analysis of Variance (ANOVA) showed that there was a significant (p<0.001) difference among different coppicing levels on the yield of *Eucalyptus globulus*, measured in terms of stand volume, basal area, and number of trees. First coppicing had the highest basal area (24.9 m² ha⁻¹) followed by second coppicing (23.5 m² ha⁻¹) and third coppicing (23.1 m² ha⁻¹), respectively. The lowest basal area was observed in the original plantation (without coppicing). First coppicing had the highest number of trees per ha with more than 19,480 trees ha⁻¹ followed by second coppicing level (16,046 trees ha⁻¹) and third coppicing (12,546 trees ha⁻¹). The number resprout/shoots increased with the increasing of coppicing level. The highest number of resprout/shoots was observed in the third coppicing with mean (±std) of 3.1 ± 0.85, whereas, the second coppicing and first coppicing had mean (±std) of 2.9 ± 0.75 and 2.26 ± 0.28 respectively.

Key words: coppicing level; *Eucalyptus globulus*; basal area
Introduction

_Eucalyptus_ is a genus which has more than 500 species in the world. This genus is native to Australia, the Malaysian region and the Philippines but it has been planted in different parts of the world since 1904 (FAO, 2011). It is adaptable to tropical, arid and temperate regions. It is one of the most widely planted tree species covering around 20 million hectares of land. It is planted for paper pulp, fuel wood, timber, amenity plantings and land rehabilitation (Girijashankar, 2010).

Coppicing is a traditional method of plantation management, which enables the new shoots emerge from the stump or roots after cutting. Forest regeneration through coppicing is the type of tree management frequently used for short-rotation trees to produce wood biomass for energy. It is mainly used for fuel wood, pulp production, and carbon sequestration efficiently into the ecosystem (Luostarinen et al., 2009). Coppice crop often has shorter rotation periods than those of seedling, because coppice stems grow faster than seedlings as they grow from large and well-established root systems.

It is recognized that tree crops developing from coppice have higher yield compared with seedlings of the same age (Muluneh, 2011). Different studies indicated that the capacity of stumps to coppice may vary with species, age of the stump, season of cutting, and the site conditions. Similarly, the ability to coppice and yield from the first coppice crop is higher than the second and third coppice cycle. However, coppicing and the effect of coppice cycle (as the age of stump increased) on biomass mainly on wood were not investigated to provide decision ideas in the highlands of northwestern Ethiopia. Thus, this study aims to investigate the effect of coppicing on yield of _Eucalyptus globulus_. It also aims to compare the wood yield of _E. globulus_ in different coppice management and coppicing cycle.

Materials and methods

Study site and sampling design

This research was conducted in Wegera and Debark highland of North Gondar. The study sites were selected based on the existing stand performance of the _E. globulus_ and farmers’ experience. A reconnaissance survey was conducted to collect basic information such as site
condition and size of the plantation to determine the sampling size. Diameter and height measurements were done using Caliper (measuring tape) and hypsometer, respectively. To avoid confusion, trees were marked using chalk. GPS was used to locate the position of plots. Compass and Suunto were used to know the direction and slope of the sites, respectively.

A farmer who have \textit{E. globulus} with a coppicing level of 1$^{st}$, 2$^{nd}$, and 3$^{rd}$ having an area of 10 m x 10 m (0.01 ha) was identified and selected purposively. After obtaining one farmer for each \textit{E. globulus} tending operation, the rest 4 farmers were identified by using snow ball sampling techniques. A total of 60 plots were established to study the effect of coppicing on biomass yield, mainly the wood yield. From each sample the stand DBH, height, resprouted shoots, number of shoots per stump (coppicing effectiveness) and stump height were collected and documented.

Each coppicing management was evaluated based on the standing volume and basal area. Basal area was calculated using the diameter at breast height (DBH, 1.3 m height) (Didita et al., 2010).

\begin{align*}
\text{Basal area} &= \frac{\pi d^2}{4} \\
\text{Where,} \quad \pi &= 3.14, \quad d = \text{diameter at breast height (DBH) in cm}
\end{align*}

Volume was calculated using the formula

\begin{align*}
V &= G \times H \times F \\
\text{Where,} \quad G &= \text{basal area (} \frac{\pi d^2}{4} \text{)}, \quad H = \text{Height of tree, and} \quad F = \text{form factor of tree. Analysis of data was carried out using quantitative methods using R version 3.2.2 software at a significant level of} \; 5\%.
\end{align*}

Result and discussion

\textbf{Yield of \textit{Eucalyptus globulus} with different coppicing level}

The Analysis of Variance (ANOVA) showed that, there was a significant (p<0.001) difference among different coppicing levels on the biomass of \textit{Eucalyptus globulus} (Table 1).
Table 1. Analysis of variance for volume of *Eucalyptus globulus* with different coppicing level in the highland of North Gondar

<table>
<thead>
<tr>
<th></th>
<th>Df</th>
<th>Sum Sq</th>
<th>Mean Sq</th>
<th>F value</th>
<th>Pr(&gt;F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>3</td>
<td>46677</td>
<td>15559</td>
<td>6.796</td>
<td>0.000548***</td>
</tr>
<tr>
<td>Residuals</td>
<td>56</td>
<td>128209</td>
<td>2289</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The ability to coppice and yield from the first coppice was higher than the plantation from the seedling (Figure 1). However, the wood yield declined with each cropping as the age increased (Mandy, 2006).

Figure 1. Analysis of variance for volume of *Eucalyptus globulus* with different coppicing level in the highland of North Gondar. Means in columns with similar letters are not significantly different at (p<0.05).

**Basal area, Number of trees and Volume**

There were clear differences between different coppicing level of *Eucalyptus globulus* regarding the stand basal area, number of trees and volume, basal area (Table 2). First coppicing had the highest basal area of (24.9 m²ha⁻¹) followed by second coppicing and third coppicing level.
(23.5 m$^3$ ha$^{-1}$) and 23.1 m$^3$ ha$^{-1}$, respectively. The lowest basal area was observed in the original plantation (without coppicing).

Table 2. Mean basal area, number of trees and volume of *E. globulus* in the highland of North Gondar

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Height (m)</th>
<th>Basal area (m$^2$/ha)</th>
<th>Number of Trees/ha</th>
<th>Volume (m$^3$/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>without coppicing</td>
<td>9.187$^b$</td>
<td>17.7$^b$</td>
<td>11853$^e$</td>
<td>108.7$^b$</td>
</tr>
<tr>
<td>First coppicing</td>
<td>9.307$^b$</td>
<td>24.9$^a$</td>
<td>19480$^a$</td>
<td>177.1$^a$</td>
</tr>
<tr>
<td>Second coppicing</td>
<td>9.62$^{ab}$</td>
<td>23.5$^a$</td>
<td>16046$^b$</td>
<td>172.1$^a$</td>
</tr>
<tr>
<td>Third coppicing</td>
<td>10.25$^a$</td>
<td>23.1$^a$</td>
<td>12546$^c$</td>
<td>169.2$^a$</td>
</tr>
<tr>
<td><strong>LSD</strong></td>
<td>0.342</td>
<td>3.866</td>
<td>2386.0</td>
<td>35.0006</td>
</tr>
<tr>
<td><strong>CV</strong></td>
<td>0.126</td>
<td>0.262</td>
<td>0.294</td>
<td>0.347</td>
</tr>
</tbody>
</table>

Means in columns with similar letters are not significantly different at (p<0.05).

During harvest, first coppicing had the highest number of stems per hectare (19480 trees ha$^{-1}$) followed by second coppicing level (16046 trees ha$^{-1}$) and the third coppice (12546 trees ha$^{-1}$). Original plantation (without coppicing) had the lowest density which is less than 11853 trees ha$^{-1}$ at the age of three years. First coppicing had the highest volume per ha with 177.1 m$^3$ ha$^{-1}$ followed by second coppicing level (172.1 m$^3$ ha$^{-1}$) and third coppicing with (169.2 m$^3$ ha$^{-1}$). Original plantation (without coppicing) had the lowest stand volume with 108.7 m$^3$ ha$^{-1}$ at the age of three years. Similar findings also indicated that coppicing crop gives higher yield than a single stem tree (*FAO, 2011*).

Number of resprout/Shoots, Stump Height and Stump DBH

The analysis of Variance (ANOVA) showed that there was a significant difference among the treatments such as number of resprout/shoots, stump height and stump dbh (Table 3).
Table 3. Mean basal area, number of trees and volume of *Eucalyptus globulus* in the highland of North Gondar

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Number of resprout/Shoots</th>
<th>Stump Height (cm)</th>
<th>Stump DBH (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without coppicing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First coppicing</td>
<td>2.247&lt;sup&gt;b&lt;/sup&gt;</td>
<td>35.21&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.573&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Second coppicing</td>
<td>2.869&lt;sup&gt;a&lt;/sup&gt;</td>
<td>55.51&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.693&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Third coppicing</td>
<td>3.089&lt;sup&gt;a&lt;/sup&gt;</td>
<td>66.58&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.433&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>LSD</td>
<td>0.501</td>
<td>7.3284</td>
<td>1.198895</td>
</tr>
<tr>
<td>CV</td>
<td>0.276</td>
<td>0.311</td>
<td>0.393</td>
</tr>
</tbody>
</table>

Means in columns with similar letters are not significantly different at (p<0.05).

This study also showed the effect of coppicing on the ability to resprout/shoots of *Eucalyptus globulus* in the highland of North Gondar. The result indicated that the mean number of resprout/shoots of the study area varied with different coppicing level. The number resprout/shoots increased with increasing of the coppicing level. The highest number of resprout/shoots was observed in third coppicing level with Mean (±std) of 3.1 ± 0.85, whereas the second coppicing and first coppicing had Mean (±std) of 2.9 ± 0.75 and 2.26 ± 0.28, respectively.

**Conclusion and recommendation**

Coppicing levels affected wood yield, diameter and number of resprouts per stump of *Eucalyptus globulus* in the study area. First coppicing had the highest basal area of (24.9 m$^2$ ha$^{-1}$), highest volume (177.1 m$^3$ha$^{-1}$) and 19480 number of trees/ha. The analysis of Variance (ANOVA) showed that, among the treatments, coppicing level and its interaction with stump diameter found to bring significant difference for the emergence of shoots, however, stump height doesn’t show correlation with the coppicing level. The number resprout/shoots increased with the increasing of coppicing level.
Reference


Evaluation of the Adaptability of Different Eucalyptus Species in the Highland Part of Amhara Region

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Abstract
Growth performances of six eucalyptus trees species were tested for five years at Wegera, in the highland areas of North Gondar, Ethiopia. The best performance in terms of survival, height and diameter growth and volume were E. globulus, E. viminalis and E. grandis. The height growth of E. globulus (7.73 m) and E. viminalis (6.06 m) was higher than the other four species. The lowest height growth was obtained from E. camaldulensis (1.85 m). Significant difference in RCD was observed among E. globulus, E. camaldulensis, and E. saligna. However, no significant difference in RCD was found among E. globulus, E. viminalis, and E. grandis. Except for E. citrodora all treatments had a survival rate of 80 % in 28-month growing period. Similarly, the volume of E. globulus, E. viminalis and E. grandis did not show significant differences. However, the highest volume was obtained from E. globulus (271.09± 109.02 m³ ha⁻¹) and the lowest volume was found from E. citrodora (29.4± 29.2 m³ ha⁻¹). Apart from E. globulus, the ecological limitations of highland areas and mono-culture plantation, growth rates of the two species are promising. This will help to contribute for sustainable wood production system. E. viminalis is recommended as an alternative species for the highlands of northwest Amhara and similar agroecology.

Key words: Eucalyptus viminalis, height, diameter, survival rate, volume
Introduction

_Eucalyptus_ is a genus which has more than 500 species. This genus is native to Australia, the Malaysian region, and the Philippines but it is planted in different parts of the world since 1890s (Dessie and Erkossa, 2011). _Eucalyptus_ is adaptable to tropical, arid and temperate regions of the world. It is one of the most widely planted tree in the world which covers around 20 million hectares of land. It is planted for paper pulp, fuel wood, timber, amenity plantings and land rehabilitation (Girijashankar, 2010).

_Eucalyptus_ was introduced to Ethiopia during the reign of Emperor Menilek II (1868-1907), in order to supply fuelwood, construction, and timber to the new and growing capital city of Addis Ababa (Bekele, 2011, Pohjonen and Pukkala, 1990). Currently, about 55 species of eucalyptus have been grown in Ethiopia (Zerfu, 2002 ), of which the most widespread species are _Eucalyptus camaldulensis, E.citrodora, E. globulussubsp. E. globulus, E. regnans, E. saligna and E. tereticornis, E. grandis_. In the highland areas of Ethiopia, _E.globulus and E. camaldulensis_ are the major species planted (Dessie and Erkossa, 2011). Specifically, Azene (2007) reported that _E. camaldulensis_ grow in the warm lowland areas and _E. globulus_ grow in the cold highland areas of Ethiopia.

Eucalyptus species have been highly preferred and appreciated by the farmers over indigenous or other exotic tree species due to its wider adaptation and fast growth characteristics. Based on FAO estimates, in 1990 the total estimated plantation forest in Ethiopia was 189,000 ha; in 2000 it increased to 216,000 ha. In 2005 the cover had increased to 419,000 ha and in 2010: 972,000 ha, of which eucalyptus covering 56% of the total plantation area (Bekele, 2011). Likewise, in the Amhara region, plantation forest is increasing substantially. The plantation forest coverage of the region is 639400 ha for small scale private plantation and 44600 ha for industrial plantation (FAO, 2015). Plantations consist mainly of Eucalyptus species, _Cupressus lusitunica, and Acacia decurrens_ (Mekonnen et al., 2016). Eucalyptus species mostly _E. globulus and E. camaldulensis_ is dominantly planted as a form of woodlots in the highland.

Increasing benefit from eucalyptus is an incentive for farmers to expand eucalyptus plantations at the expense of another land uses (Engda et al., 2008) and also as a result of the availability of
high demands for eucalyptus products the trend of expansion of eucalyptus plantation on crop and communal lands have been increasing. The market price for eucalyptus poles has grown to be 15 times greater over the last two decades (Dessie and Erkossa, 2011). Along the various exogenous factors contributing towards this demand: a domestic construction-boom, reported reduction in crop yields, population growth, and land degradation (Mekonnen et al., 2007, Duguma and Hager, 2010). However, planting of only one type of species in woodlots may be exposed to risk. For instance, if diseases breakout on this species, almost all eucalyptus growing parts of the country could be adversely affected and may result in a negative consequence on the livelihood of growers. Hence, to sustain the wood production system and to minimize the risk of loss, identifying and adapting different alternative eucalyptus tree species is a crucial step in the highlands of west Amhara. Therefore, the aim of this study was to select adaptable and best performing Eucalyptus species in the highland parts of northwest, Ethiopia.

Materials and Methods

Site description

The experiment was conducted in the highlands of North Gondar zone, Amhara Regional State (Ethiopia), specifically at Wogera district (Fig.1). It is geographically located at 12°46'17.58"N, 37°35'11.43"E and with an altitude of 3013 m.a.s.l. The rainfall pattern of the area is unimodal with mean annual rainfall ranging from 750 to 1570 mm, and the mean annual temperature ranges from 18 to 25 °C. The major soil type of the study area is dominated by Nitosols (34.53 %) and Cambisols (25.85%) in the farming system. Eucalyptus globulus is dominantly planted in the form of woodlot.
Experimental design

Seeds of selected eucalyptus species (Eucalyptus citrodora, Eucalyptus viminalis, Eucalyptus saligna, Eucalyptus grandis, Eucalyptus globulus (control) and Eucalyptus camaldulensis) were purchased from Forestry Research Center (FRC), and raised in Wogera Agricultural Development Office nursery site.

The experiment was conducted in a randomized complete block design with three replications. Each plot had 10m*10m size. The numbers of seedlings per plot were 25 with planting space of 2m*2m. The spacing between blocks and plots were 3m and 2m, respectively. Growth and survival count data were collected every six-month interval until the end of the trial, and volumes at 8-year age were included for comparison with form factor of 0.4.

Statistical analysis

The following formula was used to calculate volume of a tree:

$$ V = \frac{\pi DBH^2 \times H \times ff}{4} $$

Where DBH= Diameter at breast height, H=Height. and ff=0.4
Height, root collar diameter (RCD), survival rate and volume data of the tree species were tested for normality using Shapiro-Wilk test. Survival rate and volume data were not normally distributed, a square root transformation was applied (Gomez and Gomez, 2010). Height, Root collar diameter, Survival rate and Volume data of the treatments were analysed with one-way analysis of variance (Dowdy et al., 2011). The analysis was run using R studio (R coreTeam, 2015). The significance between means was compared using Fisher’s least significance difference (LSD) at P<0.05.

Result and Discussion

Height
The height growth of *E. globulus* was higher (7.73 m) at the age of 53 months (p<0.05) than other treatments (Table 1, and Fig.2). This result is relatively lower than the finding of Kindu et al. (2006), who found 8.25 m at 24-month, 10.87 m at 36 month and at 14.47 m at 64 month for *E. globulus* in the central highlands. However, the height growth of *E. camaldulensis* is significantly lower because of site matching problem. On the other hand, *E. camaldulensis* and *E. citrodora* demonstrated the lowest height growth i.e. 1.85 and 2.3 m at the end of the trial, respectively. *E. globulus*, *E. viminalis* and *E. grandis* attained the highest growth. However, the overall mean of height had significant difference across treatments (Fig. 2).

Table 1. Mean height of six tree species measured at different months.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>1Month</th>
<th>3Months</th>
<th>21Months</th>
<th>28Months</th>
<th>41Months</th>
<th>53Months</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>E. globulus</em></td>
<td>0.51a</td>
<td>0.95a</td>
<td>2.46a</td>
<td>3.83a</td>
<td>6.08a</td>
<td>7.73a</td>
</tr>
<tr>
<td><em>E. camaldulensis</em></td>
<td>0.40b</td>
<td>0.58bc</td>
<td>0.81b</td>
<td>0.99d</td>
<td>1.36c</td>
<td>1.85c</td>
</tr>
<tr>
<td><em>E. viminalis</em></td>
<td>0.48ab</td>
<td>0.72b</td>
<td>1.52b</td>
<td>2.37b</td>
<td>4.17ab</td>
<td>6.06a</td>
</tr>
<tr>
<td><em>E. saligna</em></td>
<td>0.42b</td>
<td>0.65b</td>
<td>0.95b</td>
<td>1.19cd</td>
<td>1.88c</td>
<td>2.69bc</td>
</tr>
<tr>
<td><em>E. citrodora</em></td>
<td>0.29c</td>
<td>0.44c</td>
<td>0.82b</td>
<td>0.96d</td>
<td>1.50c</td>
<td>2.30c</td>
</tr>
<tr>
<td><em>E. grandis</em></td>
<td>0.51a</td>
<td>0.73c</td>
<td>1.36b</td>
<td>2.09bc</td>
<td>3.56bc</td>
<td>5.07ab</td>
</tr>
</tbody>
</table>

LSD 0.09 0.19 0.82 1.08 2.21 2.66
CV 11.59 15.21 34.24 31.29 39.45 34.16

Means in columns with similar letters are not significantly different (p<0.05).
Height is usually considered an important variable in the evaluation of species and provenances (Raebild et al., 2003). However, it depends on the uses of the trees. Apart from indicating productivity, height can be used as a measure of the adaptability of trees to the environment. Trees growing faster in height usually being better adapted to the site than short provenances/trees (Raebild et al., 2003).

**Root collar diameter (RCD)**

Significant difference in RCD was observed among *E. globulus*, *E. camaldulensis*, and *E. saligna*. However, no significant difference in RCD was found among *E. globulus*, *E. viminalis* and *E. grandis* (Fig.3). The highest RCD was recorded for *E. globulus* (7.87 cm) among treatments and the lowest was found for *E. camaldulensis* (1.83 cm) at the end of the trial.

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**Figure 2.** Growth performance of six eucalyptus species in height. Bars represent standard error of mean and bars with similar letters are not significantly different at (p<0.05).

**Figure 3.** Root collar diameter (RCD) growth performance of six eucalyptus species. Bars represent standard error of mean and bars with similar letters are not significantly different at (p<0.05).
Survival Rate

Survival is regarded as one of the key variables when analyzing tree adaptability, since it indicates the performance of a tree species to the environment. Therefore, except for *E. citrodora* all treatments had more than 80% survival rate up to the 28-month growing period. However, the trend of survival rate had a constant pattern for *E. globulus* in 28 months (Fig. 4 and 5). It should be noted that survival reflects only the conditions experienced during the first year’s growth of the trial and not necessarily the climatic extremes and conditions that may be experienced during the life-span of a tree in the field (Ræbild et al., 2003).

Figure 4. Trend of six eucalyptus species in survival rate across months. Bars represent standard error of mean (P< 0.05).

Figure 5. Survival rate of six eucalyptus species in the highlands of North Gondar. Bars represent standard error of mean and bars with similar letters are not significantly different at (p<0.05).
Volume

Volume is one of the parameters which is derived from tree height and girth. It is an important parameter to compare a production potential of species in a given area. In this study, the volume is estimated on 8 years after the establishment. Among treatments, the volume of *E. globulus*, *E. viminalis* and *E. grandis* did not show significant differences (Fig. 6). But higher volume was obtained for *E. globulus* (271.09 ± 109.02 m³ ha⁻¹) and lower volume were found at *E. citrodora* (29.4 ± 29.2 m³ ha⁻¹). Similarly, annual volume increment was higher for *E. globulus*, followed by *E. viminalis* and *E. grandis*, 33.89 m³ ha⁻¹, 24.67 m³ ha⁻¹ and 18.21 m³ ha⁻¹, respectively. However, the lower increment in volume was found less than 3.67 m³ ha⁻¹ per annum for *E. citrodora*. Annual increment of *E. globulus*, *E. viminalis* and *E. grandis* were relatively higher than the result reported by Bekele (2011) who found range of increment for plantation from 10-15 m³ ha⁻¹ year⁻¹. Similarly, the finding of this study is in line with the finding of Dessie and Erkossa (2011) who reported mean annual increment of eucalyptus species ranges from 10-15 m³ ha⁻¹. However, the mean annual increment of *E. citrodora* was lower than the two ranges.

![Figure 6. Mean volume of six eucalyptus species 8 years. Bars represent standard error of mean and bars with similar letters are not significantly different at (p<0.05).](image)

**Conclusion and Recommendation**

Based on the evaluation of six eucalyptus species, *Eucalyptus viminalis* and *Eucalyptus grandis* have no significant difference from *Eucalyptus globulus* in growth performance (height and root collar diameter (RCD) survival rate and volume in the highland areas of North Gondar.
Therefore, *E. viminalis* and *E. grandis* can be used as an alternative species for smallholder plantation. These two species are adaptable and may substitute *E. globulus* in the highlands of northwest Amhara.

Acknowledgement
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ZERFU, H. 2002 Ecological impact evaluation of Eucalyptus plantations in comparison with agricultural and grazing land-use types in the highlands of Ethiopia *Doctoral thesis. Institute of Forest Ecology, University of Natural Resources and Life Sciences, Vienna.*
Assessing the Distribution and Social Perception of *Ipomea Carinea* Shrub Species, A Case Of Chiliga Woreda, North Gondar

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**Abstract**

The research was conducted at Chilga Woreda of North Gondar Zone. The samples were taken from gully, roadside and farmland. A total 36 samples were collected per each land use. Socio-economic survey was conducted in 60 households. The *Ipomea carinea* shrub species were known by its Amharic name called “Agereshemagellie” or “Mogno”. The population of matured *Ipomea* ranges 2000 – 105300 ha\(^{-1}\) and seedlings 1000 to 42500 ha\(^{-1}\). The average population of *Ipomea carinea* ranged 1900 to 10000 ha\(^{-1}\). The niches of *Ipomea carinea* are gully, roadside and farmland. From the total of respondents 43.3 % of them confirmed that *Ipomea carinea* was introduced before 10 years ago. From the total, 36.7 % and 18.3% of the respondents believe that the species was introduced to the area before 15 years and 20 years ago, respectively. About 98.3 % of respondent farmers considered *Ipomea carinea* is an invasive shrub species because it competes with other land uses. However, about 6.7% of the respondent farmers used this species for compost preparation, gully rehabilitation, fire wood, live fence and boundary demarcation.

**Key words:** Boundary demarcation, firewood, *Ipomea carinea*, rehabilitation
Introduction

In many cases invasive species occupy natural or semi-natural ecosystems and affect the provision of ecosystem services to local communities negatively (Hughes and Styles 1989; Richardson 1998). Land use changes, competitive ecological advantages, and climate change are key factors to influence the probability of invasion (Pasiecznik et al, 2001). Invasive species are characterized by rapid growth, extensive dispersal capabilities, large and rapid reproductive output and broad environmental tolerance. "Exotic", "alien", "transplanted", "introduced", "nonindigenous", and "invasive" are all words that have been used to describe plants and animals that have been moved beyond their native ranges by humans (Williams and Meffe 2005).

Williamson (1996) indicated as non-native species are now recognized as one of the major drivers of global biodiversity loss. They also cause significant damage to economies and human health (Sala et al, 2000, Jeschke et al., 2005; Daisie, 2009 and Vilà et al., 2010) An introduced species might become invasive if it can out compete with native species for resources, such as nutrients, light, physical space, water or food. Invasive species often coexist with native species for an extended time, and gradually the superior competitive ability of an invasive species becomes apparent as its population grows larger and denser and it adapts to its new location (Stohlgren et al., 1999, Sax et al., 2002) and can change the functions of ecosystems (Mack et al., 2000), hence; they are potential to hybridize and led to a decline and even extinction of native species (Hawkes et al., 2005 and Rhymer et al., 1996). Besides their economic ramifications, alien invasions may result in extensive changes in the structure, composition and global distribution of the biota of sites of introduction, leading ultimately to the homogenization of the world's fauna and flora and the loss of biodiversity (Odendall et al., 2008) and are considered a "significant component of global change" (Sakai et al., 2001). Decreasing the rate and impacts of introduced species is considered by many as important to maintaining the natural biodiversity and ecosystem functioning, which in turn, provides goods and services for humans (Rejimanek, 2003). On a global scale, it is estimated that invasive species have come to occupy about 3% of the Earth's total ice-free surface (Mooney and Cleland, 2001). The geomorphological processes, biogeochemical or hydrological cycling, and disturbance types and regimes and stand structure, recruitment rates of natives and resource competition may be altered (Vitousek, 1986) mainly due to the introduction of invasive species.
Hence, the introduction of an exotic invasive species results in undesirable side effects on the local ecological conditions. This research answered the following questions: what is the distribution rate of Ipomea species? Is this shrub species has invasiveness behavior? How the local people perceive this species? And what are the benefits and threats of the shrub? The objectives of the study were to assess the spatial distribution and extension trend of Ipomea, and assessed the community perception and attitudes of the farmers towards the shrub.

**Materials and methods**

**Site description**

The site of the study is located in the northwestern part of Ethiopia in Chilga woreda Woreda, North Gondar Zone (Fig 1).

![Figure 1. Map of the study area](image-url)
Data collection for spatial distribution

Shrub species Identification

Before conducting the spatial distribution of the *Ipomea species*, samples from different parts of a plant (leaf, flower and roots) was collected for identification purpose. The plant specimen with its local name was collected and sent to Addis Ababa, the national herbarium for identification. The local name Agereshemagelle (Mogno) shrub species was identified and specified as *Ipomea Carinea*.

Sampling Method

The study area was under different cropping patterns with varying soil and landscape characteristics. The sampling locations were selected using regular sampling interval using GIS environment, supported with a careful field observation of the most representative soil-landscape features. Hence, several samples were taken at the intersection of the co-ordinate (Nielsen and Wendroth, 2003). Therefore, the 47 Km² study area was divided into a 1000 m by 1000 m square grid using ArcGIS and a total of 47 samples across the entire area were collected for analyses. For the purpose of this study, we classified *Ipomea Carinea* shrub species into three classes based on the height of the seedling (0-40 cm), sapling (40-150 cm) and matured (> 150 cm) height.

Geostatistical analyses including semivariogram cross-semivariogram model fitting and kriging procedures were carried out using GS+ (Gamma Design Software, 2004, Geostatistics for the Environmental Sciences, St. Plainwell, Mich.) to assess the degree of spatial variability of seedling, sapling, mature and total number of Ipomea population.

Kriging is a statistical procedure for interpolating values at unmeasured locations between locations with sampled data (Nielsen and Wendroth, 2003). Kriging analysis is applicable for environmental disciplines such as agricultural yield mapping (Blackmore, 1999), spatial continuous soil surface generation (Goovaerts, 1999), spatial variability assessment of soil property (Addis et al., 2015), spatial variability assessment of rainfall (Naoum and Tsanis, 2004) and air pollution modelling (Wong et al., 2004). Ordinary kriging is a type of kriging that considers the mean is constant but unknown across the spatial domain of interest (Li and Heap,
Kriging utilizes the spatial variance structure available in a semivariogram and provides a best linear unbiased estimate of an unmeasured value calculated from weighted values measured in a local neighborhood (Nielsen and Wendroth, 2003). Semivariance ($\gamma$) is an important concept in geostatistics (Webster and Oliver, 2001) and can be estimated from the observed values as follows:

$$
\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2
$$

Where $h$ is the distance between point $x_i$ and $x_o$ and $\gamma(h)$ is commonly referred to as semivariogram (Webster and Oliver, 2001). $N(h)$ is the number of data pairs within a given class of distance and direction. A plot of $\gamma(h)$ against $h$ is known as the experimental semivariogram, which displays several important features (e.g. nugget, sill and range) (Burrough and McDonnell, 2011). If the ratio of nugget to sill is close to 1, it reflects a weak degree of spatial dependency (Hartkamp et al., 1999). The “range” is a value of distance at which the “sill” is reached (Li and Heap, 2008) and the range provides information about the size of a search window used in the spatial interpolation methods (Burrough and McDonnell, 2011). Geostatistical analyses, including semivariogram, cross-semivariogram model fitting and kriging procedures, were carried out using GS+ (Robertson et al., 2008) to assess the degree of spatial variability. In this study, the semivariogram model with the least reduced sum of squares (RSS) was selected for spatial autocorrelation process as described by Addis et al. (2015). The RSS measures the overall difference between observed data and the estimated values by a prediction model and it is one of the best criterions for parameter and model selection. Meanwhile, the four commonly used semivariogram models reported by Burrough and McDonnell (1998) were tested to find the best fitted model. This study used cross-validation procedures, which removes one data point and then estimates the corresponding data using the data points at the rest of the locations and the main use of cross-validation is to compare the estimated value to the observed value in order to obtain useful information about variables (Davis, 1987; Li and Heap, 2008). The various cross-validation statistics are vital for examining how well the semivariogram model fits with the obtained data (Willmott, 1982). Some of the good criteria that the study used to decide the best model among the tested models were the mean error (ME), the root mean square error (RMSE) and the mean squared deviation ratio (MSDR).
Block Kriging
The block kriging (BK) is a generic name for estimation of average values of the primary variable over a segment, a surface, or a volume of any size or shape (Goovaerts, 1997). It is an extension of OK and estimates a block value instead of a point value by replacing the point-to-point covariance with the point-to-block covariance (Wackernagel, 2003). Block kriging is a technique for averaging observation in a particular domain. Unlike point kriging, which is point information supported, block kriging is domain supported. Hence, whereas point kriging is rather used for estimating unsampled locations, block kriging is employed for obtaining an average value for a domain that can only be sampled with several individual measurements.

Data collection method for different land use
The study areas/kebeles were selected using purposive sampling technique taking in to consideration the availability of the shrub species. To study the distribution of the species with different land use (Gully land, Road side and Farm land), transect walk was used at an interval of 100m. The minimum distance between the first and the second quadrants were 50m and 10m x 10m quadrant were established along the transects line. From each quadrant the number of Ipomea individuals were collected and measured. Data such as DBH, height, density, environmental variables including slope, aspect, altitude, and geographic coordinates for each quadrant were recorded.

Social data collection
Semi-structured interview was carried out for the selected farmers. The interview includes management practices, perception on the growth, on the use, effect on the livestock, soil and other associated trees and its productivity. A total of 60 households were interviewed. Secondary data were collected and recorded from agricultural development offices. Qualitative and quantitative descriptions were used to analyze the data using SPSS and excel.

Result and Discussion
Spatial distribution of Ipomea carinea
Spatial prediction maps produced by the block kriging procedure using the semivariogram coefficients (Table 1) for Ipomea population were used as shown in (Figures 2). The values of
matured *Ipomea* range from 20 to 1053, seedlings range from 10 to 425 and Sapling ranges from 5 to 45 individuals/0.01 ha. The study area had *Ipomea carinea* population that ranges from 207 to 1033 with the mean value ranging from 19 to 100 individuals/0.01 ha. The descriptive statistics is shown in table 1. The interpolated maps generated based on the best value of the ME, RMSE and MSDR resulted from the cross-validation of the *Ipomea carinea* population is indicated in Figure 2.

Table 1. Descriptive statistics summary for *Ipomea carinea* distribution in the study area

<table>
<thead>
<tr>
<th>Variables</th>
<th>No. of samples</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Range</th>
<th>Mean</th>
<th>SD</th>
<th>SE</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matured</td>
<td>47</td>
<td>20</td>
<td>1053</td>
<td>1033</td>
<td>100.13</td>
<td>191.40</td>
<td>27.92</td>
<td>1.91</td>
</tr>
<tr>
<td>Seedling</td>
<td>47</td>
<td>10</td>
<td>425</td>
<td>415</td>
<td>44.34</td>
<td>88.74</td>
<td>12.94</td>
<td>2.00</td>
</tr>
<tr>
<td>Sapling</td>
<td>47</td>
<td>5</td>
<td>212</td>
<td>207</td>
<td>19.38</td>
<td>40.00</td>
<td>5.83</td>
<td>2.06</td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
<td>45</td>
<td>1617</td>
<td>1572</td>
<td>163.85</td>
<td>316.01</td>
<td>46.09</td>
<td>1.93</td>
</tr>
</tbody>
</table>

SD: is standard deviation; SE: is standard error of mean; CV: is coefficient of variation

Figure 2. Best interpolated *Ipomea carinea* map using the Gaussian ordinary kriging model a) Matured b) Sapling c) Seedling d) Total.
Table 2. The cross-validation statistics, the mean error (ME), the root mean squared error (RMSE), and the mean squared deviation ratio (MSDR) for coefficients of the theoretical semivariogram statistic produced for the Gaussian ordinary kriging models of Ipomea carinea

<table>
<thead>
<tr>
<th>Variable</th>
<th>ME</th>
<th>RMSE</th>
<th>MSDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matured</td>
<td>0</td>
<td>0.012</td>
<td>1.16</td>
</tr>
<tr>
<td>Sapling</td>
<td>0</td>
<td>0.0101</td>
<td>1.14</td>
</tr>
<tr>
<td>Seedling</td>
<td>0</td>
<td>0.0101</td>
<td>1.12</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>0.0097</td>
<td>1.08</td>
</tr>
</tbody>
</table>

ME: mean error; RMSE: root mean square error; MSDR: mean squared deviation ratio.

*Ipomea carinea* in different land use

From each land use 36 sample plots (a total of 108) were taken. *Ipomea carinea* distribution in Gully land was higher than both Roadside and Farmland land uses with the mean value of 48980, 31520 and 27060 individuals/ha, respectively. *Ipomea carinea* shrub species is used as gully control purpose in the study area.

![Figure 3. Ipomea distribution with different land use system in Chilga Woreda](image-url)
Social data analysis

For the socio-economic survey purpose, a total of 60 household sampled were taken. The summary of sampled household characteristics summarized in Table 4 below.

Table 4. Summary of sampled household characteristics for *Ipomea carinea* distribution in Chiliga Woreda

<table>
<thead>
<tr>
<th>Age Class of HH</th>
<th>N of HH</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-25</td>
<td>8</td>
<td>13.3</td>
</tr>
<tr>
<td>26-35</td>
<td>14</td>
<td>23.3</td>
</tr>
<tr>
<td>36-45</td>
<td>16</td>
<td>26.7</td>
</tr>
<tr>
<td>Greater than 45</td>
<td>22</td>
<td>36.7</td>
</tr>
<tr>
<td>Total</td>
<td>60</td>
<td>100.0</td>
</tr>
</tbody>
</table>

| N of Male HH    | 51      | 85      |
| N of Female HH  | 9       | 15      |

Farmers' perception about *Ipomea carinea*

*Ipomea carinea* shrub species were known by its Amharic name called *Agereshemagellie* or *Mogno*. This local name was given because the plant can easily grow and adapt the area. It is a popular species in the study area used as boundary demarcation by farmers. From the total respondents 43.3% confirmed that *Ipomea carinea* shrub species was introduced to the area before 10 years ago. Whereas, 36.7% and 18.3% of the respondents asserted that the species was introduced to the area before 15 years and 20 years ago, respectively. About 95% of the farmers responded that the species was introduced by the local communities whereas; only 3.4% believed that it was introduced to the area through NGOs and Natural phenomena.

In the study area 98.3% of respondent farmers considered *Ipomea carinea* as invasive shrub species because it competes with other land system. Moreover, 25% and 11.7% of the respondents informed that competition was higher in grazing land and farmland, respectively. Its competition with water bodies was much lower than other land uses systems. About 81.6%, 10%, 30% and 6.7% of respondents stated that *Ipomea carinea* competition rate with farmland,
grazing land, roadside and shrub/forestland was very high, respectively. Sixty and eighteen percent of the interviewed farmers specified the species competed for nutrient, light and water.

**Trend analysis of Ipomea carinea**

The 98.3% of the respondents confirmed that *Ipomea carinea* coverage in the study area has increased for the last two decades. While the remaining 1.7% of them said there was no change on its extent. In addition to increasing species cover, its expansion rate was also very fast which was confirmed by 78.3% of the respondents. As to the major means of *Ipomea carinea* expansion 51.7% of the respondents in the study area affirmed that it is through human beings. Despite this, 26.7% and 13.3% of the respondents also explained that through the combination of both human, water and animal and human and water as a means of expansion, respectively.

**Management of Ipomea carinea**

*Ipomea carinea* shrub species was propagated by cutting, seed and root. From the total of respondents 50% of them indicated that *Ipomea carinea* propagated through cutting, layering and rooting. It can grow in both summer and winter season. Summer season was the most favorable condition for the growth of the shrub which was explained by more than 60% of the respondents. This species can grow both vertically and horizontally. More than 75% of the respondents agreed that due to its horizontal and vertical growth pattern, the species has very fast growth rate.

Farmers in the study area used different management practices to remove this species. For example, 33%, 27%, and 18% used chemical spray cut and remove system; a combination of cutting, fire and chemical and a combination of cut and chemical techniques, respectively.

*Ipomea carinea* shrub species has both advantages and disadvantages. 40% of the farmers mentioned its advantages such as for gully rehabilitation, live fence, wind break and boundary demarcation purpose. In addition to this, 6.7% of the respondent farmers used this species for compost preparation, gully rehabilitation, fire wood, live fence and boundary demarcation. Despite all the above-mentioned advantages, 96.7% of the respondents agreed on its invasiveness. The interviewees raised many problems that occurred as a result of *Ipomea carinea* invasive shrub species in the study area. Among the problems raised; weed, host rat/insects,
poisonous for honey bee, allopatic effect, competition for nutrient and other land use systems. About 65% of the respondents reported that the *Ipomea carinea* is invasive and poisonous for honey bee.

Finally, respondent farmers put their suggestions about this invasive shrub species. Based on that 63.8% of respondents wanted to remove *Ipomea carinea* shrub species from the area, about 20% of them wanted to keep it as it is, about 6.7% of the respondents wanted to keep it as it is but improve its management, whereas, the rest 5% of the respondent farmers wanted to improve the management strategies and use it.

**Conclusion and recommendation**

The values of matured *Ipomea* ranged from 20 to 1053, seedlings range from 10 to 425 and Sapling ranges from 5 to 45 per 0.01 ha. The study area had *Ipomea carinea* population that ranges from 207 to 1033 with the mean value ranging from 1900 to 10000. *Ipomea carinea* distribution in gully land was higher than roadside and farmland land uses with the mean value of 29957, 28200 and 24755 individuals ha\(^{-1}\), respectively. *Ipomea carinea* shrub species is used as gully control. Based on the analyzed biological and socio-economics data, the trend of *Ipomea carinea* shrub species is increasing. This species is considered as invasive shrub species and about 63.8% of the respondents wanted to remove it from the area. About 20% of them wanted to keep it as it is, about 6.7% of the respondents wanted to keep it as it is and improve its management, while, 5% of the respondent farmers wanted to improve the management for its use.

**References**


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Woody species diversity and richness in enclosed area: a case of Wogello natural Forest, Ambober, North Gondar

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Abstract
The objective of the study was to determine the species composition, diversity and vegetation structure of Wogello Natural Forest. For vegetation data collection, systematic sampling designs were used. A total of 42 quadrants/plots were used and each sample plot covered an area of 100 m² (10 x 10 m). Sample plots were established at 50 m interval along a series of transects and 30 m between transects. For trees/shrubs, all woody species with diameter at breast height (DBH) ≥ 2.5 cm and height ≥ 2 m were recorded. For the regeneration study purpose, trees/shrubs species with diameter < 2.5 cm and height < 2 m were also recorded. R-software version 3.2.2 and Excel were used. The result indicates that a total of 20 woody species belonging to 12 families were identified. Based on families, Fabaceae was the dominant family by consisting of 4 species (20%), followed by Apocynaceae 2 (10%), Oleaceae 2 (10%) and the rest families share 60% from the total families of the study area. The total basal area was 28.97.3 m²/ha. Number of individuals with (DBH) ≥ 2.5cm and height ≥ 2 m was 1022 trees/ha and for the regeneration it was (6093 individuals/ha). The overall diameter and height frequency distribution of woody species showed an inverse J- shape. The population structure of the study area was determined by selecting five species based on their Importance Value Index (IVI) and it classified into three population structure distribution. Inverse J-shaped, Bell shaped and Broken inversed J-shaped.

Key words: Woody species; diversity; population structure; basal area; Importance value index; Regeneration.
Introduction

Ethiopia had dense forest and had been endowed with diverse vegetation, nevertheless, this resource has dwindled because of forest clearing for cultivation, overgrazing and exploitation without replacement resulting in reduction of the forestry area which is estimated to be 2-3% at present (ICRAF, 1998) and the rate of deforestation is estimated to be 200,000 ha/yr (FAO et al., 1998 and subsequently, large area of the forest that amounts to 1-2 billion m³/yr (FAO, 1981) is lost because of massive deforestation. Trees have been subjected to repeated man made damage and natural disaster and some studies indicated that the species growing around streams and rivers have already vanished.

North Gondar zone is well known for composing different natural forest resources mainly for ecological restoration providing direct use value of fuel wood for couple of decades and many farmers now days use community forest in the enclosed areas. Sometimes they use enclosed areas as a source of feed for live stock and other services. Many of the biodiversity resources which are currently exploited very well by the local farmers were derived from church forests and other communal wood lots while farmers deliberately planting and managing different woody species by retaining them on the farm lands for different purposes.

Ecological restoration by plantation and enclosure are the most known options to reverse land degradation. Community tree planting is the common practice in the enclosed areas for fuelwood and pole production. This in turn enhanced natural regeneration and soil seed bank for ecological restoration. The current climate change and deforestation rate threatening the forest resources in the last decades especially trees that provide multitude of benefits. There are different tree species used for different purposes in the remnant natural forests. This study aims to determine the composition, diversity and vegetation structure of woody species for possible management and conservation options.

Materials and methods

Study site description

This research was conducted in Wogello Natural Forest, North Gondar Administrative Zone of Amhara Regional State, Ethiopia. It is one of the most degraded areas in the state (Wassie et al., 2010). Wogello forest consists of both plantation and natural forest. It is located 694 Km North of Addis Ababa.
Diameter at breast height (DBH) and height were measured using caliper and hypsometer, respectively. To avoid confusion, chalk was used to mark trees. GPS, compass with 360-degree scale (Suunto), and tally sheet were used. A reconnaissance survey was conducted to collect basic information such as site condition and area of the forest. The survey was conducted to determine the sampling size. A systematic sampling method were used in a homogenous vegetation stands along an altitudinal gradient (Lamprecht, 1989).

All woody plants (trees and shrubs), which have a diameters ≥ 2 cm and ≥ 2m height were measured. Diameter measurements were done at breast Height (DBH). Three sample sites were established in three different forest types based on altitude differences. Each forest site consisted of 14 quadrants measuring 10 x 10 m = 100 m² based on (Gering et al., 2003) were taken. A total of 42 quadrants were taken for Wogelo natural forest. Sample plots established at 50 m interval along a series of transects and distance between transects were 30 m and within each plot were 30 m.

Diameter was determined by using calipers, but for those trees which have big diameter, measurement were done using tape meter. For regeneration, trees which have < 2 cm or height < 2m are counted in each compartment. Tree height was measured using a suunto-clinometer. Altitude and longitude of each sample plots were measured using GPS (Geographical Position System) (Fisaha et al., 2013; Kebede et al., 2013).

Data collection
All woody species in each quadrant were recorded. The plant specimen with their local name collected and identification was done at the National Herbarium, Addis Ababa University. Woody species were identified by referring the publication volume of flora and Ethiopian and Eritrean (Edwards et al., 1997; Bekele, 2007). Seedlings of each tree species were counted to estimate the regeneration status of Wogello natural forest.

Data Analyses
Wogello natural forest species diversity and richness were calculated using the following indices:

a) Shannon- Wiener diversity index (PEET, 1974; Gering et al., 2003)

\[
H' = -\sum_{i=1}^{k} p_i \ln p_i
\]  

(1)
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Where, $H = \text{Shannon diversity index}$, $P_i = \text{the proportion of individuals or the abundance of the } i^{th} \text{ species expressed as a proportion of a total cover}$, $K = \text{the number of plots}$, $\ln = \text{base of natural logarithm}$

b) Evenness or Equitability can be calculated based on (Peet, 1974)

$$\text{Evenness} = \frac{(D - D_{\text{min}})}{(D_{\text{max}} - D_{\text{min}})} \quad (2)$$
$$\text{Evenness} = \frac{D}{D_{\text{max}}} \quad (3)$$

Where, $D = \text{a heterogeneity value for the sampled population}$, $D_{\text{min}}$ - the minimum values possible for the given species number and, $D_{\text{max}}$ = the maximum values possible for a given species number

c) Evenness were based on (Pielou, 1966) as follows

$$J = H' - H'_{\text{max}} \quad \text{Where,} \quad (4)$$
$$J = \text{Evenness}, H' = \text{Shannon-Wiener diversity index and } H'_{\text{max}} = \ln(s) \text{ where } s \text{ is the number of species}$$

Simpson’s Index (D)

According to (Gering et al., 2003), the value of Simpson’s Index is always less than one and it is the chance that two similar species to be selected from the sample.

It is calculated as follow

$$1 - \sum pi^2 \quad (5)$$

Important Value Index (IVI)

All woody species population was examined by estimating Frequency, relative Frequency, density, relative density and Dominance (basal area). Important Value Index (IVI) measured to assess and compare the overall significance. It considers several properties of the species and those species which have a higher Importance Value Index show the dominant tree in the study area and it was calculated as follows based on (Lampecht, 1989; Kent and Coker, 1992; Tauseef et al., 2012).

$$IVI = \text{Relative density } + \text{relative dominance (basal area) } + \text{relative frequency} \quad (6)$$
$$\text{Relative density } = \left( \frac{\text{Density of each species}}{\text{Total density}} \right) \times 100 \quad (7)$$
$$\text{Relative dominance or basal area } = \left( \frac{\text{basal area of each species}}{\text{Total basal area}} \right) \times 100 \quad (8)$$
$$\text{Relative frequency } = \left( \frac{\text{Frequency of each species}}{\text{Total frequency of species}} \right) \times 100 \quad (9)$$
Relative density defined as the number of all individuals of a species/ the total number of all individuals (DBH ≥ 2 cm) times 100; whereas relative dominance (basal area) is defined as the basal area of the species /total basal area times 100 (DBH ≥ 2 cm) and relative frequency is the number of plots, where a species occurs/the total occurrence of all species in all of the plot's times 100. Basal area was calculated using the cross-sectional area of a tree trunk measured at diameter at breast height (DBH, 1.3 m height) (Didita et al., 2010).

\[
\text{Basal area} = \pi d^2/4
\]

Where, \(\pi = 3.14\), \(d = \text{Diameter at breast height in cm}\)

Analysis of data was carried out using quantitative methods. Species richness and diversity analysis were done using Shannon-Wiener diversity index and Simpson's Index. R version 3.2.1 software at a significant level of 5% was performed to analyze differences of species along altitudinal gradients and Diameter- Height curve. R version 3.2.1 software was used to draw histograms for diameter and height distribution of woody species. Excel 2007 was also performed to see the mean diameter and mean height of the stand.

Result and discussion

Stand diversity

Species area curve

Species area curve shows that the relationship between the area and the number of species found within that area (Fig. 1). It is very important to determine the sufficiency of the sample plot (Gering et al., 2003).

![Species area curve of Wogello Natural Forest](image)

Figure 1. Species area curve of Wogello Natural Forest

In the above graph, the pattern of curve increases the number of species with increasing areas up
to 3000 m² for woody species (dbh ≥ 2.5 cm) and up to 2000 m² for regeneration) since species diversity will increase with increasing of the area (Rosenzweig, 1995). But after 3,000 m² the species area curve seems constant.

Woody species composition

Wogello natural forest woody species composition was assessed. For the purpose of this study, a total of 42 quadrants or sample plots were used and each sample plot had an area of 100 m² (10 x 10 m). A total 20 woody species were identified (See Appendix 1). The total density of Wogello natural forest was (1022 individuals /ha) higher than the remnant moist Afromontane forest of Wondo Genet (379 individuals/ha) (Kebede et al., 2013), WofWasha natural forest (698 individuals/ha) (Fisaha et al., 2013), Boda Dry evergreen montane forest (682 individuals /ha) (Erenso et al., 2014) and Bale National Park, Boditi forest (498 individuals/ha) (Yineger et al., 2008).

Abundance, dominance, frequency and Important Value Index (IVI) of the study area was calculated and illustrated in (Appendix 1). In Wogello natural forest, the species with the highest Importance Value Index (IVI) were *Allophylus abyssinic* s(55) and followed by *Acacia abyssinica* (38), *Euclea racemosa subsp. schimperi* (37), *Olea europeana* (29), *Terminalia brownii* (23) and *Carissa spinarum* (21) occupied the higher importance value index (IVI) and those species with higher IVI are considered as more significant than species with low IVI (Zegeye et al., 2005). The lists of woody species ranked based on their importance value index is shown in table 1.
Table 1. The most common tree species ranked by their Importance Value Index based on a complete enumeration of all tree species

<table>
<thead>
<tr>
<th>RR rank</th>
<th>Species</th>
<th>Abundance (N/ha)</th>
<th>Dominance (m²/ha)</th>
<th>Frequency (%)</th>
<th>IVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Allophylus abyssinics</em></td>
<td>169</td>
<td>7.6</td>
<td>21</td>
<td>55</td>
</tr>
<tr>
<td>2</td>
<td><em>Acacia Abyssinica</em></td>
<td>178</td>
<td>1.1</td>
<td>29</td>
<td>38</td>
</tr>
<tr>
<td>3</td>
<td><em>Euclea racemosa subsp. schimperi</em></td>
<td>116</td>
<td>4.5</td>
<td>18</td>
<td>37</td>
</tr>
<tr>
<td>4</td>
<td><em>Olea europeana</em></td>
<td>128</td>
<td>1.89</td>
<td>18</td>
<td>29</td>
</tr>
<tr>
<td>5</td>
<td><em>Terminalia brownie</em></td>
<td>64</td>
<td>2.7</td>
<td>13</td>
<td>23</td>
</tr>
<tr>
<td>6</td>
<td><em>Carissa spinarum</em></td>
<td>119</td>
<td>0.1</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td>7</td>
<td><em>Calpurnia aurea (Alt.) Benth</em></td>
<td>57</td>
<td>2.2</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>8</td>
<td><em>Croton macrostachyus</em></td>
<td>36</td>
<td>3.2</td>
<td>6</td>
<td>18</td>
</tr>
<tr>
<td>9</td>
<td><em>Dodonaea viscosa</em></td>
<td>50</td>
<td>0.35</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>10</td>
<td><em>Domeyatorridasubsp. torrida (D. goetzenii)</em></td>
<td>16</td>
<td>0.9</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Others 11-20</td>
<td></td>
<td>89</td>
<td>4.43</td>
<td></td>
<td>37</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1022</td>
<td>28.97</td>
<td></td>
<td>300</td>
</tr>
</tbody>
</table>

Family of the dominant woody species, number of species and individuals in Wogello natural forest is indicated in Table 2 below.

Table 2. Dominant species in Wogello natural forest

<table>
<thead>
<tr>
<th>No</th>
<th>Family</th>
<th>No. of Species</th>
<th>No. of Individuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fabaceae</td>
<td>4</td>
<td>249</td>
</tr>
<tr>
<td>2</td>
<td>Apocynaceae</td>
<td>2</td>
<td>131</td>
</tr>
<tr>
<td>3</td>
<td>Oleaceae</td>
<td>2</td>
<td>135</td>
</tr>
<tr>
<td>4</td>
<td>Sapindaceae</td>
<td>2</td>
<td>298</td>
</tr>
<tr>
<td>5</td>
<td>Sapindaceae</td>
<td>2</td>
<td>219</td>
</tr>
<tr>
<td>6</td>
<td>Euphorbiaceae</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>No</td>
<td>Family</td>
<td>No. of Species</td>
<td>No. of Individuals</td>
</tr>
<tr>
<td>----</td>
<td>----------------</td>
<td>----------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>7</td>
<td>Anacardiaceae</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>Combretaceae</td>
<td>1</td>
<td>64</td>
</tr>
<tr>
<td>9</td>
<td>Sterculiaceae</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>10</td>
<td>Verbenaceae</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Others 11-12</td>
<td>2</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>20</td>
<td>1296</td>
</tr>
</tbody>
</table>

Based on families, Fabaceae was the dominant family by consisting 4 species (20%), followed by Apocynaceae 2 (10%), Oleaceae 2 (10%) and the rest families share 60% from a total family of the study area. The same finding also reported that Fabaceae were the dominant family in Dry Afromontane forest (Mengistu et al., 2004; Didita et al., 2010; Aynekulu et al., 2011; Burju et al., 2013; Tadele et al., 2013; Tesfaye et al., 2014).

**Tree species diversity**

Diversity will be high if the species distributed evenly but only few species dominate the area, the diversity will be low (Pielou, 1966). In Wogello natural forest 20 woody species and 12 families were recorded. It was rich in species composition because species richness indicates the assets of species in the community (Peet, 1974). The result was similar with Zengena forest (Tadele et al., 2013). The species richness was higher compared with other dry Afro montane forests reported by (Abiyu et al., 2011) (15 woody species) and lower than (Lemenih et al., 2004) (33 woody species); (Senbebeta and Teketay, 2001) (42 woody species); (Girma and Mosandl, 2012) (36 woody species) at Munessa-Shashemene Forest and (Teketay, 1997) (40 and 41 species) at Gera and Menagesha forest, respectively.

**Shannon index (H’)**

Wogello natural forest species diversity and richness were calculated using the Shannon- Wiener diversity index (See Equation 1) (PeeT, 1974; Gering et al., 2003). On the other hand, for evenness or equitability calculation, the most commonly and widely used methods are based on (Pielou, 1966) (See equation 4) and for Simpson's Index (See equation 5) (Gering et al., 2003). Shannon - Wiener diversity and evenness index woody species was 2.71 and 0.26, respectively.
(table 3) which means woody diversity and evenness was high.

Table 3. Shannon Index and Simpson's Index, of Wogello natural forest, Ambober, North Gondar, Ethiopia.

<table>
<thead>
<tr>
<th>Land use</th>
<th>No. of Trees/ha</th>
<th>No. of Species</th>
<th>Shannon Index (H')</th>
<th>Simpson's Index</th>
<th>Evenness (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wogello natural forest</td>
<td>1022</td>
<td>20</td>
<td>2.71</td>
<td>0.06</td>
<td>0.94</td>
</tr>
</tbody>
</table>

The Shannon diversity and Evenness index of wogello natural forest was higher due to large number of rare species (Schemitt et al., 2010).

**Basal Area**

Total Woody species basal area was 28.97.3 m²/ha (Fig. 2). More than 52 % of the basal area was shared by three species, *Allophylus abyssinics* 7.5 m²/ha (26 %), *Euclea racemosa subsp. schimperi* 4.5 m²/ha (15 %), and *Croton macrostachyus* 3.2 m²/ha (11 %), whereas the rest species share 13.7m²/ha (48 %) from a total basal area.

Figure 2. Basal area and number of Woody species of Wogello Natural Forest, Ambober, North Gondar, Ethiopia.
Generally, the basal area of Wogello natural forest was very low compared to the mean basal area of tropical forest 35 m$^2$/ha (Midgley and Niklas, 2004). But it was higher than Bale mountain national park, Boditi forest, 23 m$^2$/ha (Yineger et al., 2008), wood land and Riverine vegetation of Sire Beggo in Golocha Woreda (19.3 m$^2$/ha) (Dibaba et al., 2014); Zengena forest (22.3 m$^2$/ha) (Tadele et al., 2013) and Hugumburda forest (9.23 m$^2$/ha) (Ayenekulu, 2011). The basal area of Wogello natural forest (28.97 m$^2$/ha) was less than that of Boda dry evergreen montane forest (114.6 m$^2$/ha) (Erenso et al., 2014); Belete moist evergreen montane forest (103.5 m$^2$/ha) (Gbrehiwot and Hundera, 2014); Tara Gedam and Abebaye forest, 115.4 m$^2$/ha and 49.5 m$^2$/ha, respectively (Zegeye et al., 2011).

Stand Structure

Mean diameter and Height

The study of natural forest stand structure can be very important for future natural forest planning (Eslamiet al., 2011). Wogello natural orest mean diameter at breast Height (DBH) and mean Height was calculated. It illustrated in Table 4 as followed.

Table 4. Mean diameter and height of Wogello Natural Forest, Ambober, North Gondar, Ethiopia.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean(±std)</th>
<th>Min.</th>
<th>Max. (cm)</th>
<th>CV</th>
<th>SE (%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>DBH</td>
<td>5.32 ± 4.43</td>
<td>2.6</td>
<td>41.4</td>
<td>0.83</td>
<td>20.7</td>
<td>457</td>
</tr>
<tr>
<td>Height</td>
<td>4.3 ± 1.95</td>
<td>2.5</td>
<td>16.7</td>
<td>0.45</td>
<td>9</td>
<td>457</td>
</tr>
</tbody>
</table>

Distribution of diameter and height

Diameter distribution play a significant role in forest science and used to determine the amount of volume produced and for designing the management options to improve the stand structure (Zheng and Zhou, 2010; Sheykholeslami et al. 2011). Both diameter and height distribution showed that an inverted -J shaped which means that high number of individuals in the lower diameter class and very few numbers of individuals in the high diameter classes. On the other hand, the diameter of the trees increases with decreasing of the number of individuals. This is a general pattern of normal distribution (Didita et al., 2010). Based on the result shown in the
diameter frequency distribution (Fig. 3), 85.5 % Diameter at breast height, DBH class 2 - 6.9 cm followed by 10.3 % DBH class 7 - 11.9 cm and the rest shares only 4.5% from a total diameter frequency distribution. This means that the study area was dominated by low sized trees or shrubs species such as *Dodonia viscosa*, *Croton macrostachyus* and *Carissa spinarum*.

Generally, this pattern of diameter distribution indicated that good regeneration status of the forest (Teketay, 1997). On the other hand, according to Gondar Zuria Agricultural Office annual report, there was illegal cutting for timber, construction and fuel wood. Therefore, this selective cutting of a forest leads to decreasing in the number of trees in the higher diameter class (Zegeye et al., 2010; DWARD, 2013 unpub; Kebede et al., 2013).

Figure 3. Diameter frequency distribution of Woody species (DBH classes. 1 = 2 - 6.9 cm; 2 = 7 - 11.9 cm; 3 = 12 - 16.9 cm; 4 = 17 - 21.9 cm; 5 = 22 - 26.9 cm; 6 = 27 - 31.9 cm; 7 = 32 - 36.9 cm; 8 = 37 - 41.9 cm;)

Similar type of diameter distribution results were reported by Yineger et al., 2008; Didita et al., 2010; Zegeye et al., 2011; Tadele et al., 2013; Tesfaye et al., 2013; Dibaba et al., 2014; Kebede et al., 2014. Height distribution is indicated in Fig. 4.

Figure 4. Height frequency distribution of woody species of Wogello natural forest, Ambober, North Gondar, Ethiopia. Height classes (1 = 2 - 4 m; 2 = 4 - 6 m; 3 = 6 - 8 m; 4 = 8 - 10 m; 5 = 10 - 12 m; 6 = 12 - 14 m; 7 = 14 - 16 m; 8 = 16 - 18 m.)
Species population structure

Investigation of diameter at breast height (DBH) and height distribution gives evidence for the regeneration status of the natural forest (Senbeta and Teketay, 2001). The diameter and height distribution of all individuals showed inverted J-shape distribution (Fig 4 and 5). However, this pattern cannot indicate the general trend of a given species. Therefore, it is pivotal to analyze each species so as to get more information that can be used for conservation measures. Hence, five species were selected based on their Importance Value Index (IVI) to determine the population structure of the study area. *Allophylus abyssinicus*, *Acacia abyssinica*, *Euclea racemosa sub sp. schimperi*, *Olea europea* and *Terminalia brownii* species with highest basal area leads to high relative dominance which contributed to the highest Importance Value Index (IVI).

![Graphs of species population structure](image-url)
Fig. 5. Species population structure of selected five woody species based on diameter frequency (Diameter, 1 = 2 - 6.9 cm; 2 = 7 - 11.9 cm; 3 = 12 - 16.9 cm; 4 = 17 - 21.9 cm; 5 = 22 - 26.9 cm; 6 = 27 - 31.9 cm; 7 = 32 - 36.9 cm; 8 = 37 - 41.9 cm).

Therefore, Wogello natural forest species population structures were classified into two population distribution patterns. Inverse J-Shape and Broken Inverse J-Shape shown in (Figure 6).

a) Inverse J-Shape: *Allophylus abyssinicus*, *Olea europeana* and *Euclea racemosa subsp. schimperi*, showed Inverse J-shaped distribution, which indicated a good regeneration status (Teketay, 1997; Yineger et al., 2008; Didita et al., 2010). Inverse J-Shape characterized by its shade tolerant species (Sokpon and Biaou, 2001), which have high number of seedling and sampling growth stage (Teketay, 2005). High number of individuals in the lower diameter class that gradually decreases with an increasing in diameter classes. Similar result also reported by Yineger et al., 2008 at Bale national park, dry afromontane forest.

b) Broken Inverse J-Shape: *Acacia abyssinica* and *Terminalia brownii* showed broken Inverse J-shapped which indicated that high number of individuals in the lowest diameter class and gradual decrement of individuals in the highest diameter class even missing individuals in classes (17-26.9) and (7-11.9) for both species, respectively. This means that there is poor regeneration.

Height distributions of the selected five species also performed (Fig. 8). The species population structure based on height classified into two distribution patterns.
Figure 6. Species population structure of selected five woody species based on height frequency distribution (Height classes: 1= 2 - 4m; 2 = 4 - 6m; 3 = 6 - 8m; 4= 8 - 10m; 5 = 10- 12m; 6 = 12 - 14m; 7 = 14 - 16m)

1) Inverse J-Shape: *Acacia Abyssinica, Euclea racemosa subsp. schimperi and Terminalia brownii* classified under Inverse J- shape. This indicated that high number of individuals in the lower height class.

2) Bell-Shape: Species such as *Allophylus abyssinics and Olea European* as shown a Bell-shape height distribution. This showed that high number of individuals in the middle class and gradually decreases in both sides of lower and higher height classes.
Natural regeneration

Abundance and frequency of natural regeneration

In this study, seedlings with diameter at breast height (DBH) < 2.5 cm and height < 2 m were counted and considered as a seedling (regeneration). The result indicated that 6092 individuals/ha consisting of 22 species were found. Number of Individuals (density) of Wogello natural forest (5397 individuals/ha) was higher compared with woody density of Biyo-Kelala (1746 and 2215 individuals/ha enclosure and open area, respectively) (Mengistu et al., 2004) and Gedo Dry Evergreen Montane forest (1068 individuals/ha) (Kebede et al., 2014). et al., 2013).

Table 5. Abundance and frequency of seedlings for the most abundant species of Wogello natural forest, Ambober, North Gondar (DBH < 2.5 cm and Height < 2 m)

<table>
<thead>
<tr>
<th>No</th>
<th>Scientific name</th>
<th>Abundance (N/ha)</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dodonaeaviscosa</td>
<td>2590</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>Calpurnia aurea (Alt.) Benth</td>
<td>1076</td>
<td>88</td>
</tr>
<tr>
<td>3</td>
<td>Terminaliabrownii</td>
<td>474</td>
<td>59</td>
</tr>
<tr>
<td>4</td>
<td>Euclearacemosasubsp.schimperi</td>
<td>326</td>
<td>64</td>
</tr>
<tr>
<td>5</td>
<td>Carissa spinarum</td>
<td>307</td>
<td>74</td>
</tr>
<tr>
<td>6</td>
<td>Clutiaabyssinica Juab andSpach</td>
<td>257</td>
<td>12</td>
</tr>
<tr>
<td>7</td>
<td>Oleaeuropeana</td>
<td>236</td>
<td>45</td>
</tr>
<tr>
<td>8</td>
<td>Pterolobiumstellatiae (Forssk) Brenan</td>
<td>174</td>
<td>50</td>
</tr>
<tr>
<td>9</td>
<td>Acacia Abyssinica</td>
<td>155</td>
<td>36</td>
</tr>
<tr>
<td>10</td>
<td>Allophylus abyssinics</td>
<td>117</td>
<td>33</td>
</tr>
<tr>
<td>11</td>
<td>Senna multiglandulosa</td>
<td>93</td>
<td>24</td>
</tr>
<tr>
<td>12</td>
<td>Vernoniamamygdalina</td>
<td>86</td>
<td>14</td>
</tr>
<tr>
<td>13</td>
<td>Premna schimpi</td>
<td>71</td>
<td>36</td>
</tr>
<tr>
<td>14</td>
<td>Jasminum grandiflorle</td>
<td>64</td>
<td>24</td>
</tr>
<tr>
<td>15</td>
<td>Maytenus arbutifolia</td>
<td>31</td>
<td>7</td>
</tr>
<tr>
<td>16</td>
<td>Acokantheraschimperi</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>17</td>
<td>Acacia abyssinicasubsp. abyssinica</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>18</td>
<td>Rosa abyssinica</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>19</td>
<td>Dombeya torrida subsp. torrida ( D.goetzenii)</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>20</td>
<td>Osyris quadripartite</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>21</td>
<td>Croton macrostachyus</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>22</td>
<td>Buddleia polystachya</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>6092.857</td>
<td></td>
</tr>
</tbody>
</table>
Conclusion and recommendation

A total of 20 woody species and 12 families were identified. 1022 individuals/ha with DBH ≥ 2.5 cm and Height ≥ 2 m. *Allophythus abyssinicus* (55) followed by *Acacia abyssinica* (38), *Euclea racemosa subsp. schimperi* (37), *Olea europeana* (29), *Terminalia brownii* (23) and *Carissa spinarum* (21) occupied the highest importance value index (IVI). These species are considered as more significant than species with low IVI (Zegeye et al., 2005). Fabaceae family that consists of 4 species was the dominant. The total woody species basal area was 28.97.3 m²/ha. More than 52% of the basal area was shared by three species, *Allophythus abyssinicus* 7.5 m²/ha (26%), *Euclea racemosa subsp. schimperi* 4.5 m²/ha (15%), and *Croton macrostachyus* 3.2 m²/ha (11%). The rest species account for 13.7m²/ha (48%) from a total basal area. The basal area of the study area was very low as compared to other forests in Ethiopia.

The diameter distribution of the study area shows that an inverse -J shaped which means that high number of individuals in the lower diameter class and very few numbers of individuals in the high diameter classes. On the other hand, the diameter of the trees increases with decreasing of the number of individuals. A total of 6093 individuals /ha and 22 species were found.

Recommendations

Species with low Importance Value Index (IVI) (Appendix 1) such as *Jasminum grandiflorum*, *Buddleia polystachya*, *Premna schimpri*, and *Acokanthera schimperi* needs high conservation efforts (Zegeye et al., 2005). Ex-situ conservation method includes storage of seeds, pollen and tissue culture where as In-situ method needs management of populations in the natural stand (Ledig, 1986).

Woody species basal area was relatively low compared to other montane forest due to low diversity and illegal cutting of trees for different purposes. Rehabilitation and enrichment planting resulted in forest succession (Senbeta et al., 2002). The diverse nature of Wogello forest required detailed information on ethnobotanical knowledge.
References


Proceedings of the 9th Annual Regional Conference on Completed Research Activities of Forestry.


Assessment of Factors Hindering Seedling Survival at Sekota Woreda, Waghimra Zone
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Abstract
The study was conducted in moisture deficit areas of Amhara. The aim of the study was to assess factors hindering seedling survival. Survey was carried out in three villages (Abya, Sayda and Wolleh) from 93 respondents. The result showed that seedling grading, hardening off and seedling protection are not properly conducted. 90% of respondents indicated that there was problem of seedling survival after planting due to insect (termite) attack. Most of the respondents noted that the major abiotic factors affecting seedling survival were moisture deficit and soil fertility problems. Species that are resistant to insect attack and tolerant to drought are the most important characteristics in Sekota for successful plantation. In addition, nursery management and planting techniques are also important for the success of plantation. Appropriate water and soil harvesting structures should be combined to improve water retention and soil fertility.

Keywords: abiotic, Moisture deficit, nursery Sekota

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Introduction

Reforestation in the tropics takes place across a wide variety of edaphic and climatic conditions. Edaphic conditions have a strong effect on species growth and survival (Breugel et al., 2011). Plantations can play an important role in restoring the productivity, ecosystem stability, and biological diversity of degraded tropical lands (Eshetu Yirdaw, 2002). Plantation establishment in the landscape is based on the plan and environmental characteristics (Koeser, Gilman, Paz, and Harchick, 2014). Insufficient post-planting care (Gilman et al., 1998), poor-quality nursery stock (McKay, 1996), site conditions (Lemaire and Rossignol, 1999) have a negative implication on plantation success and there is no meaningful environmental and economic contributions to a community (Koeser et al., 2014).

According to the annual report of bureau of agriculture of the ANRS 2005, 2006, 2007, 2008 and 2009, from all planted tree seedlings, survival rate were 75, 64, 66, 79 and 81%, respectively. This indicates that there is an average of 73% survival rate within the past five years. It is estimated that a total of 362,564.24 hectares of land were covered by tree seedlings. In fact, the cover of the land is dominated by agricultural land and the forest cover is not as it is said and reported, due to failure of seedling survival rate. Governmental, non-governmental organizations and farmers have been planting many seedlings of different tree species in Sekota. However, the survivals of those seedlings are low and the lowest from other parts of the region. With this background, the objective of this study was to assess biotic and a biotic factor that influence the survival of seedlings in Sekota district.

Material Methods

Study site description

The study was conducted at Sekota district which is about 450 km from Bahir Dar, the capital of Amhara National Regional State. It is located between 12°23' to 13°16'N latitude and 38°44' to 39°21' E longitude, with altitudinal range of 1340 to 2200 above sea level (Fig.1). The mean annual temperature ranges from 16 to 27°C. The rain fall pattern is unimodal with annual rainfall of 350 to 700 mm.
Data collection

Three representative sites (Kebeles) namely: Abya, Sayda, and Wolleh were selected in Sekota district based on their agroecology. The data were collected from primary and secondary sources. For primary data collection purposive sampling technique was used. Different tools such as household survey, semi structured interview, group discussion and office visit were used. Representative Key informants were selected in different age groups. The participants were diversified, including representatives of gender, marital status, social status and education.

Data analysis

Data were coded and entered in Statistical Package for Social Scientists (SPSS version 22). Descriptive statistics were used to describe the major factor that affects seedling survival.

Results and Discussion

General household characteristics

The total numbers of the respondents at three kebeles were 93. From the total respondents, 80.6% were males and the rest were females. Most of the respondents were ordinary residents and illiterates (55.9%) and the rest can read and write only.
Factors related to nursery activities

In the study area, the seedlings were raised with 8 cm diameter size of polyethene tube and bare rooted; this contributed for poor seedling performance and incapacity to survive the long dry season. Larger seedlings out-perform better than smaller seedlings. This is the result of nutrient and carbohydrate stores in the soil (Mohammed et al. 1998). Larger seedlings may establish better and suffer less mortality than smaller seedlings, particularly in stress-prone environments, e.g. those subjected to drought or browsing damage (Close et al., 2006). Seedling size and climatic events may also influence the relative importance of different mortality agents (Gilbert, Harms, Hamill, and Hubbell, 2001).

From the total, 29% of the respondents raised bare root seedlings in their private nurseries due to lack of polyethylene tube and give less attention for tree planting. Most of the respondents applied no protection, hardening and grading of the seedlings. Seedling survival and especially growth can be reduced by desiccation, low and high temperatures, and various forms of rough handling (Mckay, 1996). Commonly, the planting site was far away over 3.5 kilometers from the nursery site. Most of the deterioration occurred in the first two days after lifting, while the plants were being handled and packed; drying during overnight storage and transportation to the sorting stand was reflected by poorer growth after each of these stages (Mckay, 1996).

Planting site

The majority of the respondents (90.77%) participate in tree planting by the government campaign mainly on planting site preparation. There is no integration of water harvesting structure. The planting pit structure is incapable to hold sufficient water and fertile soil for seedlings to escape drought. Due to this the seedling performance after planting was weak and unable to resist long dry season. In arid land systems, site preparation centers on improving moisture supply to the seedlings and reducing overall moisture loss by controlling competing vegetation (Harrington, Loveall, and Kirksey, 2004). Some 67.8% of the respondents acknowledge that the seedlings died between July to January. The respondents pointed out that the seedlings start dying in the same planting season (July) because of pitiable planting techniques and inappropriate planting site and structure preparation.
Biotic and abiotic factors affecting seedling survival

Most of the respondents (85%) noted that the major biotic factors negatively affecting seedling survival in the field are insect (termite) and animal grazing. Similarly, Chisato (2010) stated that termite mounds seem to be a negative factor for plants moisture deficit areas. Free grazing negatively affects seedling growth rate and survival by trampling and browsing (Harvey and Haber, 1999). On the other hand, the major abiotic factors affecting seedling survival are water deficit and infertile soil. In addition, lack of proper site preparation is also a contributor for seedling death in the field (Peter and Ronald, 1996). McKay (1996) also stated internal water status at planting, the condition of the nursery root system, the ability to control water loss through the stomata, the area of contact between the soil and functioning roots after planting, the soil moisture availability and the ability of the plant to produce new roots are all important. Similarly, the compaction of soil or low soil fertility results in high dry density which definitely reduced the rate of root penetration and development (Berli, 2004).

Management for seedlings and sapling

Only 1.1% of the respondents applied proper management (watering, weeding, mulching and protection from animal and human intervention) for newly planted seedlings, saplings and trees. However, suitable management and protection are crucial requirements for newly seedlings and saplings. Because, seedlings and saplings are sensitive to death in animal grazing and browsing, weed depression, herbivore, insects and other biotic and abiotic factors.

Conclusion and recommendation

The main factors that hinder tree seedling survival were water stress and termite. However, nursery production methods, seedling handling and transportation, inappropriate site preparation, planting infertile soil and animal intervention were also pointed out by the farmers as main obstacles for tree and shrub plantation development. Therefore, drought and insect resistance species are ideal for the study area to boost up seedling survival. In addition, way of nursery production methods and planting techniques that are suitable for dryland areas must be designed. In the planting site, appropriate water and soil harvesting structures must be constructed to encourage water retention and soil fertility.
Acknowledgment

We would like to thank the Amhara Agricultural Research Institute Forestry Research Directorate (FRD) for its collaboration during the implementation of this activity. We would like to extend our acknowledgement to the development agents working at Abya, Sayda, and Wolleh kebeles for their contribution during data collection. This study was conducted by the financial support of Amhara Region Agricultural Research Institute (ARARI)/Sekota Dryland Agricultural research Center.

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Assessment of woody species diversity and richness of exclosure area in Jinqaba apiculture trail site Sekota, Waghemira

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Abstract

Assessment of woody species diversity and richness of exclosure area was investigated in Jinqaba, Sekota woreda. A total of 31 woody species, representing 14 families and 1033 individuals were recorded. The most diverse family was Fabaceae, with 20% of the total species. The overall Shannon-Wiener diversity (H') of woody species in the study site was 1.8. The most dominant tree species were Acacia bussei, Combretum collinum and Ziziphus spina-christi. The least dominant tree species were Maytenus senegalensis and Albizia lophantha. Results of the study indicate that the establishment of exclosure areas is very advantageous over other methods since it is a fast, cheap and lenient method for the rehabilitation of degraded lands. However, the study site is one of the apicultural research trail sites of Sekota Dryland Agricultural Research Center which requires more sources of honey bee flora species. Both least and most dominant woody species are used as honey bee forages. Therefore, enrichment and conservation strategy should be applied to enhance the dominant species to continue with their status and survive well. Special attention should be given to the least dominant species that are nearly vanishing from the study site in terms of plantation. Further study should be mandatory to solve the challenges of regeneration of least dominant wood species and maintenance of seed banks.

Key words: Woody species, Exclosure area, species diversity, richens
Introduction

Ethiopia is rich in diversity of fauna and flora in its different agro-climatic zones. It is acknowledged intentionally as a center of biodiversity. Ethiopia has over 700 higher plant species, among them, 12% are endemic species. The vegetation diversity of Ethiopia is widely different because the country has very variable agro-climatic zones ranging from Afro alpine to desert (Zegeye, Teketay, and Kelbessa, 2011). But the vegetation diversity of Ethiopia is decreasing at alarming rate. Because of increasing human pressure in the dry lands combined with global climate change, the problem is further intensified in dry regions that are becoming increasingly arid, vulnerable and less suitable for habitation. These resulted in land unproductivity, ecosystem defragmentation, range shifting and population changes (Wale, Bekele, and Dalle, 2012).

Amhara region has a wide-range of biodiversity of flora and fauna. However, increased population number, livestock pressure, and increased demand for arable land are causing a significant depletion of forest resources. Loss of cover results in high rate of soil erosion, loss of soil fertility and degradation of ground water resources. These factors in turn, adversely affect agricultural productivity. Soil fertility is further depressed where animal dung and crop residues are diverted for fuel to compensate for the shortage of wood. The cumulative effect of this chain of events is reflected in the land degradation, poor economic performance, and accelerated poverty.

Land degradation in Sekota is extensive as a result of over exploitation of the woodlands and farming of the fragile hilly slopes. Wrong doing of agriculture towards the steeper slopes resulted in the clearing of forests for centuries. This in turn has accelerated soil erosion and destroyed the soil and vegetation of the area. Reversing land degradation is critical to return land productivity and biodiversity by different techniques. Rehabilitating natural vegetation is an important strategy to reverse land degradation. Rehabilitation of landscape integrity and realization of the environmental and socioeconomic benefits of natural resources is now widely accepted and practiced around the world to rehabilitate degraded lands. No research has been done on tree diversity and species richness on enclosed areas in eastern Amhara, mainly in Jinkaba. So, this study is designed to identify which type of area closure system is efficient for
tree diversity and species richness. It is aimed to assess woody species diversity and richness in exclosure area of Jinkaba for future management.

**Materials and methods**

**Site description**

Sekota woreda is located at 12° 32' and 39° 04' E and located at about 720 km north of Addis Ababa. It has rugged topography dominated by rock outcrops with mountainous terrain and high plateaus dissected by river basins. There are limited exclosure areas in this woreda. Jinkaba site (Sekota Dry land Agricultural Research Center apicultural research trail site) was selected for the study as mid altitude area of Sekota Woreda. The site is located to the north of Sekota town at 39° 0.5'E of Latitude and 12° 41.3' longitude with altitude range 2000-2050m above sea level. The mean annual temperature ranges from 16 to 27°C. The rain fall pattern is unimodal with annual rainfall of 350 to 700 mm. Jinkaba exclosure area were established in 2012 G.C with 16 hectares of total area.

**Sampling procedures**

First observation and delineating by using GPS were taken place to know the total area of the study site. Then, three transects were laid out and selected 9 sample plots (quadrates) based on the areas. The plot size were 20m by 20m for tree, 10m by 10m for sapling and 5m by 5m for seedlings based on the vegetation cover. The distance between the quadrat and transect were 100m. 2.5m height with 2.5cm diameter and above taken for as trees and 1m< height < 2 m and DBH < 2.5 cm for saplings (Jiangshan et al., 2009; Lu et al., 2010). (Azene and Tengnas, 2007). Natural Database for Africa (NDA) Ermiyas Dagne (2011) and two local residents who know the local name of the woody species were used for wood species identification.
Data analysis

Shannon and Wiener (1949) index were used for description of species diversity. This method is one of the most widely used approaches in measuring the diversity of species. Species richness of all identified species were calculated using the Shannon-Wiener Index as follows:

Shannon-Wiener index ($H'$) = $- \sum_{i=1}^{S} p_i \ln p_i$, Where: $H'$ = Diversity of species, $S$ = Number of species, $p_i$ = the proportion of individuals abundance of the $i$ the specie, $\ln$ = long base. Ranges from 0 to 5 and high values of $H'$ is high diversity. The vegetation data of the woody species were calculated and summarized on Excel Spreadsheet using the following formulas:

Density ($D$) = Total $N^o$ of individual a species / $N^o$ of quadrates studied

Abundance ($A$) = Total $N^o$ of individual a species/$N^o$ of quadrates the species occurred

Frequency ($F$) = $N^o$ quadrates a species occurred /Total quadrates studied

Relative density of the species ($RD$) = Total $N^o$ of individual species X 100/$N^o$ of individual of all species

Relative frequency of the species ($RF$) = Occurrence of a species X 100/Total occurrence of all individuals
Relative dominance (RDo) = \( \frac{\text{Total basal area of a species}}{\text{Total basal area of all species}} \times 100 \)

Important value index (IVI) = RD + RF + RDo

**Results and Discussions**

**Species richness and diversity**

In Jinkaba, the species richness and diversity is indicated Fig 2. and 3 respectively.

![Figure 2: woody species richness on the study site](image)

![Figure 3: woody species diversities on the study site](image)
A total of 31 woody species, representing 14 families and 1033 individuals were recorded from 9 quadrates. The most diverse family was Fabaceae, with 20% of the total number of species. The overall diversity of woody species in our study site ranges from 1.12 to 2.36 and averagely 1.8. It indicates the diversity of the study site to be in the medium range. Based on (Wale et al., 2012) the Shannon-wiener, diversity index mostly ranges from 1.5 to 3.6, rarely up to 4.5. The Shannon-wiener diversity ($H^*$) for Tiya exclosure area located around Sekota woreda and enclosed for the last ten years is 2.5 (Mengistu, Teketay, Hulten, and Yemshaw, 2005). Jinkaba exclosure area has less than by half aged compared to Tiya exclosure area. It shows that our study site has a good diversity compared to neighboring old exclosure areas. The establishment of exclosure areas is very advantageous over other methods since it is a fast, cheap and lenient method for the rehabilitation of degraded lands (Mengistu et al., 2012).

Relative Density, Relative frequency, Relative dominance and Important Value Index of common tree species (Table 1)

Table 1. Relative Density, Relative frequency, Relative dominance and Important Value Index of common tree species

<table>
<thead>
<tr>
<th>No.</th>
<th>Local name</th>
<th>Scientific name</th>
<th>Family</th>
<th>RD (%)</th>
<th>RF (%)</th>
<th>RDo (%)</th>
<th>IVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Girar</td>
<td><em>Acacia bussei</em></td>
<td>Fabaceae</td>
<td>14.48</td>
<td>9.21</td>
<td>14.06</td>
<td>37.75</td>
</tr>
<tr>
<td>2</td>
<td>Fatuqa</td>
<td><em>Combretum collinum</em></td>
<td>Combretaceae</td>
<td>14.29</td>
<td>7.89</td>
<td>14.28</td>
<td>36.46</td>
</tr>
<tr>
<td>3</td>
<td>Giba/kurkura</td>
<td><em>Ziziphus spinacristi</em></td>
<td>Rhamnaceae</td>
<td>15.43</td>
<td>9.21</td>
<td>6.13</td>
<td>30.77</td>
</tr>
<tr>
<td>4</td>
<td>Sibqana</td>
<td><em>Albizia amara</em></td>
<td>Fabaceae</td>
<td>8</td>
<td>7.89</td>
<td>11.57</td>
<td>27.46</td>
</tr>
<tr>
<td>5</td>
<td>Key sirewa</td>
<td><em>Acacia seyal</em></td>
<td>Fabaceae</td>
<td>7.24</td>
<td>5.26</td>
<td>9.96</td>
<td>22.46</td>
</tr>
<tr>
<td>7</td>
<td>Bubusha</td>
<td><em>Cassia didymobotrya</em></td>
<td>Fabaceae</td>
<td>7.24</td>
<td>6.58</td>
<td>4.81</td>
<td>18.63</td>
</tr>
<tr>
<td>8</td>
<td>Anequa</td>
<td><em>Celtis africana</em></td>
<td>Ulmaceae</td>
<td>3.62</td>
<td>3.95</td>
<td>3.43</td>
<td>10.99</td>
</tr>
</tbody>
</table>
The most dominant tree species were *Acacia bussei*, *Combretum collinum* and *Ziziphus spina-christi*. It indicates, the tree species having high dominance play significant role for the study site in terms of ecological restoration, source of seeds and honey bee flora. Three dominant woody species are used as source of bee forage in the study area. Bee colony performance as well as honey, wax and other hive products production depends on bee forage plants from which honey bees obtain nectar and pollen as main food (Abebe Jenberie et al., 2016). These food sources provide the nutritional requirements of the bee colonies: nectars as sources of honey provide heat and energy for honey bees and pollen provides protein, vitamins, fatty substance, and other nutrients (Amsalu, 2000).

The important value index (IVI) is used to determine the overall importance of each species in the community structure (relative density, relative dominance, and relative frequency) which describes the structural role of a species in a stand (Mekonen, 2013). Mohamed Adem (2014) stated that, the species having high important value index have significant role in the ecosystem.

The least dominant tree species were *Maytenus senegalensis* and *Albizia lophantha* having 1.61% and 1.54% important value index, respectively. These two leastdominant woody species are also important for Jinkaba apiculture research trail site because of their use as source of bee flora. IVI also indicates the need to give priority to conserve and manage the species.

**Structural diversity of the study site**

The structural distribution of the dominant species is indicated Fig. 4 below.
The Diameter class distribution *Acacia bussei* and *Ziziphus spina-christi* were showed inverted J shape. It indicates, there are good regeneration statuses. However, the diameter class distribution of *Combretum collinum* and *Albizia amara* were showed irregular shape. The population structure of woody species can help understand the regeneration status of species and forest stands (Mekonen, 2013).

**Conclusion and recommendation**

In general 31 woody species and 1033 individuals were recorded. The important value index showed that the dominant species are *Acacia bussei*, *Combretum collinum* and *Ziziphus spina-christi*. The least dominant species are *Maytenus senegalensis* and *Albizia lophantha*. The establishment of exclosure areas is very advantageous over other methods since it is a fast and cheap method for the rehabilitation of degraded lands. Jinkaba apiculture research trial site requires more species as a source of feed for honeybee species. Therefore, enrichment and conservation strategy should be applied to enhance the dominant species to continue surviving. Special attention should be given to the least dominant species that are nearly vanishing from the study site in terms of plantation. Further study should be mandatory to solve the challenges of regeneration of least dominant wood species and maintenance of seed banks.
Acknowledgement

We would like to thank Sekota Dryland Agricultural Research Center and the Forestry Research Directorate (FRD) of ARARI for their technical, financial and material assistance.

References


Evaluation of the adaptability of different Eucalyptus species in the highland of Amhara region.
Melkamu K., Girma N., Yonas B., Mubarak E., Haile, and Getu A.
Sekota Dryland Agricultural Center

Abstract
The experiment was conducted in Lalibela Debre loza kebele. The aim of the experiment was to give alternative eucalyptus species for construction and fuel wood over already adapted and distributed eucalyptus species to overcome problems of mono crop type eucalyptus cultivation. The experiment was laid out in RCBD in the three replications. The species were Eucalyptus citriodora, Eucalyptus grandis, Eucalyptus saligna and Eucalyptus viminalis. The data was analyzed by SAS version 9.3. Based on the result two species (E. viminalis and Eucalyptus citriodora) had shown good performance in root collar diameter, height growth and survival rate. The Eucalyptus grandis and Eucalyptus saligna had shown low performance. There was a problem of termite and pest attack. This is the main cause to reduce the survival rate of most species. Both in root collar diameter and height Eucalyptus citriodora is best; with mean height 4.3m, RCD 6.5cm and survival rate of 47.13% compared to others and the second one is Eucalyptus viminalis, with mean height of 3.8m, mean RCD 6cm and survival rate of 38.9%. The least one is Eucalyptus grandis with mean height of 2.6m, RCD 4.14cm and survival rate of 37.5%. Thus, we recommended that Eucalyptus citriodora and Eucalyptus viminalis for Lalibela and similar ecologies for fuel wood and construction material.

Key words: eucalyptus species, adaptation, highland, survival rate, height. Root collar diameter
Introduction
Eucalyptus originated between 35 and 50 million years ago, not long after Australia-New Guinea, their rise coinciding with an increase in fossil charcoal deposits (suggesting that fire was a factor even then), but they remained a minor component of the tertiary rainforest until about 20 million years ago, when the gradual drying of the continent and depletion of soil nutrients led to the development of a more open forest type, predominantly *Casuarinas* and Acacia species. Today *Eucalyptus* plantations cover at least 12 million ha throughout the tropical zone, 90% of which have been established since 1955 (Gessesse Dessie 2011).

The genus was introduced to East Africa in the late 19th and early 20th century and by the early 1970s the area of eucalypts in Ethiopia, Rwanda, Uganda, Kenya and the Sudan had reached 95,684 ha. The largest plantations at that time were in Ethiopia and Rwanda covering an area of 42,300 ha and 23,000 ha, respectively (https://en.wikipedia.org/wiki/Eucalyptus 10:20 16/09/2015).

*Eucalyptus* was introduced to Ethiopia in either 1894 or 1895 by Emperor Menelik II's French advisor Mondon-Vidalhiet or by the Englishman Captain O'Brian. Menelik II endorsed this species to be planted in the capital city of Addis Ababa. This was due to massive deforestation around the city for firewood. Plantations of eucalypts spread from the capital to other growing urban centers such as Debre Marqos. The most common species found in Addis Ababa in the mid-1960s was *E. globules*, *E. melliodora* and *E. rostrata* in significant numbers. Eucalyptus trees "have become an integral and a pleasing element in the Shoan landscape and has largely displaced the slow-growing native 'cedar' Junipers" (Gessesse Dessie 2011).

*Eucalyptus* species have been highly preferred and appreciated by the farmers over indigenous or other exotic tree species (Tadele et al. 2014). Farmers' species preference research was conducted in two Woredas in Ethiopia that in the warm lowland areas *Eucalyptus camaldulensis* is the farmers' first choice while in the cold highland areas *Eucalyptus globulus* is their first choice to plant as homestead plantation, private woodlots and in farmland areas. Similarly, *Eucalyptus globulus* and *Eucalyptus camaldulensis* at mid and low land/ are the common *Eucalyptus* species that have been dominantly planted in most part of the region.
But, if diseases or other environmental problems affect these species, most part of the country will be bare land or the advantages for fuel wood and construction will be lost. Therefore, to increase alternative energy source and secure sustainable use, identifying and adapting different eucalyptus species is very much important. Therefore, the objective of this experiment was to select best performing Eucalyptus species in the highland parts of Amhara region.

Methodology
The study was conducted from 2011 – 2015 at Debreloza, Northern side of Lalibela, Ethiopia. The woreda is geographically located at 12°35’31” N Latitude and 39°04’30” E longitudes. The altitude reaches to 3600m a. s. l. The woreda has one cropping season. Mean annual rainfall is 750mm. The annual mean maximum and minimum temperatures are 14.5 and 26.7°C, respectively. The soil is classified as vertisols.

Seeds of selected Eucalyptus species (*Eucalyptus citriodora*, *Eucalyptus viminalis* *Eucalyptus saligna* and *Eucalyptus grandis*) were purchased and raised in Lalibela (Medagie) nursery site. The experiment was laid out in random complete block design with three replications based on soil fertility gradient. Depending on the potential of the selected experimental site, the space between seedlings in a plot was 1.5m and the space between blocks and plots was 2m and 1.5m, respectively. Each plot would have about 12 seedlings. Half-moon water conservation structure was constructed. The materials used for this study was seedlings of different eucalyptus species; polythene tube, caliper, and meter were the major tools. The data RCD, DBH, height and survival rate were taken. Data analysis was carried out by one-way analysis of variance (ANOVA) on height, root collar diameter and survival rate.

Results
The height, diameter and survival of the four test Eucalyptus species is shown in Table 1, Fig. 1, 2 and 3. The highest height, diameter and survival rate was attained by *Eucalyptus citriodora*. 

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Table 1. Mean height, root collar diameter and survival of Eucalyptus species

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Height [m]</th>
<th>Root Collar diameter [cm]</th>
<th>Survival rate [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eucalyptus citrodora</td>
<td>4.3</td>
<td>6.49</td>
<td>47.13</td>
</tr>
<tr>
<td>Eucalyptus viminalis</td>
<td>3.70</td>
<td>5.99</td>
<td>38.90</td>
</tr>
<tr>
<td>Eucalyptus saligna</td>
<td>3.10</td>
<td>5.67</td>
<td>37.51</td>
</tr>
<tr>
<td>Eucalyptus grandis</td>
<td>2.60</td>
<td>4.14</td>
<td>41.47</td>
</tr>
<tr>
<td>Mean</td>
<td>3.4</td>
<td>5.6</td>
<td>41.25</td>
</tr>
<tr>
<td>CV</td>
<td>15.7</td>
<td>16.7</td>
<td>26.6</td>
</tr>
<tr>
<td>Pr &lt; f</td>
<td>0.04</td>
<td>0.06</td>
<td>0.72</td>
</tr>
<tr>
<td>Significance (0.05)</td>
<td>**</td>
<td>Ns</td>
<td>Ns</td>
</tr>
</tbody>
</table>

Note: ** indicates significance difference between treatment means

ns: not significance between treatment means

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![Height growth trends of the species](image1)

Figure 1. Trend of the height growth

![Trend of survival of the species](image2)

Figure 2. Trend of survival rate
Discussion

Height of the species

There is significant difference between mean height (P < 0.05) of the species. That means the null hypothesis is rejected, therefore environmental condition affects growth of different eucalyptus species. In 4 years growing season Eucalyptus citriodora (4.3m) and Eucalyptus viminalis (3.7m) recorded the highest height. But Eucalyptus saligna (3.1m) and Eucalyptus grandis (2.6m) recorded the least in height. Eucalyptus citriodora has the highest height growth relative to other species. It is reported that Eucalyptus citriodora has rapid growth rate and can reach a height of 50m (Australias world heritage tropical rainforest 2001) The growth rate of most Eucalyptus species is 1.99m/year. World agroforestry center (2009a) also reported that the height of Eucalyptus citriodora reached 24-40m at the age of 16 years. In Lalibela, the growth rate is 1.1m per year that means in 16 years Eucalyptus citriodora reached 17.6m. This difference is may be from site match mainly moisture deficit and low soil fertility status.

The study showed that Eucalyptus viminalis can grow 3.7m in 4 years. Cappa et al. (2010) in Australia showed that Eucalyptus viminalis reached a height of 2.25m in two years. World agroforestry center (2009b) reported that Eucalyptus grandis attains a height of 45-55 m, usually with an excellent trunk and a wide-spread at age of 25 years in Australia, but in our site the height of this species showed 2.47m in 4 years, that means in 25 years it reaches at a height of 15m. Whitesell (1988) in USA at age of 6 years Eucalyptus saligna reaches at a height of 5.07m.
which means the growth rate is 0.85m per year. Our result shows 3.12m at the age of 4 years, that means the growth rate is 0.8m per year. Also, the result of the two is similar in height and growth rate. When we see the height growth trend the pick growth of Eucalyptus citrodora and Eucalyptus viminalis is after 24 growing months. Other species were grown gradually (Fig1.).

Root collar diameter
There is no significant difference (Pr <0.068851492) between mean root collar diameters of the species. That means in our study site horizontal wood increment is not affected by species difference. In 4 years growing season Eucalyptus citrodora (6.5cm) and Eucalyptus viminalis (6cm) recorded the highest root collar diameter. But Eucalyptus saligna (5.67cm) and Eucalyptus grandis (4.14cm) recorded the least in root collar diameter. Species data sheet (2005) and World Agroforestry Center reported that Eucalyptus citriodora have 0.6m-1.3m diameter up to its life span. Our result in 4 years shows 0.65m which is a similar result when we take the minimum diameter. Cappa et al. (2010) in Australia Eucalyptus viminalis reaches 0.02m diameter in two years. In 4 years the root collar diameter of Eucalyptus viminalis at our experimental site shows 0.06m, thus our result shows the best performance in diameter. Whitesell (1988) showed that in USA at age of 6 years Eucalyptus saligna has 0.03m diameter. In our site it has 0.04 m root collar diameter in 4 years ago that is best from the provenance of USA at age of 6 years. Myers et al. (1996) explains in three growing years Eucalyptus grandis receive 0.085m diameter in Australia. Our result shows 0.04 m root collar diameter in 4 years growing, this difference is because of rainfall intensity and distribution and soil condition differences.

Survival rate of the species
There is no significant difference (Pr < 0.06) between the average survival rates of the species. All the four Eucalyptus species we have tested have almost same survivality ranged from 37% to 48%. But, Eucalyptus citrodora survive best (47.13%) followed by Eucalyptus viminalis (38.9%) and Eucalyptus grandis (41.4%) and Eucalyptus saligna (37.5%) show low survival rate. Of course, this difference comes from growth and productivity of trees depending on the genetic, climatic, and edaphic and management factors (Lugo et al. 1988). This study explained Eucalyptus citriodora is a widely adaptable species, growing in a range of soils and tolerant to moderate drought and water logging but it is susceptible to foliar and sap sucking insects. In our
study site there is unknown insect that damages the stand but *Eucalyptus citriodora* resists the insect attack and survives 50%. World agroforestry center sets the physical limits of *Eucalyptus citriodora* that is 0-1600m altitude, 17-24 °C mean annual temperature: 650-1600 mm mean annual rainfall, it is tolerant to a variety of soils, but commonly found on poor, gravelly soils, podsols and residual podsols of lateritic origin, and prefers well-drained but somewhat gravelly subsoils. This physical limit is almost similar to our study site, but at the age of 3 years termite and unknown insect minimizes the survival rate. Up to 3 years the survival rate of two species (*Eucalyptus citriodora* and *Eucalyptus viminalis*) is 80%. Thus, the low survivality is not physical limit rather insect attacks.

*Eucalyptus viminalis* has 33.38% survival rate next to *Eucalyptus citriodora*. It is moderately drought tolerant once established. It grows satisfactorily with no obvious signs of stress in dry summer and low tolerance of compaction. It grows up to the altitudinal range of 3684 m.a.s.l and adapted to sand to clay loam soil (Google plant image 2014; Cappa et al. 2010 in Australia states that *Eucalyptus viminalis* has 62.4% survival rate at the age of 6 years. In our study site in 4 years its survival rate reaches 33.38%. The difference is attributed to insect and pest attack at the age of 3 years and minimum soil compaction, but ecological limit is not that much different.

*Eucalyptus saligna* at the age of 4 has already dried out, most trees have died due to termite and unknown pest attack. Whitesell (1988) in USA at the age of 6 years *Eucalyptus saligna* survive 75%. Our result is low, this is may be because of pest and insect damage and may associated with climatic condition. The *Eucalyptus grandis* was highly attacked by pests at the age of 4 years. Because of this, survival rate was the least when we compared it with other species. Browsing by wallabies, particularly black wallaby and the red-legged pad melon can seriously affect height increment and even cause death of young plants. Young trees of *Eucalyptus grandis* at 2 years of age after planting are extremely susceptible to termite attack where they occur (Skies and Technologies 2008).

**Conclusion**

Based on our findings the height root collar diameter of *Eucalyptus citriodora* is the highest compared to other species. *Eucalyptus viminalis* performed well next to *E. citriodora*. The main
reason for decreased survival rate of most species as explained above was termite and other some unknown insects. Therefore, these different *Eucalyptus* species have significant difference in mean height, but not significantly different in terms of mean survival rate and mean root collar diameter. Of course, this difference comes from the difference of specie, height growth increment of root collar diameter; survival rate and adaptation of harsh conditions were dependant on the type of species. The seedlings were attacked by termite and other insects. The stems and the roots were attacked and dried out. This has to be accounted during plantation establishment. *Eucalyptus viminalis* and *Eucalyptus citriodora* had better resistance of diseases.

**Recommendations**

*Eucalyptus citriodora* is a multipurpose tree contributing for high quality and quantity honey production, pulp production in low and mid altitude areas, construction, extraction of essential oils and medicines and for intercropping with maize and sorghum (World agroforestry center 2009a). *Eucalyptus viminalis* can adapt the highlands of Wag Lasta area and can be used for different purposes. The two species (*Eucalyptus citriodora* and *Eucalyptus viminalis*) are recommended for for fuel wood, construction and reforestation purposes in Wag areas.

**References**


Proceedings of the 9th Annual Regional Conference on Completed Research Activities of Forestry


Population Viability Analysis of Threatened Selected Species in Church Forests

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Abstract

This study was conducted in Amhara regional state, Ethiopia with the aim of testing and evaluating the viability of Juniperus procera and Olea europaea sub. sps. cuspidata gene pool for local seed supply. The experiment was carried out in laboratory and field conditions with the objective to verify differences in the growth and survival rate of progenies of trees seeds collected from different populations. Germination test was undertaken in complete randomized design with four replications. 25 seeds were used per Petri dish from each seed sources. Field experimentation was implemented in a randomized complete block design with three replications. The result indicated that germination rate of local seeds had shown a significant difference ($p<0.05$). But height, root collar diameter and survival rate did not vary significantly between local and FRC seed sources. However, the highest height ($105±7.19$ cm) for Olea recorded for Neakutoleab at 48 months and for Juniperus ($104.19±9.38$ cm) under Yimrhane Kirstos at 48 months. All in all, the local seeds are viable under their biophysical limit. Therefore, in terms of cost use of local seed sources for plantation purpose is encouraging than outsourcing.

Key words: Church forest, Juniperous procera, Petridish, Progeny
Introduction

Ethiopia’s natural forest land is diminishing at an escalating rate. According to (FAO, 2015) estimation, the country’s deforestation rate since 2010 is estimated as 1.25% per year and for other woodlands 1.8% per year. High population pressure and its related consequences such as: the need for agricultural land, resettlement, income generation, fuel, and construction wood (Girmay and Singh, 2012, Aerts and Maes, 2006, Girma and Mosandl, 2010, Haile, 2006) are the leading factors for forest loss. Currently, an old aged natural forest of the country is fragmented, isolated in small patches around churches, monasteries, palaces and inaccessible hill sides. Particularly, remnant forests in church and monasteries has been protected more than a century (Wassic et al., 2005) and they are benefiting local communities as seed, seedling and pollen source, a sanctuaries of many plant and animal species (Amare et al., 2016) and serving as a good point of reference to illustrate the previously forested landscape of the nearby areas.

Commonly, in most parts of the country including our study site, remnant churches and monasteries forests comprise old aged indigenous and rare species like Juniperus procera, Olea europiana, and Cordia africana (Wassic et al., 2009, Wassie et al., 2010, Haile, 2006, Bongers et al., 2006). Along with Haile (2006) in his study particularly for this area reported that proportion of Juniperus procera and Olea europiana is 52.34% and 30.20%, respectively. They are predominant species of the remnant churches and monasteries forest, but these species do not have an adequate seedling and samplings undergrowth. Likewise, a number of studies stated that the remnant old aged churches and monasteries forests are not perpetuating in the normal manner (Wassic et al., 2005, Teketay, 2005), due to no or minimal regeneration. However, depletion of indigenous trees and shrubs species seen pronounced in some parts of the country including Wag and Lasta districts (Haile, 2006). Therefore, to solve this situation and boost up the natural and artificial regeneration, evaluating the viability of the gene pool within and outside the forest is a crucial step before any silvicultural interventions. Therefore, the aim of this study was to test seed germination and viability of selected remnant church forest for local seed supply.

Materials and methods

Description of study area

The experiment was carried out in Amhara regional state, Ethiopia. Laboratory experiment was conducted in Sekota Dryland Agricultural Research Centre (SDARC), and the field experiment...
was carried out in Lalibela, Debre-loza site (Fig.1). Geographically, located on Latitude: 12°04'40'' N, Longitude: 37°59'58''E and Altitude: 2129 m.a.s.l.

The rainfall is unimodal and the mean annual temperature ranges 13-25 °c (Fig.2). Based on the economic, social, ecological value and risk of being endangered; two species namely Juniperus procera and Olea europiana were selected for population viability test. Two populations of remnant church forests were selected as a source of mother trees.
Sampling and Selection of Mother Trees
Mother trees of respective species were selected randomly to represent the genetic pool of the whole forest and marked at the distance of 50m. Based on the size of the forest, 15 to 30 mother trees were selected along the gradient.

Experiments

Phase I: Laboratory experiment
Germination and viability tests were conducted on seeds collected from mother trees. The processed seeds were dried until it attains appropriate moisture content. Considering dormancy period of each species seeds of all forest including FRC (Forest research center) were treated and germinated on petri dish separately. The experiment was undertaken for each species of all location using complete randomized design (CRD). For this experiment, 25 seeds were germinated for each species in four replications per location. Appropriate moisture at room temperature was maintained until the end of the trial. All germinated and contaminated seeds were recorded and discarded every three days interval.

Phase II: field experiment
A field experiment was conducted to test early growth and survival rate of the progeny. For each location, eight seedlings of a species were planted in RCBD with three replications. Half-moon, with 1.5m radius, was used as moisture retention techniques. Half-moon within a plot was separated with 1 m and 1.5 m horizontally and vertically, respectively. In addition, 1.5m and 2.5m spacing were used between plots and blocks, respectively. Starting from the date of planting at every three months for one year and every six months up to the end of the trial; root collar diameter, height and survival rate were recorded.

Data analysis
The data analysis performed with R version 3.2.4 statistical software, to test the significant difference between treatments, one-way ANOVA with 0.05 alpha level were used.
Result

Germination test [%]

The laboratory experiment was carried out using seeds obtained from Neakutoleab and Yimrhane kirstoss; *Olea europiana* (Fig.3A) and *Juniperus procera* (Fig. 3B), respectively. The local seeds had shown significantly higher germination percentage than seeds from FRC (Forest research center /Menagesha) at P<0.05. Germination of *Juniperus procera* varied from 32 to 44% for FRC seeds and 52 to 75 % for seeds from Yimrhane. Similarly, *Olea europiana* was wide-ranging from 36-68 % for FRC seeds and 68-84 % for Neakutoleab seeds.

![Germination graph](image)

Figure 3. Germination rate of seeds from Neakutoleab and Yimrhane kirstoss *Olea europiana* (Fig.3A) and *Juniperus procera* (Fig. 3B). Different letters indicate significant differences (P < 0.05).

Height [cm]

Growth performance of *Olea europiana* in height was not significantly different (P<0.05) between the two seed sources (Fig.4). The highest growth in height (105+7.19 cm) was recorded for Neakutoleab at 48 months. The height of *Olea europiana* from FRC was shocked at an early phase and desiccated at 42-month growth period, and decreased for Neakutoleab at 18 months (Fig.4). Similarly, growth performance of junipers (Fig.4) had no significant difference in height (p<0.05). However, the highest growth in height (104.19±9.38 cm) was recorded for Yimhane KIRSTOS at 48 months.
Figure 4. Height growth of *Olea europiana* (4A) and *Juniperus procera* (4B). Different letters indicate significant differences (P < 0.05).

**Root collar diameter [cm]**

The root collar diameter (RCD) had no significant difference (P<0.05) between the two seed sources (Fig.5A and Fig.5B). The RCD was not changed for 9 months for *Olea* and 12 months for *Juniperus*. However, the highest in RCD for *Olea* was obtained under FRC (2.75±0.16 cm) at 42 months and for *Juniperus*, relatively higher RCD was found under FRC (1.72±0.28 cm) at 36 months.

Figure 5. Root collar diameter (RCD) growth performance of *Olea europiana* (5A) and *Juniperus procera* (5B). Different letters indicate significant differences (P < 0.05).
Survival Rate [%]
The performance of both the species and seed sources had no significant difference (P<0.05) in survival rate (SR). But the higher death of seedlings was recorded from the 6-9 month for *Olea europiana* and from 24-30 month for *Juniperus procera*. However, relatively higher percent of survival rates at the end of the experimentation period were recorded 54.2±11.0% for *Olea* seed from Neakutoleab and 70.8±11.0% for junipers seed from Yimrhave Kirstos. The trend of SR across months had shown relatively stable for both *Olea* seed sources (Fig.6) and junipers from Yimrhave Kirstos, but junipers from FRC still not stable and it has been followed a declining trend (Fig.6).

![Figure 6 Survival Rate [%] of *Olea europiana* (6A) and *Juniperus procera* (6B) across months. Different letters indicate significant differences (P < 0.05).](image)

Discussion
Germination [%]
The local seeds of both species had superior germination rate than seeds from FRC. The germination rate of *Juniperus procera* varied from 32 to 44% and 52 to 75% for FRC and Yimrhave seeds, respectively. This result is concurrent with the result of Mamo and Mebrate, 2006, El Juhany et al., 2009, Azene and Tengnas, 2007, Orwa et al., 2009. Similarly, *Olea europiana* varied from 36-68 % for FRC seeds and 68-84 % for Neakutoleab seeds. But this value is relatively higher than the germination percent of Forest Research Center, Kenyan Forest Research Institute and Amhara Forest Enterprise, which ranges from 20 to 60%.
Height [cm]
The height of *Olea europiana* from FRC was shocked at an early phase and desiccated at 42 months growth period. This could be due to the vulnerability of the seedlings to hazards from environmental and biotic factors are higher at an early stage of seedling establishment (Fenner, 1987, Whitmore, 1996, Teketay, 2005). There was a decreasing trend in height at 18 months for Neakutoleab because of browsing effect and moisture deficit as a result of the drought. However, the height growth of *J. procera* had shown a steady trend for both seed sources across months. This probably due to non-palatability and suitability of the site, i.e. actual range of the species; 1100-3500 m.a.s.l and difference as a result of growth strategy of the species.

Root collar diameter [cm]
The RCD was not changed for 9 months for *Olea europiana* and 12 months for Junipers. This could be due to during the establishment phase of seedlings give more emphasis for below ground development (Fenner, 2000). In addition, they developed symbiotic relationship during the establishment phase. But, both species form an association with different mycorrhiza species (Wubet and Weiss, 2006, Wubet, 2003).

Survival rate [%]
The trend of SR was declining with increasing months for *Juniperus* from FRC. But both *Olea europiana* seed sources and local *Junipers* had shown stable survival rate. However, higher mortality of seedlings was recorded from 6-9 (December to March) months for *Olea europiana* and from 24-30 (June to December) months for *Juniperus procera*. This may be due to lack of moisture as a result of the recurrent drought. Particularly, in December, January and February the rainfall amount was very small and drier (Fig. 1). Along with high fluctuation in temperature was recorded between July to August and May to June, respectively (Fig. 1). Consequently, tree seedlings are relatively poor in tolerating seasonal moisture deficit and temperature fluctuation (Tingstad et al., 2015, Weiskittel et al., 2011). The reason for the difference in tolerance of the two species may be associated to mortality in the early stages of growth which may result from a wide range of biotic and a biotic factors, that vary from place to place, from year to year (Fenner, 2000) and also from species to species.
Conclusion
In general, the germination rates of both local seeds were relatively higher than seeds from FRC. But height, RCD and survival rates did not vary with FRC. Height growth fluctuated for *Olea europiana* but steady for junipers. Root collar diameter was not changed in 9 months for *Olea europiana* and in 12 months for *Juniperus*. Survival rate was higher for both local species. Therefore, the local seeds for both species viable in their biophysical limit. And in terms of cost, use of local seeds is more advantageous than outsourcing.

Recommendation
The seed of local species are viable to use for plantation purpose, but additional work should be done to facilitate seedling growth inside the remnant forest.

Acknowledgements
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Selection of Different Trees/Shrubs Species for Rehabilitation of Degraded Lands in the Highlands, Mid Altitudes and Lowlands of Wag-Lasta Area

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Sekota Dryland Agricultural Research Center, P.O. Box 62, Sekota, Ethiopia

Abstract
Due to human and livestock population pressure, land degradation is the main problem in many parts of Ethiopia. To avert the situation, tree and shrub species selection on degraded lands is valuable tool for ecological restoration. Therefore, the aim of this study was to select the best performing tree and shrub species in three agro-ecological zones of Wag-Lasta area, Ethiopia. The experiment was conducted in randomized block design with three replications in the highland, mid altitude, and lowland sites. Growth and survival rate data were collected every 3 months interval for one year and every 6 months up to the end of the experiment. The result indicated that L. pallid (2.52±0.19 m) at lowland site, A. senegal (1.32±0.23 m) at mid altitude and A. decurrence (4.0±0.46 m) at highland site had shown better performance in height. Similarly, M. stenopetala at lowland, J. carcus at mid altitude and A. saligna at highland site had shown 8.63± 2.37 cm, 3.1±0.2 cm and 7.06±0.75 cm performance in root collar diameter, respectively. However, the survival rate was higher for A. senegal (43±7 %) and M. stenoptella (44±17 %) at lowland site, A. senegal (98±2 %) at mid altitude and A. saligna (63.9±20.0 %) at highland site. Therefore, to restore degraded lands and to support the on-going land rehabilitation programs of Wag-Lasta area, we recommend A. senegal and M. stenoptella for lowland site, A. senegal for mid altitude areas and A. saligna for highland site of Lalibela, Abergale and Sekota and similar agro-climatic zones. Knowledge on soil nutrient dynamics and tree nursing should be integrated to develop sound ecological restoration strategies.

Key words: Acacia saligna, highland, Lalibela, Moringa stenopetala, Rehabilitation
Introduction

Land degradation is both a natural and human-induced process (Zdruli et al., 2010), which diminishes the capacity of land resources to perform essential functions and services (Humi et al., 2010). Land degradation is a global-scale, ongoing, and the relentless problem that poses a major long-term challenge to humans in terms of its adverse impact on biomass productivity, food security, biodiversity and environmental sustainability (Mueller et al., 2014). Land degradation is the broad term that includes soil erosion degradation (acidification, fertility depletion, hard-setting), biological degradation (reduction of total biomass and carbon and decline of biodiversity) and ground water depletion. In Ethiopia, land degradation has become a serious problem affecting all spheres of social, economic and political life of the population (Tekle, 1999). It is one of the major challenges to agricultural development and food security of the country. A large portion of the agricultural land, which is mainly located in the highland parts of the country, is affected by severe to moderate land degradation (Humi et al., 2010).

Particularly, Amhara region is extremely affected by land degradation. Due to soil erosion, about 29% of the total area of the region experiences high erosion rates (51–200 t/ha per year), 31% experiences moderate erosion rates (16–50 t/ha per year), 10% experiences very high erosion rates (>200 t/ha per year) and the remaining 30% experiences low erosion rates (<16 t/ha per year) (Desta and ILRI, 2000). The leading factors of land degradation in the region are deforestation, soil erosion, growth of human and livestock population, overgrazing, and mismanagement of land. For instance, accelerated growth of human and livestock population coupled with per capital demand for goods and services, land degradation has gone beyond the limits of reversal, and the problem is expanding at large, although, the trend of land rehabilitation is becoming an increasingly significant tool to manage, conserve, and repair the worlds degraded ecosystems. Hence, rehabilitation of degraded ecosystems is a critical tool for protection of the remaining natural resource.

Therefore, restoring degraded lands through afforestation is crucial step to return back the productive potential of land. However, previous reforestation programs attempting to counteract the effects of deforestation have failed mainly due to lack of knowledge on site–species matching (Gebrekirstos et al., 2006).
Thus, an appropriate tree/shrub species selection for different agro-ecologies is a sound step to assist the rehabilitation of the degraded lands. Therefore, the main focus of this research was to select the best performing trees or/and shrubs species on the degraded lands of wag-lasta area.

Materials and methods

Site description

The experimentation was conducted in Amhara region of Wag-himera and Semen wollo, in three agro-ecologies namely; lowland, mid-altitude, and highland. The lowland site is located at Abergele, which ranges in altitude from 1150-2500 m.a.s.l. The mean annual temperature and rainfall varies from 23°C to 43°C, 250 to 750 mm, respectively. Also the district’s agro-ecology can be classified as lowland (Abebaw et al., 2013). Mid altitude site is located at Sekota (Woleh), the altitude of the district ranges from 1340 to 2200 m.a.s.l. The rainfall pattern is unimodal with erratic and uneven distribution. But mean annual rainfall ranges between 350 to 700 mm, and the mean annual temperature varies from 16°C to 27°C (Deribe and Taye, 2013). The highland is located at Lalibela and the altitude of the site is 2129 m.a.s.l. Lalibela area has two rainy seasons from June to September and from March to April. The annual rainfall varies from 500 to 1000 mm, Lalibela area is characterized by mean annual temperature of 24.5°C and relative humidity is 52.9% (Kiros et al., 2013).

Experimental design and management

Treatments were laid out in Randomized Complete Block Design (RCBD) with three replications. The space between blocks and plots were 3 m and 2 m, respectively. The size of the plot was 12 m X 10 m for lowland, 10 m x 8 m for mid altitude and 6 m X 6 m for the highland site. The spacing between trees in a plot was 2.5 m x 2 m (lowland), 2 m x 2 m (mid altitude) and 1.5 m x 2 m (highland).

For the total experimental set up 21 treatments (6 for the lowland, 8 for mid-altitude and 7 for highland) were used (Table 1). In a plot, 25 trees for lowland, 16 trees for mid-altitude and 12 trees for highland were planted. Water harvesting structures (half-moon), which is recommended in our mandate area, was constructed following the contours.
Table 1. Treatment set up in three agro-ecologies

<table>
<thead>
<tr>
<th>No</th>
<th>Highland (Lalibella/Debre-loza)</th>
<th>Mid altitude (Wolleh, Sekota)</th>
<th>Lowland (Abergele)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td><em>Acacia Abyssinica</em></td>
<td><em>Sesbania aculeata</em></td>
<td><em>Sesbania aculeata</em></td>
</tr>
<tr>
<td>2</td>
<td><em>Acacia decurrens</em></td>
<td><em>Acacia senegal</em></td>
<td><em>Acacia albida</em></td>
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<tr>
<td>3</td>
<td><em>Acacia melanoxylon</em></td>
<td><em>Cordia Africana</em></td>
<td><em>Acacia senegal</em></td>
</tr>
<tr>
<td>4</td>
<td><em>Acacia saligna</em></td>
<td><em>Gravilea robusta</em></td>
<td><em>Luecaena pallida</em></td>
</tr>
<tr>
<td>5</td>
<td><em>Chamaecytisus palmensis</em></td>
<td><em>Jatropha carcus</em></td>
<td><em>Leucaena leucocephala</em></td>
</tr>
<tr>
<td>6</td>
<td><em>E. viminalis</em></td>
<td><em>Melia azandarchata</em></td>
<td><em>Moringa stenoptella</em></td>
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<td></td>
<td></td>
<td><em>Moringa stenoptella</em></td>
<td><em>Sesbania sesban</em></td>
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<td></td>
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<td><em>Sesbania sesban</em></td>
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Data collected
Growth (Height and Root collar diameter) and survival data were collected every 3 months interval for 21 months and every 6 months interval since 21-month period up to the end of the experimentation.

Data analysis
Data were analyzed by using SPSS statistical analytical software version 22 to compare height, root collar diameter, and survival rate among treatments.

Results and Discussion
Lowland site (Abergele)
The growth and survival rate data of Abergele trial had shown significant difference across months and treatments in height, root collar diameter and survival rate at p<0.05. The performances of all species except survival rate were increasing with increasing growing months. The mean comparison result indicated that *L. pallida* and *M. stenoptella* had shown significant growth in height (2.52±0.19 m) at 45 months (Figure 1), and root collar diameter (8.63± 2.37 cm) at 39 months (Table 2), respectively. This may be due to the difference in growth strategy of the plants. *Acacia senegal* and *Moringa stenoptella* scored relatively highest (43±7 % and 44±17 %) survival rate at the end of the experimentation (Table 3). This result is relatively lower than
the finding of Haile, (2012), who found 83.3% survival rate for *Moringa stenoptella* and 52.08% for *Acacia senegal* in similar location. However, *L. leucocephala*, *S. aculeata*, and *S. sesban* were not survived after 27 month lifetime. Particularly, poor survival and growth response was observed on *L. leucocephala*, *S. aculeata*, and *S. sesban*, probably due to longer period of dry season which extends from 9 to 10 months, and also lifetime of the species and need of special treatment like pruning, looping, and coppice. Specifically, *L. leucocephala* does not tolerate very dry and acidic soil (Azene and Tengnäs, 2007).

Figure 1. Growth performance of tree/shrub species in height (m) across months at Abergele. Means with similar letters are not significantly different at (p<0.05).
Table 2. Growth performance of tree/shrub species in root collar diameter (cm) across months at Abergele

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Months</th>
<th>Mean±SE</th>
<th>6</th>
<th>12</th>
<th>18</th>
<th>27</th>
<th>33</th>
<th>39</th>
<th>45</th>
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<tr>
<td>A.albida</td>
<td></td>
<td>0.23±0.09&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.4±0.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.9±0.39&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.13±0.73&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.73±0.73&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.43±0.43&lt;sup&gt;b&lt;/sup&gt;</td>
<td>d</td>
<td></td>
</tr>
<tr>
<td>A.senegal</td>
<td></td>
<td>0.47±0.12&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.1±0.35&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.03±0.79&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Nd</td>
<td>Nd</td>
<td>Nd</td>
<td>Nd</td>
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<tr>
<td>L.leucocephala</td>
<td></td>
<td>0.37±0.07&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.53±0.07&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.23±0.19&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.77±0.33&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>d</td>
<td>d</td>
<td>d</td>
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<tr>
<td>L.palida</td>
<td></td>
<td>0.6±0.06&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.6±0.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.17±0.28&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.43±0.32&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.87±0.48&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.1±1.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.7±0.44&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
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<tr>
<td>M.stenopetala</td>
<td></td>
<td>1.53±0.09&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.83±0.41&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.57±1.12&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>5.97±0.97&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.27±0.18&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.63±2.37&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.87±0.72&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>S.andeala</td>
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<td>1.23±0.13&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.53±0.12&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>d</td>
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<tr>
<td>S.sesban</td>
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<td>1.7±0.17&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.97±0.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.43±1.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>d</td>
<td>d</td>
<td>d</td>
<td>d</td>
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</tbody>
</table>

Means in columns with similar letters are not significantly different at (p<0.05), Nd: No data, d; died out, SE: standard error of mean

Table 3. Growth performance of tree/shrub species in Survival rate (%) across months at Abergele

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Months</th>
<th>Mean±SE</th>
<th>6</th>
<th>12</th>
<th>18</th>
<th>27</th>
<th>33</th>
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<tr>
<td>A.albida</td>
<td></td>
<td>96±2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>77±3&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>4±4&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
<td>A.senegal</td>
<td></td>
<td>79±3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>72±6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>76±4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>57±13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>43±22&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>43±7&lt;sup&gt;ab&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>L.leucocephala</td>
<td></td>
<td>64±15&lt;sup&gt;b&lt;/sup&gt;</td>
<td>45±12&lt;sup&gt;b&lt;/sup&gt;</td>
<td>35±5&lt;sup&gt;d&lt;/sup&gt;</td>
<td>19±4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8±8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8±5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8±2&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>L.palida</td>
<td></td>
<td>87±3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72±7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>60±0&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>53±5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>52±6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>33±12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>23±9&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>M.stenopetala</td>
<td></td>
<td>83±3&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>73±6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72±5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>64±7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>59±10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>47±14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>44±17&lt;sup&gt;a&lt;/sup&gt;</td>
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</tr>
<tr>
<td>S.andeala</td>
<td></td>
<td>99±1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>48±10&lt;sup&gt;b&lt;/sup&gt;</td>
<td>40±10&lt;sup&gt;ad&lt;/sup&gt;</td>
<td>d</td>
<td>d</td>
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<tr>
<td>S.sesban</td>
<td></td>
<td>96±4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>45±7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>41±10&lt;sup&gt;ad&lt;/sup&gt;</td>
<td>d</td>
<td>d</td>
<td>d</td>
<td>d</td>
<td></td>
</tr>
</tbody>
</table>

Means in columns with similar letters are not significantly different at (p<0.05), d; dry out, SE: standard error of mean

**Mid-altitude (Sekota/Wolch)**

The performance of tree/shrubs in this site was significant across months. The trends in height (Fig. 2) and root collar diameter (RCD) (Fig. 3) were increased with increasing months. The
highest growth in height was recorded for *A. senegal* (1.32±0.23 m) and the lower height was obtained for *M. stenopetala* (0.15±0.15 m) at the end of the trial. This might be due to nitrogen fixing ability of the species helps to perform in degraded soil (Githae et al., 2011). Similarly, the RCD was higher for *J. carcus* (3.1±0.2 cm) and the lower value was recorded for *G. robusta* (0.5±0.3 cm). The performance of *A. senegal* was higher in survival rate and lower for *M. stenopetala* at the end of the experimentation 98±2 % and 4±4 %, respectively.

This is probably because *A. senegal* is one of the species which is classified as drought avoider (Gebrekirstos et al., 2006), and there was drainage problem during the rainy season, which affects the survival ability of *M. stenopetala*. Besides, *M. stenopetala* does not grow well on waterlogged or swampy areas (Orwa et al., 2009).
Table 2 Survival rate performance of tree/shrub species in percent across months

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Months</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6</td>
<td>12</td>
<td>18</td>
<td>24</td>
<td>33</td>
<td>39</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Mean±SE</td>
<td>Mean±SE</td>
<td>Mean±SE</td>
<td>Mean±SE</td>
<td>Mean±SE</td>
<td>Mean±SE</td>
<td>Mean±SE</td>
</tr>
<tr>
<td>A. senegal</td>
<td>100±0*</td>
<td>100±0*</td>
<td>98±2*</td>
<td>98±2*</td>
<td>98±2*</td>
<td>98±2*</td>
<td>98±2*</td>
</tr>
<tr>
<td>C. africana</td>
<td>100±0*</td>
<td>83±14*</td>
<td>85±12*</td>
<td>81±13*</td>
<td>73±9*</td>
<td>69±16ab</td>
<td>67±15ab</td>
</tr>
<tr>
<td>G. robusta</td>
<td>85±8*</td>
<td>83±6*</td>
<td>56±17*</td>
<td>47±34*</td>
<td>27±27b</td>
<td>17±17bc</td>
<td>11±15b</td>
</tr>
<tr>
<td>J. carcus</td>
<td>100±0*</td>
<td>88±10a</td>
<td>85±12a</td>
<td>85±12a</td>
<td>85±12a</td>
<td>83±10ab</td>
<td>76±12ab</td>
</tr>
<tr>
<td>M. uzadarchaia</td>
<td>100±0*</td>
<td>98±2*</td>
<td>94±4*</td>
<td>81±10a</td>
<td>56±28abc</td>
<td>56±28abc</td>
<td>46±23ab</td>
</tr>
<tr>
<td>M. stenoptela</td>
<td>83±9*</td>
<td>75±10a</td>
<td>64±4*</td>
<td>48±15a</td>
<td>4±4c</td>
<td>4±4c</td>
<td>4±4b</td>
</tr>
</tbody>
</table>

Means in columns with similar letters are not significantly different at (p<0.05). . SE: standard error of the mean.

Highland site (Lalibela D/Loza)
The performance of tree/shrubs in growth and survival rate was significant across months (p<0.05). Significantly higher plant height was obtained for *A. decurrence* (4.0±0.46 m) and the lower height was recorded for *A. melanoxylon* (2.30±0.1 m) at the end of the experiment. This result is relatively lower with the result of Kindu et al., (2006), who found 6.89 m and 3.90 m height growth at 36 months on *A. decurrence* and *A. melanoxylon*, respectively. However, *C. palmensis* was not survived after 21 months. Similarly, the survival rate was decreasing with increasing growing months (Fig.3). The higher survival rate was recorded for *A. saligna* (63.9±20.0 %) and the lower survival rate was recorded for *A. decurrence* (16.7±4.8 %) at the end of the experimentation except for *A. decurrence*, there was no significant difference in survival rate among *A. saligna, A. melanoxylon, A. abyssinica* and *E. viminalis* at (p<0.05).

In addition, the root collar diameter (RCD) performance of tree/shrubs was increased with increasing growing months (Table 4). The higher RCD value was found for *A. saligna* (7.06±0.75 cm) and lower value was obtained under *A. melanoxylon* (4.18±0.27 cm) at 45 months lifetime. This result is similar with the value found by Tesfaye et al. (2015), who found higher root collar diameter for *A. saligna* in the central highlands of Ethiopia. However, all treatments did not show any significant difference (p<0.05) in RCD at the end of the experiment.
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Figure 2. Growth performance of tree/shrub species in height (m) across months at Lalibela. Means with similar letters are not significantly different at (p<0.05).

Table 3. Growth performance of tree/shrub species in root collar diameter (cm) across months

<table>
<thead>
<tr>
<th>Treatments</th>
<th>6</th>
<th>12</th>
<th>18</th>
<th>33</th>
<th>39</th>
<th>45</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. abyssinica</td>
<td>0.59±0.08ab</td>
<td>0.91±0.10b</td>
<td>1.67±0.08c</td>
<td>4.01±0.13b</td>
<td>4.47±0.48b</td>
<td>6.11±0.76a</td>
</tr>
<tr>
<td>A. decurrence</td>
<td>0.31±0.01b</td>
<td>0.53±0.09bc</td>
<td>0.56±0.20b</td>
<td>3.31±0.75a</td>
<td>4.38±0.59b</td>
<td>6.55±1.90b</td>
</tr>
<tr>
<td>A. melanoxylon</td>
<td>0.65±0.14ab</td>
<td>0.80±0.12bc</td>
<td>1.08±0.21b</td>
<td>2.80±0.24a</td>
<td>3.44±0.20b</td>
<td>4.18±0.27a</td>
</tr>
<tr>
<td>A. saligna</td>
<td>1.15±0.23a</td>
<td>1.37±0.21b</td>
<td>1.55±0.19a</td>
<td>4.06±0.38a</td>
<td>5.04±0.27a</td>
<td>7.06±0.75a</td>
</tr>
<tr>
<td>C. palmensis</td>
<td>0.50±0.00c</td>
<td>0.65±0.00c</td>
<td>0.35±0.00c</td>
<td>d</td>
<td>d</td>
<td>d</td>
</tr>
<tr>
<td>E. viminalis</td>
<td>0.71±0.05ab</td>
<td>1.22±0.05ab</td>
<td>1.05±0.11ab</td>
<td>2.54±0.11a</td>
<td>3.54±0.11a</td>
<td>4.24±0.33a</td>
</tr>
</tbody>
</table>

Means in columns with similar letters are not significantly different at (p<0.05), d; dry out, SE: standard error of the mean.

Conclusion and recommendation

Across agroecological zones, the performance of tree and shrub species were varied in height, root collar diameter and survival rate. In the lowland site, better performances observed for L.palida and Moringa stenoptella in height and RCD, also A.senegal and Moringa stenoptella in survival rate. Similarly, in the mid altitude, A.senegal in height and survival rate, and J.carac in
RCD, had shown good performances. Also in the highland sites, relatively higher performances were observed for *A.deccurence* in height, *A.saligna* in RCD and survival rate at the end of the experimentation. Therefore, to restore degraded lands and to support the on-going land rehabilitation programmes of Wag-Lasta area, we recommend *A.senegal* and *Moringa stenoptella* for lowland site, *A.senegal* for mid altitude areas and *A.saligna* for highland site of lalibela, abergele and sekota and similar agroclimatic zones. However, additional studies regarding soil nutrient dynamics, fostering effect and tree nursing should be integrated to develop sound ecological restoration strategies in the growth corridor as well as in the region.

**Acknowledgements**

The authors would like to thank the Amhara Agricultural Research Institute (ARARI), Sekota Dryland Agricultural Research Center (SDARC) for financial and technical support; we extend our gratitude for Lasta wereda, Abergele wereda, Sekota Zuria wereda Agricultural Development offices for their support during experimental site selection.

**Reference**


Promotion of the role of area exclosure with enrichment planting for rehabilitation of degraded land

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Debre Birhan Agricultural Research Center, P.O. Box 112, Debre Birhan, Ethiopia

Abstract

Promotion of the role of area exclosure in Ethiopia has been developed as a strategy to mitigate the negative effects of environmental change. However, this strategy has not been promoted to different parts of Amhara due to lack of knowledge on soil seed bank or enrichment planting and limitation of understanding the economic importance of the area exclosure. Hence, this study focused on promotion of area exclosure with enrichment planting by different tree species to rehabilitate degraded land at a faster rate. The tree species used for rehabilitation were Acacia polycantha, Acacia nilotica and Acacia saligna. The study was conducted at Tarma Ber district in Arimaniya Kebele. The tree species performances were evaluated in terms of tree height, root collar diameter and survival rate. Soil physico-chemical properties and species abundance under area exclosure and planting was evaluated. Acacia polycantha performed the highest in all parameters. This species showed a height of 3.5 m, root collar diameter of 6.75 cm, and a survival rate of 86.67%. The species abundance was 16.33. The farmers' evaluation indicated that Acacia nilotica, Acacia saligna and Acacia polycantha improves soil fertility. However, farmers who participated in the field days selected Acacia polycantha as a fast growing and multipurpose tree species compared to the two species. The less attention given by the government and NGOS on fast growing tree species technologies was raised; which help to recover degraded areas in short time and in abundance of biodiversity conservation. Therefore, A. polycantha is recommended to recover the degraded areas thereby to enhance biodiversity in areas like Tarma Ber. Moreover, the area exclosure with enrichment planting requires proper planting material, adequate management, monitoring and evaluation to further promote and benefit farmers residing in degraded areas.

Key words: Enrichment planting, exclosure, promotion, degraded area, Acacia polycantha, rehabilitation
Introduction

Land degradation refers to worsening of land resources and hence decreasing of sustainable productive capacity of agricultural lands in the world (de-Queiroz, 1993, UNFPA and POPIN, 1995). Particularly land degradation is a severe problem across sub-Saharan Africa and Ethiopia is among the most affected countries and cause of land degradation was deforestation (37%), overgrazing (35%), inappropriate agricultural practices such as over-cultivation, nutrient depletion (28%) and industrialization (1%) are major human factors accelerating land degradation in the world (Betru et al., 2005). Rangeland degradation is a widespread problem throughout sub-Saharan Africa and its restoration is a challenge for the management of many semi-arid areas (Yaynishet, 2008). Land degradation affects livelihoods of the rural population in developing countries; it is a major contributor for food insecurity (Dasgupta and Maler, 1991). Similarly, land degradation in Ethiopia is triggered by population expansion and over-exploitation of the natural resources and degradation is a major threat to sustainable land uses (Hurni et al., 2005).

Exclosures are a type of land management, implemented on degraded land for environmental restoration using different land management options (Tucker and Murphy, 1997). Area exclosure in the Ethiopian context can be defined as the degraded land that has been excluded from human and livestock interference for rehabilitation (Betru et al., 2005). Establishment of area exclosure has been considered as an important strategy for the rehabilitation of degraded hillsides. This practice has become very common, especially in the highlands of Ethiopia, due to its significant role in improving land productivity and reduction in soil erosion (WFP/MoA, 2002).

Exclosure established in the northern Ethiopia are effective in restoring species composition, improving diversity, increasing biomass and key woody structural attributes of degraded communal grazing lands (Yayneshet et al., 2008). This in turn led to improved ecosystem function and health. Exclosures have the potential to reduce water erosion (Mekuria et al., 2009). Exclosure is cheap and fast but productive degraded land rehabilitating mechanism (Emru et al., 2006).

Rehabilitation of degraded areas can be fostered either through exclosure without intervention (e.g. soil seedbank) or with intervention (such as enrichment planting). However, the soil seed
bank in Ethiopia is generally poor (Teketay 1996, Lemenih and Teketay 2004) once the standing vegetation is cleared. Enrichment planting can also be carried out to accelerate canopy closure, add useful tree species, and increase floristic diversity. Enrichment planting using nitrogen-fixing fodder trees and shrubs would contribute to the amelioration of soil fertility.

The challenge of initiating rehabilitation of degraded areas is looking for a successful tree species and establishment in such poor soil nutrient. This is because at the initial stage of area exclosure there are different stresses, poor soil seed bank, different damages and mortality (Burdett, 1990). Selection and promotion of the tree species adaptable to degraded areas is required to rehabilitate the sites at a faster rate and to bring the economic benefits in a short time (Founoune et al., 2002). In northern Ethiopia, different tree species have been planted. However, the performance was very poor and hence there is a need to promote the best performing tree/shrubs species on degraded closed areas to contribute in the mitigation of land degradation. The objective of this study was to select and promote best performing tree species in Tarma Ber district for the rehabilitation of degraded lands.

Materials and Methods

Site description

The study was conducted at Tarma Ber district in Aremaniya Kebele and the area located in 9°52'60" N latitude and 39°49'38" E longitude with an average elevation of 1981 m.a.s.l. Reconnaissance survey was done to identify the degraded areas. Planting *Acacia polycantha*, *Acacia nilotica* and *Acacia saligna* was carried out in three replications with spacing of 1 m between plants, 1 m between plots and 2 m between blocks. The number of seedlings per plot was 36. The seedlings were raised in the mid-altitude agro ecology zone. The seedlings were planted by integrating with trench for water-harvesting. In total, 35 farmers were selected within the surrounding to follow, manage and utilize the output of the area exclosure. The farmers were organized as a farmer research extension group (FREG). The perception of the farmers about the area exclosure and the tree species performance was collected. Purposive sampling was used to select the respondents from the FREG groups to obtain information about the biological growth of tree species and socioeconomic information.
Statistical analyses
Data was coded and analyzed by GLM- univariate- ANOVA (SPSS, version 20). Descriptive statistics were used to show the major factors that farmers considered as mostly dominant.

Result and Discussion
The growth parameters of the tree species that used for restoration of degraded areas were as shown below in fig (a-1) and fig (b-1 tree height and root collar diameter respectively in 46 months of the three Acacia species; Acacia polycantha, Acacia nilotica and Acacia saligna.

![Figure 1a](tree_height.png)  ![Figure 1b](root_collar_diameter.png)

Figure 1. Height and RCD of the three planted species

![Figure 2](survival_rate.png)

Figure 2. Survival rate of the 3 Acacia species

There was a significant difference on tree seedling survival among the three test tree species (ANOVA, F=9.089, p=0.015)
Table 1. Mean values of survival rate

<table>
<thead>
<tr>
<th>Tree Species /Treatments</th>
<th>Average survival rate in %</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acacia nilotica</em></td>
<td>38.89a</td>
</tr>
<tr>
<td><em>Acacia saligna</em></td>
<td>45.5a</td>
</tr>
<tr>
<td><em>Acacia polyacantha</em></td>
<td>86.67b</td>
</tr>
<tr>
<td>C.V</td>
<td>15.3</td>
</tr>
<tr>
<td>Sig. (5%)</td>
<td>**</td>
</tr>
</tbody>
</table>

The effect of tree species on soil bulk density and moisture content was tested and thus the three tree species showed a significant effect on moisture content (ANOVA, F=9.496, p=0.005), but not on bulk density (ANOVA, F=3.237, p=0.082). However, there is no effect on bulk density.

Table 2. Mean value of soil bulk density and moisture content

<table>
<thead>
<tr>
<th>Tree Species/trt</th>
<th>Bulk density</th>
<th>Moisture content (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acacia nilotica</em></td>
<td>1.1028a</td>
<td>34.087a</td>
</tr>
<tr>
<td><em>Acacia saligna</em></td>
<td>0.9964a</td>
<td>32.428a</td>
</tr>
<tr>
<td><em>Acacia polyacantha</em></td>
<td>1.1a</td>
<td>33.399a</td>
</tr>
<tr>
<td>Control</td>
<td>1.27a</td>
<td>13.71b</td>
</tr>
<tr>
<td>C.V</td>
<td>9.9</td>
<td>16.4</td>
</tr>
<tr>
<td>Sig. (5%)</td>
<td>ns</td>
<td>***</td>
</tr>
</tbody>
</table>

The overall correlation between soil moisture content (%) and bulk density in the rehabilitation of degraded lands.
Soil physico-chemical properties such as, pH, OC, N, P, sand, clay and silt

The result is shown in Table 3 below. The three species plant in the exclosure showed insignificant effect on soil physico-chemical properties except C: N. The C:N showed significant change between planted and the control (ANOVA, CV=9.11=, p=0.048). Acacia tree species are known to improve soil nitrogen and carbon because they can fix atmospheric nitrogen into the soil and finally changes it into usable form. Other soil chemical properties require long time to bring a change. In Tarma Ber district, there is free grazing that exposes the soil to erosion and most of the areas are degraded. Those agricultural lands located below the free grazing are strongly affected by erosion.

Table 3. Mean values of Soil physico-chemical properties

<table>
<thead>
<tr>
<th>Tree species</th>
<th>PH</th>
<th>P</th>
<th>k</th>
<th>OC</th>
<th>OM (%)</th>
<th>TN</th>
<th>C:N</th>
<th>Sandy</th>
<th>Clay</th>
<th>Silt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia nilotica</td>
<td>7.400</td>
<td>7.560</td>
<td>3.500</td>
<td>1.009</td>
<td>1.735</td>
<td>0.063</td>
<td>15.43</td>
<td>60.00</td>
<td>23.33</td>
<td>16.67</td>
</tr>
<tr>
<td>Acacia saligna</td>
<td>7.303</td>
<td>6.040</td>
<td>3.167</td>
<td>1.018</td>
<td>1.751</td>
<td>0.085</td>
<td>11.85</td>
<td>50.67</td>
<td>30.00</td>
<td>19.33</td>
</tr>
<tr>
<td>Acacia polycantha</td>
<td>7.413</td>
<td>6.720</td>
<td>3.500</td>
<td>0.819</td>
<td>1.409</td>
<td>0.063</td>
<td>12.75</td>
<td>50.00</td>
<td>34.67</td>
<td>15.33</td>
</tr>
<tr>
<td>Control</td>
<td>6.940</td>
<td>13.380</td>
<td>4.000</td>
<td>1.210</td>
<td>2.081</td>
<td>0.102</td>
<td>11.84</td>
<td>82.00</td>
<td>4.00</td>
<td>14.00</td>
</tr>
<tr>
<td>CV</td>
<td>3.96</td>
<td>71.99</td>
<td>7.64</td>
<td>24.50</td>
<td>24.50</td>
<td>15.84</td>
<td>9.11</td>
<td>23.73</td>
<td>43.94</td>
<td>28.62</td>
</tr>
<tr>
<td>Sig. (5%)</td>
<td>0.883</td>
<td>0.942</td>
<td>0.136</td>
<td>0.563</td>
<td>0.563</td>
<td>0.130</td>
<td>0.048</td>
<td>0.628</td>
<td>0.548</td>
<td>0.621</td>
</tr>
</tbody>
</table>

The effect of planted tree species on grass cover and undergrowth regenerations: the grass cover (%) and species type were not significantly different among the treatments (Table 4). However, there was a significant difference on species abundance.
Table 4. Mean values of undergrowth vegetation in the treatments

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Grass cover (%)</th>
<th>Species richness</th>
<th>Total number of regeneration</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acacia nilotica</em></td>
<td>81.9a</td>
<td>2a</td>
<td>6.67a</td>
</tr>
<tr>
<td><em>Acacia saligna</em></td>
<td>82.2a</td>
<td>3a</td>
<td>14b</td>
</tr>
<tr>
<td><em>Acacia polyacantha</em></td>
<td>80.2a</td>
<td>3.33a</td>
<td>16.3b</td>
</tr>
<tr>
<td>C.V</td>
<td>20.3</td>
<td>23.3</td>
<td>27.5</td>
</tr>
<tr>
<td>Sig. (5%)</td>
<td>ns</td>
<td>Ns</td>
<td>*</td>
</tr>
</tbody>
</table>

Socio-economic potential of exclosure and enrichment planting

Most of the interviewed FREG members (90%) have positive response about exclosures. The farmers mentioned that the value of the land increased after exclosures. From the interviewee, 80% of the respondents confirmed that they obtained economic benefits from exclosures. From their observation, the exclosure improved land productivity. The improvement of land productivity was expressed as benefits they obtained from the exclosure for example, grass for animal feed, honey production and construction material. They also obtained grass for thatching their hut. Most respondents (75%, n = 30) found grasses for thatching after exclosure is more attractive because they are able to cover the individual farmer’s demand. In the previous days, they incur cost to purchase grass from other areas at considerable expense. Hence, area exclosure has got an appreciation by the local farmers. At the same time, 46% of the respondents indicated that land restoration is effective and has to be promoted to other areas. The major benefit that influences the farmers to have positive opinion for area exclosure is the biomass i.e. the grass for feed and for thatching.

Discussion

The study showed that *Acacia polyacantha* had the highest performance in the survival rate, root collar diameter and height growth parameters in restoration of degraded lands. Planting of *Acacia polyacantha, Acacia saligna* and *Acacia nilotica* on degraded areas had highly significant effect on soil moisture contents but not on bulk density. Planted tree species had not significant effect on soil physico-chemical properties except C: N (ANOVA, CV=9.11, p=0.05). The study done by Lemma Tiki et al., 2015) at Hawassa district showed that sand, silt and clay fractions and soil bulk density had no significant difference with land uses while moisture content varied.
significantly. Mulugeta and Karl (2010) and Yihenew et al. (2009) also reported that soil under non-conserved treatment was found to exhibit higher soil bulk density than treatments. The effects of planted tree species on grass cover and undergrowth regenerations were not significantly different among the treatments. However, there was a significant difference on species abundance.

Conclusion and Recommendations

From the result, it is shown that area exclosure can improve annual household income and environment. At the same time, 46% of the respondents indicated improvement in land cover. The restoration is hastened due to enrichment. The biomass mainly grass production influences the farmers to have positive opinion on area exclosure. The survival rate of Acacia polyantha is higher than other species. From the study area, the soil moisture is affected by three Acacia species. Most of the farmers perceive that Acacia nilotica, Acacia saligna and Acacia polyanantha improve soil fertility. Therefore, closing the degraded lands with enrichment using tree species such as Acacia polyanantha is worthy to enhance restoration and regeneration process in areas like Tarma Ber district.

Reference


Demonstration of *Jatropha curcas* (Physic Nut) Plantation for its Biodiesel in Arid and Semi-Arid Area of north shewa district.

Reta Eshetu, Getabalew Teshome, Melese Bekele, Mesafint Minale, Abeje Tedela, Haile Sheferawand Abrham Tezera

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**Abstract**

The demonstration was conducted in Shewarobit experimental site to prove and disseminate *Jatropha curcas* for its biodiesel in the rural people. *J. curcas* is regarded as relatively underutilized and not commonly cultivated for its biodiesel. It can be propagated easily by seed and layering. It is a succulent plant and widely cultivated in arid regions. Four provenances, namely; Jewuha, Chiro, Mersa and Assosa were demonstrated in the experimental site of Shewarobit. The populations of seedling per plot were 36 and the space between plot and plant were 3m and 2m, respectively. Height, root collar diameter, survival and seed were collected. Jewuha and Chiro were better in survival. Jewuha and Mersa were better in height growth compared to other provenances. The farmer selected Jewuha and Mersa first and second, respectively based on their height, number of pods per tree, pod size and number of branch per tree.

**Key words:** *Jatropha curcas*, demonstration and provenance.
Background and Justification

More than half of the total land area in Amhara region is arid to semiarid. These areas are by definition isolated and fragile, with soils susceptible to erosion and subjected to environmental stresses. They are exposed to deforestation, prolonged drought and decreasing soil and ground water due to land degradation. The use of tree and shrub adapted to arid and semi-arid regions alleviates different human demands and environmental deteriorations (Ben salem and Palmberg 1985).

*Jatropha curcas* is regarded as a relatively underutilized and less cultivated in the Amhara region. It can be propagated easily by seed and layering. It is a succulent plant and is widely cultivated in arid regions. It can grow on degraded land and supply raw material for industry as a biodiesel. It is adaptable to low moisture and grows well under moisture deficit areas. It is low moisture demanding species, adapts under low fertile soil and tolerant to high temperatures (Diwaker et al., 1993; Tiwari et al., 1994).

Therefore, scaling up of *Jatropha curcas* plantation in the dry land parts of the Amhara region which can grow this species is required to utilize the huge potential. *J.curcas* is an oil crop used for biodiesel. Since it is an environmentally friendly, *Jatropha curcas* plantation can be established in arid and semi-arid regions of Amhara to utilize the degraded areas. The objective of this study was to demonstrate and disseminate *Jatropha curcas* for the rural people as an option for income generation in degraded areas of arid and semi-arid regions.

Material and methods

The study was conducted at Shewarobit experimental site. It is endowed with a mean annual rain fall of 750mm, mean annual temperature of 25°C, and altitude range of 1500-2500m a.s.l. According to the study by Dereje Hailu (2010), provenance of Assossa, Chiro, Jewuha and Mersa had high oil content and seed yield among 18 different *Jatropha* provenances. The planting materials were prepared from seeds and cuttings. Seedlings were grown under potting substrates (sand, manure, forest soil and local soil). Seedlings of *Jatropha curcas* were raised at the nearby nurseries of the study site. The experiment was demonstrated using four different provenances (Assossa, Chiro, Jewuha and Mersa). Distance between plant and plots were 2m and
3m, respectively. Each provenance had 36 seedlings per plot. In the field experiment seed yield, seeds per pod, insect and disease incidence, survival rate and plant height were measured for comparison. The experimental design was complete random design. The analysis was carried out using SPSS version 20. Descriptive statistics and analysis of variance was carried out to compare the treatments. Farmers' opinions during field demonstration were incorporated in the analysis.

Result and discussion
Survival rate and height of *Jatropha curcas* provenances at the age of 57 month after planting is indicated in figure 1 below. (MAP stands for month after planting).

![Graphs showing survival rate and height of J. curcas provenances](image)

(a)

(b)

Figure 1. The *J. curcas* (a) Survival rate (%) and (b) height (cm)
The survival rate of all provenance were more than 88%. From all species, Chiro and Jewuha showed better survival than others. At the age of 57 months, height of all provenance were more than 1.6m. From these Mersa provenance showed a height of 2.5 m in 57 months. Mean seed yield, number of branches per plant and seeds per pod were measured and shown below (Table 1).

Table 1. Mean number of branch/plant, number of seeds/pod, seed yield k.g/ha of the study population at Shewarobit site

<table>
<thead>
<tr>
<th>Provenances</th>
<th>Seed yield kg/ha/yr</th>
<th>No. branch/plant</th>
<th>No. seeds/pod</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jewuha</td>
<td>309.6</td>
<td>6.9</td>
<td>2.7</td>
</tr>
<tr>
<td>Mersa</td>
<td>1642.3</td>
<td>8.9</td>
<td>2.7</td>
</tr>
<tr>
<td>Assosa</td>
<td>283.9</td>
<td>6.2</td>
<td>2.6</td>
</tr>
<tr>
<td>Chiro</td>
<td>212.3</td>
<td>6.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

According to the collected data, *Jatropha carcus* provenances of Mersa provided the highest seed yield compared to other provenances. In addition, Mersa gave 9 branches per plant. Chiro provided the least seed yield.

**Farmer’s perception**

In total, 17 (Male= 13 and Female= 4) farmers were interviewed to give their opinion about the *Jatropha* provenances.

Table 2. Rank of provenance of *Jatropha carcus* by farmer selection.

<table>
<thead>
<tr>
<th>Provenances</th>
<th>No. of pod per tree</th>
<th>Pod size</th>
<th>height</th>
<th>No. of branch</th>
<th>Total</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jewuha</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>Mersa</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Assosa</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Chiro</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>

Note. 4=Excellent, 3= Very good, 2= good, 1=poor. These remark is not include in the rank.

Farmers selected the provenance of Jewuha and Mersa as first and second choice, respectively. The criteria for selection were number of pods per tree, pod size, height and number of branches.
**J. curcas** which is a drought tolerant and is used for fencing can grow in low fertile soil. However, it has drawbacks, i.e. it is poisonous and has no market at the current condition.

**Conclusion and recommendation**

*Jatropha curcas* is adaptable to moisture deficit, high temperature and low fertile soils in areas like Shewarobit. It gave good seed and oil yield for biodiesel. Mersa provenance provided higher seed yield (1642.32 kg ha⁻¹). Farmers also selected Jewuha and Mersa as best performing provenances. This coincides with the biological data. Hence, Mersa is recommended for Shewarobit and similar agroecologies. *Mersa* should be maintained as a future seed sources to use for biodiesel purpose.

**References**


Evaluation of Survival, Growth Performance, Feed Value and Biomass Production of Multipurpose Tree and Shrub Species in North Shewa

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Abstract

In the Ethiopian highlands there are limited multipurpose tree species due to human disturbance and land degradation. This in turn requires introducing adaptable multipurpose tree species that are used for feed, fuelwood, soil improvement and rehabilitation. There have been some efforts to introduce multipurpose tree species for the highland areas. However, only few species are adaptable to these harsh environments and less adopted by the local farmers. The aim of this study was to select the best multipurpose tree species for the highland areas to improve land productivity. In total, eight multipurpose tree species were introduced and evaluated for their uses. The study showed that Leuceana diversifolia showed the highest height growth. Albizia chinensis, Genista monsposulana, Femenia macrophyla and Desmanthus virgatus showed better growth and height performance. Medicag oarboria, Caliandra houstunian and Robinia pseudoacacia not performing well in height growth. The crude protein content of Albizia chinensis, Desmanthus virgatus, Caliandra houstunian and Leuceana diversifolia ranges between 18.02 to 19.69%. The presence of this crude protein value is the most suitable feed quality for dairy cows. The highest leaf biomass production was obtained from L. diversifolia (3644 kg/ha). The laboratory analysis showed that L. diversifolia trees increased soil pH and organic carbon under soil depth of 0-15cm. Desmanthus virgatus has highest Phosphorus uptake at depth of 15-30 cm.

Key words: Multipurpose; Species; Biomass; Survival; Trees; Highlands; Soils
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Introduction

Nowadays, the highland areas of Ethiopia are facing shortage of wood, feed, and other tree biomass due to increased human and livestock population. Highlands are endowed with little or no tree cover in agricultural fields (Kindu et al., 2006). Highlands in North Shewa are following mixed farming systems. Soil erosion, land degradation, and deforestation are the major causes for the deterioration of trees per farm in rural communities. The conversion of forest land for agriculture put high pressure in the highlands (Bishaw and Abdelkadir, 2003; Bewket, 2003; Tesfaye et al., 2015). This resulted in soil degradation in the highlands of Ethiopia contributing to aggravated food insecurity (Amede et al., 2001). Farmers in the highlands grow trees for different purposes including for forage. Different progresses have been made around the world to describe and evaluate multipurpose tree species for different climatic conditions and purposes (Solanki et al., 2008). Smallholder farmers in tropics use legume as a feed for animals (Gutteridge and Shelton, 1993).

In Ethiopia, there are limited exotic species used as feed for livestock. Considering this fact, exotic multipurpose trees have been introduced in Ethiopia as fodder trees by different organizations. However, the adoption by smallholder farmers has been poor (Mekoya et al., 2008). In addition, the feed value, propagation techniques, and growth potential of the fodder is not well known in the case of Ethiopian highlands (Mekoya et al., 2008). The growth rates of multipurpose trees and shrubs species in the semi-arid regions of southern Ethiopia is promising and sustainable productivity can be achieved if proper agroforestry techniques are implemented (Abebe, 1994).

Multipurpose trees/shrubs are valuable sources of feed during drought periods (D’Mello, 1992). However, some are not useful as a feed due to phenolic compounds. Tropical forage plants have high levels of these compounds and this limit protein presence (Lowry et al., 1995). Perennial MPTs such as *Acacia* spp, *Albizia* spp, and *Leucaena* species possess diverse morphological and agronomic attributes (Hassen et al., 2006). There are also limited indigenous forage species in the highlands. Hence, it is required to diversify the forage species by introducing from other regions. Although some work has been done to identify some multipurpose trees species in Ethiopia, little is known about their variation in terms of survival, forage production, potential...
The nutritive value and soil improvement abilities in different climatic regions.

The objective of the study was to evaluate the survival, biomass yield, nutritional value and soil improving potential of different promising multipurpose tree species for different farming systems.

**Material and methods**

**Study site**

The study was done at Armania kebele in Tarma Ber district, northern Shewa Zone of Amhara Regional State (Fig. 1). Elevation of the study area is on average 1981 m a.s.l., annual rainfall ranges from 1500 - 2000 mm, annual temperature ranges 11-25 °C. The study area is found 9°52'59.89" N and 39°49'38" E.

![Map of the study site at Tarma Ber district in North Shewa Zone, Amhara region, Ethiopia](image)

**Figure 1** Map of the study site at Tarma Ber district in North Shewa Zone, Amhara region, Ethiopia
Experimental design

Eight multipurpose tree and shrub species were planted in Random Complete Block Design (RCBD) with three replications. Seeds for this study were obtained from International Livestock Research Institute (ILRI).

Tree species

*Albizia chinensis*, *Desmanthus virgatus*, *Caliandra houstumian*, *Genista monspoullana*, *Femingia macrophylla*, *Robinia pseudoacacia*, *Leteana diversifolia* and *Medicago arborea* were included in this study.

Spacing

The spacing between trees was 1m. The spacing between blocks and plots were 3 meters and 2 meters, respectively.

Data collection

Tree height, root collar diameter, survival rate, leaf biomass and nutrient content were the parameters to evaluate the multipurpose species. Soil data such as soil pH, organic content, total nitrogen, AP, soil texture (sand, silt, clay) content, soil bulk density were also taken and analyzed.

Data analysis

Descriptive and other statistical analysis were carried out using SPSS Version 20. Analysis of variance was conducted to see the difference among treatments. Tukey's Honest Significance Difference test was used for multiple comparisons when significant differences were found between treatments. Analysis was done also for mean calculation. All statistical analyses were carried out using general linear model - univariate.

Results

Survival rates

Seedlings survival rate among the treatments were significantly different (F=15.002, p=0.001) (Fig.2). The survival % of *L. diversifolia* and *D. virgatus* were found better (Fig.1). However, *M.*
arboria and R. pseudoacacia had the least survival rate. There was significant difference (p<0.05) in survival rate of the forage species at the age of 57 months after planting (MAP).

Figure 2. Mean and standard error of survival rates of multipurpose trees

Growth performance

Leueana diversifolia has shown the highest height than the eight species studied in this experiment (Fig. 3). Albizia chinensis, Genista monsprossulana, Femingia macrophylla and Desmanthus virgatus have shown also better height (Fig. 2). Medicago arboria, Caliandra houstunian and Robinia pseudoacacia had poor height growth performance (Fig. 2)

Figure 3 Height of eight multipurpose trees from three months to thirty nine months after planting (MAP)
Feed value and biomass yield

Ash, acid detergent fiber (ADF) and acid detergent lignin (ADL) significantly varied among leaves of the multipurpose tree species (MPTS) at (P<0.01). *A. chinesis* and *F. mayacrypyla* contained the highest ADF (Table 1). These species had also the highest ADL content (Table 1). On the other hand, *L. diversifolia, C. houstunia* and *D. vigratus* had lowest ADL content. *A. chinesis, D. vigratus, C. houstunia*, and *L. Diversifolia* had high crude protein (CP) content and *F. macrophylla* had low protein content (Table 1). The highest leaf biomass production was obtained from *L. diversifolia* (3644 kg/ha), whereas *C. houstunia* gave the least leaf biomass.

Soil characteristics

**Soil depth (0 - 15cm)**

There is a significant change (P < 0.05) in soil pH and organic carbon in 0-15 cm soil depth. Organic carbon higher under the canopy of *L. diversifolia* trees showed significant (P < 0.05). However, phosphorus, total nitrogen, clay, and sand were not significantly changed (P > 0.05) (Table 2).

**Soil depth (15.1 - 30cm):**

Significant changes (P < 0.05) in soil phosphorus, organic carbon, and organic matter were observed, while other soil properties were not significantly changed (P > 0.05) (Table 2).

Table 1. Mean leaf biomass production potentials and nutrient content of different multipurpose tree species (MPTS). Dry matter (DM), crude protein (CP), nitrogen (N), acid detergent fiber (ADF), acid detergent lignin (ADL), leaf dry biomass (LDBM), total dry biomass (TDBM).

<table>
<thead>
<tr>
<th>Species</th>
<th>DM</th>
<th>Ash</th>
<th>CP</th>
<th>N</th>
<th>ADF</th>
<th>ADL</th>
<th>LDBM</th>
<th>TDBM</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>A. chinesis</em></td>
<td>89a</td>
<td>12.23</td>
<td>19.69</td>
<td>3.14</td>
<td>39.9</td>
<td>20.22</td>
<td>1371</td>
<td>9395</td>
</tr>
<tr>
<td><em>D. vigratus</em></td>
<td>89.33</td>
<td>9.96c</td>
<td>19.08</td>
<td>0.05</td>
<td>28.88</td>
<td>14.66</td>
<td>2383</td>
<td>16642</td>
</tr>
<tr>
<td><em>C. houstunia</em></td>
<td>89a</td>
<td>12.59</td>
<td>18.13</td>
<td>2.89</td>
<td>28.88</td>
<td>13.33</td>
<td>195</td>
<td>448</td>
</tr>
<tr>
<td><em>F. macrophylla</em></td>
<td>89.66</td>
<td>11.85</td>
<td>15.33</td>
<td>2.45</td>
<td>40.73</td>
<td>19.9</td>
<td>1303</td>
<td>4261</td>
</tr>
<tr>
<td><em>L. Diversifolia</em></td>
<td>89.33</td>
<td>14.07</td>
<td>18.02</td>
<td>2.86</td>
<td>25.18</td>
<td>13.33</td>
<td>3644</td>
<td>19156</td>
</tr>
<tr>
<td>Mean</td>
<td>89.26</td>
<td>12.13</td>
<td>18.05</td>
<td>2.88</td>
<td>32.73</td>
<td>16.3</td>
<td>1779</td>
<td>10040</td>
</tr>
<tr>
<td>CV</td>
<td>0.4</td>
<td>7.23</td>
<td>12.23</td>
<td>12.47</td>
<td>10.07</td>
<td>10.25</td>
<td>76.31</td>
<td>100.7</td>
</tr>
<tr>
<td>Significance (5%)</td>
<td>ns</td>
<td>***</td>
<td>ns</td>
<td>***</td>
<td>ns</td>
<td>***</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>
Table 2. Mean values of soil pH, phosphorus (P), organic carbon (OC), organic matter (OM), total nitrogen (TN), carbon: nitrogen (CN), sand, clay, and silt as influenced by MPTs at Armania (soil depth, 0 – 15cm).

<table>
<thead>
<tr>
<th>Species</th>
<th>pH</th>
<th>P</th>
<th>OC</th>
<th>OM</th>
<th>TN</th>
<th>CN</th>
<th>SAND</th>
<th>CLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. chinensis</td>
<td>7.32a</td>
<td>5.14a</td>
<td>1.26b</td>
<td>2.17ab</td>
<td>0.13a</td>
<td>9.67b</td>
<td>26.67a</td>
<td>48.67a</td>
</tr>
<tr>
<td>F. macrophylla</td>
<td>7.08a</td>
<td>2.28b</td>
<td>1.06b</td>
<td>1.82a</td>
<td>0.11a</td>
<td>9.59b</td>
<td>37a</td>
<td>43a</td>
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<tr>
<td>D. vigratus</td>
<td>7.23a</td>
<td>4.44a</td>
<td>1.24bc</td>
<td>2.13ab</td>
<td>0.14a</td>
<td>8.35b</td>
<td>30a</td>
<td>44.67a</td>
</tr>
<tr>
<td>C. houstunia</td>
<td>7.25a</td>
<td>3.09ab</td>
<td>1.34b</td>
<td>2.3a</td>
<td>0.13a</td>
<td>10.55b</td>
<td>22.67a</td>
<td>51.67a</td>
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<tr>
<td>L. diversifolia</td>
<td>7.3a</td>
<td>3.9ab</td>
<td>1.8a</td>
<td>2.4ab</td>
<td>0.15a</td>
<td>9.4b</td>
<td>23.33a</td>
<td>50.67a</td>
</tr>
<tr>
<td>Control</td>
<td>6.81b</td>
<td>4.02ab</td>
<td>1.39abc</td>
<td>1.84ab</td>
<td>0.12a</td>
<td>14.83b</td>
<td>38ab</td>
<td>38b</td>
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<tr>
<td>Mean</td>
<td>7.170</td>
<td>3.81</td>
<td>1.34</td>
<td>2.11</td>
<td>0.13</td>
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<td>29.61</td>
<td>41.11</td>
</tr>
<tr>
<td>C.V</td>
<td>2.090</td>
<td>30.97</td>
<td>15.19</td>
<td>18.63</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Significance (5%)</td>
<td>*</td>
<td>ns</td>
<td>*</td>
<td>ns</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

Table 3. Mean values of soil pH, phosphorus (P), organic carbon (OC), organic matter (OM), total nitrogen (TN), carbon: nitrogen (CN), sand, and clay as influenced by multipurpose tree species (MPTs) at Armania (soil depth, 15.1-30cm).

<table>
<thead>
<tr>
<th>Species</th>
<th>pH</th>
<th>P</th>
<th>OC</th>
<th>OM</th>
<th>TN</th>
<th>CN</th>
<th>SAND</th>
<th>CLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. chinensis</td>
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<td>3.1abc</td>
<td>1.19b</td>
<td>2.04a</td>
<td>0.13a</td>
<td>10.29a</td>
<td>25.3b</td>
<td>48.67a</td>
</tr>
<tr>
<td>F. macrophylla</td>
<td>7.32a</td>
<td>1.71bc</td>
<td>0.77b</td>
<td>1.33a</td>
<td>0.09a</td>
<td>9.42a</td>
<td>47a</td>
<td>37a</td>
</tr>
<tr>
<td>D. vigratus</td>
<td>7.00ab</td>
<td>3.36a</td>
<td>1.01b</td>
<td>1.75a</td>
<td>0.10a</td>
<td>9.2a</td>
<td>36.67ab</td>
<td>40.67a</td>
</tr>
<tr>
<td>C. houstunia</td>
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<td>1.01b</td>
<td>1.74a</td>
<td>0.12a</td>
<td>10.01a</td>
<td>27ab</td>
<td>48a</td>
</tr>
<tr>
<td>L. diversifolia</td>
<td>7.15ab</td>
<td>2.72abc</td>
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<td>0.12a</td>
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<td>0.13a</td>
<td>14.39b</td>
<td>36ab</td>
<td>34a</td>
</tr>
<tr>
<td>Mean</td>
<td>7.18</td>
<td>2.54</td>
<td>1.18</td>
<td>1.71</td>
<td>0.11</td>
<td>10.49</td>
<td>32.67</td>
<td>43.50</td>
</tr>
<tr>
<td>CV</td>
<td>2.12</td>
<td>29.84</td>
<td>24.18</td>
<td>42.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Significance (5%)</td>
<td>ns</td>
<td>*</td>
<td>**</td>
<td>*</td>
<td></td>
<td></td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>
Discussions

*Leucaena diversifolia* had better survival rates compared to other test tree species (Bray, 1994). *L. Diversifolia* was identified to be cold tolerant and poorly surviving under dry areas and conditions. *L. diversifolia* and *D. virgatus* had higher survival in the degraded land. *A. chinensis* and *L. diversifolia* had good ability to tolerate dry environment (Shelton, 2004). The adaptive characteristics of these species is because of their deep root systems (Stewart and Salazar, 1992), whereas, *M. arboria* and *R. pseudoacacia* showed low survival in the marginal areas. All the planted multipurpose tree species had high crude protein (CP) concentration (>18%) this in turn is an indicator for good nutritive value. This can be used as protein supplements for low quality tropical pastures and crop by-products (Norton, 1994). Crude protein content of these tree species is higher than wheat bran (Van Soest, 1994). On average these species have 17.1 percent crude protein, which is a recommended value for lactating animals feeding (National research council, 2001). The recommended crude protein is 16.1 percent. For the proper functioning of the rumen microorganisms, a minimum CP content of 7% is required in the diet (survival diet). The degradable part of the CP can be utilized up to a maximum level of 13% CP (Naseri, 2005). Therefore, they could be used as possible protein supplements to increase utilization of crop residues for ruminant animal feeding and this increases animal production and productivity.

In Kenya supplementation with *Mimosa scabrella* enabled local goats to gain 50 gm daily compared with 31 gm gain by feeding grass alone (Roothaert et al., 1997). Kennedy et al. (2002) showed that feeding 15% *A. lebbeck* (siris) supplement increased intake of dry native grass (*Dichanthium aristatum*) hay by 52% and digestibility of the diet by 67%. Hindrichen et al., (2002) indicated that nitrogen in *L. diversifolia* reach up to 32.7 gm per dry matter per kilogram. However, *L. diversifolia* has low value as a supplement to maize stover because of poor protein digestibility (Hindrichsen et al., 2002).

Goats fed on *L. diversifolia* gained 37.8 gm per day which is good for fast weight gain (Nherera et al., 1998). *L. diversifolia* had high condensed tannin contents (Dalzell et al., 1998). The leguminous shrub *Desmanthus virgatus* has been proposed as an alternative fodder tree, the leaves of which could be used as animal feed. As Evans et al., (1992) and Battad (1993)
mentioned *Desmanthus virgatus* is a legume woody species recommended as feed source for browsers. The protein content of *Desmanthus* leaves reached up to 30 percent and provides 23 to 35 tonnes of dry matter per hectare. *Desmanthus* foliage could be given to monogastric animals and it has a dangerous effect on their health (Gutteridge, 1994). This factor enables *Desmanthus* leaves to be used as a supplement to pig diets. The mean ADF content of these multipurpose tree species was 32.73 percent in our study. This is higher than minimum dietary requirements of ADF which is 17 percent for dairy cows (National research council, 2001).

However, *L. diversifolia* had 25.18 percent ADF and agreeable with the recommended concentration of total dietary NDF for cows fed diets with alfalfa or corn silage 25 (National research council, 2001). The result revealed that *L. diversifolia, Choustonia and D. virgatus* had lowest ADL content. The low ADL means an indicative of its high palatability. *L. diversifolia* contained a balanced intake of protein, mineral and with low fiber content and moderate tannin. These traits make it good supplement for animal feeding (Nherera et al., 1998).

*Leucaena diversifolia* trees increased soil pH and organic carbon significantly under soil depth (0-15cm). This is agreeable with Wong et al., (2000) *Leucaena diversifolia* resulted in increased soil pH in tropical soils. Multipurpose trees significantly changed soil phosphorus, organic carbon and matter. *Desmanthus virgatus* has highest phosphorus uptake at 15-30 depth of soil. Comia (1999) showed *Desmanthus* prunings have highest phosphorus per dry matter than other plants. This species also showed a promising result for clay soils (Vertisols) in subcoastal, north-eastern Queensland (Clem and Hall, 1994).

Different species varied greatly to ameliorate these soils depending on quantity and quality of organic matter lying on the floor. *L. leucocephala* species produces higher biomass per unit area. It has greater efficiency to ameliorate fertility status of these soils. It helps to ameliorate the soil and recover degraded soil (Goel and Behl, 2002). This species could not perform well on alkaline soil (pH 8.6 - 10.5).
Conclusion and recommendation

*L. diversifolia, D. virgatus and C. houstunia* had the highest survival rates in the marginal lands. Relatively higher leaf biomass yield and the moderate ADL and ADF content in *L. diversifolia, C. houstunia, D. virgatus and A. chinensis* make the species valuable for livestock feed supplement in the dry seasons. These multipurpose trees species can contribute to improve the soil fertility and support rehabilitation of degraded areas. These multipurpose species can be planted as an agroforestry species. Awareness creation and seedling or seed provision and promotion need to be conducted for further expansion in the farmlands.

References


Assessment of *Rhamnus prinoides* provenance and its constraints in North Shewa zone
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Debre Birhan Agricultural Research Center, P.O. Box 112, Debre Birhan, Ethiopia

Abstract

The study was conducted in Ankober, Asagirt, Tarimaber, Ensaro and Efratana Gidim woredas to assess the growing potential of *Rhamnus prinoides*. It was conducted to assess the production and distribution constraints of *R. prinoides* in north shewa zone. The potential woredas in North shewa that have been growing *R. prinoides* were Asagret (100%) and Efratana Gidim (50%). According to the opinions of the farmers, there are no different cultivars of *R. prinoides* (100%), but this has to be ascertained by further research and also checked by taking biological data. The major constraints for *R. prinoides* production were market problem, insect, lack of chemical, labor intensiveness and short storage life.

**Key words:** *R. prinoides*, Constraints and Woredas.
Introduction

*R. prinoides* L’Herit, Amharic name: Gesho is in the family of Rhamnaceae. It is a plant which grows up to 6 meters. It is known to occur outside Ethiopia in Cameroon, the Sudan, throughout East Africa, South Africa, Angola and also in Arabia. It is cultivated in Ethiopia and domestically brewed for beverages such as “Tella” and “Teji”. This species is an important shrub cultivated in most parts of the region and the country. Tigray, Kara Kori, and Sebeta are important centers of production of Gesho. For example, in Kara Koriethe Gesho is chopped and sold along the highway passing through the town (Berhanu M. 1995).

The powder from the leaves and stems of *R. prinoides* are used as a starter. The powder is mixed with water together with malted grain of barley, wheat, maize and sorghum or finger millet (Bikil) to finally obtain the local beer. *R. prinoides* is used for fire wood and has a medicinal value (Azene 1993).

*R. prinoides* is cultivated in Ankober, Tegulet, Debresina, Asagirt and low land part of north Shewa, Wollo (Wolidiya), east and west Gojam (indigenous knowledge). It is used both as cash crop and for home consumption. However, the production constraints and its silvicultural management practices are not well known. Hence, the objectives of this study are to assess the growing potential areas of *R. prinoides* in north shewa zone, the existence of provenances and its production constraints.

Material and methods

Table 1. Description of the Study area

<table>
<thead>
<tr>
<th>Study area</th>
<th>Altitude (m)</th>
<th>Rainfall (mm)</th>
<th>Temperature (°C)</th>
<th>Soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankober</td>
<td>1300-3700</td>
<td>1200</td>
<td></td>
<td>Clay loam</td>
</tr>
<tr>
<td>Asagirt</td>
<td>600-2750</td>
<td>521</td>
<td>13</td>
<td>Light soil</td>
</tr>
<tr>
<td>Tarimaber</td>
<td>1450-3186</td>
<td>1250</td>
<td>20</td>
<td>Brown and gray</td>
</tr>
<tr>
<td>Efratana Gidm</td>
<td>1250-3600</td>
<td>1018</td>
<td>21.6</td>
<td>Black and red</td>
</tr>
<tr>
<td>Ensaro</td>
<td>2600</td>
<td>929</td>
<td>15.2</td>
<td></td>
</tr>
</tbody>
</table>

149
Assessment was done in Ankober, Asagir, Tarimaber, Ensaro and Efratana Gidm districts using Participatory Rapid Appraisal and transect walk was conducted in the three experimental sites. Then, three potential kebeles (from 4 districts) and two Kebeles (from Efratana Gidm district) were selected for interview. Focus group and individual discussions were also part of the assessment.

Data analysis
Qualitative and quantitative (descriptive statistics) studies were carried out using SPSS version 16.0.

Result and discussion
From the group and individual discussions results were obtained.

Productivity of the *R. prinoides*
The potential areas that have long experience to grow *R. prinoides* were Asagret (100%) and Efratana Gidm districs (50%) based on farmers response. The niches to grow this shrub are homestead, soil and water conservation areas and crop land. *R. prinoides* gives high yield in December and January (28.6% respondents) and low yield in July and August (28.6% respondents).
Table 1. Trees and crops that grown in different niches using ranking

<table>
<thead>
<tr>
<th>Major area crop and tree grown</th>
<th>1&lt;sup&gt;st&lt;/sup&gt;</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt;</th>
<th>3&lt;sup&gt;rd&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major crop under irrigation</td>
<td>Onion</td>
<td>Tomato</td>
<td>coffee</td>
</tr>
<tr>
<td>Tree grown in homestead</td>
<td>R.prinoides</td>
<td>Croton macrostachyus</td>
<td>Cordia africana</td>
</tr>
<tr>
<td>Tree grown in crop land</td>
<td>R.prinoides</td>
<td>Croton macrostachyus</td>
<td>Coffee, juniper and Acacia spp</td>
</tr>
<tr>
<td>Tree grown in wetland</td>
<td>Sugarcane</td>
<td>Vegetable, R.prinoides, sugarcane, banana and mekacoba</td>
<td>Eucalyptus, Banana, Enset</td>
</tr>
<tr>
<td>Tree grown as biological conservation in farm land</td>
<td>R.prinoides</td>
<td>Croton macrostachyus</td>
<td>Fodder tree, Cordia and Cuppers</td>
</tr>
</tbody>
</table>

Figure 1. (a) Method of propagation

Figure 1. (b) Source of seedling

Figure 1. (c) Productive trend of R.prinoides before 5 yrs

Figure 1. (d) R.prinoides tree planting trend
Farmers emphasized that they are dependant on crop and animal production for their livelihoods. But as shown in the tree or crop order rank (table 2), *Rhamnus prinoides* helps to alleviate poverty and it can grow around the homestead, on the crop land and on conservation areas. So, it is used either for household and/or market consumption. In North Shewa, there are different methods of propagation of *R. prinoides* like by seedling, layering and rooting as shown in figure 1(a). The study reveals that 78.4% of the respondents propagate *R. prinoides* by seedling, whereas 21.6% of the respondents propagate gesho by layering. The source of seedlings in the study areas as shown in figure 1(b) was from self-production/ production by their own effort (7.1%) and own and market seedling (92.9%). As shown in figure1(c), about 28.6% of the respondent farmers have confirmed that the productivity trend of *R. prinoides* has increased since the past 5 years while 71.4% of the respondents, on the contrary, have said that the production of gesho has decreased. Likewise, as indicated in figure 1(d), 28.6% the respondent farmers affirmed that the trend of planting of *R. prinoides* has decreased as compared to the previous years, but 71.4% of the respondents, on the other hand, have asserted that the trend of planting of the tree has increased since the past 5 years.

**Provenance of Rhamnus prinoides**

Assessment of *Rhamnus prinoides in terms of* test, color, provenance, productivity and tree biomass was conducted, and thus as shown in table 2, table 3 and table 4 below; there were market preference and price difference with respect to taste, color, tree biomass and productivity but not cultivar or provenance difference. Furthermore, the consumption and market price of *Rhamnus prinoides* has increased from time to time.
Table 2. *R. prinoides* provenance/cultivar difference study or survey table

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
<th>Total</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Different type of cultivar grown</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>14</td>
<td></td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Percent</td>
<td>100</td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Difference in color</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>10</td>
<td>4</td>
<td>14</td>
<td>The black is productive than others</td>
</tr>
<tr>
<td>Percent</td>
<td>71.4</td>
<td>28.6</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Difference in productivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>9</td>
<td>5</td>
<td>14</td>
<td>The black have most biomass, height and diameter</td>
</tr>
<tr>
<td>Percent</td>
<td>64.3</td>
<td>35.7</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Plant difference in height, biomass and diameter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>10</td>
<td>4</td>
<td>14</td>
<td>The red have highest test (57.1%)</td>
</tr>
<tr>
<td>Percent</td>
<td>71.4</td>
<td>28.6</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Test difference</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>10</td>
<td>4</td>
<td>14</td>
<td>The red have highest test (57.1%)</td>
</tr>
<tr>
<td>Percent</td>
<td>71.4</td>
<td>28.6</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Market difference on *R. prinoides* preference

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
<th>Total</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference market preference</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>10</td>
<td>4</td>
<td>14</td>
<td>The red have highest market value (57.1%)</td>
</tr>
<tr>
<td>Percent</td>
<td>71.4</td>
<td>28.6</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Market trends within 5 years and market price of *R. prinoides* (Birr per Quintal)

<table>
<thead>
<tr>
<th>Market price trend before 5 years</th>
<th>Frequency</th>
<th>percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase</td>
<td>11</td>
<td>78.57</td>
</tr>
<tr>
<td>Decrease</td>
<td>3</td>
<td>21.43</td>
</tr>
<tr>
<td>total</td>
<td>14</td>
<td>100</td>
</tr>
</tbody>
</table>

The opportunities and challenges for the growth and management of *R. prinoides* were investigated using the questionnaire (Table 5).
Table 5. Opportunities and challenges of *Rhamnus prinoides*

<table>
<thead>
<tr>
<th></th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opportunity to grow this tree</td>
<td>Use for HH consumption and resistance to climate change than crop.</td>
<td>source of income</td>
<td>high market demand</td>
</tr>
<tr>
<td>Production challenge to grow this tree</td>
<td>insect</td>
<td>labor intensiveness</td>
<td>not stored for long period</td>
</tr>
<tr>
<td>Market challenge to grow this tree</td>
<td>market fluctuation</td>
<td>low bargaining power (due to middiet or, monopolized)</td>
<td>no standard measurement</td>
</tr>
<tr>
<td>Communities want to have access</td>
<td>seedling supply and market connection</td>
<td>remove brokers and have strong bargaining power and insecticide chemical</td>
<td></td>
</tr>
<tr>
<td>Escaping strategies to solve the problems</td>
<td>finding chemical by themselves</td>
<td>management to protect drying</td>
<td>take chemical from agriculture offices and spray</td>
</tr>
<tr>
<td>Advantages of R.P production</td>
<td>preparation of valle and teje for income generation</td>
<td>-</td>
<td>planting on unsuitable for crop production</td>
</tr>
<tr>
<td>Disadvantages of R.P production</td>
<td>it requires high management</td>
<td>none</td>
<td>easily attacked by disease</td>
</tr>
</tbody>
</table>

In general, *R. prinoides* production in North shewa as shown in table 7, figures 3 and figure 4 had its own opportunity, advantage and challenges of production like chemical consumption, high management, labor intensiveness and low bargaining power. The species is used for household consumption and source of income. It is an important component for preparation of "Tella" and "Tef" and income generate.
Household characteristics
In total, 23 farmers were interviewed. The average age of the interviewees was 45 years. The average farm size is 1.03ha and the average number of household members is 5. Family labor is primarily allocated for crop production (73.9%) and tree planting (26.1%). The interviewees are engaged in crop, livestock and tree production.

Land allocation
The majority of the farmers allocated their land for crop production. Insignificant amount of land is allocated for *R.prinoides* production. The annual income generated from *R.prinoides* compared to other practices is indicated in Fig 2 below. It is integrated with other farming practices.

![Average annual income generated in birr from different agricultural produces](image)

Figure 2. Average annual income generated in birr from different product

The farmer sold *R. prinoides* for 2217 Birr in one harvest. They obtain on average 3628 Birr per year. On average the leaf production from *R.prinoides* started at the age of 1.4 years. The production is 1.3 times in a year. Disease, insect and scarcity of water are the major constraints for the production of *R.prinoides* leaves.
Proceedings of the 9th Annual Regional Conference on Completed Research Activities of Forestry

Figure 3. Major obstacles for *R. prinoides* production

**Conclusion and Recommendation**

*Rhamnus prinoides* showed difference in height, diameter, biomass and leaf quality for locally brewed drinks. There are no different species of *R. prinoides*, but there is a difference in provenance. We investigated that there are differences in leaf colour, production, taste and market value. The difference in soil type resulted in the difference in the quality of leaf. The niches to grow *Rhamnus prinoides* are homestead and soil and water conservation (SWC) structures. The land allocated for *R. prinoides* decreased over time. This resulted in an increase in the market price of leaves and seedlings. This crop is subsidizing the smallholding farmers to improve the household income. This species has to be promoted with its full management package to improve the production and benefit the farmers.
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The Interaction between Fertilization and Arbuscular Mycorrhizal Inoculation on Growth of *Eragrostis tef* in Amhara Region, Ethiopia

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Abstract

*Tef* (*Eragrostis tef* (Zucc.) Trotter) is a staple food for Ethiopians and Eritreans. It grows under a wide range of agro-ecological conditions. The growth and the associations of arbuscular mycorrhizal fungi (AMF) and dark septate endophyte (DSE) with *Eragrostis tef* and the effect of fertilization is not well known. A pot experiment was set up to test the effect of fertilization and arbuscular mycorrhizal inoculation with forest soil on the occurrence of AMF and DSE on the roots of *Eragrostis tef*. AMF spores occurrence in the soil and *Eragrostis tef* plant growth. The top soils of agricultural fields and natural forest were collected from Tara Gedam, Gelawdiwos and Injibara in Amhara region, Ethiopia. Quncho teff was used as an experimental variety. The shoot biomass and nutrient uptake were analysed. *Eragrostis tef* fine roots were stained by using 5% ink- acetic acid solution and counted with a 200x, 400x and 1000x magnifications. AMF spores were extracted from the soil and counted with 230x magnifications. The results showed that, *Eragrostis tef* shoot biomass, straw weight and grain yield increased by the use of full recommended urea and di-ammonium phosphate fertilizers. However, forest inoculum has no effect. This may be due to nitrogen limitation. AMF and DSE colonization was higher with the use of forest inoculum. However, there was lower colonization of AMF when full recommended fertilizers are used; nevertheless, DSE colonization has no change by the use of fertilizers. The use of forest inoculum increased the spore density, but the use of fertilizers reduced the spore density. Additionally, the mycorrhizal host plant, *Eragrostis tef* increased the spore density due to sporulation.

**Key words**: AMF, DSE, *Eragrostis tef*, Forest inoculum and N-P fertilizer

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2 Author for corrrespondance: Email: ggezahagn@gmail.com
Introduction

Teff is a tropical and sub-tropical crop which belongs to the family Poaceae, subfamily Eragrostoidae and genus Eragrostis (Ketema, 1997). It is primarily grown and a major crop and food sources for Ethiopia and Eritrea but also grown in USA, Brazil, Canada, South Africa and Australia (Ketema, 1997; Gebremariam et al., 2014; Stoyanov, 2014; Asefa et al., 2014; Baye, 2014; Haileselassie et al., 2011; van Delden et al., 2012; Araya et al., 2010; Yimer and Kebede, 2015). Teff grows under a wider range of agro ecologies such as Kolla (tropical zone, < 1830 meters above sea level), Woinadega (subtropical zone, 1830 - 2440 meters above sea level) and Dega (cool zone, > 2440 meters above sea level) and in different site conditions (Laekemariam et al., 2012; Creech et al., 2012).

Ethiopian agriculture depends on rainfall. It is susceptible to climate change and thereby affects the livelihoods (Evangelista et al., 2013). Mycorrhizal fungi have direct importance like nutrient gaining and drought resistance of crops (Olawuyi et al., 2014) and indirect effects on weed control, soil carbon storage and etc (van der Heijden et al., 2008; Rinaudo et al., 2010). Specifically, arbuscular mycorrhizal fungi (AMF) are more important for plants in mobilizing phosphorus under a limited condition and enhancing above ground biomass in the tropics (Jeffries et al., 2003; van Delden et al., 2012; Aggarwal et al., 2011; Sharif et al., 2012; Fahramand et al., 2014; Godbold and Sharrock, 2003).

Most farmers in Ethiopia use fertilizer, but not the required recommended rate (Asefa et al., 2014). Land productivity has diminished through time due to erosion (Oicha et al., 2010). Soil is a limited resource and its health is critical for any sustainable development (Jeffries et al., 2003) and its quality depends not only by physical and chemical properties, but also on the diversity and activity of biota (Doran and Linn, 1994 cited in Jeffries et al., 2003). Soil aggregation is an important indicator of soil quality and is known to have increased in the present of AMF hyphae (Leifheit, 2014; Aggarwal, 2011). AMF hyphae produces a glomalin which increases soil aggregation, stabilize the soil and thereby reduce soil erosion (Boric et al., 2008; Leifbeit, 2014; Singh, 2012; Jansa et al., 2006; Mardhiah et al, 2016).
Dark septate endophytes (DSE) are capable of forming mutualistic associations similar to that of arbuscular mycorrhizas (Jumpponen, 2001). They function mainly in root fragments where arbuscules are absent (Gucwa-Przepiora et al., 2016). DSE are beneficial for plant growth and survival (Fernando and Currah, 1996) and often frequent colonists of plants under extreme conditions such as drought (Barrow, 2003). Crop productivity can be improved by introducing bio-fertilizers like inoculating arbuscular mycorrhizal fungi and dark septate endophytes.

In Ethiopia, specifically in Amhara region, nutrient and productivity loss is aggravated by severe soil erosion. This can be reduced by using AMF inoculum. To understand this process, pot experiment was conducted to fill the knowledge gap. This research was necessitated to understand the interaction of AMF and fertilizer, and the associations of AMF and DSE on *Eragrostis tef*. Hence, the objective of the study was to evaluate the effect of fertilization and arbuscular mycorrhizal inoculation on the yield of *Eragrostis tef*.

**Material and Methods**

**Site description**

Soil samples were collected from three different sites in Amhara region, northwestern Ethiopia. The sites were Gelawdiwos, Tara Gedam Askunabo. The three sites are located in different agro-ecological zones, especially with different altitude and soil types. Injibara is from the highland (Dega) parts, Gelawdiwos and Tara Gedam are from a mid-altitude range (Woina Dega). At each site there were both agricultural fields and natural forest stands.

**Soil sampling technique**

Soil samples were taken from both the crop land and the natural forest at the sites called Tara Gedam, Injibara and Gelawdiwos during 13-17 July, 2015. Composite sampling technique was used to make the soil samples homogeneous and a clear avoidance of error by addressing to the whole crop land and natural forest. The sample soils were taken from the top 5-10cm depth. In total, 800 kg of agricultural soil and 100 kg of forest soil were collected from all three experimental sites. The soils were dried from three to five days in a shaded house in Bahirdar. The dried soils were sieved with a two millimetre mesh sieve for separating boulders and stones.
Setup of pot experiment, growth measurement and harvest

The research was conducted at Amhara Agricultural Research Institute (ARARI) nearest to the main greenhouse by making a mini greenhouse with plastic mesh (0.425 mm) net and metal bars. In the experiment, we used seeds of *Eragrostis tef* (which is quncho variety), plastic buckets of three litre size (180 in number), potting substrates (forest soil and agricultural soil) and 70% ethanol alcohol for preserving tef roots. The experiment was laid out in block design. The treatments have five replications per treatment. The space between pots was 10 cm horizontally and vertically.

A total of 630 kg of agricultural soil and 11 kg of forest soil were used for 180 pots. Forest soils were used as inoculum of arbuscular mycorrhizal fungi and dark septate endophytes. A 130 kg per hectare of Di-Ammonium phosphate (DAP) during sowing and 36 kg per hectare of Urea fertilizer at the time of tillering were used. This is equivalent to 40 kg/ha of nitrogen and 26 kg/ha of phosphorus. Seed of *Eragrostis tef* was obtained from Adet agricultural research centre (AARC). The seeding rate was 5 kg per hectare (0.02 gm per pot). It was sown on July 23, 2015 and germinated on July 30, 2015. After germination, 30 plants were left on each pot by thinning in order to make equal plant distribution and effective growing. The experiment was watered using tap water. Weeding was carried out when necessary.

The experiment was set up in two harvesting time. The first was harvested before the vegetative parts turn to yellowish colour, which was done on September 19, 2015. This harvest was used for root colonization determination. A total of 45 pots were harvested during the first harvest which is 15 pots per treatment and per location. The second harvest was carried out after plant senescence (after vegetative parts turn to yellowish) which was on November 7, 2015. This final harvest was used to estimate the above ground biomass and quantify AMF spore densities in the soil. Also, during the second harvest 45 pots were harvested for estimating growth performance. Totally, 90 pots were used for soil spore extraction from which, 45 pots were tef cropped pots and the remaining 45 pots were without tef plant. After harvesting, the semi dried soils were carefully removed from the pots and placed on a plastic sheet separately and air dried in a shaded area. After drying, each soil was mixed to homogenise and sieved through a two-millimetre mesh sieves. Then, 50 grams of soil per each pot were sampled.
**Eragrostis tef root staining**

Vierheilig et al., (1998 and 2005) method was used. This is a new and cheapest method compared to Philips and Hayman (1970). Vierheilig et al., (1998 and 2005) uses ink with acetic acid for staining of plant root and got as good results as the standard protocol of using trypan blue. First, 10% KOH was prepared by using weight to the volume relationship method of each 20 gram of KOH pellet adding in 180 millilitre distilled water and stirred using a magnetic stirrer for 3-5 minute at 300 m/s resolution speed. Then, PVLG (polyvinyl alcohol lactic acid glycerol) was made by following Koske and Tessier (1983) lab protocol. Additionally, 5% ink- and 5% acetic acid staining solution was prepared by using Pelikan blue ink (Pelikan Vertriebsgesellschaft, Hanover, Germany) with 5% acetic acid.

**Assessment of AMF and DSE colonization**

Each two-centimetre Eragrostis tef root fragments were observed using 100X, 200X, 400X and 1000X magnifications of Zeiss Axiophot microscope (Carl Zeiss, Oberkochen, Germany) in the institute of Forest Entomology, Forest pathology and Forest protection (IFFF) laboratory, BOKU, Vienna, Austria. The percentage of arbuscular mycorrhizal fungi, AMF and dark septate endophyte (DSE) colonization was estimated by using a magnified intersection method which was developed by McGonigle et al. (1990) without any modifications.

**Extraction of AMF soil spores and data analysis**

Arbuscular mycorrhizal fungi spores were extracted by using Brundrett et al., (1996) protocol and counted by using 10 by 23X magnifications of dissecting microscope (Stemi 2000.CS with Axiocam ERC5S, Zeiss, Germany) in the Institute of Forest Ecology (IFE) laboratory, BOKU, Vienna, Austria. And, the more frequent spores were taking an image by using 100X and 200X in the IFFF laboratory, Boku University, Vienna, Austria. Aanalysis of variance (ANOVA) was carried out using R_3.2.2 Software. And, Tukey HSD (Tukey's Honest Significant Difference) with a 95% of family wise confidence level was conducted after ANOVA to clarify and determine which specific treatments were significantly different from the other.
Results

Biomass of *Eragrostis tef*

*Eragrostis tef* biomass was significantly higher (p<0.05) in the fertilized treatment than the inoculated and control treatments. There was no statistically significant difference between inoculated and control treatments (Figure 1). The addition of 5% forest soil inoculant did not significantly increase the total biomass of *Eragrostis tef*. However, the use of full recommended N-P fertilizers increased the biomass of *Eragrostis tef*. The highest mean above ground biomass was recorded in Injibara fertilized treatment (14.2 grams/pot) and the lowest mean was in Gelawdiwos control treatment (3.04 grams/pot).

![Figure 1. Total above ground biomass (gram/pot) of *Eragrostis tef*. Different letters indicate significant difference between treatments of within a location (P<0.05).](image)

Arbuscular mycorrhizal fungal colonization (AMFC)

AMF colonization of *Eragrostis tef* roots was significantly higher in the inoculated treatment as compared to the fertilized as well as the control treatments (Fig.2). However, application of fertilizer reduced the AMF colonization as compared to the control treatment. The highest mean of AMF colonization was recorded in the inoculated treatment of Gelawdiwos (99.8%) and the lowest mean was found in Tara Gedam of the fertilized treatment (21.5%).
Arbuscular mycorrhizal fungi colonization (%) of roots of *Eragrostis tef*. Different letters indicate significant difference between treatments of within a location ($P<0.05$).

Arbuscular mycorrhizal fungal spore density

Arbuscular mycorrhizal fungal spore density was higher in the inoculated treatment as compared to the fertilized and control treatments. The fertilized soil was significantly lower in spore densities as compared to the control treatment (Fig. 3). Application of N-P fertilizer reduced the spore density as compared to non-fertilized agricultural soil. On the other hand, the mycorrhizal host plant *Eragrostis tef* was significantly increased the spore densities by sporulation. The highest mean spores were recorded in Tara Gedam inoculated soil with tef (12.08 spores/gram) and the lowest mean was found in Tara Gedam fertilized soil without tef (2.12 spores/gram). And, the most abundant spores were Glomus, Gigaspora and Entrophospora genera (Fig. 3).
Dark septate endophyte colonization

The dark septate endophyte colonization (sum of sclerotium and dark septate hyphae) of *Eragrostis tef* roots were significantly higher in the inoculated treatment as compared from both fertilised and control treatments. But, there was not significant differences between the fertilized and control treatments (Figure 4). This means, the use of forest inoculant increased the dark septate endophyte colonization of *Eragrostis tef* roots, however, the use of N-P fertilizer did not bring change on the colonization as compared to the control. The highest mean dark septate endophyte colonization was recorded in Injibara of the inoculated treatment (59.5 %) and the lowest mean was recorded at Gelawdiwos fertilized treatment (12.1 %).

Figure 3. AMF spore density in soil collected from three locations. Different letters indicate significant difference between treatments of within a location (*P* <0.05).

Figure 4. Dark septate endophyte colonization (%) of roots of *Eragrostis tef*. Different letters indicate significant difference between treatments of within a location (*P*<0.05).
Discussion

The result indicated that forest inoculum has no effect on *Eragrostis tef* biomass without nitrogen fertilizer application (Fig. 1). *Eragrostis tef* requires nitrogen fertilizer for more biomass production (Mamo et al., 2001). This research also confirmed that *Eragrostis tef* was increased by three times using full recommended fertilizer. Shoot biomass of tef (quncho variety) with a recommended seed rate and fertilizer application was 4.8 t/ha. However, the research conducted in Debre Zeit resulted in 8.1 t/ha (Assefa et al. 2011).

Arbuscular mycorrhizal fungi (AMF) and dark septate endophyte (DSE) structures were frequently found in the roots of *Eragrostis tef*. An arbuscular mycorrhizal fungal structure (Fig. 5) of *Eragrostis tef* root was significantly higher in the inoculated treatment but, applications of urea and DAP fertilizer reduced AMF colonization as compared to the control (Fig. 2). These findings are similar to that of Majewska et al., (2015) on *Eragrostis albensis* alien grass species in Europe of its mycorrhizal frequency was around 80% / Mamo and Killham, (1987) indicated that AMF root colonization of *Eragrostis tef* ranged 30-60%. However, Shenkutie, (2015) showed 22% of the root length of *Eragrostis tef* was infected by AMF. Urea and DAP fertilizers reduced 50% of the total AMF colonization. This result is similar to Camenzind et al. (2014).

![Figure 5. AMF structures: A-arbuscules, V-vesicles and H- AM hyphae](image-url)
AMF spore density was higher in the inoculated treatment. Addition of forest soil increased the spore density, but application of urea and DAP fertilizers reduced the spore density. The presence of *Eragrostis tef* significantly increased the spore density. This indicated that there is sporulation by *Eragrostis tef* on the inoculated treatment. The mycorrhizal host plant increases the AMF spore density (Jansa et al. 2006). The finding is in line with Shenkutie (2015) i.e 4.8 spores/gram and Belay et al., (2015) with a range of 5.8 - 6.1 spores/gram. Hailemariam et al. (2013) indicated that the spore density ranges between 5.5 to 8.8 under *Acacia gummifera* and *Croton macrostachyus*. Chanie, (2006) found a range of 5.78 - 13.13 spores/gram in Araliaceae, Moraceae, Boraginaceae families. Arbuscular mycorrhizal fungi spores (Fig. 6) were significantly correlated to its fungal colonization. Higher spore densities are more important to produce intra radical and extra radical hyphae. The extra radical hyphae are more important to reduce soil loss by enhancing its aggregate stability (Mardhiah et al., 2016).

The highest of DSE colonization was recorded in Injibara. The higher value of sclerotium colonization in Injibara may exchange the role of arbuscules by occupying the space in the root cortex of *Eragrostis tef*. Microsclerotia which are the structures of DSE are observed in the root cortex together with AMF (Gucwa-Przepiórna et al., 2016). And, the high presence of DSE colonization might be due to the lower pH of the soil in Injibara location (Fig. and). This happened either microsclerotia might tolerate acidic soils than arbuscules or there is higher DSE in the forest soils. The use of forest inoculant increased the dark septate endophyte structures. Majewska et al., (2015) study on *Eragrostis albensis* alien grass species showed a DSE frequency ranged between 15 - 20 %. 

![Figure 6. Arbuscular mycorrhizal fungal spores, bar = 50 μm](image)
Conclusion and Recommendation

From this pot experiment, it is concluded that AMF and the DSE colonizations were high when the agricultural soil was inoculated by forest inoculum. Application of N-P fertilizers reduced the colonization of AMF by half. The use of N-P fertilizers reduced AMF association but not affected DSE communities. This needs further study to answer why DSE colonization is not affected by N-P fertilizers and a clear role of DSE to *Eragrostis tef*. AMF spore densities were increased when forest soil inoculum added to the agricultural soil. This improved the soil aggregate stability and has an ability to reduce soil erosion. The result also showed the association of AMF and DSE with *Eragrostis tef* plants. A diversity classification is needed both for AMF community and spores to easily quantify the effects on crop productivity. Field experiment is required to understand the process at large scale mainly on the yield of food crops including *Eragrostis tef*.
References


Assessment of Factors Hindering Seedling Survival in Lowlands of Eastern Amhara, Ethiopia

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Sirinka Agricultural Research Center, P.O. Box, 74 Woldia, Ethiopia

Abstract

Planting trees is carried out in different parts of Amhara for different purposes. However, the seedlings are failed to survive due to a number of factors. The major factors that affect the survival of tree seedlings in the drylands of Eastern-Amhara are assumed to be soil, method of planting, seedling size and pot size. These need to be identified for further action. Questionnaire was developed and a total of 120 randomly selected farmers were interviewed. The analysis showed that 47% of the respondents assumed that drought and moisture are the major factors for the failure of seedling survival. However, 43% of the respondents noted soil fertility is the major factor that hinders seedling survival. The remaining, 10% of the respondents indicated that tree seedlings survival is hindered by termite attack. Livestock, seedling quality and site are also factors that influence the survival of tree seedlings. Proper seedling size, soil mix and site matching can improve the forest development.

Key words: Degraded land, Drought, Moisture deficit and Seedling survival,
Introduction
Dryland forests are degraded due to agricultural expansion, overgrazing, improper utilization, charcoal production and other human activities (EARO, 2000 as cited in Kindu, 2002). This is triggered more by the increasing population, level of awareness management and weak implementation of policies. Dryland forests are becoming vulnerable to the process of desertification and land degradation (EARO 1999). Plantation on degraded lands can play a key role in harmonizing long-term forest ecosystem rehabilitation or restoration goals (Lamb, 1998). Forest plantations, using appropriate tree species can play an important role in the tropical ecosystem rehabilitation (Founoune et al., 2002). In such cases, planting of nursery raised seedlings may accelerate regeneration (Yirdaw and Luukkanen, 2003).

Plantation establishment and growth depends on the soil condition, (soil moisture and nutrient status), farming system and other land management options (Warren et al., 2005). Plantation is also influenced by seedling quality (Chavasse, 1980), dry spells (Engelbrecht et al., 2007), weeds (Richardson, 1993); vertebrates (Porteous, 1993); invertebrates (Gadgil et al., 1995) and other natural processes.

Farmers are planting seedlings of different tree species in the Northern Ethiopia particularly Wollo area. The survival of these seedlings is very poor. This is due to moisture deficit, termite and soil fertility problems (Abraham et al., 2013). In order to solve this problem several tree planting attempts have been carried out in this area. However, most of the attempts were not successful because all the efforts have lacked integrated approach including farmers’ participation. This study aims to identify the bottlenecks for the survival of seedlings in the field at the early stage. The objective of the study is to assess major factors that affect seedling survival after planting in the field.

Materials and Methods
The research was conducted in three administrative Zones, namely: South Wollo, North Wollo and Oromia Administrative Zones of Amhara Region. The study sites are described below.
Kobo (Menjelo)
It is characterized by soil moisture deficit. It is situated 39°37’ 29.1’ latitude and 12°01’08.4’ longitude. The altitude is 1611 meter above sea level (m.a.s.l) and receives average annual rainfall of 648.4 mm/year (woreda BOA). The mean maximum and mean minimum temperature of the area is 34°C and 18°C, respectively. Soil type of the area is Eutricfluvisols (SARC 2010).

Kalu (Harbu)
Kalu is found in south Wollo administrative zone and located at 39°37’ 29.1’ latitude and 12°01’08.4’ longitude. Annual average rain fall ranges from 750-900 mm. The temperature also ranges from 25 to 35°C. The altitude is 1713 meter above sea level. The soil is black coated and clay dominated.

Dawachefa (Shekla)
It is found in Dawa Chefa woreda of Oromia Zone. The altitude is 1875-meter a.s.l. and receives a rain fall of about 600-900 mm per year. The temperature ranges between 27-34°C. The soil is shallow and grey in color.

Data collection and analysis
Different data collection techniques were used. Household survey, semi-structured interview, group discussions and office visit were some of the methods used to obtain the necessary social data. A preliminary survey was carried out. A total of 120 representative key informants were selected from different age categories. Most of the meetings were organized at community and village level. The participants were diversified including representatives of local political-social organizations, gender, and with or without forest planting activities. Purposive samplings with 5 - 10% (depending on the population size) sampling intensity in each sampling village were carried out for interview.

The participants for interview were asked based on the semi structured questionnaire. Focus group interview along with different ranking methods of single list ranking, pair-wise ranking, and preference ranking were employed. Discussion with concerned development workers, local
leaders, key informants and NGOs were held. The discussions focused on strengths, weaknesses, opportunities and threats to forest development and facts about the failure of forest development. Perception towards future forestry development and other activities that are relevant to the study were addressed.

Overall assessments of the arrangement on forest development methods were done. Multi-stakeholder dialogues were carried out to have clear image for the failures of plantation. Farmers/Land users are key informants on the reasons why seedlings are not survived and the identification of solutions - improved practices and required support. Local decision makers and stakeholders were involved to review effectiveness of past technical or policy measures and help identify adaptive responses for the existing problem. Data from the questionnaire responses was coded and entered in Statistical Package for Social Sciences (SPSS version 16). Descriptive statistics was used to show the major factors that farmers considered as mostly dominant.

Result and Discussion

Socio economic information

All of the respondents are mainly engaged in agriculture. The house holds characteristics of the assessed areas in the three administrative zones i.e. North WWollo, South WWollo and Oromia zone of Amhara region. Average family size per house hold is five persons. About 91.7% of the total populations are in productive age. With respect to the sex composition of the interviewees, 75% were males and 25% were females. The education back ground of the respondents was almost the same in all zones i.e. 41.7% of the population are illiterate and only 16.7% are above grade four. Most of the farmers are engaged only in agriculture, only few persons are working as marcants, hand crafts men and daily labourers in towns when they have their spare time.

Niches for plantation

The study has shown that homesteads are the most common niches for tree planting. More than 47.7% of the seedlings are planted and well survived around at the homestead. This is due to better management and follow up (Weeding, watering and fencing). The trees can be used as a shade for residential areas and their cattle. Trees around homestead are well-protected by the
owners and farmers having the feeling of ownership. The most dominant trees grown around homesteads were *Eucalyptus camaldulensis* (21.7%), *Delonix regia* (13.5%), *Cordia africana* (13.5%), *Melica azadirachta* and *Gravilea robusta* (12%). List of species planted around homestead (table 1). Least focus niche is farm boundary (17.4%). From the observation and interviews it was understood that most farmers have not shown willingness to plant the tree on their farmlands. Their justifications were land is very small and fragmented: the production is not enough to feed the household and secure their consumption even when they fully utilize land for crop production. The other reason is that trees may be home to birds and insects that affect their crops. Some farmers have planted tress on borders and gullies and also manage naturally regenerating tree species for fence and farm tools. Among those *Ziziphus spina-christi*, *Acacia seyal*, *Eucalyptus camaldulensis* and *Cordia africana* are the most tree species found on farm boundaries.

Even though the government attempted tree planting program annually as a campaign at hillsides and communal lands, most of the attempts were not successful because of lack of ownership in the community. The data shows that at hillsides (watershed) 34.8% of seedlings were planted. The large areas are covered by *Grevilea robusta* (21.6%), *Acacia nilotica* (20.8%), *Acacia polyachanta* (16.4%) and *Eucalyptus camaldulensis* (12.8%) tree species.

Table 1. Distribution of main tree species across different growing areas

<table>
<thead>
<tr>
<th>Tree species</th>
<th>Homestead</th>
<th>Farm lands</th>
<th>Hillsides</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kobo</td>
<td>Kalu</td>
<td>D.chefa</td>
</tr>
<tr>
<td><em>Eucalyptus camaldulensis</em></td>
<td>22.5</td>
<td>18.2</td>
<td>23.7</td>
</tr>
<tr>
<td><em>Gravilea robusta</em></td>
<td>11.5</td>
<td>15.2</td>
<td>9.6</td>
</tr>
<tr>
<td><em>Melica azadirachta</em></td>
<td>22.5</td>
<td>0</td>
<td>10.5</td>
</tr>
<tr>
<td><em>Cordia africana</em></td>
<td>9.3</td>
<td>14.1</td>
<td>17.5</td>
</tr>
<tr>
<td><em>Schinus molle</em></td>
<td>5.4</td>
<td>7.1</td>
<td>10.5</td>
</tr>
<tr>
<td><em>Ziziphus spina-christi</em></td>
<td>6.2</td>
<td>6.1</td>
<td>1.8</td>
</tr>
<tr>
<td><em>Olea europaea</em></td>
<td>8.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><em>Acacia nilotica</em></td>
<td>3.9</td>
<td>2</td>
<td>0.9</td>
</tr>
<tr>
<td><em>Acacia seyal</em></td>
<td>0</td>
<td>2</td>
<td>0.9</td>
</tr>
<tr>
<td><em>Acacia polyachanta</em></td>
<td>0</td>
<td>21.2</td>
<td>4.4</td>
</tr>
<tr>
<td>Forage spp</td>
<td>0.8</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

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Problems of seedling survival

Most seedlings (75%) die out from April-June while the rest (25% seedlings) dried up during planting from October-December. From the total respondents, 20% said that seedlings dried out because of natural phenomena and 80% of the respondents affirmed that seedlings fail to survive due to lack of management.

Natural problems

Drought and moisture stress were perceived by 47% of the respondents in the study area as causes for drying of seedlings which is actually smaller than the finding of Mehari (2014) i.e. 78.3%. Peter and Ronald (1996) also stated that severe water stress can injure tree seedlings and may kill them. Seedling growth and survival can be affected by either an excess or deficit of water (Kozlowski et al., 1991). Davis and Langer (1994) noted that poor growth and high mortality of indigenous plants placed in depressions on an overburden dump, indicating that drainage is likely to be important on such sites where rainfall is medium to high. Seedlings are more sensitive to water stress than mature plants, and will grow much slower if soil moisture is below field capacity (Zahner in Kozlowski et al., 1991).

However, the severity of water stress is unpredictable as it depends on many factors such as occurrence and distribution of rainfall, evaporative demands and moisture storing capacity of soils (Wery et al., 1994). Most notably seedlings in the drylands are highly affected by limited water availability and may have less survival in the dry and moisture stressed areas where desiccation is highly probable during the dry season. Similar results have been reported by Holl et al. (2000) that tree seedling death during drought can occur both as a direct result of water stress, or because drought can exacerbate the effects of non-drought factors such as pathogens, herbivores, competitors or light.

First-year seedlings are particularly vulnerable because they have neither the deep roots to tap a fast receding water table nor the extensive root system to access a large soil volume. This chronic water shortage, along with other stresses like competition with herbaceous species, makes seedling establishment a limiting step in tree population dynamics (Lytle and Merritt, 2004).
The temperature also continuously increases time to time due to global warming. Most of seedlings had not resisted it with high water stress. In this particular investigation, 43% of the respondents noted that soil fertility problem as the main bottleneck for seedling survival. The study site has a very shallow soil and several inches below the soil surface is hard calcareous bedrock. The root of the seedling could not penetrate the hardpan and formed J-rooted that would suffer mortality. The vegetation cover is now sparse with heavily browsed trees and shrubs, stunted growth and poor vitality. Berli (2004) and Casper and Jackson (1997) also stated that compaction of soil or low soil fertility results in drying due to reduced root penetration and development. 10% of the respondents also acknowledge that termites are most importantly affecting the survival of tree seedlings. According to Chisato (2010), the rate of tree seedling withering in termite mounds was about three times higher than that of trees outside the mounds.

Field management
Cattle grazing, weeding, hoeing and other field management activities also contributed for the survival of seedlings. In the survey, 59.1% of the respondents indicated that livestock is affected survival of tree seedlings by grazing and trampling. Lillian et al. (1992) and Harvey and Haber (1999) livestock are as a principal cause for poor survival and recruitment of seedlings in developed countries.

Seedling quality is one of the main factors affecting field performance (Chavasse, 1980). 13.3% of the respondents noted that low quality seedlings are the main causes of seedling survival. Seedling quality is affected by nursery site, genetic make-up of the stock, seed, methods of production, the space occupied by the seedling in the nursery bed, time of sowing, age of seedling, time of year seedlings are lifted, nursery weed control methods and effectiveness, seedling nutrition, methods of seedling conditioning, insect attack, diseases and care in lifting, handling and transporting, (Chavasse, 1980; Menzies et al., 1995; Smith, 1986). Nursery practice is beyond the scope of this report. Almost all (98%) farmers did not have their own nursery site, they get seedling only from government nurseries without payment/cost and did not get chance to grade and choose the seedlings; they simply planted whatever seedling they got be it deformed or unwanted size.
The other major problem is the use of bare-rooted seedling. Davis et al. (1995) experimented with indigenous seedlings. Planting of tree seedlings out of their niche is also another problem for survival. Especially at kaluworeda, 54.2% of *Acacia polyachanta* have been planted at homesteads and farmlands. The 55% of *Grevillea robusta* were planted at hillsides and 30% and 15% planted at homesteads and farmlands respectively. Low coppice and low tolerance of water logging. *Grevillea* is successful at homesteads and farmlands with food crops than hillsides.

Eucalyptus is more preferable species by the farmers. Late planting is also a major problem for seedling survival. From the total (12.5%) respondents stated that late planting is a cause for seedling failure. Metcalf (1987) recommends planting indigenous species from March to May or from July to the end of August.

Generally the most dominant managerial and natural factors that hinders seedling survival are as seen in table 2 below.

**Table 2. Respondents’ opinion on severity of factors hindering seedling survival**

<table>
<thead>
<tr>
<th>Managerial problems</th>
<th>Kobo</th>
<th>Kalu</th>
<th>Dawachefa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Severity</td>
<td>weighted</td>
<td>Severity</td>
</tr>
<tr>
<td>Dalliance of planting date</td>
<td>15  8  2</td>
<td>63</td>
<td>14  8  3</td>
</tr>
<tr>
<td>Use of damaged seedlings</td>
<td>10  1  2</td>
<td>63</td>
<td>13  1  4</td>
</tr>
<tr>
<td>Weed problem</td>
<td>14  9  2</td>
<td>53</td>
<td>0  1  2</td>
</tr>
<tr>
<td>Improper seedling management at Nursery site</td>
<td>10  9  5</td>
<td>53</td>
<td>3  1  7</td>
</tr>
<tr>
<td>Planting of large seedlings</td>
<td>5  1  5</td>
<td>46</td>
<td>0  1  2</td>
</tr>
<tr>
<td>Lack of excavations after planting</td>
<td>3  9  4</td>
<td>31</td>
<td>0  2  6</td>
</tr>
<tr>
<td>Poor construction SWC structures</td>
<td>10  1  2</td>
<td>57</td>
<td>5  1  6</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Managerial problems</th>
<th>Kobo</th>
<th>Kalu</th>
<th>Dawachefea</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Severity</td>
<td>weighted</td>
<td>Severity</td>
</tr>
<tr>
<td>Lack of fencing</td>
<td>3 2 1</td>
<td>weighted 3 2 1</td>
<td>3 2 1</td>
</tr>
<tr>
<td>Animal trespass</td>
<td>10 7 8</td>
<td>62</td>
<td>5 5 2</td>
</tr>
<tr>
<td>Planting bare-root seedlings</td>
<td>16 9 3</td>
<td>69</td>
<td>7 7 0</td>
</tr>
<tr>
<td>Density and identity of neighboring plants</td>
<td>4 1 5</td>
<td>41</td>
<td>1 1 5</td>
</tr>
<tr>
<td>Digging of planting pits at the time planting</td>
<td>3 1 11 2</td>
<td>44</td>
<td>3 6 2</td>
</tr>
<tr>
<td>Letting the soil unstable after planting</td>
<td>6 2 9</td>
<td>31</td>
<td>1 5 4</td>
</tr>
<tr>
<td>Natural problems</td>
<td></td>
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<td></td>
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<tr>
<td>Water stress</td>
<td>38 1 0</td>
<td>116</td>
<td>38 2 0</td>
</tr>
<tr>
<td>Increasing local T°</td>
<td>38 2 0</td>
<td>118</td>
<td>36 2 1 112</td>
</tr>
<tr>
<td>Termite attack</td>
<td>11 12 6</td>
<td>63</td>
<td>21 6 5 80</td>
</tr>
<tr>
<td>Infertile soil depth</td>
<td>10 13 6</td>
<td>52</td>
<td>4 12 5 41</td>
</tr>
<tr>
<td>Flood effects</td>
<td>16 10 5</td>
<td>73</td>
<td>1 6 7 22</td>
</tr>
<tr>
<td>Water logging</td>
<td>5 6 6</td>
<td>33</td>
<td>2 2 2 12</td>
</tr>
<tr>
<td>Rodent attack</td>
<td>1 3 5</td>
<td>14</td>
<td>5 5 2 27</td>
</tr>
</tbody>
</table>

Key: degree of severity: 3=very sever, 2=sever 3=least sever
Weighted = sum of degree of severity multiplied by the number of respondent

Conclusion and Recommendations

The study showed that the most contributors for seedling survival are field management (weeding, hoeing, watering, and mulching). However, the contribution of drought, infertile and shallow soil depth, and termite impacts were also pointed out by the farmers as main barriers for forest development in the study area. Therefore, to improve seedling survival at field condition requires proper allocation of species to suitable site, drought resistant species, awareness creation on silvicultural managements, and active participation and fully
involvement in plantation and conservation activities of the government. BOARD, NGOs and other stake holders is needed to address the problem and improve the forest development.

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130: 39-58.


Evaluation of the Adaptability of Different Eucalyptus Tree Species in the Highland Parts of Eastern Amhara Region

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Abstract
Different species of Eucalyptus are grown in different niches of the country. Nowadays, Eucalyptus species are affected by diseases and insects in different agroecologies including the highlands. To alleviate this problem, other alternative species need to be introduced in the highlands of Amhara region, Ethiopia. This study was conducted aiming to evaluate six Eucalyptus tree species in the highlands of eastern Amhara region. The experimental design was randomized complete block design replicated three times. The parameters were root collar diameter, diameter at breast height (DBH), survival rate and height. The parameters measured showed statistically significant difference in 39 months. The results revealed that Eucalyptus viminalis and Eucalyptus saligna performed well in DBH and height. Among all species, Eucalyptus viminalis, Eucalyptus saligna and Eucalyptus grandis have a survival rate of 60.4%, 56.3% and 50%, respectively. The other species survived below these species. Eucalyptus citrodora is the least performing (35.4). Therefore, Eucalyptus viminalis and Eucalyptus saligna are recommended as an option for similar agroecology.

Key words: Eucalyptus globulus, E. Viminalis, E. saligna, DBH, height
Introduction

According to Woody Biomass Inventory and Strategic Planning Project (WBISPP), the land use types in Ethiopia showed that the coverage of woodland and forests constituted more than 50% of the total land forest cover (WBISPP, 2005). Plantation in the highlands is increasing because of increase fuelwood and other wood related products. *Eucalyptus* species is dominantly grown in the region. It is growing in a range of diverse climates and soil types (Janice et al, 2016). Europeans introduced *Eucalyptus* as plantation for eastern Africa during the second half of the 19th century and at the beginning of the 20th century. The introduction of the eucalypts to East Africa seems to have followed the serious forest decline and emergence of wood deficit in these countries.

According to Nduwamungu et al. (2007) in our country Ethiopia, this exotic species was introduced during the regime of Emperor Menilek II (1868-1907) in 1894/95 (Von Breitenbach, 1961). It was introduced to satisfy high fuel and construction wood demands and the plantation was started in the capital city of the county (Addis Ababa Ethiopia). In Ethiopia, eucalyptus tends to be better than other exotic species and native species in terms of production and farmer income generation. This can be recognized by various biological and physiological uniqueness including high productiveness, rapid growth rates, allelopathic properties and a tolerance for a wide range of soil and climate niches. *Eucalyptus* species are also tolerant of severe periodic moisture stress and low soil fertility with xeromorphic leaves (structural modifications that enable the reduction of water loss) and specifically ecto- and endomycorrhizae systems which increase nutrient consumption (Janice et al, 2016). Currently about 55 eucalyptus species have been grown in Ethiopia, from these species six are widely planted throughout the country and are *Eucalyptus camaldulensis*, *E. citrodora*, *E.globulus*, *E. regnans*, *E.saligna* and *E.tereticornis* (Friis, 1995).

Eucalyptus growing in Ethiopia is mostly confined to the highlands, because the area has suitable annual precipitation and temperature. They are generally superior to other exotic and native species in their performance, thus farmers plant large numbers of Eucalyptus, particularly *E. globulus*, on pieces of land and manage them to get a variety of products such as leaves and small branches for fuel, poles and posts for house building and other farm uses. According to Demel (2000), many people in Ethiopia are absolutely dependent on eucalyptus
as a source of fuel, income generation and construction material. *Eucalyptus globules* known locally as ‘Nech-Baharzaf’ or ‘White Eucalypt’ and *Eucalyptus camaldulensis* known as ‘Key-Bahirzaf’ or ‘Red Eucalypt’ being the species by Ethiopians most referred by farmers (Minda, 2004; Amare, 2002; Zerihun, 2002; Gebre-Markos, 1998; Daba, 1998). Kelemu and Tadese (2004, 2010) stated that in the northern part of Ethiopia eucalyptus provides a proportional increase for income of the rural small-scale farmers (20%) in the year 2008/09 (Excluding its value for household consumption such as fuel wood, construction).

Due to its economic importance, the land allocated for Eucalyptus plantation increased by around 30% from the year 2004/05 to year 2009/2010 (Kelemu and Tadese, 2010). *Eucalyptus* species have been highly preferred and appreciated by the farmers over indigenous or other exotic tree species. According to the research conducted in two woredas of Ethiopia on farmers’ species preference, *E. camaldulensis* (mid and low land areas) and *E. globulus* (highland areas) were their first choices for planting (Kahurananga et al., 1993).

Similarly, *E. globulus* and *E. camaldulensis* are the most common Eucalyptus species that have been dominantly planted in most parts of the region. However, there is a disease and insect attack in these plantations. This necessitates the presence of alternative species that can adapt and provide comparable wood product. The objective of this study was to evaluate the adaptability of different *Eucalyptus* species in the highlands of east Amhara region.

**Material and Methods**

**Description of the Study Area**

The study was conducted in North Wollo zone particularly Hamusit Kebele (029). And, geographically it has been located at 11°44'13.9"N and longitude of 38°59'43.4"E and has an altitude of 3114 meter above sea level. The mean annual rainfall ranges from 800-1200 mm, and the mean minimum and maximum temperature are 17 and 22 °C, respectively.

**Experimental Design**

Seeds of *Eucalyptus camaldulensis, Eucalyptus globulus, Eucalyptus citrodora, Eucalyptus grandis, Eucalyptus viminalis* and *Eucalyptus saligna* species were purchased from Forestry Research Center (FRC) and raised in a Boya nursery site. The experiment was laid out in randomized complete block design with three replications. The space between blocks and plots
was 3m and 2m, respectively and had 16 seedlings per plot. Polyethylene tube, a mixture of compost, agricultural soil, forest soil and sand were used to grow as a planting media for sown seeds of Eucalyptus species in the nursery.

Data collection and analysis
Root collar diameter, height and survival rate were measured every three months for thirty nine months. The analysis was carried out using SAS software and Microsoft excel.

Result and discussion
The result showed that there is a significant difference among those Eucalyptus tree species in all growth parameters. The maximum root collar diameter (RCD) was recorded by *E. viminalis* (8.21 cm) and *E. saligna* (7.27 cm). However, the least RCD was observed from *E. citrodora* (2.4cm) (Fig. 1).

![Mean root collar diameter](image)

Figure 1. Average root collar diameter (MAP = month after planting)

The survival rate of *E. Camaldulensis* (91.7 %) was the highest. The least was recorded from *E. citriodora* 35.4%. Except *E. citrodora*, all the other *Eucalyptus* species attained more than 50% of survival rate. Similar result was reported by King et al., (1980) that *E. viminalis* and *E. camaldulensis* showed better performance which is more than 50%. *Eucalyptus citrodora* was statistically significant with other *Eucalyptus* tree species, however, the rest *Eucalyptus* species were not significantly different (Fig. 2).
Figure 2. Survival rate of different Eucalyptus tree species

Diameter at breast height of E. citrodora is significantly different compared with other five Eucalyptus species and the least thicken species which was around 3.7 cm in diameter. However, the maximum diameter at breast height was recorded in both E. globulus and E. viminalis (Fig 3).

Figure 3. Average diameter of Eucalyptus tree species with error bars

Height of E. globulus, E. viminalis and E. saligina were significantly higher than that of E. camaldulensis, E. grandis and E. citrodora (Fig. 4). But, E. citrodora has significantly different with other five Eucalyptus tree species and also the least species in height. Therefore, based on the growth parameters, Eucalyptus viminalis and Eucalyptus saligna were the promising alternative species for Eucalyptus globulus (local check).
Figure 4. Average height of *Eucalyptus* tree species with error bars

**Farmer's perception**

In addition to that of the biological data, this research included the social data i.e. the farmers' perception. In this case, pair wise ranking was conducted to evaluate different *Eucalyptus* tree species by using farmers' preference with matrix scoring. From the scoring, *Eucalyptus viminalis* and *Eucalyptus grandis* were selected as best *Eucalyptus* tree species by the respondent farmers because of their adaptability, biomass and early growth characteristics than the other *Eucalyptus* tree species (Table 3). *Eucalyptus saligna* is also selected as a candidate *Eucalyptus* tree species and it is feasible for high land areas as an alternative tree species for *Eucalyptus globulus* due to its fast growth and uprightness quality in that particular area (Hamusit, 029 Kebelle).

<table>
<thead>
<tr>
<th>Adaptability</th>
<th>Early/fast growth</th>
<th>Straightness</th>
<th>Biomass</th>
<th>Total count</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Adaptability</td>
<td>Adaptability</td>
<td>3</td>
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<td>X</td>
<td>Early growth</td>
<td>Early growth</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Straightness</td>
<td>X</td>
<td>Straightness</td>
<td>X</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Biomass</td>
<td>X</td>
<td>X</td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Rank of criteria by farmers for the selection of adaption of different Eucalyptus species
Table 2. Rank of species by the rank of farmers' criteria

<table>
<thead>
<tr>
<th>Eucalyptus Species</th>
<th>Criteria of farmers used in the selection of Eucalyptus Species</th>
<th>Total Score</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adaptability(1) Early growth(2) Straightness(3) Biomass(4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. globulus</td>
<td>4</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td>E. grandis</td>
<td>3</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td>E. viminalis</td>
<td>2</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td>E. saligna</td>
<td>5</td>
<td>32</td>
<td>3</td>
</tr>
<tr>
<td>E. camalhdenisia</td>
<td>1</td>
<td>43</td>
<td>4</td>
</tr>
<tr>
<td>E. citriodora</td>
<td>6</td>
<td>60</td>
<td>5</td>
</tr>
</tbody>
</table>

Conclusion and Recommendation

Based on this study, we understood that implementation of tree species adaptation was very relevant to classify which species suited for a particular growing area. *Eucalyptus* tree species are taken as an alternative means of livelihood/income for many poor farmers which live on unsuited or degraded lands of eastern Amhara region, Ethiopia. Height and diameter at breast height of *Eucalyptus viminalis*, *Eucalyptus grandis* and *Eucalyptus saligna* were significantly higher than that of the other *Eucalyptus* species. Based on the farmers' selection criteria, *Eucalyptus viminalis*, *Eucalyptus grandis* and *Eucalyptus saligna* were the top three species selected as first priorities. Hence, we recommend *Eucalyptus viminalis*, *Eucalyptus grandis* and *Eucalyptus saligna* for Wollo highlands like Meket district.

References


Nduwamungu J (2005) performance of Eucalyptus hybrid clones and local landraces in various agro-ecological zones in Kenya
Evaluation of mycorrhizal inoculation on early seedling performance of selected indigenous tree species
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Abstract
Arbuscular mycorrhizal fungi (AMF) have a symbiotic relationship between plant roots and fungus in the soil growing media. Early growth performance of seedlings can be enhanced by inoculations of the required mycorrhiza’s are important. The study aims to evaluate the effect of mycorrhizal inoculation on the early growth performance and survival of indigenous tree seedlings. The experiment was conducted in Sirinka and Jari with six treatments and had three replications. Forest soil was used as inoculant and was used at the nursery stage. The result showed that, forest soil inoculation significantly increased the survival rate, root collar diameter and height of some selected tree species mainly on Ehretia cymosa. The tree seedlings showed the necessity of inoculation of forest soil for degraded areas like eastern Amhara region, Ethiopia. The study recommended understanding of the AMF diversity and efficiency. Hence, further study is suggested to deal with the diversity of AMF and efficiency should be analyzed with appropriate methods.

Key words: Mycorrhiza, Arbuscular mycorrhizal fungi, Ehretia cymosa and Seedling survival
Introduction

Mycorrhizas are a symbiotic relationship between plant roots and fungus in the soil growing media as shown in Figure 2 (Brundrett, 2004; Godbold and Sharrock, 2003; Gupta and Sharma, 2010; Aggarwal et al., 2011). The association is mutualistic, which involves nutrients and water for the plants and starch for the fungus as a source of food. From mycorrhizal groups, arbuscular mycorrhiza fungi (AMF) are the most common root associated fungus in plants found on the earth’s surface in 80% of vascular plant families existing today. It occurs in many stressful environments to enhance water and nutrient uptake in dry conditions (Godbold and Sharrock, 2003; Birhane et al., 2010).

AMF are abundant in the soil which creates symbiotic relations with most terrestrial plants (Rillig and Allen, 1999). In the presence of AM fungi, the plant’s ability to resist stress increases as a result of morphological and physiological changes. It helps for plants to adapt the biotic and abiotic conditions for their better survival, growth and development of plants and crops (Lone et al., 2015; Johnson et al., 2015). It controls plant fungal diseases (Pierre et al., 2014). An efficient and effective method to add micro-organisms is to inoculate either nursery soils or adding a few grams of top soil from well-established plantations or healthy forests in planting holes. Therefore, in order to enhance the early growth performance of seedlings, inoculations of the required mycorrhizas are important.

There is also increasing evidence that mycorrhizal inoculation increases the survival of tropical woody plants after planting in the field (Sieverding, 1991; Micheslen, 1993). Thus, knowledge of the susceptibility of indigenous tree species to mycorrhizal fungi infection, mycotrophic growth and mineral nutrition response as they relate to species potential for reforestation and land rehabilitation may be of great importance for silvicultural practices. Therefore, the main objective of this paper was to evaluate the effect of mychorrizal inoculation on the early growth performance and survival of indigenous tree seedlings.
Material and Methods

Seeds of selected indigenous tree species, nursery equipment and soils for mycorrhizal fungal inoculum were used for the establishment of the project. Then the collected soils were mixed for potting and the seedlings were raised in the nearby nursery of the representative sites of the study area. During the experimental time, the inoculated soils were mixed in the pots for planting of seedlings. The field experiment was conducted using randomized block design with three replications. The treatments had two levels: non-inoculated (control) and inoculated with native mycorrhizal fungi. A total of twenty five (25) seedlings were planted per plot and the inner nine plants (leaving guard rows to avoid border effect) were recorded for every three months.

Description of the study area

The eastern part of Amhara region is part of the northeast landmass of Ethiopia representing most of the undulating and dry land areas of the country. The research was conducted in the two administrative zones of South and North Wollo of eastern Amhara region.

Sirinka

The assessment began in Harbu woreda in Sirinka Kebele (03), located at 39°36'36" latitude and 11°45'00" longitude. The altitude is 1850 m.a.s.l. with an average annual rainfall of 648.4 mm/year. The mean maximum and mean minimum temperature of the area is 34°C and 18°C, respectively. Most of the soils are deep and loamy (would be fine if you specify the type of the soil like nitisols or regosols).

Tehuledere (Jari)

Jari is one of the districts of south Wollo administrative zone and located at 39.63° latitude and 11.35° longitudes. Annual average rainfall ranges from 750-900 mm. The yearly average temperature also ranges between 25-35°C. The altitude is 1680 m.a.s.l. It has black and clay soil type.

Data collection and analysis

The soil samples from intact soil cores at 10 cm depth (containing fine roots) were collected under the canopy of natural forest and identified from national soil lab. The identified soils of
mycorrhizal fungi inoculant were mixed with normal nursery soils by 1:1 ratio and filled in Polythene tubes. Equal number of polythene tubes was prepared by filling with normal nursery soil. Selected tree/shrub species were planted on polythene tubes which were filled with the mixture of mycorrhizal fungi and others were filled by nursery soils only. Generally, the treatments were six tree/shrub species: *Ehretia cymosa* without inoculant, *Ehretia cymosa* with inoculant, *Cordia africana* without inoculant, *Cordia africana* with inoculant, *Olea Europaea* without inoculant, and *Olea Europaea* with inoculants. Survival rate, root collar diameter and height of the tree were collected for analysis. Comparisons between treatments were carried out using ANOVA and Tukey's HSD test using SAS software.

**Result and Discussion**

The mean height of *E. cymosa* with mycorrhizal inoculum was significantly higher at the time of 33 months at both locations among the treatments. And, the reverse is true for *O. europaea* with mycorrhizae and *C. africana* without mycorrhiza which was significantly lower than the others (Figure 1).
In Sirinka the survival rate of *C.africana* with out, *E.cymosa* with and *C.africana* with mycorrhiza relatively have shown better performance than others. Especially *E.cymosa* with mycorrhizae has shown significantly better performance than *E.cymosa* with out mycorrhizae (Figure 3). Likewise, in Jari *E.cymosa* with and *E.cymosa* without mycorrhizae had shown better performance among the treatments.
Figure 3. Survival rate of tree species in Sirinka (left) and Jari (right) in different months. In Sirinka, *Cordia africana* without *C. africana* with and *E. cymossa* with mycorrhiza has shown better performance than other treatments with their mean root collar diameter. And in Jari, the mean root collar diameter was significantly higher for *Cordia africana* with mycorrhizae and *E. cymossa* with mycorrhizae (Figure 4).

Figure 4. Root collar diameter of different tree species in Sirinka (left) and Jari (right) at different months.
The combined analysis showed that, the mean height, root collar diameter and survival rate were significantly different among those treatments. The highest values of mean heights were observed on \textit{E. cymosa} with (128.47 cm), \textit{C. africana} with out (94.13 cm) and \textit{C. Africana} with (91.52 cm) mycorrhizae. On the other hand, the maximum root collar diameter was observed on \textit{C. africana} with out (3.14 cm), \textit{C. africana} with (3.88 cm) and \textit{E. cymosa} with mycorrizal inoculant (2.83 cm). And, the highest value of survival rate was attained by \textit{E. cymosa} with (94.33 %), \textit{C. africana} with (79.25 %) and \textit{C. africana} without (74.28 %) mycorrhizae (Table 1).

In general, the contribution of mycor rhizal inoculant was significantly higher than the non-inoculated treatments on the growth performance of different tree species. And, other literature says, nursery based grown seedlings have higher survival rate if the seedlings are inoculated by arbuscular mycor rhizal fungi (Fisher and Jayachandran, 2002).
Table 1. The mean value of height, root collar diameter and survival rate

<table>
<thead>
<tr>
<th>Treatments</th>
<th>height(cm)</th>
<th>Mean RCD(cm)</th>
<th>Mean survival rate %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jari</td>
<td>Sirinka</td>
<td>Combined</td>
</tr>
<tr>
<td>C. africana w/out</td>
<td>52.32b</td>
<td>135.94b</td>
<td>94.13b</td>
</tr>
<tr>
<td>C. africana with</td>
<td>63.16a</td>
<td>119.87b</td>
<td>91.52b</td>
</tr>
<tr>
<td>E. cymosa w/out</td>
<td>56.25b</td>
<td>67.02</td>
<td>61.63</td>
</tr>
<tr>
<td>E. cymosa with</td>
<td>90.47a</td>
<td>166.47a</td>
<td>128.47b</td>
</tr>
<tr>
<td>O. europea w/out</td>
<td>56.35b</td>
<td>60.56</td>
<td>58.46</td>
</tr>
<tr>
<td>O. europea with</td>
<td>49.09</td>
<td>53.54</td>
<td>51.31</td>
</tr>
<tr>
<td>Mean</td>
<td>61.27</td>
<td>100.56</td>
<td>80.92</td>
</tr>
<tr>
<td>CV (%)</td>
<td>22.48</td>
<td>27.60</td>
<td>18.55</td>
</tr>
<tr>
<td>LSD (5%)</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

Conclusion and Recommendation

Forest soil inoculation significantly increases the survival rate, root collar diameter and height of some selected tree species. The contribution of inoculum for E. cymosa showed significant performance in survival rate, height and root collar diameter compared to other treatments. The growth performance of indigenous tree species like E. cymosa can be improved by inoculation. This is an important strategy for nutrient deficient and drought affected areas. This study did not address the type, diversity and efficiency of the fungi mainly arbuscular mycorrhiza. Therefore, the diversity of AMF and its efficiency should be analyzed with appropriate methods.

References


Population Viability Analysis of Threatened Selected Species in Church Forests: the case of Yedogit Michael, Eastern Amhara Region

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Abstract

In the Ethiopian highlands, church forests have a substantial contribution to landscape restoration, and conservation of endangered indigenous tree species and biodiversity. However, the environmental and economic benefits of church forests are declining due to a combination of economic, environmental, and cultural factors. The objective of this study was to evaluate population viability and seed status of remnant church forests to use as local seed source. Seeds of Juniperus procera were collected from Warkaye Mariam, Yedogit Michael and Adisge Abo church forests. For comparison purpose seeds of Juniperus procera were purchased from Ethiopian Environmental and Forest Research Institute, Forest Research Center, Addis Ababa (Jimma, Gera). And, the result showed that, there is no variation in germination and seedling growth in the field among provenances of Juniperus procera except at the nursery stage. At the nursery stage, Juniperus procera from Adisge was the first in plant height (10.67cm), root collar diameter (0.17cm) and root length (11cm) followed by Yedogit. This means that the provenance had similar response in germination percentages and field growth parameter at Yedogit Michael. Any of the provenances can be used as a seed source but considering cost and accessibilities, it is better to use the local provenances around Yedogit Michael. Additionally, the mother trees should be treated with different silvicultural practices like soil management, open canopy, protection from animals, and artificial plantation for sustaining the seed sources.

Key words: Germination, Viability, Juniperus procera, Seed source and Open canopy
Introduction
The recent forest resources assessment estimated that the global forest cover at just over 4 billion hectares, which is 31% of total land area of the world. Protected areas cover more than 10% of the total forest area (FAO, 2010). Concerning deforestation, mainly the conversion of tropical forests to agricultural land, the same report indicated signs of decreasing in several countries but continues at a high rate in others. Around 13 million hectares of forest were converted to other uses (YitebituMoges et al, 2010). It is often reported that about 35 percent of the landmass of Ethiopia was once covered with closed forests, but this figure is based on a study of the possible climatic climax vegetation types of the country which was included in reports by FAO.Unfortunately, the Ethiopian natural tree populations have been, and still are, subject to indiscriminate destruction. Shifting cultivation and traditional grazing have been practiced for centuries in Ethiopia. This and the relentless cutting for fuel and building needs by a dense and rapidly growing population, have led to deforestation of the Ethiopian highlands (Engels, 2002).

In the central and northern highlands of Ethiopia, native forest and forest biodiversity is almost confined to sacred groves associated with churches (Aerts et al., 2016). Mainly the local communities rely on these 'church forests' for essential ecosystem services including shade and fresh water but little is known about their region-wide distribution and conservation value. With a wide distribution over the landscape, these church forests have high conservation value. In the Ethiopian highlands, church forests have a substantial contribution to landscape restoration, and conservation of endangered indigenous tree species and biodiversity. However, the environmental and economic benefits of church forests are declining due to a combination of economic, environmental, and cultural factors (Amare, 2016). In undisturbed natural forests, it is common to see the number of seedlings > number of saplings > number of matured ones for a species. Long-term conservation of bio-diversity of individual patches and evolutionary potential of species may be threatened by isolation, small sizes of tree species populations and disturbance, especially when considering climate change. Forest management interventions are essential and should be supported by environmental education and other forms of public engagement (Aerts et al., 2016). Therefore, it is vital to evaluate population viability and seed status of remnant church forests to use as local seed source to develop orchard and Conservation strategy.
Material and Methods

Description of Study Area
The experiment was conducted in Yedogit Michael which is in Delanta Dawunt District. Yedogit Michael church forest is situated in the North Wollo Zone of the Amhara Regional State located between 11°30′17″ N latitudes and 39°09′23″ E longitudes with an altitude of 2400-3500 meter above sea level. And are located 110 Km northwest of Dessie town and 115 Km west of Woldia town. The climate of the area is characterized by dry seasons (from October to February cold-dry and March to June hot-dry) and wet season (from mid-June to September). The rainfall pattern is bimodal with peak periods from mid-July to early September. The mean annual rainfall is about 812 mm of which 60-70% is received in summer (Kiremt) and 40-30% in the spring (Belg) seasons. The mean annual minimum and maximum temperatures are 6.8 and 19.6°C, respectively.

Seed collection
Mother tree species were selected from Warkaye Mariam, Yedogit Michael and Adisge Abo purposively based on the standard criteria to represent the genetic pool of the whole forests. The selected mother trees were marked at the distance of 100m to forest area less than 250ha and 300m to forest area greater than 250ha. Based on size of forest and existing eco line nine to twenty five mother trees were selected along gradient through the church forests. From those mother trees, seeds of *Juniperus procera* were collected during November to December.

Experimental Design
The experiment was established to evaluate the germination and viability percentage of *Juniperus procera* that were collected from different seed sources at laboratory level. The survival rate and growth performance were evaluated at the nursery and field phases. Seeds of *Juniperus procera* were collected from Warkaye Mariam, Yedogit Michael and Adisge abo church forests. For comparison purpose seeds of *Juniperus procera* were obtained from Forest and Environment Research Center, Addis Ababa (Jimma Gera). The experimental design for laboratory phase was complete randomized design (CRD) with four replications and used for analyzing germination and viability tests.
Twenty-five seeds were sown for each site with four replications on each petri dish and a total of 100 seeds were used per treatment. Seeds of *Juniperus procera* from different locations were sown at polythene tube in the nursery site with randomized complete block design (RCBD) with four replications. For each location, 100 polythene tubes were sown per plot in four replications and number of germinated seeds was counted at every eight days. Finally, when the seedling attained optimum condition for out planting, seedling root collar diameter, seedling height and seedling root length for inner nine sample seedlings were recorded for each location. And also forfieid establishment, randomized complete block design (RCBD) was used with three replications. The space between seedlings was 1.5m and between blocks was 2m according to the area we got. The number of seedlings in each plot was 16 seedlings. The experiments were established to evaluate the survival of *Juniperus procera* seedlings in Yedogit Michael which is in Wadila district and were planted on 09/11/2005 E.C. At the end, Root collar diameter, height and survival rate were taken every three month's interval until the experiment was completed. And, all collected data were analyzed using SAS software and Microsoft excel.

**Result and Discussion**

*Juniperus procera* from Yedogit Michael was the leading in germination percentage as well as viability percentage while *Juniperus procera* from Warkaye Mariam was the least in both germination and viability percentages at laboratory phase of the experiment. According to Negash Mamo et al., (2006), he used nine *Juniperus procera* provenances and shakiso shows the highest germination percentage than the other provenances. Seed of *Podocarpus falcatus* provenances from central, south-eastern, southern and western Ethiopia showed significant differences in germination between provenances. From these investigations, it is concluded that reproductive capacity of the species is rapidly declining, fertility of the tree varies from region to region, and successful fruiting in the female tree is greatly influenced by such factors as climatic conditions and sexual dimorphism (Legesse Negash, 2003). According to H.S.Ginwal et al., (2005) study revealed that considerable genetic variability exists in *Jatropha curcas* collected from ten locations in central India with respect to seed morphology, seed germination and seedling growth characteristics. The study also shows variation on seed length, seed width and seed weight among 12 African provenances of *Faidherbia albida* examined. The southern
African provenances had the largest seeds and West African provenances were the smallest (Dangasukand et al., 1997). The use of local seed provenances is often recommended in restoration and habitat creation because they are thought to be better adapted to local habitat conditions. However, degree of population, space coverage and age also matter on germination and viability of provenances.

**Germination test of Juniperus procera in laboratory**

Germination percentage, viability, average seed width and 1000 seed weight were significantly different but average seed length and average seed weight were not statistically significant (Table 1).

**Table 1. Germination and viability analysis of Juniperus procera provenances at laboratory**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Germination (%)</th>
<th>Viability (%)</th>
<th>Seed Width</th>
<th>Seed Length</th>
<th>Seed Weight</th>
<th>1000 Seed Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warkaye</td>
<td>25b</td>
<td>35c</td>
<td>3.27a</td>
<td>4.96a</td>
<td>0.433b</td>
<td>20.0b</td>
</tr>
<tr>
<td>Yedogit</td>
<td>30a</td>
<td>44a</td>
<td>3.06ab</td>
<td>4.92a</td>
<td>0.567a</td>
<td>19.53bc</td>
</tr>
<tr>
<td>Adisge</td>
<td>28ab</td>
<td>39b</td>
<td>2.85b</td>
<td>4.85a</td>
<td>0.433b</td>
<td>18.40c</td>
</tr>
<tr>
<td>Jimma Gera</td>
<td>28ab</td>
<td>40b</td>
<td>2.85b</td>
<td>4.75a</td>
<td>0.50ab</td>
<td>22.50a</td>
</tr>
<tr>
<td>LSD (5%)</td>
<td>ns</td>
<td>**</td>
<td>*</td>
<td>Ns</td>
<td>Ns</td>
<td>**</td>
</tr>
<tr>
<td>CV</td>
<td>7.64</td>
<td>4.56</td>
<td>4.54</td>
<td>3.25</td>
<td>14.63</td>
<td>4.0</td>
</tr>
</tbody>
</table>

**Status of Juniperus procera at nursery**

The experiment was established to evaluate the germination percentage and seedling vigorosity of Juniperus procera at SARC Forestry nursery. There were significant differences among provenances for seedling root collar diameter, seedling height and seedling root length at nursery. Juniperus procera from Adisge Abo was the first in plant height (10.67cm), root collar diameter (0.17cm) and root length (11cm) followed by Yedogit Michael (Fig. 1). Jimma Gera was the least in plant height (7.33cm) and root collar diameter (0.11cm).
Figure 1. Root collar diameter (RCD), Height (H) and Root length (RL) of *Juniperus procera* provenances at SARC nursery site with error bars.

Other studies on *Abies Guatemalaensis* species provenances subjected that, there were significant differences among provenances in Guatemala for all traits. Two provenances showed superior germination and growth characteristics; one had the highest germination percentage and the densest distribution of secondary branches and the other produced tallest seedlings (Andersen and et al., 2008). Patterns of genetic variation in *Cordia africana* were evaluated at the population level. Bulk seed samples were collected from six natural populations in Ethiopia and examined for variations in seed morphometric traits, seed germination, and seedling growth at nursery stage. Analysis of variance revealed significant differences among provenances in all studied attributes except root collar diameter after 4 months of growth (Loha, 2006).

**Field experiment**

Based on the field result at Yedogit Michael, root collar diameter, height and survival rates were not shown significant differences among provenances. The maximum mean root collar diameter (11.5mm), height (49.67cm) and survival rate (66.67%) were attained by *Juniperus procera* from Abo. And, the minimum root collar diameter (7.5 mm), height (33.24 cm) and survival rate (37.5%) were recorded for *Juniperus procera* from Warkaye Mariam (Table 2).
Table 2. Root collar diameter (RCD), Height (H) and Survival rate of *Juniperus procera* provenances at Yedogit Michael (Kone)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>RCD (mm)</th>
<th>Height (cm)</th>
<th>Survival rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warkaye</td>
<td>7.5</td>
<td>33.2</td>
<td>37.5</td>
</tr>
<tr>
<td>Yedogit</td>
<td>9.9</td>
<td>45.4</td>
<td>45.8</td>
</tr>
<tr>
<td>Adisge</td>
<td>11.5</td>
<td>49.7</td>
<td>66.7</td>
</tr>
<tr>
<td>Jimma Gera</td>
<td>10.1</td>
<td>48.20</td>
<td>39.6</td>
</tr>
<tr>
<td>LSD (5%)</td>
<td>ns</td>
<td>Ns</td>
<td>Ns</td>
</tr>
<tr>
<td>CV</td>
<td>28.9</td>
<td>26.8</td>
<td>37.29</td>
</tr>
</tbody>
</table>

Additionally, there were no significant differences of *Juniperus procera* seedling survival rate at different months.

Adaptive genetic differentiation between populations has been found to increase with geographical distance (Kristine Vander Mijnsbrugg et al, 2010). Genetic quality is of crucial importance in establishment of new stands, whereas decisions related to quantity and quality of the production must be based on experience from long-term provenance trials, genetic, eco-physiological and the present studies provide information about genetic variation, adaptability and resistance. The variability in phenotypic expression across an environmental gradient is a central gene-ecological trait, because this feature provides important information about adaptability.

Study at Kulumsa, Arsi Zone reveals that there were no significant differences among eight provenances of *Juniperus procera* in survival rate, height, root collar diameter and diameter at breast height (GirmaShumi et al, 2012). Opposed to the result of this study, provenances of *Acacia mangium*, a total of 24 local provenances of *Acacia mangium* were tested for height and/or diameter at breast height (dbh). The provenances were varied from site to site and showed significant differences among provenances tested (Harwood and Williams, 1991).
Conclusion and Recommendation

In general, there were no variations in germination and seedling growth at the field among provenances of *Juniperus procera* from Yedogit Michael, Adisge Abo, Warkaye Mariam and Jimma Gera. This means, the provenances has similar response on survival and other growth parameters at similar environments of Yedogit Michael. In general, by considering germination and other growth parameters of seedlings at all stages had poor performance even if the provenances from FRC (Jimma Gera). But, by analyzing the cost and accessibilities, the local provenances around Yedogit Michael are the best to use for the purpose of plantations by governmental and non-governmental organizations. Additionally, the mother trees should be treated with different silvicultural practices like soil management, open canopy, protection from animals, and artificial plantation for sustaining the seed sources.

References

Abraham Loha (2006) “Provenance variation in seed morphometric traits, germination, and seedling growth of *Cordia africana* Lam”


FAO (2010). “Global forest resources assessments”.


Yitebitu Moges et al., (2010). "Ethiopia Forest Resources Current Status and Future Management Options ECRN-UNDP ". 
Selection of different trees/shrubs species for rehabilitation of degraded lands in eastern Amhara, Ethiopia

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Abstract
The objective of the study was to compare the performance of selected indigenous and exotic tree species for rehabilitating the degraded lands. The plantation was established in 2008. Root collar, height and survival rate were measured for five years. There was a significant difference among the species in survival, height and root collar diameter in all agro-ecologies. The highest survival rate was observed from Leucaena glabrata, Dodonea angustifolia and Ziziphus spina christii 95.5%, 91.6% and 75 % respectively and the maximum heights and root collar diameters were recorded from Acacia saligna, and L.glabirata, respectively in the low-altitude. The highest survival rate in mid-altitude was observed in the species Cordia africana and A.saligna with values of 85.42% and 73.1%, respectively. The maximum heights and root collar diameters were attained by A.saligna, and C.africana. In the highland of Wollo A.saligna and A.decurrens performed well. In all agro-ecologies almost all the species that have maximum diameter and height growth have shown higher survival rate. The lowest survival rates, height and root collar diameters were recorded from C.equistifolia, J.curcu and S.susban in low-altitude, H.abyssinca and O.africana in high altitude and A. decurrence, A. abyssinica and C.equistifollia with a zero values in all parameters. It was concluded that the above listed tree species could be used for the rehabilitation of degraded lands for the intended agro-ecology.

Key words: Agro-ecology, Dodonea angustifolia Rehabilitation, Survival rate
Introduction

Dry land regions all over the world are increasingly facing with huge environmental challenges and are suffering from a dramatic loss of soil and biodiversity as a consequence of long-term land degradation (Reynolds et al. 2007; White and Nackoney 2003). “Land degradation” is the temporary or permanent lowering of the productive capacity of land (UNEP, 1992b). The term “degradation” is taken to mean a loss of forest structure, productivity and native species diversity. A degraded site may still contain trees (that is, a degraded site is not necessarily deforested) but it will have lost its former ecological integrity. In practice, however, degradation is much more subjective.

The world’s forests are the focus of international attention because of the many environmental issues being discussed recently. According to FAO (2002), cited from Rashid (2004), the world’s forests are estimated to cover 3.9 billion hectares or 29.8% of the earth’s land surface. From this total, an estimated 1,751 million hectares or 44.9% are located in the developed countries while the balance of 2,149 million hectares or 55.1% are within the developing countries. About 95% of these forests are natural forests while 5% being plantation forests. As globalization increases, the forest plantation has the potential to contribute to industrial wood and fiber in the coming decades. However, natural forest will not be able to supply all the demands. Therefore, plantations are expected to provide an increasing share of total industrial requirements and may even contribute a larger than natural forests (Hummel, 2001).

Extensive deforestation in the tropics has resulted in the formation of large areas of degraded vegetation that support greatly reduced biodiversity. Between 2000 and 2005, 13 million ha of forest was cleared annually worldwide with most of the deforestation occurring in the tropics (FAO 2005). Tropical deforestation is often followed by conversion of forestlands to agricultural uses mostly to replace land that has lost productivity due to unsustainable farming practices (Harwood et al. 1993). Such degraded lands are subsequently abandoned as wastelands that could potentially regenerate to forest but in areas subjected to intensive anthropogenic effects, the natural successional processes are often very slow because of the degradation of soil resources, recurring disturbance and isolation from intact forests.
Numerous studies have demonstrated that the establishment of tree plantations on degraded lands can reverse the effects of physical and biological barriers to forest regeneration and initiate the recovery of native forest communities (Lugo 1997, Parrotta et al. 1997). Most reforestation projects aim to restore productive capacity of the forest for future timber yield, but integrating short-term economic objectives with long-term biodiversity conservation is becoming increasingly important (Lugo 1997, Lamb 1998, FAO 2001). Due to the incomplete silvicultural knowledge of native tree species, a limited number of exotic timber species, e.g. species of Acacia, Eucalyptus and Pinus, and selected other species such as Gmelina arborea continue to be favoured in reforestation projects for their proven ability to grow rapidly on degraded lands (FAO 2001). The human disturbance which led to excessive deforestation and to a very limited forest cover in the Afromontane zone of Ethiopia, which forms a large part of the country, had been started around 5000 years BP with the inception of agriculture (Anon. 1997). Seasonal variation in the distribution of rainfall is also one of the most important and dominant ecological factors in tropical dry forests. Generally as few as two to three dry months period are sufficient to alter the composition and structure of the forest ecosystem (Murphy and Lugo 1986). The major forest destruction on Mount Badda in Arsi region (Ethiopia) for example is occurred around 1850 BP suggesting extensive deforestation in the Afromontane forests. Dodonaea is found among the species with increasing pollen quantities, which is believed to be associated with human disturbances on the vegetation (Bonnefille and Hamilton 1986). Carbon dating of charcoal buried in the agricultural highlands in Wollo dates back to 2450 BP (Hurni 1987). Besides deforestation for fuel and house construction, the inception of agricultural activities has very much influenced the natural vegetation of the Ethiopian highlands in general and that of Wollo in particular for several thousands of years (eg. Hurni 1982, Tewolde 1988, Mesfin 1991, Demel 1996). At the end of the 17th century a change in land holding system in northern Ethiopia also resulted in a total lack of responsibility for uncultivated rural land (Tewolde 1989). Local people could herd their animals and collect firewood and other products from uncultivated rural lands without restrictions (Tewolde 1989, Anon 1997). In recent times, there has been a dramatic decline of forest cover indicating rapidly vanishing forest resources in the country (Aklog, 1990).
Integrated conservation, rehabilitation and community-based management of natural resources are therefore of vital importance, not only to maintain local biodiversity or livelihoods, but also for the protection of off-site (downstream, urban) ecosystems and livelihoods (German et al. 2006). Forest rehabilitation by introduction enrichment plants is commonly practiced in Ethiopia for the purpose of regenerating degraded land forests. Before introducing any tree species to a given agro-ecology there is always a need for well conducted field trial for matching the species/provenance to a particular site (Zobel and Jabret 1984; AbebeYadessa, 2000; Mebrate Mihretu et al, 2004). Therefore, the main objective of this proposal is to select the best performing tree/shrub species for rehabilitation of degraded forest land (referred to forests where trees are removed and are being farmed in an unsuitable manner) in the three agro-ecologies of eastern Amhara, Ethiopia.

Material and Methods

Description of the study area

Kombolcha (Chorisa)
The Chorisa testing site for selection tree/shrub species for rehabilitation of degraded lands at mid-altitudinal agro-ecology is found in KaluWoreda, South Wollo Zone of Amhara Region. It receives rainfall of about 800 mm per annum. The slope is gentle and the soil is deep and black in color. It is about 15 km far from Borkena River that flows along the valley towards the Afar region.

Kobo
The tree planting (testing) site in the highly moisture stressed low-altitudeWoredas of North Wollo Administrative Zone is found in Kobo Woreda called keyou Gariya. The altitude is 1450 m.a.s.l and receives 692.8 mm/year (1973-2000 average, SARC 2010). The mean maximum and mean minimum temperature of the area is 30°c and 22°c. The soil type is Eutricfluvisols.

Were-illu
The tree planting(testing) sites in the highly moisture stressed high- altitudeWoredas of south Wollo Administrative Zone is found in Were-illuWoreda called Segno-Gabeya. As estimated
from the nearby meteorological station. The mean annual rainfall of Were-illuWoreda is 998.4 mm/year (1973-2000 meteorological data) with mean maximum and mean minimum annual temperature of 26.19°C and 13.43°C (1980-2000 meteorological data), respectively.

**Seedling preparation**

The seedlings of the testing species were raised first at Sirinka Agricultural Research Center nursery site and planted in the three testing agro-ecologies with recommended establishment techniques depending on the site condition. Different water-harvesting structures suitable for each testing site were constructed. The experiment was laid out in complete block design with three replications. The spaceings between seedlings in a plot, blocks and plots were 2m*2m, 3m and 2 m, respectively. A total of 16 seedlings/tree species were used for the experiment (Table 1) and the 12 trees are the boundaries; only the four inner tree species have been taken as a sample seedling for data collection and for final analysis. The analysis table indicates the values for the four central sample trees as the data was collected only from these trees/shrubs. The planting pattern of seedling was staggered following in constructed water-harvesting structures. Comparisons between treatments were carried out using ANOVA.

**Table 1. Species used for the experimentation for different agroecology**

<table>
<thead>
<tr>
<th>Tree/shrubs for low-altitude</th>
<th>Tree/shrubs for mid-altitude</th>
<th>Tree/shrubs for high-altitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ziziphus moutania, Leucaena glabirata, Dodonaea angustifolia, and Acacia saligna</td>
<td>Acacia saligna, Gravilla robusta, Olea europaea, and Cordia africana</td>
<td>Acacia saligna, Acacia melanoxilon, Chamaecytisus paleminensis, Dodonaea angustifolia, Acacia abyssinica, and Acacia decurrence</td>
</tr>
</tbody>
</table>

**Result and Discussion**

**Summary result for low-altitude agro-ecologies**

A total of seven species were planted to select or test tree/shrub species for rehabilitation of degraded lands in low-altitudinal agro-ecologies of Kobo (keyu-gariya). At the age of 39 months, root collar diameter, height, and survival rate were significantly different among species. The highest values of survival rates were observed from *L. glabirata, D. angustifolia and*
Activities of Forestry

The maximum heights were recorded from *A.saligna* and *L.glabirata*. The highest values of root collar diameters were recorded from *L.glabirata* and *A.saligna*. All the species that have maximum diameter and height growth have shown higher survival rate except in *A.saligna* which shows lower values of survival rates as compared to those which shown higher height and root collar diameters. The lowest survival rates, height and root collar diameters were recorded from *C.equistifolia, J.curcas* and *S.sesban* with a zero values in all parameters.

Table 2. Growth performance of different tree species at the age of 39 months (Kobo Woreda)

<table>
<thead>
<tr>
<th>Species</th>
<th>Root collar diameter (cm)</th>
<th>Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>L.glabrata</em></td>
<td>3.8a</td>
<td>168.42a</td>
</tr>
<tr>
<td><em>A.saligna</em></td>
<td>3.5a</td>
<td>199.7a</td>
</tr>
<tr>
<td><em>D.angussifolia</em></td>
<td>2.8b</td>
<td>160.5ba</td>
</tr>
<tr>
<td><em>Z.mouritania</em></td>
<td>0.8b</td>
<td>47.67bc</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>CV (%)</td>
<td>13.88</td>
<td>8.78</td>
</tr>
</tbody>
</table>

Figure 1. Survival rates of tree/shrub species tasted in the low-altitude agro-ecologies

Summary result for mid-altitude agro-ecologies

Seven species were used for this study. At the age of 39 months, root collar diameter, height, and survival rate were significantly different among species. The highest values of survival rates were observed from *C.africana* and *A.saligna* with values of 85.42% and 73.1%, respectively (Table 3).
2). This result is in line with Chibissa et al. (2006) that higher survival rate were obtained from A. saligna and C. africana but against for the results of G. robusta which show low survival rates. The maximum heights and root collar diameters were recorded from A. saligna and C. africana. All the species that have maximum diameter and height growth have shown higher survival rate except in O. africana which decreases to below 50%. The lowest values of survival rates, height and root collar diameters were recorded from A. deccurens, A. abyssinica and C. equisetifolia with a zero values and survival rate of 8.33%, 6.25% and 4.17%, respectively.

Table 2. Growth performance of different tree species at the age of 39 months (Kalu Woreda)

<table>
<thead>
<tr>
<th>Species</th>
<th>Root collar diameter (cm)</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. saligna</td>
<td>7a</td>
<td>231.2a</td>
</tr>
<tr>
<td>C. africana</td>
<td>0.3b</td>
<td>53.58b</td>
</tr>
<tr>
<td>O. africana</td>
<td>0.3c</td>
<td>34.67cb</td>
</tr>
<tr>
<td>G. robusta</td>
<td>0.1dc</td>
<td>17.67cb</td>
</tr>
<tr>
<td>LSD</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>CV (%)</td>
<td>12.89</td>
<td>18.5</td>
</tr>
</tbody>
</table>

Figure 2. Survival rates of tree/shrub species tasted in the mid-altitude agro-ecologies
Summary result for high land agro-altitude ecologies

At the age of 51 months, root collar diameter, height, and survival rate were significantly different among species. The highest values of root collar diameter were observed from *A.saligna*, *A.decurrens*, *A.abbyssinica* and *D.angustifolia* with values of 4.6cm, 2.5cm, 2.22cm and 1.64cm, respectively (Table 3). The maximum heights were recorded from *A.saligna*. The highest values of survival rate were obtained from *A.saligna* and *D.angustifolia* (58.33 % and 70.33 %), respectively which is in line with the results of Chibissa et al. (2006).

Table 3. Growth performance of different tree species at the age of 39 months (Wereilu woreda)

<table>
<thead>
<tr>
<th>Species</th>
<th>Root collar diameter (cm)</th>
<th>Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>A.saligna</em></td>
<td>4.6a</td>
<td>177.33a</td>
</tr>
<tr>
<td><em>A.decurrens</em></td>
<td>2.5ba</td>
<td>149ba</td>
</tr>
<tr>
<td><em>A.abbyssinica</em></td>
<td>2.22ba</td>
<td>96.5ba</td>
</tr>
<tr>
<td><em>D.angustifolia</em></td>
<td>1.64b</td>
<td>80.33ba</td>
</tr>
<tr>
<td><em>C.paleminensis</em></td>
<td>0.9b</td>
<td>33.33ba</td>
</tr>
<tr>
<td><em>A.melanoxilon</em></td>
<td>0.8b</td>
<td>44.17ba</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>CV (%)</td>
<td>51.81</td>
<td>30.41</td>
</tr>
</tbody>
</table>

Figure 3. Survival rates of tree/shrub species tasted in the high-altitude agro-ecologies
Results of the study reveal that enrichment planting can improve the degraded land with careful selection of species suitable to the locality (Mihretu et al., 2004). The establishment of tree plantations can reverse the effects of physical and biological barriers to forest regeneration and initiate the recovery of native forest communities (Lugo 1997, Parrotta et al. 1997). Trees can bring unproductive/degraded area to productive using different restoration techniques (Marcar et al. 1999).

The treatments reduce their growth and survival rates and finally gone out themselves from the competition through time because of different environmental, human and animal problems. Prolonged drought, tress-pass of animals, cutting of seedlings by the people and lack of awareness were the main problems for the rehabilitation of degraded lands. Most of the treatments have been dried every year in the months from April to June. Seasonal variation in the distribution of rainfall is also one of the most important and dominant ecological factors in tropical dry forests (FAO 2001). A few i.e. two to three dry months period are sufficient to alter the composition and structure of the forest ecosystem (Murphy and Lugo 1986). Most reforestation projects aim to restore productive capacity of the forest for future timber yield, but integrating short-term economic objectives with long-term biodiversity conservation is becoming increasingly important (Lugo 1997; Lamb 1998; FAO 2001).

Conclusion and Recommendation

Generally, selection of tree/shrub species for rehabilitation of degraded lands is a time intense and a work that can be identified after a long study and follow up. And hence, different factors affect the experiment as it was conducted through-out the year for long period. These factors had a negative impact in all tree growth parameters and generally affect the total results of the study. Application of silvicultural practices in addition to strong follow-up helps for the trees/shrubs species to be planted in the recommended particular agro-ecologies.

In this study, the selection was made for tree/shrub species which grow and survive better by resisting to these biotic and natural problems in the trial site. *D. angustifolia* shows a wide range of adaptability i.e. survive well both in the high-altitude and low-altitude agro-ecologies. It can grow form 500-2900 m.a.s.l Fekadu Fullas, 2001 and 1000-2,700 m.a.s.l.
Azene B. 2007. In addition to this, *A. saligna* also shows a better performance both in the low and mid-altitude agro-ecologies. Dry and Moist Kolla and Dry Weyna Dega agroclimatic zones (Azen B., 2007).

Finally, it was recommended that planting of *L. glabrata*, *D. angustifolia* and *Z. mouritania* in the low altitude agro-ecologies, *C. africana* and *A. saligna* in mid-altitude agro-ecologies and *A. saligna*, *A. decurrens*, *A. abyssinica* and *D. angustifolia* tree species in high-altitude agro-ecologies could be used for the better rehabilitation of degraded lands.

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Spatial Heterogeneity and Fragmentation Trends of Land Cover/Use Types and Ecosystem Services: The Case of Tara Gedam Watershed

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Abstract
Landscape fragmentation and heterogeneity have been well documented in different parts of the world, but their states and impacts in the Ethiopian highlands are poorly understood and documented. This study aims to spatially describe and analyze the state of heterogeneity and fragmentation of the land cover/use types (1957, 1980 and 2013) and the ecosystem services. The data were obtained from the aerial photograph and the field. Indices were used to analyze fragmentation and heterogeneity. A total of 1869 parcels were mapped using GPS. Average crop landholding size and number of parcels per household was 0.18 ha and 4.5, respectively. The density of cropland was 150 parcels/100 ha and of shrubland was one parcel/100ha. The highest number, density, dominance and smallest size were revealed for food providing parcels, which is an indication of fragmentation. However, cultural service providing parcels are larger in size and are limited for further subdivision. The increase in demand and the different use rights for ESs caused an increase in the heterogeneity of the LCUTs. The analyses indicated that there has been an increasing trend of land fragmentation. Such condition deteriorates productivity of the resource base and diminishes benefits from the ESs. Hence, in the case of highlands proper research, development and policy tools should be designed to halt further fragmentation. In addition, further studies are suggested on the implication of heterogeneity and fragmentation on the livelihood of local farmers and the choice of land management.

Key words: Cultural services, Density, dominance, Landscape metrics, Parcel
Introduction
The subsistence-oriented and the long history of agricultural practices in the highlands of Ethiopia have changed or modified the structural and functional unit of the landscape. This resulted in modification and change of the landscape and the likely occurrence of fragmentation and heterogeneity over the ecosystem processes and functions. The pattern, composition and characteristics of the landscape are affected by the level of subdivision (Donnelly and Evans, 2008). Parcelization of land is the result of landscape management and socio-economic changes (Demetriou, 2014). These situations have a direct influence on economic development and sustainability (Malinowska and Szumacher, 2013). In the Ethiopian highlands, population growth has proportionally increased the demand for agricultural products and is substantially linked to landscape transformations (Wondie et al., 2016). The increase in family size per household in the highlands reduces the average holding size per household. As the size of land holdings per household declines, the land use choices become more constrained and become too small to sustain family demands (Donnelly and Evans, 2008).

Some degree of land fragmentation may be beneficial to farmers as it creates opportunity to own plots of different quality, that will be useful to diversify crops, spread labor requirements and reduce production and price risks (Hung et al., 2007). However, land fragmentation is a major obstacle for sustainable rural development (Tan et al., 2006; Demetriou, 2014) and a threat to biodiversity (Wu et al., 2000) at the national/community level. Also, at the farm household level, fragmentation is a source for negative externalities (e.g. conflicts), higher costs of production, land degradation (Niroula and Thapa, 2005) and an impediment to adopt agricultural technologies (Hung et al., 2007). Landscape heterogeneity also influences ecosystem dynamics, structure and processes that, in turn, affect the sustainability of ecosystem services (ESs) (Turner et al., 2012). Status and quantitative information about heterogeneity and fragmentation of land resources (land cover/use and ESs) are still limited and underexplored for rational decision-making in the northwest Ethiopian highlands, specifically in Tara Gedam Watershed. Also, the causes and effects of fragmentation and heterogeneity of the landscape are less perceived and, hence, given less due attention by decision makers and resource managers. This resulted in underestimation of its effect during development planning.
and research. Consideration of parcellation must be a priority to enhance the productivity of small landholding farmers and choose the right land management intervention.

Land fragmentation has been well documented worldwide, but its trend and impacts in the highlands of northwest Ethiopia are not reported quantitatively using historical remote sensing and spatially referenced data. Most studies on farmland fragmentation, based on survey data, are analyzed using the production function, regression analyses and other econometric models (Xiao et al., 2013). However, these models fail to provide quantitative information and in a spatially explicit information on land fragmentation and heterogeneity to inform policy makers to take appropriate decisions. Furthermore, only few studies have examined the effects of landscape structure on the distribution of ESs (Eigenbrod, 2016) using geographically referenced data. There are different metrics/indices to explore spatial heterogeneity and fragmentation that are often used as indicators in determining the structure, function and mosaics of landscape elements (Yiet al., 1996; Hong, 1999; Leitaao and Ahern, 2002; McGarigal et al., 2002; Wu et al., 2002; Zha et al., 2008). The metrics/indices used are patches, patch density, patch diversity, richness, evenness, variation, contagion and fractal dimension. These indices provide information on the state of the mosaicked physical features (including LCUTs and ESs) and landscape changes (Leitaao and Ahern, 2002; Junhonget al., 2008; Malinowska and Szumacher, 2013) and help to deal with the relationship between landscape pattern and ecological processes (Cardille et al., 2005).

Understanding the status of land fragmentation and heterogeneity in the Ethiopian highlands is important to deliver decision support tools for policy makers. Such decision tools will enable relevant authorities to make appropriate interventions for reducing the pitfalls of fragmentation (Tan et al., 2006) and implement proper land management practices to enhance production in small landholding farmers. Therefore, the objective of this study was to spatially describe and identify the state of heterogeneity and fragmentation of the LCUTs and ESs at a fine scale.
Materials and Methods

Study area

The Tara Gedam watershed is located approximately at 12° 8' 30" - 12° 10' 30" N and 37° 43' 35" - 37° 46' 05" E in the Amhara National Regional State (ANRS), northwestern Ethiopia (Fig. 1). The watershed is characterised by a rugged topography with an altitudinal range of 2000 - 2600 m. The watershed covered an area of 900 ha.

Figure 1. Study area

The average annual rainfall is 1175 mm, with the peak rainfall season between June and August and the dry season between December and April. The monthly mean temperature ranges from 18 to 34 °C.

Tara Gedam watershed has 392 households with a total population of 1889. The livelihood of the local communities is based on mixed farming, which integrates crop with livestock production (Feyisa, 2012). About 16% of the people are food aid-dependent, and the remaining 84% are based on small-scale agriculture. Most of the crops produced are used mainly for household consumption while some part of the produce is used for income generation.
Methods

Data preparation
The 1957, 1980 and 2013 datasets were used to synthesize the land cover/use types. The land cover of 1957 and 1980 was acquired from the interpretation of the aerial photograph using photogrammetric procedures. The land cover of 2013 was mapped using the data obtained from a field survey using GPS. The 2013 dataset was used to analyse the landscape (spatial) metrics both for LCUTs and for ESs. However, the 1957 and 1980 aerial photographs were used for LCUTs only. The field dataset of 2013 was used to generate fine scale and vector-based information; whereas aerial photographs were interpreted on the basis of polygons produced from the field data.

Field data collection
The field survey to collect point data using GPS was carried out between 2012 and 2013 (dry months). Point data for each parcel of the farm were collected as land mapping units (LMUs). The point data misplacement, deviation and errors were corrected by re-measurement and by the support of Google Earth. These point data were area-referenced (converting point into polygon feature data) to calculate area and perimeter of each parcel. Area and perimeter were described in hectare and meter, respectively. The GPS data were used to estimate the gaps and spaces of land that remained underutilised between neighbouring parcels. Spatial explicit representation of parcels in map forms was conducted prior to landscape metrics analyses. Field verifications were undertaken to check and readjust the corresponding land user. Individual farmers were met informally in their farmland to understand the benefits and demands of the local residents due to change of fragmentation.

Using GPS data, LCUTs were categorised into seven types namely: cropland (CR), fruit-based agroforestry (FAF), forestland (FO), grassland (GR), Rhamnus-based agroforestry (RAF), shrubland (SH) and tree-based agroforestry (TAF).

Classification of aerial photographs
Polygons derived from GPS data were the basis to classify the aerial photograph into different LCUTs. The polygons of each parcel of cropland, forestland, grassland and shrubland obtained
using GPS were first mapped and prepared in vector format. The polygons in the vector (feature) format were superimposed on the stereo image. Assignment of the respective polygon to LCUTs of the 1957 and 1980 was conducted by marking manually (visual interpretation) using point feature. Point features were collected for the LCUTs, corresponding to the superimposed polygon data.

**Classification scheme**

The classification schemes (table 1), both for LCUTs and ESs, were defined and specified prior to analysis.

**Table 1. Land cover classes and ecosystem services used in the classification scheme.**

<table>
<thead>
<tr>
<th>Land cover/use types (LCUTs)</th>
<th>Characterization of features of the LCUTs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropland (CR)</td>
<td>The land used for cultivation of annual crops such as cereals, pulses and oil crops.</td>
</tr>
<tr>
<td>Forestland (FO)</td>
<td>Land covered with natural or plantation forest specifically used for fuelwood production, conservation and cultural values.</td>
</tr>
<tr>
<td>Grassland (GR)</td>
<td>Land under permanent pasture and grass used for cattle grazing or hay production.</td>
</tr>
<tr>
<td>Shrubland (SH)</td>
<td>Shrubs, bushes and young tree species managed for grazing, browsing and collecting wood for household use only.</td>
</tr>
<tr>
<td>Fruit-based agroforestry (FAF)</td>
<td>Land or a parcel used for annual crops integrated with fruit species (e.g. Maize ( \textit{Zea mays} ) L. with ( \textit{Carica papaya} ) L., ( \textit{Psidium guajava} ) L., ( \textit{Mangifera indica} ) L.).</td>
</tr>
<tr>
<td>Rhamnus-based agroforestry (RAF)</td>
<td>Land use integrating annual crops with ( \textit{Rhamnus prinoides} ) L’Herit in space and time.</td>
</tr>
<tr>
<td>Tree-based agroforestry (TAF)</td>
<td>Land use integrating annual crops with trees in different spatial and temporal combinations.</td>
</tr>
</tbody>
</table>

**Ecosystem services**

<table>
<thead>
<tr>
<th>Food</th>
<th>Products obtained from crops e.g. grains from maize, teff, sorghum and finger millet.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood protection and biodiversity conservation</td>
<td>Forest protected and used for environmental protection and conservation purposes.</td>
</tr>
<tr>
<td>Cultural/spiritual</td>
<td>Benefits obtained from the forests of churches or monasteries for spiritual/cultural services.</td>
</tr>
<tr>
<td>Feed</td>
<td>Products used by livestock, i.e. grasses or shrubs.</td>
</tr>
<tr>
<td>Wood-fruit</td>
<td>Products obtained from agroforestry practices, specifically from FAF, RAF and TAF in combination.</td>
</tr>
</tbody>
</table>
Landscape metrics

This study emphasises on spatial heterogeneity and fragmentation of the 2013 data for LCUTs and ESs using landscape metrics. The 1957 and 1980 data were used to analyse trend of heterogeneity. The analyses were focused on structural metrics, i.e. based on the physical configuration of LCUTs and the ESs. Spatial and non-spatial (statistical) analyses were conducted using the respective method (formula). The spatial component includes the attribute of classes and measurements, such as area (ha), perimeter, patch density, fractal dimension and effective mesh size (Rutledge, 2003). The non-spatial (statistics) describes the type and number of classes of LCUTs and ESs, proportions, coefficient of variation, human disturbances and diversity (McGarigal and Marks, 1994; Gustafson, 1998; Rutledge, 2003).

Heterogeneity

Heterogeneity gives emphasis on ecological structure represented by the mosaics of LCUTs and ESs. It was assessed by using patch mean, standard deviation, the coefficient of variation, class density, diversity and dominance (McGarigal and Marks, 1994; Gustafson, 1998; Zha et al., 2008; Malinowska and Szumacher, 2013). The homogeneity index (HI) was included to understand variations within and between classes. Standard deviation (SD) was used as a measure of absolute variation of the size of each parcel, but the coefficient of variation (CV) was used to measure relative variability (%) about the mean. The Shannon-Weiner index was chosen to calculate the diversity as an indicator of heterogeneity and complexity of LCUTs and ESs (Krauss et al., 2003; Morelli et al., 2013).

Data analyses

Fragmentation analyses

Fragmentation is often analyzed using indices (Hung et al., 2007). The attributes used to describe fragmentation were composition, configuration, shape and size (area) of each class. The quantitative characteristics used to analyse fragmentation were the number, size (area), perimeter, parcellation, proportion, class (patch) density (CD), shape complexity, human disturbance, fractal dimension and dispersion/aggregation of parcels (McGarigal and Marks, 1994). Shape complexity of LCUTs and ESs was measured using perimeter-to-area ratio and fractal dimension (Herold et al., 2005). The proportion of each class was used to look into the trend of human population with the subdivision of farm parcels.
Results

Characteristics of farm households

The average family size in Tara Gedam is 4.8 per household. The density of the population is about 213 individuals km$^{-2}$, which is slightly higher than the regional and national averages. The illiterate made up 30% of the 392 households. The average size of crop landholding per individual household was about 0.18 ha with an average number of parcels (plots) of 4.5, scattered in the watershed. However, the study conducted in the central highland of Tigray of northern Ethiopia showed that the average number of plots is three and the average land holding is 0.39 ha (Beyene et al., 2006). Irrigation accounted for less than 10% of the total cropland area. Major rainfed cereal crops grown in the watershed are sorghum \textit{(Sorghum bicolor (L.) Moench)}, maize \textit{(Zea mays L.)}, tef \textit{(Eragrostis tef (Zucc.) Trotter)} and wheat \textit{(Triticum aestivum L.)}. Agricultural technologies have been adopted by 3.7% of the households indicating a low technology transfer/adoption rate and, hence, poor extension services. The average livestock owned by the households was 4.5 TLU$^3$ and the dominant species kept are cattle and goat. Agroforestry, including production of \textit{Rhamnus prinoides} was also practiced on 23.5% of the cropland plots. Around 36 different species of trees were identified in the various land uses of the farm households (Zegeye et al., 2011).

Spatial distribution of land cover/use types

Current land cover of cropland (CR), forest (FR), fruit-based agroforestry (FAF), grassland (GL), Rhamnus-based agroforestry (RAF), shrubland (SH) and tree-based agroforestry (TAF) was estimated at 26.04, 24.89, 0.55, 20.83, 3.97, 4.8 and 5.6%, respectively. The land covered by cropland and agroforestry practices, in combination, increased by three-fold between 1957 and 2013 while the areas of shrubland, forestland and grassland declined by 30, 50 and 60%, respectively (Fig. 2). Agroforestry practices, i.e. FAF, RAF and TAF, evolved from the crop producing parcels due to the integration of annual crops (cereals, pulses and oil crops) with trees/shrubs including fruits. Here, the three agroforestry practices (FAF, RAF and TAF) were placed independently due to the variation of the components integrated. The net land gain of CR, FAF, RAF and TAF was from the conversion of forests, grassland and shrubland.

$^3$ 1 TLU = 250 kg live weight
Figure 2. Spatial distribution of LCUTs in 1957, 1980 and 2013.

Description of land cover/use types

In the case of Tara Gedam, the minimum parcel size was 0.026 ha. However, the Regulation No.51/2007 of the Amhara National Regional State (ANRS) set a minimum plot of land to be granted for any person may not be less than 0.2 ha (Council of ANRS, 2007). This showed the discrepancy between the reality on the ground and the land regulation. Shrubland, forestland and grassland exhibited higher values of standard deviation (SD) (arranged in increasing order) (Table 2). The SD of shrubland and forestland was higher because of the existence of higher area (ha) difference among sizes of parcels.

Table 2. The statistical description of the LCUTs in 2013.

<table>
<thead>
<tr>
<th>Land Cover/Use Type</th>
<th>Min (ha)</th>
<th>Max (ha)</th>
<th>Median (ha)</th>
<th>Mean (ha)</th>
<th>Sum (ha)</th>
<th>SD (ha)</th>
<th>CV (%)</th>
<th>Skewness (-)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropland</td>
<td>0.03</td>
<td>1.11</td>
<td>0.14</td>
<td>0.18</td>
<td>230.8</td>
<td>0.11</td>
<td>65</td>
<td>2.3</td>
<td>1333</td>
</tr>
<tr>
<td>Fruit-based Agroforestry</td>
<td>0.05</td>
<td>0.42</td>
<td>0.13</td>
<td>0.16</td>
<td>4.9</td>
<td>0.07</td>
<td>44</td>
<td>1.9</td>
<td>31</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.18</td>
<td>23.73</td>
<td>1.93</td>
<td>2.72</td>
<td>184.6</td>
<td>3.41</td>
<td>126</td>
<td>4.3</td>
<td>68</td>
</tr>
<tr>
<td>Rhamnus-based Agroforestry</td>
<td>0.04</td>
<td>0.88</td>
<td>0.15</td>
<td>0.19</td>
<td>35.2</td>
<td>0.12</td>
<td>65</td>
<td>2.7</td>
<td>190</td>
</tr>
<tr>
<td>Shrubland</td>
<td>0.47</td>
<td>19.63</td>
<td>2.48</td>
<td>4.72</td>
<td>42.5</td>
<td>5.88</td>
<td>124</td>
<td>2.5</td>
<td>9</td>
</tr>
<tr>
<td>Tree-based Agroforestry</td>
<td>0.03</td>
<td>3.08</td>
<td>0.18</td>
<td>0.24</td>
<td>49.7</td>
<td>0.27</td>
<td>116</td>
<td>7.5</td>
<td>211</td>
</tr>
</tbody>
</table>

Min = Minimum, Max = Maximum, SD = Standard deviation, CV = Coefficient of variation and N = Number of parcels.

The CV of FAF (44%), CR (65%), RAF (65%) and FR (71%) were lower compared with those of GL (126%), SH (124%) and TAF (116%) (Table 4). All LCUTs showed positively skewed distribution, indicating most of them have smaller parcel sizes (ha). The higher skewness was observed for TAF.
Spatial distribution of ecosystem services

The spatial distribution of the farm parcels providing various types of ESs in 2013 was dominated by food, feed, fruit and wood, whereas cultural/spiritual services accounted for the least coverage (Fig. 3). About 58% of the watershed area was covered by food, feed, fruit and wood (subsistence providing) producing parcels. Food producing parcels covered the largest (26%) and those providing cultural/spiritual services covered the least (8%). The flood protection and biodiversity conservation areas were estimated to cover about 22% of the parcels. The remaining land was covered by asphalt (road), paths, marginal/underutilised and rock.

![Ecosystem services in 2013](image)

Figure 3. Spatial distribution of the various ecosystem services.

Description of ecosystem services

The mean area covered by parcels used for cultural/spiritual (CS) services was 8.5ha and was the highest. For parcels used for protection/biodiversity conservation (PC) and feed (FE), the mean areas were 5.9 and 3 ha, respectively. The SD also followed a similar trend. The parcels used to provide cultural/spiritual, protection/biodiversity conservation and feed services covered areas of 6.2, 5.2 and 4.1 ha, respectively (Table 3).
Table 3. Statistical description of the parcels is providing ESs.

<table>
<thead>
<tr>
<th>Ecosystem services</th>
<th>Min (ha)</th>
<th>Max (ha)</th>
<th>Median (ha)</th>
<th>Mean (ha)</th>
<th>Sum (ha)</th>
<th>SD (ha)</th>
<th>CV (%)</th>
<th>Skewness (%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultural/Spiritual (CS)</td>
<td>2.50</td>
<td>21.38</td>
<td>8.45</td>
<td>5.8</td>
<td>67.6</td>
<td>6.22</td>
<td>1.49</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Food (FO)</td>
<td>0.03</td>
<td>1.11</td>
<td>0.17</td>
<td>0.14</td>
<td>230.9</td>
<td>0.11</td>
<td>6</td>
<td>2.30</td>
<td>1333</td>
</tr>
<tr>
<td>Feed (FE)</td>
<td>0.18</td>
<td>23.73</td>
<td>2.96</td>
<td>1.93</td>
<td>189.7</td>
<td>4.09</td>
<td>3.63</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Protection/Conservation (PC)</td>
<td>0.84</td>
<td>19.6</td>
<td>5.95</td>
<td>4.33</td>
<td>190.5</td>
<td>5.19</td>
<td>1.26</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Wood-food-fruit (WF)</td>
<td>0.03</td>
<td>3.08</td>
<td>0.21</td>
<td>0.16</td>
<td>89.6</td>
<td>0.21</td>
<td>19</td>
<td>8.59</td>
<td>432</td>
</tr>
</tbody>
</table>

Min = Minimum, Max = Maximum, SD = Standard deviation, CV = Coefficient of variation and N = Number of parcels.

The results showed that CVs of the parcels providing FE, CS and PC were 565, 458 and 452%, respectively (Table 3). However, FO providing parcels showed the smallest CV value, i.e. 6%.

The least variability in size (ha) of food providing parcels is due to higher modification during ploughing and frequent subdivision of the land to share the land for the extended family. These cases have implications on parcellation, fragmentation and heterogeneity of the farm parcels. However, CS and PC providing parcels of churches and state forests are relatively stable and face little change or modification. A little change observed in the parcels of forests in the watershed because of the reason that churches forests are given respect for spiritual purpose and protection of state forests are enforced by laws.

Landscape metrics/indices for land cover/use types

The highest and lowest numbers of parcels were shown for CR (1333) and SH (9), respectively. Similarly, the highest and lowest densities were observed for CR (150/100ha) and SH (1/100ha), respectively. The calculated values of the metrics/indices were presented for the 2013 LCUTs (Table 4).
Table 4. Landscape metrics/indices of the LCUTs in 2013.

<table>
<thead>
<tr>
<th>LCUT</th>
<th>Number of parcels</th>
<th>CD (N/100 ha)</th>
<th>SC (m/ha)</th>
<th>Mean (ha)</th>
<th>SD (ha)</th>
<th>CV (%)</th>
<th>HI</th>
<th>DO</th>
<th>PAR (%)</th>
<th>FD (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR</td>
<td>1333</td>
<td>150</td>
<td>1034</td>
<td>0.14</td>
<td>0.11</td>
<td>65</td>
<td>1.0</td>
<td>2.97</td>
<td>71.19</td>
<td>1.69</td>
</tr>
<tr>
<td>FR</td>
<td>27</td>
<td>3</td>
<td>165</td>
<td>5.76</td>
<td>5.77</td>
<td>71</td>
<td>0.6</td>
<td>1.28</td>
<td>1.39</td>
<td>1.44</td>
</tr>
<tr>
<td>FAF</td>
<td>31</td>
<td>3</td>
<td>1091</td>
<td>0.13</td>
<td>0.07</td>
<td>44</td>
<td>1.0</td>
<td>1.48</td>
<td>1.60</td>
<td>1.59</td>
</tr>
<tr>
<td>GR</td>
<td>68</td>
<td>8</td>
<td>322</td>
<td>1.93</td>
<td>3.41</td>
<td>126</td>
<td>0.8</td>
<td>1.69</td>
<td>3.58</td>
<td>1.52</td>
</tr>
<tr>
<td>RAF</td>
<td>190</td>
<td>21</td>
<td>989</td>
<td>0.15</td>
<td>0.12</td>
<td>65</td>
<td>1.0</td>
<td>2.22</td>
<td>10.10</td>
<td>1.64</td>
</tr>
<tr>
<td>SH</td>
<td>9</td>
<td>1</td>
<td>199</td>
<td>2.48</td>
<td>5.88</td>
<td>124</td>
<td>0.6</td>
<td>0.89</td>
<td>0.43</td>
<td>1.40</td>
</tr>
<tr>
<td>TAF</td>
<td>211</td>
<td>24</td>
<td>858</td>
<td>0.18</td>
<td>0.27</td>
<td>115</td>
<td>1.0</td>
<td>2.25</td>
<td>11.22</td>
<td>1.63</td>
</tr>
</tbody>
</table>

CD = class density, SC = Shape complexity, SD = Standard deviation, CV = Coefficient variation, HI = homogeneity index, DO = Dominance, PAR = Parcellation and FD = Fractal dimension.

The shape complexity (m ha⁻¹) of FR, SH, GR, TAF, RAF, CR and FAF showed an increased order (Table 4). The higher the shape complexity, the higher is the modification of the land parcels and resulted in fragmentation (Gautam et al., 2003; Rutledge, 2003). The parcellation (PAR) was highest for CR (71.2%) and lowest for SH (0.43%). This parcellation is the result of the effect of land management by local farmers. Soil erosion also contributed to the subdivision of the parcels into smaller parts. The CR is the most dominating among LCUTs, whereas the SH is the least covered. Cropland dominated as a result of the conversion of one LCUT to cropland because of increase of human food demand. The homogeneity index (HI) for FAF, CR, RAF and TAF was closer to one. The value closer to one showed that the parcels have insignificant variation in size (ha) due to the frequent subdivision. However, SH and FO showed higher differences among parcel sizes due to the level of disturbance and the type of use right or ownership.
An overview of the trend of metrics/indices was seen to partially characterise fragmentation of the LCUTs (Table 5) during the 56 years covered by the study.

Table 5. Landscape metrics/indices for the LCUTs in 1957, 1980 and 2013.

<table>
<thead>
<tr>
<th>Year</th>
<th>PR</th>
<th>EMS</th>
<th>DI</th>
<th>SC</th>
<th>HD</th>
<th>DO</th>
<th>FD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1957</td>
<td>4</td>
<td>294.00</td>
<td>0.48</td>
<td>548.74</td>
<td>0.09</td>
<td>2.77</td>
<td>1.63</td>
</tr>
<tr>
<td>1980</td>
<td>4</td>
<td>187.94</td>
<td>0.60</td>
<td>546.64</td>
<td>0.87</td>
<td>2.65</td>
<td>1.63</td>
</tr>
<tr>
<td>2013</td>
<td>7</td>
<td>159.71</td>
<td>0.65</td>
<td>554.22</td>
<td>2.48</td>
<td>2.63</td>
<td>1.64</td>
</tr>
</tbody>
</table>

PR = patch richness, EMS = Effective mesh size, DI = Diversity index, SC = Shape complexity, HD = Human disturbance, DO = Dominance and FD = Fractal dimension.

The number of parcels, class density (CD) and dominance were the highest and lowest for CR and SH, respectively (Table 4). The values of fractal dimension (FD) of CR (1.69 m²) and TAF (1.63 m²) showed higher values, indicating less fragmentation. The patch richness (PR) increased from 4 to 7 from 1957 to 2013 (Table 5). This result was revealed because of the detailed spatial characterization of the 2013 mapping. Similarly, diversity index (DI) increased from 0.48 to 0.65, and human disturbance (HD) showed an increase from 0.09 to 2.48 when traced from 1957 to 2013. The DI showed a positive correlation with HD. This implies that the local people required various types of products from the ecosystem over time. The increased demand causes the change or modification of the land. This change resulted in the availability of heterogeneous LCUTs to obtain the desired ESs.

The heterogeneity of the LCUTs was revealed by the HD value that increased from 0.09 in 1957 to 2.48 in 2013. This, in turn, resulted in the decreasing of naturalness and semi-naturalness of the LCUTs. For example, historical data analyses showed that the natural forests of churches and the community owned forests get shrunk due to conversion into other LCUTs. FD exhibited slight change, i.e. from 1.63 to 1.64 m², and no change was observed between 1957 and 1980. In both cases, it uses the same polygons for analysis and, hence, had more or less similar values. Hence, FD cannot be used as a good indicator to understand the trend of fragmentation among years.
However, the effective mesh size (EMS) value showed a decreasing order, i.e. from 294 ha in 1957 to 159.7 ha in 2013. Besides, the dominance (DO) showed a decline. These cases showed the intensity of fragmentation increased. A larger value of DO (2.8) in 1957 was revealed and may indicate the dominance of one or more LCUTs. This value may indicate the lowest human disturbance. However, the low DO (2.63) in 2013 indicated the representation of different LCUTs dominated by CR. The decreasing DO may show the replacement of different LCUTs into CR and/or the replacement of one by the other due to human intervention. The result is supported by Wondie et al. (2016). Consequently, the landscape is dynamic and likely to change.

Metrics of ecosystem services

From the analyses of the 2013 data, the FO producing parcels showed the highest number of parcels (1333) and the lowest number of parcels was observed for CS. The FO and CS producing parcels showed a density of 150/100 and 1/100 ha, respectively. Due to the human disturbance, the mean and the SD values of the FO and WF producing parcels were the least compared with other ES providing parcels (Table 6). The human modification and change of parcels resulted in having smaller farm parcel size. These ESs also showed the highest FD due to high fragmentation as a result of modification and frequent changes.

Table 6. The metrics of ecosystem services recorded in 2013.

<table>
<thead>
<tr>
<th>Ecosystem services</th>
<th>Number (N)</th>
<th>CD (N/100 SC ha)</th>
<th>Mean</th>
<th>SD</th>
<th>CV (%)</th>
<th>HI</th>
<th>DO</th>
<th>PAR (%)</th>
<th>FD</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS</td>
<td>8</td>
<td>1</td>
<td>166.4</td>
<td>8.4</td>
<td>6.2</td>
<td>73.6</td>
<td>0.5</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>FO</td>
<td>1333</td>
<td>150</td>
<td>1034.0</td>
<td>0.2</td>
<td>0.1</td>
<td>64.9</td>
<td>1.0</td>
<td>2.9</td>
<td>71.2</td>
</tr>
<tr>
<td>FE</td>
<td>64</td>
<td>7</td>
<td>301.1</td>
<td>3.0</td>
<td>4.1</td>
<td>138.1</td>
<td>0.8</td>
<td>1.7</td>
<td>3.4</td>
</tr>
<tr>
<td>PC</td>
<td>32</td>
<td>4</td>
<td>189.0</td>
<td>6.0</td>
<td>5.2</td>
<td>87.1</td>
<td>0.7</td>
<td>1.4</td>
<td>1.7</td>
</tr>
<tr>
<td>WF</td>
<td>432</td>
<td>49</td>
<td>922.8</td>
<td>0.2</td>
<td>0.2</td>
<td>100.5</td>
<td>1.0</td>
<td>2.5</td>
<td>23.0</td>
</tr>
</tbody>
</table>

CD = class density, SC = shape complexity, SD = Standard deviation, CV = Coefficient of variation, HI = Homogeneity index, DO = Dominance, PAR = Parcellation and FD = Fractal dimension.

The homogeneity index (HI) for FO and WF was closer to 1, whereas that of CS was the least (0.67). This showed the sizes (ha) of land parcels providing FO and WF had insignificant
variation due to human modification and land use dynamics. However, CS and PC exhibited irregularities because of their semi-naturalness and less human intervention.

Discussion

The metrics of land cover/use types

The result showed an increase in PR, DI, HD and FD since 1957. However, EMS showed a decline. SC did not show consistent changes because of unplanned change of parcel perimeter and area due to socioeconomic interests and biophysical situations. The DI as an indicator for heterogeneity also increased from 0.48 to 0.65. The increase in diversity of LCUTs was obtained because of the level of detail and finer scale.

Heterogeneity in the context of this study is the spatial variation, composition and size due to land management practices. The best explanatory index for heterogeneity is diversity (Wu et al., 2002; Song et al., 2008). The results showed an overall increase of diversity, i.e. from 0.48 in 1957 to 0.65 in 2013. This showed an extensive modifications of LCUTs were practiced since the 1950s. These dynamics of LCUTs increased due to the conversion of one LCUT to another to obtain the respective ES. For example, forestland was converted into cropland because of food demand by the increased population (Wondie et al., 2016). The detailed information obtained from 2013 data revealed the presence of different agroforestry practices due to the requirement for diverse ESs by the local people.

The presence or absence of agroforestry practices (FAF, RAF and TAF) in the watershed were the main causes for the change of diversity value and improved the availability of various products. The spatial heterogeneity was caused by land subdivision, policy (land redistribution), household characteristics, land quality and environmental gradients. The higher values of SD for forestland, shrubland and grassland indicated size irregularities due to less modification and the variability of size due to ownership reason. For example, the parcel size for the individual farmer for grassland was a smaller size, whereas the community owned grassland is relatively larger. The higher value of CV indicates the lower impact of human modification and restructuring. On the contrary, the cropland and other LCUTs showed lower SD and CV. The lowest SD, relative uniformity, distinctive spatial pattern and sharp edges
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within the same LCUTs were the consequence of human modification and restructuring of parcels for different uses. Also, the higher density (e.g. 150 parcels per 100 ha for cropland) is the result of fragmentation, modification and extensive spatial distribution. Moreover, the skewness of the parcel size also indicates the degree of heterogeneity. Heterogeneity in turn is the result of fragmentation. A low dominance (DO) value implied that the diversity index (DI) is close to Hmax indicating the higher diversity of a class. For example, the DO of the 2013 was 2.63, the Hmax was 3.27, and the DI was 0.63. Overall, the SD, CV, density and skewness described quite well the spatial heterogeneity discrepancies among LCUTs.

Fragmentation of LCUTs was explained using number of parcels, SD, CV, FD and EMS. The higher number of parcels was revealed from CR, FAF, RAF and TAF. This attribute is because of conversion and subdivision of other land uses, e.g. forests and grasslands into these LCUTs. The number and density of croplands were the highest, which is an indication of higher fragmentation (subdivision) per unit area of croplands in Tara Gedam Watershed. The fragmentation status was also complemented by effective mesh size (EMS). The EMS showed a decreasing trend from 1957 to 2013. This implied that the watershed became more fragmented. The lower the effective mesh size, the more fragmented is the landscape, and the more disconnected the parcels are or vice versa (Jaeger, 2000; Baldi et al., 2006).

Case study/historical approach

The average number of plots for farming (agricultural practices) other than forestland and shrubland was 4.8 plots per household, but the report of Gebreslassie (2006) showed that the average number of farm plots in Ethiopia is 2.3 per household and (Beyene et al. (2006) showed that the number of plots per household is 3. Hence, Tara Gedam Watershed showed higher fragmentation of farm plots compared with the national and regional average. Inheritance from family or relatives highly influences the trend of fragmentation. Ato Mersha (80 years old farmer born, raised and still living in Tara Gedam Watershed) had experienced three generations of land parcelization and witnessed fragmentation as a life long experience. Large plots were first divided into the number of the children and the farmer (Fig. 4). Later, the children subdivide their parcel into the number of their children plus for the farmer, and this trend continued over generations.
Figure 4. Trend of parcellation of cropland over time.

The use right has influence and, in general, government and church owned parcels showed less fragmentation because of administration/ownership reasons.

**Status of ecosystem services**

Class size of the LCUTs has the influence on the capacity of land to produce ESs to support the livelihoods of the local people. The smaller-sized parcels of cropland, fruit-based agroforestry, *Rhamnus*-based agroforestry and tree-based agroforestry practices provided food, feed, fruit, wood and related products. Smaller farm parcels produced insufficient products to support the household. This is because subdivision minimised effective production area (Donnelly and Evans, 2008). The presence of larger-sized plots, mainly, administered and managed by the Government and churches are allocated to forestland, which provides protection/conservation and cultural/spiritual services. For example, larger-sized patches of government-protected forest provide flood protection, headwater protection, microclimate improvement and biodiversity conservation. The concentrated patches of forest administered by the churches gave cultural, spiritual and religious services. The result showed that size determines the type of ESs obtained in the watershed. This, in turn, showed that parcel size has an effect on the type and amount of ESs produced.

Size also governs the diversification of products per unit area. The smaller the size of the parcels, the lesser is the possibility of product diversification. Most small farms are subjected to mono-cropping and are allocated to annual crops because of limitation of space. As a result, most of the farm plots (approximately 72%) have no timber or fruit trees and lesser activities of
soil and water conservation structures. This is the outcome of land fragmentation that leads to low integration of farm practices for diversified products. Food producing parcels can be examples for this problem.

**Heterogeneity of ecosystem services**

Tara Gedam Watershed is endowed with a diverse mosaic of ESs due to the needs added by the farmers, community, government and churches. Farmers focused on food, wood, feed and income generation. Community managed land parcels are mainly used for grazing and browsing. State protected forests, shrublands and grasslands are used for protection and conservation purposes, while the church-owned forests provide cultural and spiritual services. The trend in increased population has increased the land use intensification and diversification because of diversified demands. As a result, the diversity index (DI) for the mosaic of LCUTs increased from 1957 to 2013. The DI indicated the heterogeneity of LCUTs, which, in turn, indicated the increase in the demand of the people residing in the watershed. Since LCUTs are sources for ESs, the higher modification of LCUTs implicitly indicates human modification of the environment to obtain various types of ESs. This, in turn, contributed to the availability of diverse ESs.

Tara Gedam Watershed is endowed with diverse ESs compared with the nearby landscapes. The presence of protected forests for conservation and cultural/spiritual services indicated the diverse characteristics of ESs. This might be the consequence of various interested parties (farmers, communities, government and churches). Due to its uniqueness and presence of heterogeneous ES, different ecological studies have been conducted in the Tara Gedam Watershed, such as floristic diversity (Zegeye et al., 2011), the pattern of forest seed dispersal (Abiyu, 2012) and soil variability (Workneh, 2008; Feyisa, 2012).

Landscape diversity has been suggested as a key measure to mitigate the decline of farmland biodiversity in intensive agricultural contexts (Chiron et al., 2010). Nevertheless, care should be taken in the interpretation of heterogeneity. It cannot be used as an absolute indicator for internal qualities of the environment. More diverse does not necessarily mean that the ecosystem is healthy and sustainable. From the ecological point of view, frequent change and
modification of the LCUTs may increase heterogeneity (diversity of mosaicked components). However, it may end up with negative implication on the environment and may challenge sustainable productivity. Tews et al. (2004) noted that from an ecological point of view, heterogeneity could be perceived as fragmentation depending on the spatial scale and species preferences.

**Fragmentation of ecosystem services**

The average landholding size and number of plots in ANRS is less than one hectare and 4.6, respectively (SANYU Consultants, 2009, unpublished). In the case of Ethiopia, the average number of plots is 2.3 per household (Gebreselassie, 2006). The average landholding size and number of plots in the central Tigray is 0.39 ha and 3, respectively (Beyene et al., 2006). However, in the case of Tara Gedam Watershed, the average size and number of plots providing different ESs were 0.78 ha and 4.5, respectively. A higher number of farm plots and smaller land size per household was documented. This is the outcome of fragmentation, which results in a negative impact on land productivity, agricultural technology use and sustainability.

**Sustainable provisions of ESs from Tara Gedam watershed have been affected by the following social and policy/institutional factors:**

The land is provided by parents for children as a capital to sustain their livelihoods in the form of inheritance or gift. Parcels are subdivided into the number of children or family members. As the number of family members increases, the fragmentation (i.e. a subdivision of land parcels) is proportionally increased. The redistribution of land among family members results in land fragmentation (Jose and Padmanabhan, 2016).

Resettlement programme in the former time were carried out to cluster settlements in one place for administration, counselling and rehabilitation purposes. In the new area, they were provided with a parcel of land for farming. Moreover, farmers have the right to use the land at their previous village. Consequently, it resulted in the parcels distributed sparsely and becoming fragmented and, hence, undervalued.
During land redistribution, the difference in land quality was balanced by providing better and least quality land for equity, irrespective of considering the location of the farm plots and the consequence of fragmentation.

There were restrictions on the movement of livestock from one village to another for grazing land. This results in conflict among villages. The government assigned grazing lands based on the proximity of the villages by disregarding the number of livestock to resolve the conflict on grazing land. There is limited space as a corridor for the movement of livestock. This makes the fragmentation among LCUTs worse for the production of feed and food.

Competition among different demands and LCUTs increased the conversion of one LCUT to another, e.g. conversion of forests to crop cultivation. On the other hand, forests used for protection/conservation and cultural/spiritual services are relatively permanent. They are not part of the rotational farming and, therefore, do not change on an annual basis. The severe soil erosion in this watershed contributes to land subdivision, which resulted in land degradation and the land parcels marginalized for production.

**Human effects on ecosystem services**

The study revealed that the indices of HD in 1957, 1980 and 2013 were 0.09, 0.87 and 2.48, respectively. The HD indices significantly increased suggesting the influence of human activities in the fragmentation of food, wood and fruit providing parcels. This result concurs with those of Hong (1999) and Herold et al. (2005) who reported that the higher the HD, the stronger is the human modification or change on ecosystem and the probability of mismanagement, especially, in the case of developing countries. The evidence of human impact was complemented by other indices, such as SD, CD and CV values. The impacts of human action were revealed by having lower SD, lower CV and higher CD values. Besides, the extent of fragmentation for cropland and TAF was shown with the highest FD values, indicating fragmentation.

It is quite clear that increased population density leads to increased human settlements. In the case of food insecure regions, land located in the vicinity of settlements is allocated for
cropland or agroforestry practices. Metrics and indices showed higher fragmentation and heterogeneity for these LCUTs and their respective ESs. This explicitly showed the direct relationship between the metrics and socioeconomic activities, and that socioeconomic activities are the primary causes of heterogeneity and fragmentation. Such conditions as the absence of off- and non-farm employment/incomes intensified the fragmentation in the watershed. The higher the fragmentation is, the more likely that the economy of the local farmers is unstable and the more probable is the persistence of food insecurity. Fragmentation, socioeconomic situation and the economy of the people showed interconnectedness. In the case of the data obtained in 2013, about 13% of the watershed remained underutilised or as path because of the space left as the demarcation between neighbouring parcels to avoid conflict.

Consequences of fragmentation

The decrease of land holding size per farm household and the dispersion of farmland in Ethiopia were reported by different scholars (Gebreselassie, 2006; Headey et al., 2014; Josephson et al., 2014). The landscape metrics/indices in this study indicated how the fragmentation is worsening over time. The existing fragmentation has different negative consequences. It caused difficulty for farm operations, high cost of production, wastage of time by walking long distance for work, lower possibility of land management, less frequent monitoring, risk of dispute between neighbors (e.g. farmers who owned land in the upper part of the given parcel may not safely remove runoff) and less interest or difficulty to grow economically important timber and/or fruit trees. In the case of communal grazing land, fragmentation caused overstocking of cattle due to the small parcels allocated for grazing. Overstocking, in turn, caused soil compaction and soil erosion. This resulted in land degradation and deterioration of land productivity. Shrinkage of land due to fragmentation also creates difficulty in applying land management practices. Space left between neighbouring farm parcels is under-utilised, contributing to the decline in land productivity.

From ecological point of view, fragmentation disconnects ecological processes and threatens the ecosystem (Joly et al., 2003; Rutledge, 2003; Echeverria et al., 2006), decreases habitat quality or loss of habitat and may result in migration or extinction of local population, decreases the diversity of species (Eriksson et al., 2002), negatively affects seed dispersal of indigenous
species (e.g. triggered by animals) due to habitat isolation, limits the movement of wildlife and population viability, and gives less emphasis on protection and conservation of the fragile ecosystems. The regeneration of shade-tolerant species that are dependent on biotic pollinators are negatively affected by the fragmentation (Bustamante and Castor, 1998). Lack of regeneration of these species negatively influences the ecosystem productivity and the diversity of species.

Conclusions and implications
Tara Gedam Watershed represents densely populated areas compared with other highland parts of Ethiopia. Hence, it experiences more parcellation of land because of inheritance or gift, poor land management and nature of biophysical configuration than similar farming communities. Tan et al. (2006) who studied in China showed that two-thirds of the increase in the number of plots and one-third of average plot size resulted from an increase in family members in a household. It is observed that the fragmentation of land resources, in general, and ESs, in particular, retard efforts of the local people geared towards food security. A deterioration of the landscape and decline of production per unit area were observed due to the subdivision of the land. This parcellation resulted in the decline of efficiency of agricultural production and modernization, wastage of the workforce and increased production costs. These, in turn, worsen availability of food required to feed the increased population and influence the agricultural production negatively. Therefore, this study recommends understanding the connotation of land fragmentation and its implication on ESs provision for promoting sustainable land management.

From the findings of our study, we recommend that the FD index, which has been used often, is not a good indicator to understand the trend of land fragmentation over the years and shall not be used solely for such studies. Otherwise it has to be used in compliment with other measurements.

Fragmentation reduces the effective land that can be used for the provision of ESs. Special efforts are needed to maximise the yield per unit area to fill the gaps between the existing food demand and supply. Land consolidation is one of the efforts to optimize land productivity.
Land consolidation through clustering a group of farmers who have land adjacent to each other is very necessary. This in turn requires political decision to bring all neighboring farmers on board for decision and reach to consensus to cluster their land.

Knowing minimum farm parcel size is also required to choose and implement best possible solutions and/or suitable land management practices. In addition, proactive measures, such as off-farm activities, family planning and agriculture intensification per unit area need to be considered to balance the supply and demand for agricultural products. The increase in land coverage for crop production can be a solution to compensate the increased food demands. However, cropland expansion stagnated (Wondie et al., 2016) due to land policy restriction. This can be compensated by using improved agricultural technologies (e.g. improved crop varieties) and improved land management, as recommended by Kruseman et al. (2006) for the highlands of Ethiopia.

Unless a fixed land use system that recognizes landscapes and associated potentials is established, we do not think that people will continue to reap the ESs and improve their livelihoods with the observed dynamic systems.

The results revealed that land fragmentation is one of the underlying causes for the presence of heterogeneous LCUTs and ESs. The heterogeneity of the ESs is also the result of the existing uneven land distribution and diverse demand of residents in the watershed. However, Turner et al. (2012) indicated that fragmentation may either increase or decrease landscape heterogeneity. In other words, there is no optimal mosaic of LCUTs that will increase all ecosystem services.

The spatial arrangements of LCUTs coupled with fragmentation constrain the production of ESs. Further study is needed to ascertain the relationship between farmland fragmentation and economic loss under different agroecologies and social structures. Strategic policy decisions on land consolidation and farmland transfer in the form of gift have to be considered to retard further fragmentation. The trend of fragmentation and heterogeneity require development of agricultural technologies suited to small holding farms (e.g. an average size of 0.17 ha) to enhance productivity.
Acknowledgement

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Estimation of biomass and carbon stock of *Acacia decurrens* forest under farmers’ management using allometric models

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**Abstract**

The quantification of carbon stocks in the forest ecosystems is important to know the carbon cycle, sinks, forest carbon accounting and to guide forest management decisions of the farmers. This study aimed to estimate the biomass and carbon stock of *Acacia decurrens* under smallholding plantation using different allometric equations. The study was carried out in Fagita Lekuma district. Reconnaissance survey was conducted prior to start field work to design the sampling. The four years old plantations were selected to measure diameter, height, and density in nine sites. In total, 2961 trees were sampled from farmer managed stands. The biomass and carbon stock were estimated using different allometric equations. The diameter ranged 11 - 15 cm the height ranged from 7 to 10 m in four years’ time. The total basal areas for all sites ranged from 4.1 to 5.8 m\(^2\)/ha. The biomass estimated ranged from 1 to 38 Kg tree\(^1\), the carbon 0.47 - 17.91 kg tree\(^1\) carbon (only bole) and the CO\(_2\) varied from 1.7 to 64.5 kg tree\(^1\) from four year old tree. The pattern of biomass increases proportionally with increasing diameter. The result helps to understand the pool and fluxes of CO\(_2\) in a plantation. This information can be used to encourage and is an additional privilege for smallholding farmers to plant trees. Carbon stocks continue to accumulate more in live biomass as the *A. decurrens* forest ages.

**Keywords:** Diameter, Fagita Lekoma, Height, Plantation
Introduction

Nowadays, there is a trend of the increase of plantation due to increase of wood-and wood related products. A large proportion of plantations in different parts of the world are mainly monotype species (FAO, 1984) that are exotic and fast growing. Similarly, plantation forest development efforts in ANRS are engaged by smallholder farmers. Smallholder farmers are growing exotic species. Exotics are given more priority than natives because of wide adaptability, competitive products, faster growth, access for planting materials (germplasm) and relatively the availability of sufficient information on the silviculture and management of the respective species (Tolentino, 2008).

Most of the plantations involve the use of fast growing exotic tree species such as Eucalyptus species (e.g. *E. camaldulensis, E.globulus, E.grandis etc*) (Bantider et al., 2011) and *Cupressus lisitanica*. Amongst these, *E. globulus* and *A. decurrens* are dominantly grown in the highlands of Ethiopia for the purpose of wood products due to its adaptability, fast growth and versatile uses. In a decade time, *Acacia decurrens* is becoming the most popular and important tree species for plantation in Awi highlands of ANRS specifically Fagita Lekoma, Banja and Ankasha districts. Small scale farmers in these districts grow *A.decurrens* for the purpose of charcoal and firewood production. Farmers allocated from 0.13 ha to 1 ha of land for plantation. In recent time, the expansion of this species is increasing at an alarming rate mainly in Fagita Lekoma district, primarily for firewood and charcoal production. Farmers are harvesting at the age of 4 – 5 years old to get quick financial return. Some of the farmers are harvesting at the age of 5-6 years when the wood size reached for charcoal and firewood use. Land conversion from cropland or grassland into *A. decurrens* plantation becomes more dynamic and a primary land use change in Awi zone.

Estimation of carbon stocks in plants provides information about photosynthetic characteristics and carbon budget. This has an effect on the increase in atmospheric CO2. Field based actual measurements give accurate carbon stock, but the application is limited due to its laborious or destructive nature. Biomass and carbon stock modeling are important prerequisites for evaluating the consequences of forest management on the future ecosystem (Tewari and Gadow, 2015). Because tree biomass estimation has a relationship to climate change
Tropical forests are contributing to mitigate climate change (Vieilldent et al., 2012). The quantification of carbon stocks in the forest ecosystems is important to know the carbon cycle, sinks and removals of carbon from the atmosphere (IPCC, 2006), forest carbon accounting under the Kyoto protocol (UNFCCC 1997; Gibbs et al., 2012), and to guide forest management decisions of the farmers. Several studies showed that there is a possibility to estimate biomass by using diameter at breast height (DBH), tree height and wood density (Kuilen and Pretzsch, 2014; Mugasha, Bollandsás, and Eid, 2015). There are limited studies in different species (e.g. Berhe et al., 2013; Demissie et al., 2014; Denu et al., 2016) conducted in different areas. Estimation of tree biomass and carbon stock is required to assess the wood production potential of *A. decurrens* plantation and its contribution for climate change. This is because no information is available for accumulated in a given point.

No information about the biomass accumulated and carbon stock of *A. decurrens* considering the farmers’ management. Knowledge on biomass and carbon stocks are vital for climate change (Maniatis and Mollicone, 2010; Asner, 2011), for compensation mechanism under REDD+ (UNFCCC, 2010; Gibbs et al., 2012). REDD+ is to provide financial incentives for developing countries to reduce emissions (IPCC, 2000; UNFCC, 2010). There are three methods to estimate biomass and carbon stock. These are destructive sampling, allometric equations (Brown, 1997; Chave et al., 2005; Chave, 2014), and remote sensing techniques (Saatchi et al., 2007; Asner, 2009; Houghton et al., 2009; FAO, 2010). The most accurate method for the estimation of tree biomass is through destructive method, however, it is a costly method. Allometric equations developed on the basis of destructive methods are more easily to use and are reasonable in terms of cost. Because of time and cost reasons, in this study we decided to use allometric equations developed for tropical forests (Brown et al., 1997; Chave et al., 2005; Feldspauach et al., 2011; Chave et al., 2014). Main questions to be answered in this study are how much biomass and carbon are stored in *A. decurrens* forest? And how much CO₂ would be emitted if the forest is converted to another use? The objectives of this study are (1) to examine the growth and yield performance of *Acacia decurrens* under farmers’ management until it reaches for fuelwood and charcoal production; (2) to estimate the biomass and carbon stock of *Acacia decurrens* under smallholding plantation using different allometric equations.
Materials and methods

Study sites selection

Fagita Lekoma district is located at approximately 36°40'00"E - 37°06'00"E longitude and 10°56'00"N - 11°12'00"N latitude. It is found in the Awi Administrative Zone, Amhara National Regional State [ANRS] (Fig 1). The study area encompasses about 67734 ha. The altitude ranges from 1888 to 2915 meter. The livelihood of the people in the district is based on mixed crop-livestock farming system, which combines the cultivation of crops and trees, and livestock production. The predominant exotic tree species grown in the area are *Acacia decurrens* and *Eucalyptus* species, which mainly used to meet the demands for energy and construction materials.

Reconnaissance survey was conducted prior to the starting of the field work to design the sampling procedures. The first sampling phase involved the selection of sites. Nine sites were selected to represent the *Acacia decurrens* plantation growth and yield performance under farmers’ management. The specific study villages (kebeles) in Fagita Lekoma district (Figure 2).
GPS point data were collected to spatially locate the sampling sites and the plots in a study area. The study was made on 2961 trees sampled at four ages from farmer managed stands. The samples were selected in four ages. The 4 years old plantations were selected to take the diameter, height, and density per plot. The upper age limit was 4 years, because farmers cut the tree after four years for charcoal and pole size wood production. The forests chosen are even-aged silvicultural system i.e. all trees in a sampled stand of similar age were planted at the same point in time. The stands of the sample forests are relatively simple to conceptualize and understand the management practices.

**Sampling and data collection**

Compartments of the private smallholding forests were selected randomly based on the occurrence of *A. decurrens* plantations as a monocrop. The samples represent the range from lower to higher elevations where *Acacia decurrens* is grown. We established 3 randomly located square plots (10mX10 m) in the selected plantation. In total 3 plots for each year, and 12 plots for all sampled years per site were selected and the data were measured. Within each of the plots, total enumeration of all parameters in a plot was conducted. Large sample size with a large variation in diameter provides relatively precise estimates of biomass and an insight about differences in the tree allometry (Rutishauser et al., 2013)Navar, 2009; Rutishauser et al., 2013).
Growth and yield parameters

The number of trees was counted to know the stock (density) per hectare. The diameter and height were measured for all trees found in the sample plots. The diameter at breast height (1.3 m above ground) over bark was measured using caliper. The height was measured using graduated stick and automatic hypsometer. The specific gravity of *A. decurrens* was obtained from literature. These parameters were used to estimate the carbon stock and the amount of CO2 sequestered by individual trees until it reaches for charcoal production and firewood use.

Biomass estimation

The most sited allometric equations developed for tropical regions were used in this study (Brown, 1997; Ketterings et al., 2001; Chave et al., 2005; Chave et al., 2014)

**Biomass**

Brown (1997) AGB=exp(-2.134 + 2.53 ln(dbh)) .................................. Equation 1

Chave et al. (2005) moist:

AGB=ρ · exp(-1.499 + 2.148 · ln(dbh) + 0.207 · (ln(dbh))^2 + -0.0281 (ln(dbh))^3) .................................. Equation 2

Ketterings et al. (2001): AGB=r*(pavg * dbh^2)^0.976 .................................. Equation 3

Chave et al. (2005) wet:

AGB=ρ · exp(-1.239 + 1.98 · ln(dbh) + 0.207 · (ln(dbh))^2 + -0.0281 (ln(dbh))^3) .................................. Equation 4

Chave et al. (2005) moist: AGB=0.0509*ρ* dbh^2 · h .................................. Equation 5

Chave et al. (2005) wet: AGB=0.0776*(ρ* dbh^2 · h)^0.94 .................................. Equation 6

Chave et al. (2014): AGB=0.0673*(ρ* dbh^2 · h)^0.976 .................................. Equation 7

ρ =specific gravity (g/cm³)

dbh=diameter at breast height

h=height

AGB=Above ground biomass

Carbon stock is estimated by multiplying the above ground biomass by the values ranging from 0.45 to 0.50 depending on the nature of the tree species. However, we used a fraction of 0.47 was used using the method ((IPCC, 2006; Skog and Nicholson, 1998; McGroddy et al., 2004; IPCC, 2006).
Statistical analysis

Stand density was estimated from the total number of trees enumerated in the 10mX10m plot. The basal area of each tree was calculated with diameter as stated by Avery and Burkhart (2002) using equation (1). Analysis of variance was used to determine the relationship among the effects of sites on height and diameter of *Acacia decurrens*. One-way analysis of variance (ANOVA) was performed on the values of allometric based biomass and carbon stock. Posthoc using Scheffe method was used for pair-wise comparisons of allometric equations. This was used to determine which allometry best describes the biomass and carbon stock of A. decurrens plantation. Spatial mapping of sampling sites was conducted using ArcGIS 10.

Results

Tree stock

The density has a relationship with the amount of biomass and carbon stock. The number of stems was obtained from the plot level measurement at the age of 4 years varied from 6300 - 10300 trees ha\(^{-1}\) under the farmer management (Table 1).

<table>
<thead>
<tr>
<th>Site</th>
<th>Density in 100 m(^2)</th>
<th>Density ha(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akuta</td>
<td>98.9</td>
<td>9890</td>
</tr>
<tr>
<td>Bekta</td>
<td>62.8</td>
<td>6280</td>
</tr>
<tr>
<td>Danguri</td>
<td>103</td>
<td>10300</td>
</tr>
<tr>
<td>Kabi</td>
<td>74.6</td>
<td>7460</td>
</tr>
<tr>
<td>Karnanta</td>
<td>78.2</td>
<td>7820</td>
</tr>
<tr>
<td>Kesmender</td>
<td>93.4</td>
<td>9340</td>
</tr>
<tr>
<td>Killaje</td>
<td>97.2</td>
<td>9720</td>
</tr>
<tr>
<td>Medinta</td>
<td>107</td>
<td>10700</td>
</tr>
<tr>
<td>Wudeta</td>
<td>86.9</td>
<td>8690</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>8911</td>
</tr>
</tbody>
</table>

The minimum and maximum number of *A. decurrens* trees per hectare was found at Bekta and Medinta sites, respectively. The average estimated number of trees was 8911 trees ha\(^{-1}\) under the farmer management.
The total density in all sites showed variability due to variability in differences due to site suitability and management of each farmer. The highest density may be the result of planting two seedlings per hole, the ability of the regeneration of seedling to provide additional shoots, the protection of forest from damage by livestock and no intermediate harvest. On the other hand, the lowest densities may be the result of cutting trees for intermediate benefit for household consumption (e.g. fuelwood) or lowest density during planting seedlings.

**Diameter and height growth**

The growth of the diameter generally followed a trend of exponential pathway. The age-diameter and the age-height curves showed that a strong correlation for the sites Kesmender, Kabi and Danguri. The highest average diameter growth is observed in Danguri and Kabi (Fig. 3). The diameter of Danguri showed normally distributed as compared to other sites. This site also showed the longest box and wider interquartile. This showed that the diameter has a possibility to expand more in either cases (to lower or higher diameter performance) depending on the tree management, tree genetic potential and site quality.

![Figure 3. Diameter distribution across sites](image)

The highest and lowest diameter growth in four years was 11 cm and 1.5 cm, respectively. The difference in diameter growth is the result of land management. If the plantation is established after ploughing and with cereals in the first year, the plantation showed better performance in height growth.
Regarding the height performance, as indicated in figure 4 below the plantation in all sites ranged from 7 to 10 m in four years' time. However, Bekta, Danguri and Medinta indicated the highest average height growth compared to other sites. Kilaje and Kabi areas showed the lowest height growth. From diameter-height curve (Fig. 5 below), the pattern of diameter-height relationship showed in general an increase at the earlier stage, but tends to flattened at the later stage. The growth patterns are the results of the inherent characteristics of the tree species, forest management and the site quality.

Analysis of the growth parameters measured across all the 9 sites showed that there were significant differences in diameter and height between sites in the earlier stages. The species performance was the highest diameter growth rates found in Kes Mender and Kernanta and the lowest diameter growth rates found in Akuta and Kernanta. In a Scheffe's comparison of means, the diameter growth rates of the two highest performing sites were found to be significantly (P<0.05) different from the remaining seven sites. The diameter and height growth increments for the highest performing sites were found to be statistically similar. The height increment of seven others sites was also found to be statistically similar.
Figure 6. Biomass modeled using: (a) polynomial function (b) power function

From the two models power function has an $r^2$ of 0.98. The trend of biomass production has similar trend with the study of Basuki et al., 2009. Individual tree based biomass and carbon stock is indicated Table 2 and 3, respectively.

Table 2. Biomass per tree

<table>
<thead>
<tr>
<th>Allometric model</th>
<th>Count</th>
<th>Mean</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Std. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown</td>
<td>733</td>
<td>7.75</td>
<td>5.62</td>
<td>0.12</td>
<td>38.11</td>
<td>6.73</td>
</tr>
<tr>
<td>Chave 1</td>
<td>733</td>
<td>6.81</td>
<td>4.83</td>
<td>0.12</td>
<td>35.19</td>
<td>6.10</td>
</tr>
<tr>
<td>Chave 14</td>
<td>733</td>
<td>8.10</td>
<td>6.23</td>
<td>0.09</td>
<td>36.63</td>
<td>6.60</td>
</tr>
<tr>
<td>Chave 2</td>
<td>733</td>
<td>6.55</td>
<td>4.84</td>
<td>0.16</td>
<td>31.10</td>
<td>5.49</td>
</tr>
<tr>
<td>Chave 3</td>
<td>733</td>
<td>6.94</td>
<td>5.27</td>
<td>0.07</td>
<td>32.34</td>
<td>5.79</td>
</tr>
<tr>
<td>Chave 4</td>
<td>733</td>
<td>7.74</td>
<td>6.08</td>
<td>0.11</td>
<td>33.48</td>
<td>6.09</td>
</tr>
<tr>
<td>Ketterings</td>
<td>733</td>
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<td>2.37</td>
<td>0.06</td>
<td>14.54</td>
<td>2.60</td>
</tr>
<tr>
<td>Polynomial</td>
<td>733</td>
<td>7.32</td>
<td>5.47</td>
<td>0.05</td>
<td>34.24</td>
<td>6.10</td>
</tr>
<tr>
<td>Power</td>
<td>733</td>
<td>7.28</td>
<td>5.39</td>
<td>0.13</td>
<td>34.39</td>
<td>6.12</td>
</tr>
</tbody>
</table>
Table 3. Carbon stock per tree

<table>
<thead>
<tr>
<th>Allometric model</th>
<th>Count</th>
<th>Mean</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Std. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown</td>
<td>733</td>
<td>3.64</td>
<td>2.64</td>
<td>0.06</td>
<td>17.91</td>
<td>3.16</td>
</tr>
<tr>
<td>Chave 1</td>
<td>733</td>
<td>3.20</td>
<td>2.27</td>
<td>0.06</td>
<td>16.54</td>
<td>2.87</td>
</tr>
<tr>
<td>Chave 14</td>
<td>733</td>
<td>3.81</td>
<td>2.93</td>
<td>0.04</td>
<td>17.22</td>
<td>3.10</td>
</tr>
<tr>
<td>Chave 2</td>
<td>733</td>
<td>3.08</td>
<td>2.28</td>
<td>0.08</td>
<td>14.62</td>
<td>2.58</td>
</tr>
<tr>
<td>Chave 3</td>
<td>733</td>
<td>3.26</td>
<td>2.48</td>
<td>0.03</td>
<td>15.20</td>
<td>2.72</td>
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<tr>
<td>Chave 4</td>
<td>733</td>
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<td>2.86</td>
<td>0.05</td>
<td>15.73</td>
<td>2.88</td>
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<tr>
<td>Ketterings</td>
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<td>1.11</td>
<td>0.03</td>
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<tr>
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<td>3.42</td>
<td>2.54</td>
<td>0.06</td>
<td>16.16</td>
<td>2.88</td>
</tr>
</tbody>
</table>

In a similar condition, the carbon dioxide is indicated in figure 7 below.

Figure 7. Carbon dioxide per tree

From all allometric equations, Ketterings (2001) model underestimated compared to other models. Analysis of variance showed significant variations (p <0.05) among allometric equations.
For firewood production, a rotation of 4 years is applied and annual volume increments of 5-15 m³/ha of wood was obtained by excluding branches and leaves. However, the rotation of 5-6 years is optimum to produce quality and substantial amount of charcoal. In this case, the economic status of the individual farmers determines the time (age) of tree harvest. Farmers who have better wealth and sufficient land for crop production retain the Acacia decurrens plantation to grow for 6 and 7 years to get quality wood for charcoal production and pole.

Density and basal Area
The comparison of the initial stocking with the numbers of trees per hectare obtained in this study revealed the reduction in population of trees in each of the plots except site 5 (Kamatua). The reduction of the density of trees may be due to natural competition, natural, initial planting condition and the state of the farmers management. The total basal areas for all sites ranged from 4.1 to 5.8 m²/ha. The sites with the lowest basal areas were site 9 (Wudeta) and site 1 (Akuta), both of which are found in the lowest altitude compared to other study sites. This finding showed that the basal area increased with altitude. The sites with the highest total basal areas were site 3 (Danguri) and site 6 (Kesmender) that provide 5.94 and 5.76 m² ha⁻¹, respectively. Higher basal area is observed in the fast growing forests of the highest altitude. This may indicate that the higher altitudes are more suitable sites than lower altitudes for the growth of A. decurrens. However, the range of basal areas showing that the variance could be due to differences in forest management, seedling size, species provenance and soil variability.

Biomass using allometric equations
The biomass was estimated using different allometric equations. The trend (Fig 5) below showed that there is similar trend except Ketterings model.
The pattern of biomass increases proportionally with increasing diameter. The variability in the performance of the models for biomass estimation is the result of differences in the type of parameter used. It is expected that the height increment may stagnate as the tree gets older. Large trees produce more biomass than small trees. A specific diameter increment represents more absolute biomass in a large tree than in a small tree (Prior et al., 2004). Analysis of the growth parameters measured across all the 9 sites showed that there were significant differences in diameter and height between sites.

Two new equations were developed from the allometric equations developed using polynomial and power equations (Fig 6).
This variability could be the result of variability in model difference due to differences in parameters such as diameter, height, tree specific gravity, forest management and site quality (e.g. soil). This study does not take into consideration several important factors that influence tree growth and yield performance. This includes social, economic, ecology, location of the plantation for marketing, the situation of plantation, site management and frequency and intensity of weeding around planted trees. Future studies should also be taken into account smallholder farmers’ specific challenges in tree planting, access for tree germplasm, knowledge about plantation management, and information about markets.

Conclusion

The biomass estimated ranged from 1 to 38 Kg tree\(^{-1}\), the carbon 0.47 – 17.91 kg tree\(^{-1}\) carbon (only bole) and the CO\(_2\) varied from 1.7 to 64.5 kg tree\(^{-1}\) from four year old tree. We compared seven allometric equations including the model developed using polynomial functions. We developed two new allometric models using polynomial and power method. We choose the power method using DBH only. Using this new equation, the result estimated for biomass, carbon and CO\(_2\) was 64.2 ton ha\(^{-1}\), 30 ton ha\(^{-1}\) and 108.5 ton ha\(^{-1}\), respectively. The study resulted in reasonable estimate of biomass and C-stock per tree basis compared to some other studies (e.g. Gibbs et al., 2007 and Berhe et al., 2013). Development of species and location specific allometric equations (A.decurrens and restoration areas) is important to support the regional REDD+. The result helps to understand the pool and fluxes of CO\(_2\) for forest management and planning.

The carbon stock of smallholding farmers is an additional privilege for the establishment of plantations and gets additional benefits for farmers. Biomass stocks and C sink may become higher after four years. Estimating the amount and distribution of AGB is crucial for improving land management planning and for engaging in REDD+. Our understanding of AGB is enhanced by including ecologically meaningful predictor variables in a model-based approach. The relationship between biophysical characteristics/land management and AGB/carbon stock can be modeled for future forest management and utilization.

The limitations of this study are the estimation of biomass/carbon stock did not include small branches and below ground biomass or carbon stock, large trees (DBH, height) were not
included in the modeling, tree management differences among woodlots were not considered during analysis. Most of the allometric models used DBH. However, accounting for height, wood density and other tree parameters may provide better estimation and improves the quality of the study. Continuous assessment of tree biomass and carbon stocks and the fluxes for future modeling are needed to get reasonable prediction and contribute for climate change. Carbon stocks continue to accumulate more in live biomass as the *A. decurrens* forest ages.

References


Evolution and magnitude of land cover changes in Fagita Lekoma district, northwestern highlands of Ethiopia

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Abstract

Understanding the magnitude and drivers of land cover changes in a landscape are keys to designing effective natural resource management interventions and restoring degraded landscapes. We quantified the magnitude of land cover change in Fagita Lekoma. Landsat images were used to analyze spatiotemporal dynamics and obtain quantitative information in the changes in land cover in the past 20 years (1995-2015). Results demonstrated that forest cover increased by 1.2% year⁻¹, while areas covered by cropland decreased by 1% year⁻¹. The increase in forest cover is mainly attributable to increased plantation of Acacia decurrens. The expansion of A. decurrens plantations could be attributed to its potential to provide short-term economic benefits. This indicates that economic activities that generate short-term benefits may strongly influence the selection of land uses in the study area. In addition, planting of A. decurrens in the landscapes generates job opportunities to the landless and support farmers to diversify livelihood. Further, planting A. decurrens rarely restrict agricultural practices, as farmers able to grow cereals in the first two years following the establishment of A. decurrens plantation. This in turn enhances the efficient utilization of farm lands and diversifies agricultural products. Providing training to farmers on silvicultural practices and presenting alternative tree species is crucial to enhance their benefits and sustain charcoal production in such mountainous regions. Studies are required to understand the impacts of the observed land cover change on land productivity, landscape and biodiversity.

Key words: Acacia decurrens, Ecology, Land cover change, Landsat images, Silviculture
Introduction

The economy of Ethiopia largely depends on agriculture and natural resources (Dejen, 2003). Increases in human demands for food, feed, energy, and other benefits have led to increased land use conversion, particularly the conversion of forest and grazing lands into agricultural lands (Zeleke and Humi, 2001; Humi et al., 2005; Amsalu et al., 2007). Similar to other parts of Ethiopia, the dominant land use conversion in the highlands of northwestern Ethiopia - our study area - is the conversion of forests to agricultural lands, which is attributed to widely practiced cereal-based crop production (Abegaz, 2005). This has led to a reduction in forest cover (Zeleke and Humi 2001, Bewket, 2002; Wondie et al., 2011), increases in runoff and soil erosion (Mekuria et al., 2009), loss of biodiversity (Mekuria et al., 2015), and decreases in ecosystem services (Mekuria et al., 2011). The dominant form of land use conversion has also brought heterogeneity and modification of landscape configuration and ecology (Barasa et al., 2011; Ruishan and Suocheng, 2013).

While land use and land cover change (LULCC) studies by Zeleke and Humi (2001), Humi et al. (2005) and Amsalu et al. (2007) have shown that forest cover has decreased due to increased deforestation and conversion to agricultural lands, Bewket (2002) and Wondie et al. (2011) have shown an increase in forest cover at the expense of agricultural lands. These results seem to contradict one another, but they come from different site-specific studies: moreover, degradation of natural resources including expansion of soil acidity in the highlands of Ethiopia is a dominant phenomenon that compromises the livelihoods of the local communities (Bewket and Teferi, 2009; Endalew et al., 2014; Humi et al., 2015).

In response to the problems of the degradation of natural resources and associated negative impacts on the environment and livelihoods, the government of Ethiopia launched a country-wide sustainable watershed management campaign since 2010. Such government initiatives require proper design and implementation of natural resource management interventions. In

4 Land cover is the observed (bio-) physical cover on the earth's surface, whereas land use is characterized by the arrangements, activities and inputs people undertake on a certain land cover type to produce, change or maintain it (Choudhury and Jansen (eds.), 1998).
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this line, understanding the evolution, dynamics and magnitude of land cover change is a key to design effective natural resource management interventions and thereby enhance agricultural productivity and ensure food security. Also, analysis of the dynamics of land covers is useful in developing a methodological framework for analyzing the economic costs of land cover changes (Hein et al., 2008), soil dynamics (Bruun et al., 2013) and the benefits of sustainable land management (Girmay et al., 2008; Hein et al., 2008).

The conversion of forests into other land uses is a common phenomenon in mountain regions of Ethiopia. Opposite to such common practice, planting of *A. decurrens* on degraded mountains has been expanding in Fagita Lekoma, northwestern highlands of Ethiopia. The expansion of this tree-based farming or biomass production can be attributed to the increased short-term economic benefits, and enhanced access to fuelwood and construction materials following the introduction of *A. decurrens*. Also, the expansion of *A. decurrens* could be attributed to the adaptability of the tree to acidic soil conditions and its fast growth (Endalew et al., 2014).

However, the magnitude of such changes in the study area and implications on reductions of cropland is not well understood or not quantified. Understanding the status of land conversion in study area is important to deliver decision support ideas and identify the incentives and requirements to out scale plantation activities. This in turn enables practitioners to effectively implement development interventions and reduce the degradation of forest and natural resource in the highlands of Ethiopia, whilst improving stallholder’s livelihood.

Therefore, the present study was conducted in Fagita Lekoma Woreda, northwestern Ethiopia, to assess the evolution and magnitude of land cover changes caused by human activity during a period of 20 years (1995-2015) using remote sensing data. It also aims to provide an insight into the state of landscape dynamics linked to tree-based farming. Fagita Lekoma, the district in the northwestern part of Ethiopia with considerable expansion of *A. decurrens* plantations, provide us an opportunity to understand the requirements and incentives to enhance local communities’ participation in the restoration of degraded mountains through plantations. Our study adds knowledge on the successful implementation of restoration measures on degraded
mountains by providing science-based evidence on site specific drivers of land cover changes. This in turn helps to introduce effective forest restoration or development programs that would be supported by local communities. Based on our observations, we hypothesized that the expansion of *A. decurrens* in croplands and marginalized lands is mainly driven by its effectiveness to improving livelihood diversification and adaptability to acidic soil condition.

**Materials and Methods**

**Study area**

Fagita Lekoma district, the study area, is located at approximately 36°40'00"E – 37°06'00"E longitude and 10°56'00"N – 11°12'00"N latitude. It is situated northwest of Addis Ababa, the capital of Ethiopia, in the Awi Administrative Zone, Amhara National Regional State [ANRS] (Fig 1). The study area encompasses about 67,734 ha and the projected population size based on the 2007 census is about 148,967. Elevation ranges from 1888 to 2915 meters above sea level. The nearby major town, and river and road networks are included in Fig. 1.

The average annual rainfall is 1700 mm using the closest meteorology stations (for the years 1983 to 2012), with the peak rainfall occurring between June and August, and the dry season between January and April. Major crops cultivated are cereals and pulses. The main land cover types (LCTs) in the study area include cropland, forestland, grassland, shrubland, and settlement. The dominant soil types in the study woreda include Acrisols and Nitosols and exhibit very severe soil erosion (Nigussie et al., 2017b). The predominant exotic tree species grown in the area are *Acacia decurrens* and *Eucalyptus species*, which are mainly used to meet the demands for energy and other wood related products.
Subsistence agriculture is the predominant economic activity in the Fagita Lekoma district, as in other parts of the Amhara region and country as a whole (Tesfaye et al., 2014). The sector primarily consists of smallholder farming, with an average farm size of 0.25 hectare per household. The smallholder farmers in the study area predominantly practice cereal-based production, tree-based farming, livestock production, or a combination of these practices (Abegaz, 2005). In this line, Nigussie et al. (2017a) indicated that the most important motivations for tree-based farming in the study area include income, soil fertility management, and soil and water conservation. Over 95% of the annual agricultural output is produced by cultivation of fragmented micro-holdings (Tesfaye et al., 2014). The average production of agricultural crops varies with crop types. For example, the average production of tef is estimated at 800 kg per hectare, while the average production of potato is about 6500 kg per hectare.

Limited off-farm activities, mainly related to charcoal production, nursery management and production of local household furniture using bamboo are also available in the study district. The administrative system of the study district is composed of (from the lowest to the highest level): village, kebele and district administrative systems.
Data source and preparation

Temporal and spatial changes were analyzed using Landsat Thematic Mapper (TM) and Landsat Operational Land Imager (OLI). These images were acquired from the website of the U.S. Geological Survey (USGS) at earthexplorer.usgs.gov at no cost. In total, four datasets of different dates were used (Table 1). These datasets were chosen based on the availability of the data and because they were cloud-free. Data preparation of these multispectral images such as layer stacking, enhancement and haze reduction was done using ERDAS Imagine software. For the Landsat images, geometric correction was not considered necessary due to the near-nadir viewing characteristics of Landsat.

Table 1. Data source and date of acquisition

<table>
<thead>
<tr>
<th>Source/Sensor</th>
<th>Path/row</th>
<th>Year/DOY</th>
<th>Spatial resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat 5/TM</td>
<td>170/052</td>
<td>1995/044</td>
<td>30</td>
</tr>
<tr>
<td>Landsat 5/TM</td>
<td>170/052</td>
<td>2000/042</td>
<td>30</td>
</tr>
<tr>
<td>Landsat 5/TM</td>
<td>170/052</td>
<td>2010/357</td>
<td>30</td>
</tr>
<tr>
<td>Landsat 8/OLI</td>
<td>170/052</td>
<td>2015/035</td>
<td>30</td>
</tr>
</tbody>
</table>

DOY: Day of the year

To generate elevation and slope information, a digital elevation model (DEM) with a 30m spatial resolution was obtained from the USGS website. GPS point data were obtained during a reconnaissance survey conducted between September and October 2015. These GPS data were then used to get familiar with the study area and to facilitate the selection of training sites (areas of interest, hereafter referred to as AOI) for classification. A total of 143 AOIs were collected as a training data for accurate land cover classification. The number of AOIs for crop land, forest land, grassland and urban areas were 50, 51, 31 and 11, respectively. The AOIs were selected randomly following identifying the availability of representative land cover types in an image. In addition, different parts of the study area were visited to facilitate the collection of training samples for each land cover type (LCT).

Further, we conducted key informant interviews to understand the temporal variations on the type of dominant forest cover in the study district. Nine key informants were interviewed. The key informants were farmers (six in number), and forest, land administration and soil and water conservation experts.
Farmers were selected from a range of interests (members of village level administrative bodies, elders, and model farmers). The key informants were selected in consultation with the local administrative bodies and district agricultural office and were chosen due to their active involvement in natural resources management initiatives, including community mobilization, construction of SWC structures, and afforestation and reforestation programs. The key informants were included to strengthen and triangulate the information obtained from Landsat image analysis, and better understand the historical land cover changes in the study area.

**Classification approaches and methods of classification**

To classify the different LCTs, two methods were applied in combination: analysis of Landsat satellite images and field survey. Four land cover classes were defined, and the classification scheme was developed to be used as a reference during image analysis. The land cover classification scheme was developed based on the context of the study area (Table 2).

<table>
<thead>
<tr>
<th>LULCT</th>
<th>Description/Characterization of the class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropland</td>
<td>Cultivated land used for annual crop production i.e. cereal, pulses and oil crops.</td>
</tr>
<tr>
<td>Forestland</td>
<td>It includes plantation forest, shrubland and natural forests.</td>
</tr>
<tr>
<td>Grassland</td>
<td>Land allocated for grazing/pasture or hay production.</td>
</tr>
<tr>
<td>Settlement/urban</td>
<td>Settlements that are concentrated in urban areas were large enough to be recognized by Landsat image during classification. Urban areas were considered as settlement because rural settlements are scattered and were not large enough to be detected by the 30m pixel.</td>
</tr>
</tbody>
</table>

A supervised classification method was chosen using a maximum likelihood algorithm. This algorithm was chosen because it accounts for the variance and covariance, and assumes the data is normally distributed. The enclosed polygons - referred to as Areas of Interests (AOIs) - were used to train for classification. AOIs were defined as a signature for the respective LCT to enable supervised classification. Relatively homogenous AOIs were selected visually to minimize mixture of signatures and misclassification. Each AOI was assigned based on the
description of the classification scheme. The size and number of AOIs depends on the availability of the respective land cover signature. AOIs were distributed throughout the study area to represent the signature of the respective LCT. Additional training areas that are homogeneous were chosen when misclassification had to be assumed. Multiple attempts were made with modified training areas by looking at the separability values obtained from AOI of each LCT.

The accuracy of the classification of the 2015 image was evaluated using GPS point data collected from the study area. The assessment of the accuracy of the classification was conducted to compare the classification results to geographically referenced GPS point data. In this line, error matrix was developed and the accuracy of each classification was evaluated (van Oort, 2007; Table 3). Error matrix enables to conduct comparisons between field data and the corresponding results of automated classification. The comparison was done by overlaying the GPS reading of a certain land cover on the corresponding classified data. Then, the accuracy of each of the classified land cover was computed by dividing the number of correctly classified GPS readings by the total number of GPS reading collected from the field. Producer’s accuracy indicates the accuracy of the classification of a certain land cover (e.g., cropland or forest land), while user’s accuracy demonstrates the overall accuracy of the classification process (Table 3).

Analysis of Changes in land cover
Change detection was performed by comparing image values of 1995 with the corresponding values from 2015. The ERDAS modeler was used to detect Land Cover Change (LCC) between the two-date datasets (Fig. 2). ERDAS modeler is a toolbox in ERDAS IMAGINE software. The ERDAS modeler has an interface where the required functions and/or modeling can be developed for change analyses. In other word, the modeler has an interface where scripts for change analyses can be developed. Then, the conditional formula to detect the change was used as follows:

\[
\text{Difference of 1995 to 2015} = \text{CONDITIONAL} \{(<\text{test1}>) <\text{arg1}>, (<\text{test2}>) <\text{arg2}>, \ldots\}
\]
The result of the conditional operation gave a change map for every pixel. There were 16 change classes, corresponding to the transition from each of the four land cover classes of one date to each one of the other date (including “no-change”). A ‘conversion matrix’ between 1995 and 2015 was obtained and compiled to quantify LCC in terms of number of pixels for the corresponding LCT. The number of pixels was then changed into hectare or percent for presentation.

The change rates of LCT were analyzed using the method of Peng et al. (2008) (equation 1):  

\[ K_1 = \left( \frac{A_t - A_0}{A_0} \right) \times \left( \frac{100}{T} \right) \]  

\[ \text{equation 1} \]

Where \( K_1 \) is the LC dynamics, measuring the change rate of the LCT; \( A_t \) and \( A_0 \) are the area of the target LCT at the beginning (1995) and at the end (2015) of the study period, respectively, and \( T \) is the study period in years.

**Limitations of the Classification**

A precise definition of LCTs was difficult. There were mixtures of spectral values from the selected pixels for training. Such mixture of spectral values could be explained in two ways. Firstly, seedling and young trees (1 to 1.5 years old) were not detected as a forest by the current spatial resolution of the acquired Landsat image due to their smaller size, which could
result in underestimation of areas covered by forests (Wulder et al., 2004). These seedlings and/or young trees might be classified as cropland or grassland, depending on the undergrowth or LCT surrounding them, which could result in an overestimation of crop and/or grazing lands. This was confirmed using GPS point data obtained through field assessment. Also, individual trees scattered in the farm plots used for agroforestry with a smaller crown size than the pixel size of Landsat were not recognized and, therefore, not classified as a forest. This resulted in the assignment of pixels similar to the dominant LCT (e.g., as cropland or grassland) surrounding them. Secondly, AOIs selected to represent settlement were selected from urban surface by looking at the pattern and texture of clustered villages. However, houses in rural settlement areas are scattered, and the roofs are not large enough to be recognized by Landsat pixel. These classes were probably assigned into other classes. Consequently, the land allocated for settlement might be underestimated.

Results and Discussion
Accuracy of the classification process
The overall accuracy and Kappa values were 88 and 83%, respectively. The classification of forest displayed a 100% producer’s accuracy indicating no pixel was incorrectly excluded from its category (Table 3). However, the classification of settlement/urban areas displayed the least producer’s accuracy (71%).

Table 3. Error matrix to show the accuracy of the classification

<table>
<thead>
<tr>
<th>Classification data</th>
<th>Field data</th>
<th>Row total</th>
<th>User's Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cropland</td>
<td>Forest</td>
<td>Grass</td>
</tr>
<tr>
<td>Cropland</td>
<td>17</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Forest</td>
<td>0</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>Grass</td>
<td>2</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Urban</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Column Total</td>
<td>20</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td>Producer's accuracy</td>
<td></td>
<td>85%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Land cover types and changes over time
The results demonstrated that cropland is the dominant land cover type during the entire study
period (i.e., 1995-2015) (Fig.3, Table 4). The second dominant land cover was forest land (Table 4). At the aggregate level, the overall farming system changed over the last 20 years and the results displayed that there were considerable changes in land cover types (Fig. 3. Table 4).

Figure 3. The land use and land cover types of the four datasets: a) for the year 1995, b) for the year 2000, c) for the year 2010, and d) for the year 2015 of the study site.

Area coverage of each land cover type in the study seasons (table 4)

Table 4. Area coverage of each LCT from 1995-2015.

<table>
<thead>
<tr>
<th></th>
<th>1995</th>
<th></th>
<th>2000</th>
<th></th>
<th>2015</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ha</td>
<td>%</td>
<td>ha</td>
<td>%</td>
<td>ha</td>
<td>%</td>
</tr>
<tr>
<td>Cropland</td>
<td>44390</td>
<td>65.5</td>
<td>49581</td>
<td>73.2</td>
<td>38581</td>
<td>57.0</td>
</tr>
<tr>
<td>Forestland</td>
<td>13935</td>
<td>20.6</td>
<td>12369</td>
<td>18.3</td>
<td>11397</td>
<td>16.8</td>
</tr>
<tr>
<td>Grassland</td>
<td>9357</td>
<td>13.8</td>
<td>5528</td>
<td>8.2</td>
<td>17284</td>
<td>25.5</td>
</tr>
<tr>
<td>Urban</td>
<td>56</td>
<td>0.1</td>
<td>259</td>
<td>0.4</td>
<td>476</td>
<td>0.7</td>
</tr>
<tr>
<td>Total</td>
<td>67737</td>
<td>100.0</td>
<td>67737</td>
<td>100.0</td>
<td>67737</td>
<td>100.0</td>
</tr>
</tbody>
</table>
The results indicated that the area covered by cropland increased in the first five years (i.e., 1995-2000) and showed a deceasing trend afterwards (Table 4). In 20 years period, the area covered by crop land decreased by 8946 ha, which is translated to a 20% decrease in 20 years. This could be attributed to the increase in forest cover and other land uses. Also, settlements/urban areas increased from 0.1% in 1995 to 0.8% in 2015 (Table 4). This remarkable increase in urban settlements along the highway is an indication of the population growth and is one of the economic drivers for the LCC. Urban sprawl has led to increased construction of infrastructure, which competes with the peri-urban land that was previously used to produce food crops and grass.

All LCTs except cropland showed an increasing rate of change per year (Table 5). Cropland declined by 1% year⁻¹, while settlements/urban areas increased by 44.5% year⁻¹. Compared to the overall change, plantation forests, grassland, and urban expansion shows the most significant changes in 20 years. With the present rate of change, the study area would mostly be covered by forest and grassland in 15 to 20 years. This was indicated by the change analysis of the twenty-year period (Figure 4).

Table 5. Rate of change of LULC per year, calculated using the equation (1).

<table>
<thead>
<tr>
<th>Period</th>
<th>Rate of change (percent per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cropland</td>
</tr>
<tr>
<td>1995-2000</td>
<td>2.3</td>
</tr>
<tr>
<td>2000-2010</td>
<td>-2.2</td>
</tr>
<tr>
<td>2010-2015</td>
<td>-0.8</td>
</tr>
<tr>
<td>1995-2015</td>
<td>-1.0</td>
</tr>
</tbody>
</table>
According to key informants, in 1995, the forest in the study area was predominantly natural forest, and the contribution of plantation to the total forest cover was negligible till 2010. Consequently, forest cover displayed a decreasing trend from 1995 to 2010. This could be attributed to population growth and the associated increases in demand for agricultural lands, fuelwood and construction materials as well as limited tree planting activity during this period. For example, within five years (i.e., 1995-2000), crop land increased by 5191 ha (2.3% year$^{-1}$). However, from 2010 onwards, an increase in forest cover was observed (Table 4). This could partly be explained by the recent expansion of *Acacia decurrens* in the area, which farmers are planting around homestead, farmlands and communal lands due to its economic importance (Picture 1). Particularly, *A. decurrens* is important to meet the demand for energy and earn money from the sale of charcoal produced from it. According to development experts and local farmers (personal communication), the area covered by *Acacia decurrens* plantation keeps increasing because of the market demand for charcoal and firewood, and its contribution to household income. Notably, the expansion of *A. decurrens* plantations is considerable along the roads (Fig. 4), which could be related to access to market for forest products.
Benefits and tradeoffs of Acacia decurrens plantation

*A. decurrens* is preferred by the smallholder farmers in the study area because of its fast growth and wide adaptation potential. Farmers harvest *A. decurrens* 4 or 5 years after planting (Picture 3). The trees are planted either after clear-cut or on farm plots that were used for other purposes. At early stage of plantation (i.e., the first 2 years after plantation), farmers usually grow cereals together with *A. decurrens* in their farmland (Picture 4). This is a new farming system in the study area that is introduced to efficiently use the space between seedlings at the early stage of plantation and maximize the benefits from unit area. It also minimizes the decline in agricultural productivity due to planting of *A. decurrens*. These activities indicate the possibility of maximizing benefits by integrating fast growing trees with annual crops. Key informant interviews and focus group discussion demonstrated that expansion of *A. decurrens* plantations in degraded landscapes created additional jobs to the landless youth and provide opportunity to diversify livelihood. For example, it creates job opportunities in the various stages of forest development, such as planting, managing, and harvesting, as well as during charcoal production and marketing of products. However, it could also lead to a reduction in crop production, as it leads to a decrease in crop land. For example, the results of our study displayed that the area covered by cropland decreased by 8946 ha, which is translated to a 20\% decrease in 20 years, which is partly attributed to the expansion of *A. decurrens* plantation. Other studies (e.g., Cao et al., 2010) also demonstrated that expansion of such monoculture plantation in a landscape should be seen carefully. In such kind of plantations, there might be long-term negative impacts due to the occurrence of diseases and pests as well as due to reduction in water availability in a landscape.

Our results are consistent with the results of Bewket (2002) who demonstrated that forest cover has increased around homestead in the highlands of Ethiopia, which is related to growing trees to meet household energy demand, as the surrounding forests are degraded. Wondie et al. (2011) demonstrated increases in forest cover in Semen Mountain national park, though the increase in forest cover is not due to plantation. In contrast to the results of our study, studies by Tekle and Hudlund (2000) and Zeleke and Hurni (2001) have shown a general decrease in natural forest and an increase plantation in the highlands of Ethiopia.
This information indicates that site specific evidence is needed to understand the drivers of deforestation and restoration of degraded landscapes in the highlands of Ethiopia.

**Drivers of change**

The probability of conversion from one LCT to another is dependent on demographic changes, as well as the economic and financial return of the chosen farm enterprise - that is, the market demand, land availability, policy decisions, and social or cultural values. Most rural people in the Ethiopian highlands allocate more land for crop production than for other LCTs to feed their families. The increase of forestland in Fagita Lekoma, the study area, between 1995 and 2015 is, thus, in contrast with the typical characteristics of most of the rural areas of Ethiopia. The observed unique change in our study area is driven by soil fertility, and market demand for charcoal. Farmers are major contributors to the decline or increment of a LCT. Because trees require more space than annual crops, farmers who have more land can diversify their livelihood by planting trees to supplement their income and reduce the risk of failure. The soil of the Awi Zone - specifically Fagita Lekoma - is highly acidic (Endalew et al., 2014). Soil acidity causes difficulties for annual crop production because of nutrient fixation. This compels farmers to either grow crop types that are tolerant to acidity, or plant trees that can restore soil fertility and/or generate additional income for the household.

**Conclusions and recommendations**

The results demonstrated that the landscape of the study area was modified due to human activities; due mainly to the expansion of *A. decurrens* plantation and expansion of urban centers. Farmers in the study area have been planting *A. decurrens* by replacing different land cover mainly croplands, which consequently increased the forest cover. The expansion of *A. decurrens* plantation is mainly attributed to its adaptability, fast growth, and the potential short-term economic benefits that can be obtained from the sale of charcoal and fuelwood. This in turn indicates that introducing economically important tree species could support efforts related to the restoration of degraded landscapes. The expansion of plantation benefited smallholder farmers, hence, we suggest out scaling of planting *A. decurrens* to similar agroecology. While out scaling the planting of *A. decurrens* in degraded landscapes, the investigation of the multiple uses of the tree would help maximize the benefits. Although our study showed that the
expansion of *A. decurrens* plantation is effective at increasing forest cover and income of smallholders, the expansion of *A. decurrens* plantation would reduce land that can be allocated for crop production. In addition, monocropping of *A. decurrens* plantation requires careful decision with regard to disease and pest occurrence. Evaluation of the social consequences of such a decision is also an additional merit to promote for similar agroecology.

References


Web: earthexplorer.usgs.gov